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Capillary blood flow and arteriolovenular shunt in various organs in hypotensive states induced by nitroglycerine, nitroprusside, and nicardipine

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Abstract: The capillary blood flow of 14 organs was measured in dogs using the microsphere (9 μm diameter) trapping method under hypotension induced by administration of either nitroglycerin (NTG), nitroprusside (SNP), or nicardipine (NIC). Simultaneously, blood flow through the arteriolovenular shunt in the brain, kidney, liver, mesenteric organs, skeletal muscles of the pelvic limb, and all organs in the body, except the lungs, were measured by collecting venous blood drained from the organs at 4.8 ml·min^{-1} for 2 min. Capillary blood flow remained unchanged in most organs under hypotension with either NTG or SNP, but it increased in most organs, together with an increase in cardiac output, under hypotension with NIC. Arteriolovenular shunt tended to increase in four organs, with the exception of the liver, and increased in the whole body under hypotension with NTG. However, arteriolovenular shunt remained unchanged under hypotension with SNP. Arteriolovenular shunt increased in the mesenteric organs under hypotension with NIC, but decreased in the skeletal muscles of the pelvic limb. These results indicated that none of these hypotensive drugs impairs the nutrient supply to organs; further, NIC protects it much more since it does not increase the shunt flow through major organs.

Key words: Hypotensive anesthesia—Nitroglycerine—Nitroprusside—Nicardipine—Arteriolovenular shunt—Capillary blood flow—Organ microcirculation

Introduction

Many drugs are used in practice either to treat accidental hypertension or to induce deliberate hypotension to prevent massive hemorrhage during surgery. A number studies have reported the changes in hemodynamics during hypotensive anesthesia induced by these drugs [1–3]. Few studies, however, have dealt with the effects of drug-induced hypotension on microcirculation, particularly with reference to the nutrient supply to organs and tissues. Some hypotensive drugs dilatate arterioles and may also dilatate arteriolovenular shunt vessels. In such a case, a question arises as to whether or not capillary blood flow can be maintained sufficiently to deliver nutrients. Therefore, we decided to measure capillary blood flow and arteriolovenular shunt flow in dogs in which hypotensive states of two grades were induced by either nitroglycerine (NTG), nitroprusside (SNP), or nicardipine (NIC) and to observe the effect of deliberate hypotension on the nutrient supply to organs and tissues.

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Materials and methods

The protocol for this study was approved by the Ethics Committee and Animal Experiment Committee of Kawasaki Medical School.

Eighteen adult mongrel dogs weighing 9–14 kg which supplied from animal experimentation center of Kawasaki Medical School were anesthetized with 2 mg·kg^{-1} of ketamine and intubated with a cuffed endotracheal tube. The animals were fixed in the supine position and ventilated with a mixture of oxygen and nitrous oxide (1:2) via a piston respirator (R-60, Aika Instrumentation, Tokyo). Their tidal volume was fixed at 15 ml·kg^{-1} and the respiratory rate was adjusted to maintain $Paco_2$ of 35 ± 5 mmHg. The animals' rectal temperature was monitored and kept at 38–39°C by using a cooling-warming water jacket. Two milligrams of pancuronium bromide was administered after the endotracheal intubation and, if necessary, an additional 1 mg was administered. Additional ketamine of 0.5 mg·kg^{-1} was administered every 1.5–2.0 h.

A polyvinyl catheter (O.D. 2 mm) was inserted into the left femoral artery and was advanced 5 cm in the proximal direction to monitor arterial blood pressure and to collect blood samples. A thoracotomy was done in the fourth intercostal space and a polyvinyl catheter was inserted into the left atrium via the appendage for measurement of left atrial pressure and injection of microspheres. Teflon intravenous indwelling needles (22 gauge) were inserted into the internal maxillary vein (corresponding to the internal jugular vein in humans) and into the right femoral vein. These teflon needles were fixed to the venous wall with biological glue. Then a laparotomy was performed and another teflon needle of the same type was inserted into the left renal vein via either the left testicular vein or ovarian vein. This needle was also fixed to the venous wall. A polyvinyl catheter (O.D. 2.4 mm) was inserted into a branch of the splenic vein and the tip of the catheter was left in the portal vein. A J-shaped polyurethane catheter (O.D. 2.5 mm) was inserted into the hepatic vein via the left femoral vein. Another polyvinyl catheter was inserted into the right jugular vein, and the tip of catheter was left in the main pulmonary artery for the collection of mixed venous blood.

Measurements

Mean arterial blood pressure and mean left atrial pressure were measured with a strain gauge transducer (MPU − 0.5, Nihon Kohden, Tokyo, Japan) and recorded on a polygraph (RM-6200, Nihon Kohden). ECG waves were recorded on the same polygraph and heart rate was determined by measuring the R-R interval. Pao_2, $Paco_2$, and pH were measured potentiometrically with a blood gas analyzer (BME 33 Radiometer, Copenhagen, Denmark). Microspheres with a diameter of 9 ± 1 μm (3M, St. Paul, MN, USA) and labeled with either ^{51}Cr, ^{125}I, or ^{46}Sc were suspended in 2 ml of saline containing 0.05 ml Tween 80 (Nakarai Chemical, Kyoto, Japan) and injected into the left atrium as a bolus. Immediately, venous blood was withdrawn at a rate of 4.8 ml·min^{-1} by a continuous withdraw pump (Truth A-2, Nakagawa Tokyo, Japan) from the internal maxillary, renal, hepatic, portal, and right femoral veins, and from the pulmonary artery. These collections of venous blood were continued for 2 min. Then, 60 ml of dextran solution was infused intravenously to compensate for the loss of circulating blood. The radioactivities of the blood samples collected were measured by a gamma scintillation counter (Aloka ARC-361, Tokyo, Japan) and the numbers of microspheres that passed through the brain, kidney, liver, mesenteric organs, skeletal muscles of the pelvic limb, and all organs in the systemic circulation were calculated. Then blood flows through the arteriolovenular shunt vessels were calculated. Simultaneously with the venous blood collections, other blood was collected at a rate of 19 ml·min^{-1} from the femoral artery for 15 s and the radioactivities of this blood were measured. Then cardiac output was calculated by Archie's formula [4]. The body surface area was predicted by Dubois' formula [5] and was used to calculate the cardiac index.

After the first measurements of the above-mentioned variables, the animals were randomly divided into three groups. In the first group, with a mean body weight of 11.3 ± 2.1 kg ($n = 6$), animals received NTG continuously. As a result, their mean arterial pressure decreased to 85% of the initial level. The second group, with a mean body weight of 10.9 ± 1.7 kg ($n = 6$), and the third group, with a mean body weight of 11.5 ± 1.8 kg ($n = 6$), received SNP and NIC, respectively, in the same fashion with the same results. This hypotensive state (85%H) was maintained for 30 min and then second measurements were done in the same manner as the first measurements. After the second measurements, the mean arterial pressure in all three groups was reduced to 70% of the initial level by increasing the infusion rate of the hypotensive drug. This second hypotensive state (70%H) was also maintained for 30 min and a third set of measurements was done. Microspheres labeled with different isotopes were used in random sequence for each measurement. The animals were killed by electrical induction of ventricular fibrillation at the end of the experiment.

Measurement of capillary blood flow and arteriolovenular shunt rate

The brain, thyroid glands, heart, kidney, adrenal glands, liver, spleen, pancreas, major omentum, stomach, small intestine, large intestine, and skeletal muscles of the right pelvic limb were excised and weighed. The organs were cut into pieces small enough to be put in a counting vial, and their radioactivities were measured with a gamma scintillation counter. Capillary blood flow in each organ was calculated from the radioactivities of the microspheres trapped in the organ and was presented as the blood flow per 100 g of wet tissue. As described above, shunt blood flow through a particular organ was calculated from the radioactivities in the venous blood drained from the organ. Hepatic capillary blood flow was estimated from the summed radioactivities of the microspheres trapped in the liver and all of the mesenteric organs. The shunt rate for all organs in the systemic circulation was calculated as follows:

$$\frac{A_{SA}}{A_I} \times 100\ (\%)$$

where A_{SA} = total number of microspheres collected from the pulmonary artery excluding recirculated microspheres

A_I = number of microspheres injected into the left atrium The shunt rate for individual organs was calculated as follows:

$$\frac{A_s}{A_O + A_S} \times 100\ (\%)$$

where A_S = the total number of microspheres that passed through the organ and appeared in the draining vein

A_O = total number of microspheres trapped in the organ

Data are expressed as mean ± standard deviation. Changes in a variable following the induction of hypotension were examined by the paired *t*-test and those changes were compared between groups by analysis of variance. A P value less than 0.05 was considered significant.

Results

No significant difference between groups was noted in any of the variables measured prior to hypotension. NTG 15.6 ± 10.8 and 56.0 ± 52.5 $\mu g \cdot kg^{-1} \cdot min^{-1}$ were administered to obtain 85%H and 70%H, respectively. Similarly 3.1 ± 0.3 and 9.0 ± 2.2 $\mu g \cdot kg^{-1} \cdot min^{-1}$ of SNP, and 0.9 ± 0.2 and 3.9 ± 1.7 $\mu g \cdot kg^{-1} \cdot min^{-1}$ of NIC were administered.

The heart rate increased from 196 ± 25 to 209 ± 8 $beat \cdot min^{-1}$ at 85%H in the NTG group and from 190 ± 34 to 223 ± 18 $beat \cdot min^{-1}$ at 70%H in the SNP group. In the NIC group, on the other hand, it remained unchanged (Table 1). Mean left atrial pressure decreased from 6.9 ± 1.4 to 5.2 ± 2.4 mmHg at 85%H and further to 4.7 ± 2.1 mmHg at 70%H in the SNP group, but it remained unchanged in the other groups throughout the experiment. While the cardiac index remained unchanged in the NTG and SNP groups, it increased from 3.7 ± 1.8 to 8.1 ± 3.6 $l \cdot min^{-1} \cdot m^{-2}$ in the NIC group at 70%H.

Pao_2 and $Paco_2$ remained unchanged in all groups throughout the experiment. Arterial pH and base excess also remained unchanged in the NTG and SNP groups but decreased slightly in the NIC group at 70%H.

In general, capillary blood flow remained unchanged in most organs in the hypotensive state with NTG and SNP but increased with NIC (Table 2). However, it increased or tended to increase in the left ventricle, kidney, and adrenal glands in the hypotensive state regardless of the hypotensive agents used. On the other hand, it decreased in the major omentum of all groups and tended to decrease in the skeletal muscles in the NTG and SNP groups.

In the hypotensive state with NTG, capillary blood flow increased from 44 ± 29 to 89 ± 43 $ml \cdot min^{-1} \cdot 100\ g\ tissue^{-1}$ at 70%H in the pancreas and it tended to increase in the left and right ventricle, kidney, and adrenal glands. On the other hand, capillary blood flow decreased from 10 ± 6 to 7 ± 3 $ml \cdot min^{-1} \cdot 100\ g\ tissue^{-1}$ in the major omentum and tended to decrease from 6 ± 8 to 2 ± 1 $ml \cdot min^{-1} \cdot 100\ g\ tissue^{-1}$ in the

Table 1. Administration rate of drugs, hemodynamics and blood gases

	NTG			SNP			NIC		
	Control	85%H	70%H	Control	85%H	70%H	Control	85%H	70%H
Administration rate of drug ($\mu g \cdot kg^{-1} \cdot min^{-1}$)		15.6 ± 10.8	56.0 ± 52.5		3.1 ± 0.3	9.0 ± 2.2		0.9 ± 0.2	3.9 ± 1.7
Heart rate ($beat \cdot min^{-1}$)	196 ± 25	209 ± 8*	210 ± 20	190 ± 34	216 ± 15	223 ± 18*	204 ± 33	213 ± 27	205 ± 29
Mean arterial blood pressure (mmHg)	118 ± 16	101 ± 18**	87 ± 12**	108 ± 16	90 ± 11**	77 ± 12**	118 ± 12	96 ± 9**	79 ± 10**
Mean left atrial pressure (mmHg)	5.3 ± 1.5	4.6 ± 1.2	4.3 ± 1.6	6.9 ± 1.4	5.2 ± 2.4*	4.7 ± 2.1**	8.1 ± 2.8	7.3 ± 2.1	7.4 ± 1.5
Cardiac index ($l \cdot min^{-1} \cdot m^{-2}$)	3.1 ± 0.8	2.6 ± 0.8	3.8 ± 1.6	4.4 ± 1.6	4.8 ± 3.9	4.2 ± 2.3	3.7 ± 1.8	5.4 ± 2.2	8.1 ± 3.6*
Pao_2 (mmHg)	122 ± 14	116 ± 22	118 ± 22	111 ± 10	109 ± 10	111 ± 11	117 ± 13	116 ± 12	113 ± 12
$Paco_2$ (mmHg)	39 ± 3	37 ± 2	38 ± 2	38 ± 2	36 ± 1	35 ± 1	35 ± 4	36 ± 3	37 ± 4
pH	7.42 ± 0.03	7.42 ± 0.02	7.42 ± 0.04	7.43 ± 0.03	7.42 ± 0.02	7.42 ± 0.02	7.41 ± 0.02	7.39 ± 0.03	7.37 ± 0.04*
Base excess ($mEq \cdot l^{-1}$)	−1.0 ± 1.2	−1.8 ± 0.3	−1.7 ± 1.9	−0.6 ± 2.7	−2.8 ± 1.7	−2.4 ± 1.4	−3.4 ± 1.2	−4.1 ± 1.7	−5.3 ± 1.7*

Values are mean ± SD.
NTG, nitroglycerine; SNP, nitroprusside; NIC, nicardipine; H, hypotensive.
* $0.01 < P < 0.05$ and ** $P < 0.01$ versus control values.

Table 2. Capillary blood flow in organs (ml · min^{-1} · 100 g tissue^{-1})

	NTG			SNP			NIC		
	Control	85%H	70%H	Control	85%H	70%H	Control	85%H	70%H
Brain	39 ± 14	36 ± 12	49 ± 22	39 ± 17	37 ± 18	43 ± 27	36 ± 10	45 ± 19	57 ± 24*
Thyroid glands	49 ± 20	47 ± 25	60 ± 36	81 ± 43	87 ± 75	80 ± 74	63 ± 24	53 ± 24	67 ± 25
Left ventricle	127 ± 41	158 ± 62	220 ± 80	135 ± 64	204 ± 112	147 ± 90	167 ± 157	194 ± 77	370 ± 176**
Right ventricle	74 ± 40	75 ± 37	120 ± 78	74 ± 45	114 ± 57	94 ± 56	52 ± 27	186 ± 74**	307 ± 131**
Kidney	174 ± 168	233 ± 153	264 ± 124	124 ± 64	345 ± 189	335 ± 196	217 ± 128	290 ± 151	329 ± 157
Adrenal glands	100 ± 17	101 ± 30	144 ± 28	93 ± 52	118 ± 44	134 ± 47*	96 ± 8	155 ± 47*	184 ± 35**
Liver	96 ± 45	91 ± 43	136 ± 79	98 ± 20	99 ± 25	93 ± 34	98 ± 66	115 ± 51	157 ± 62*
Spleen	121 ± 9	100 ± 35	132 ± 52	175 ± 43	122 ± 90	88 ± 45*	177 ± 118	99 ± 115	86 ± 70
Pancreas	44 ± 29	43 ± 20	89 ± 43*	57 ± 28	65 ± 34	60 ± 38	35 ± 13	27 ± 15	51 ± 46
Major omentum	10 ± 6	6 ± 3	7 ± 3*	13 ± 9	8 ± 7*	7 ± 5*	8 ± 4	5 ± 4**	3 ± 3*
Stomach	26 ± 27	19 ± 14	18 ± 8	25 ± 13	17 ± 11	12 ± 4	15 ± 9	26 ± 21	22 ± 17
Small intestine	21 ± 5	20 ± 9	30 ± 10	31 ± 10	32 ± 12	31 ± 6	24 ± 13	47 ± 15*	69 ± 33*
Large intestine	9 ± 4	11 ± 8	13 ± 8	13 ± 5	13 ± 8	13 ± 6	12 ± 5	26 ± 7**	35 ± 16*
Skeletal muscles[a]	6 ± 8	2 ± 2	2 ± 1	8 ± 4	5 ± 2	3 ± 1*	7 ± 7	14 ± 15	26 ± 25

Values are mean ± SD
NTG, nitroglycerine; SNP, nitroprusside; NIC, nicardipine; H, hypotensive.
* $0.01 < P < 0.05$ and ** $P < 0.01$ versus control values.
[a] All skeletal muscles of the pelvic limb.

skeletal muscles at 70%H. In the remaining organs, no marked change was observed at either 85%H or 70%H.

In the hypotensive state with SNP, capillary blood flow increased from 93 ± 52 to 134 ± 47 ml·min^{-1}·100 g tissue^{-1} in the adrenal glands at 70%H and tended to increase from 124 ± 64 to 335 ± 196 ml·min^{-1}·100 g tissue^{-1} in the kidney. Capillary blood flow decreased from 13 ± 9 to 8 ± 7 ml·min^{-1}·100 g tissue^{-1} at 85%H and further to 7 ± 5 at 70%H in the major omentum. It also decreased from 8 ± 4 to 3 ± 1 ml·min^{-1}·100 g tissue^{-1} in the skeletal muscles at 70%H. No marked change, however, was observed in the other organs at either 85%H or 70%H.

In the hypotensive state with NIC, capillary blood flow increased in the brain, ventricles, adrenal glands, liver, small intestine, and large intestine at 70%H and tended to increase in the kidney and skeletal muscles. In the major omentum, however, it decreased from 8 ± 4 to 5 ± 4 ml·min^{-1}·100 g tissue^{-1} at 85%H and further to 3 ± 3 at 70%H. And in the spleen it tended to decrease from 177 ± 118 to 99 ± 115 ml·min^{-1}·100 g tissue^{-1} at 85%H and to 86 ± 70 at 70%H. No marked change was noted in the remaining organs.

The arteriolovenular shunt rate increased from 4.7 ± 1.5 to 9.8 ± 5.4% in the whole systemic circulation at 70%H of NTG and tended to increase in the brain, kidney, mesenteric organs, and skeletal muscles of the pelvic limb (Table 3).

However, in the SNP group, the arteriolovenular shunt rate remained unchanged in all organs throughout the experiment.

The shunt rate increased from 17.6 ± 8.3 to 41.3 ± 9.8% in the mesenteric organs of the NIC group at

Table 3. Arteriolovenular shunt rate (percentage)

	NTG			SNP			NIC		
	Control	85%H	70%H	Control	85%H	70%H	Control	85%H	70%H
Brain	5.1 ± 3.9	7.4 ± 7.5	17.7 ± 11.9	8.9 ± 4.0	8.1 ± 7.0	9.2 ± 5.4	12.7 ± 8.6	5.9 ± 4.8	14.3 ± 14.0
Kidney	3.9 ± 2.1	5.1 ± 4.5	5.2 ± 4.5	12.8 ± 8.9	9.9 ± 5.1	8.3 ± 5.3	7.2 ± 9.0	3.9 ± 4.7	3.8 ± 3.9
Liver	0.2 ± 0.3	0.2 ± 0.2	0.2 ± 0.3	0.7 ± 0.7	0.6 ± 0.5	0.4 ± 0.2	1.0 ± 1.9	0.3 ± 0.5	0.9 ± 1.7
Mesenteric organs[a]	23.2 ± 19.0	31.0 ± 20.1	32.5 ± 23.9	18.1 ± 9.2	22.1 ± 5.5	22.0 ± 7.9	17.6 ± 8.3	28.4 ± 18.9	41.3 ± 9.8*
Skeletal muscles[b]	19.7 ± 14.8	22.1 ± 8.0	29.4 ± 13.6	20.5 ± 26.7	20.0 ± 19.2	27.4 ± 12.8	15.8 ± 8.4	3.1 ± 4.2	0.6 ± 0.8*
All organs in systemic circulation	4.7 ± 1.5	5.6 ± 2.6	9.8 ± 5.4*	6.3 ± 1.2	5.5 ± 2.5	5.7 ± 2.6	6.3 ± 4.1	2.7 ± 1.4	4.8 ± 4.5

Values are mean ± SD.
NTG, nitroglycerine; SNP, nitroprusside; NIC, nicardipine; H, hypotensive.
* $0.01 < P < 0.05$ versus control value.
[a] All splanchnic organs except the liver.
[b] All skeletal muscles of the pelvic limb.

70%H, but it decreased from 15.8 ± 8.4 to 0.6 ± 0.8% in the skeletal muscles and tended to decrease in the kidney at 70%H. No marked change was observed in the shunt rate of the brain, liver, and whole systemic circulation.

Discussion

Folkow and Neil [6] reported that the diameter of the capillary vessels is mostly uniform and is approximately 6 μm. The diameter of the shunt vessels between arterioles and venules, on the other hand, varies widely. Fan et al. [7] injected microspheres of two sizes, 9 and 15 μm in diameter, simultaneously into the left ventricle and observed their passage through the brain, myocardium, kidney, and intestines. Subsequently, they noted that the passage rate of the 15-μm microspheres was less than 2% in all of these organs, but with the smaller microspheres, it was 3% in the myocardium and 24% in the splanchnic organs. They also observed that the passage rate of 9-μm microspheres in these organs increased in an acidotic state. Marcus et al. [8] reported that the passage rate of 7–10 μm microspheres was 8% in the brain, but it was less than 2% with 15-, 25-, and 50-μm microspheres. Therefore, 9-μm microspheres appear to be most suitable not only for the measurement of capillary blood flow but also for the measurement of arteriolovenular shunt flow.

It has been reported that NTG dilates venous vessels but not arterial vessels [9]. Consequently, NTG reduces the preload and decreases cardiac output. The changes in mean left atrial pressure and the cardiac index observed in this study seem to reflect those responses. Nevertheless, the response in cardiac output after NTG administration is still controversial. Vatner et al. [1] reported that cardiac output increased after NTG administration in awake dogs. On the other hand, Dumont et al. [10] reported that cardiac output decreased after administration of NTG. In this study, the cardiac index tended to decrease at 85%H and to rebound over the initial level at 70%H. Since regional blood flow is essentially affected by changes in cardiac output, the capillary blood flow increased in the pancreas and the capillary blood flow tended to increase in the ventricular walls and some other organs, such as the kidney and adrenal glands.

Arteriolovenular shunt tended to increase in a dose-dependent fashion in most of the organs in the NTG group. It appears likely that the increase in capillary blood flow would cause an increase in the arteriolovenular shunt flow in the brain, kidney, liver, and mesenteric organs. It is presumed that sufficient nutrients, e.g., oxygen, would be supplied to organs, but a sort of "luxury perfusion", which might force some loads on the heart, would exist in the hypotensive state with NTG. Therefore, the use to NTG induced hypotension cannot be fully recommended.

SNP has a potent vasodilating effect on both capacitance and resistance vessels [11,12]. As shown in this study, the mean left atrial pressure decreased gradually and the preload for the heart decreased simultaneously. The cardiac index, however, remained essentially unchanged. These changes probably reflected a decrease in the afterload [2,13]. Nakagawa [3] decreased arterial systolic pressure down to 70% of control by administration of SNP in dogs and observed changes in blood flow in the carotid, renal, mesenteric, and femoral arteries, as measured by a magnetic flowmeter. He noted that the blood flows through these arteries were well maintained at the initial level prior to the hypotension, and the cardiac index also remained unchanged.

In this study, capillary blood flow to such life-supporting organs as the brain, heart, kidneys and liver was well maintained in the hypotensive state with SNP. Similar data have been reported by Fan et al. [2], who measured organ blood flow using 16-μm microspheres. It has been recognized that the arterioles in skeletal muscle exhibit strong intrinsic basal tone [14]. Therefore, it is anticipated that hypotension per se narrows the vessels and decreases blood flow through the skeletal muscle. The decrease in capillary blood flow in skeletal muscles in SNP-induced hypotension may be explained by the mechanism mentioned above. Although SNP is said to have a vasodilating effect on resistance vessels as well as capacitance vessels, the effect of SNP on arterioles does not seem to be as strong as on venules since no marked change was observed in arteriolovenular shunt flow.

NIC can dilatate resistance vessels much more than capacitance vessels [15,16], and it does not suppress contractility of the myocardium [16,17]. Consequently, a great increase in cardiac output is associated with NIC-induced decrease in arterial pressure. A similar increase in the cardiac index was also observed in the present study.

Corresponding to the increase in cardiac output, capillary blood flow increased in most organs. In the right ventricle, it increased markedly. It has been reported that right ventricular work increased under NIC-induced hypotension [18]. Therefore, the increased right ventricular work may cause the increase of the capillary blood flow in the right ventricle. Although the capillary blood flow increased in most mesenteric organs in this study, the arteriolovenular shunt flow in the mesenteric organs also increased. It was presumed that the increased blood flow in the mesenteric organs was shunted through arteriolovenular anastomoses. Nevertheless, the decrease in arteriolovenular shunt flow through the skeletal muscles seemed to indicate that

NIC could cause more intense relaxation in the capillaries than in the arterioles.

In conclusion, capillary blood flow in most organs remains unchanged even in the hypotensive states induced with either NTG, SNP, or NIC. Therefore, this finding may support the idea that the nutrient supply is not disturbed by deliberate hypotension. NIC in particular increases capillary blood flow markedly without an accompanying increase in arteriolovenular shunt flow through the organs, except in the mesenteric organs. Thus, NIC might protect the nutrient supply for major organs even when the increse in cardiac output is less.

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