REGIONAL BLOOD FLOW IN NORMOVOLAEMIC AND HYPOVOLAEMIC HAEMODILUTION

An experimental study

B. Rosberg and K. Wulff

SUMMARY

The effects on the circulation of limited normovolaemic haemodilution with dextran 70 and subsequent haemorrhage to a mean arterial pressure of 60 mm Hg were studied with isotope-labelled microspheres in the dog. Following haemodilution, cardiac output, stroke volume and systemic oxygen transport increased. The distribution of oxygen to the heart, liver (hepatic artery), spleen and carcass (mainly muscle, skeleton and skin) was increased, while a decrease in oxygen supply to the brain was found. Following haemodilution and haemorrhage, cardiac output, systemic oxygen transport and mixed venous oxygen tension decreased. Blood flow was redistributed to maintain the cerebral, renal, hepatic arterial and coronary circulations, mainly at the expense of blood flow to the carcass and through systemic arterio-venous shunts. Thus, limited normovolaemic haemodilution does not affect the normal circulatory response to moderate haemorrhagic hypotension.

Haemodilution is practised widely, particularly in situations where bank blood is not available, for increasing blood flow in low-flow states and, during operation, to reduce the need for transfusion of bank blood. Oxygen supply to tissues is maintained, following haemodilution (Laks et al., 1973; Messmer et al., 1973; Kessler and Messmer, 1975) by an increased cardiac output or by increased oxygen extraction from blood (Carey, 1974), or both. However, increased cardiac output is useful only if oxygen supply to tissues is maintained. Few reports are available on regional blood flow distribution in normovolaemic haemodilution. Race, Dedichsen and Schenk (1967), using flow meters, demonstrated a redistribution of blood flow towards the coronary and vertebral artery systems, and away from the renal, hepatic and carotid arteries. In anaemia, reduction in renal blood flow with no change in flow through the common carotid and femoral arteries was found by Grupp and others (1972). No study demonstrating the effect of haemorrhage on flow distribution in the haemodiluted animal is available.

Using the microsphere technique in studies of regional coronary blood flow, Buckberg and Brazier (1975) showed that the endo-epicardial ratio of flow was unchanged in moderate haemodilution, with a haemoglobin concentration in the range 5–10 g dl⁻¹.

In canine hearts, working under load, there was a reduction of the proportion of flow to the subendocardium, which is the part of the heart most vulnerable to ischaemia (Hoffman and Buckberg, 1975).

This investigation was designed to study the distribution of cardiac output in the dog following normovolaemic haemodilution with dextran 70, using the microsphere technique (Rudolph and Heymann, 1967). In addition, the effect of uncompensated haemorrhage was studied.

METHODS

Six mongrel dogs, weighing 16–18 kg (mean 16.7 kg), were used in the experiment, while one dog and three rabbits were used for methodological studies. The animals were deprived of food for 12 h before the experiment.

Four to six days before the experiment a polyethylene catheter was implanted in the left atrium via a thoracostomy, performed under pentobarbitone anaesthesia and controlled ventilation. The catheter was filled with heparin and its distal end was knotted and buried subcutaneously. On the day of the experiment the dogs were anaesthetized with pentobarbitone 25 mg kg⁻¹, and anaesthesia was maintained during the study with additional doses. The trachea was intubated, the dog placed in a supine position and the lungs ventilated artificially at a rate of 13 b.p.m. with a tidal volume adjusted to produce a constant end-tidal carbon dioxide concentration of
about 5%. The subcutaneous end of the left atrial
catheter was retrieved and rinsed with saline. A
catheter was placed in the aorta, via the femoral
artery, for pressure recordings, to obtain samples for
blood-gas analysis and for collecting blood during
the haemodilution procedure. A Swan–Ganz catheter
was introduced into the pulmonary artery and a

catheter was placed in the inferior vena cava for
inducing haemorrhagic hypotension. The positions
of the catheters were checked by fluoroscopy.

Initial measurements (measurement I) about 1 h
after the induction of anaesthesia comprised:

(a) mean arterial and pulmonary arterial pressure
recordings using appropriate transducers;
(b) determination of cardiac output, arterial blood-
gas analysis and measurement of haematocrit and
haemoglobin concentrations;
(c) regional flow measurements by injection of the
first dose of microspheres, labelled with stron-
tium-85 through the left atrial catheter.

Haemorrhage of 20 ml kg\(^{-1}\) was then effected and
this volume was replaced simultaneously with the
same volume of dextran 70 (Macrodex 6% in saline,
Pharmacia AB, Sweden). Five minutes following
haemodilution measurements (a) and (b) were
repeated and a second dose of microspheres (labelled
with ytterbium-169) was injected (measurement II).

Blood was then withdrawn from the catheter in the
inferior vena cava until the mean arterial pressure
was approximately 60 mm Hg. Immediately following
the bleeding, measurements (a) and (b) were repeated
(measurement III). The third dose of microspheres,
labelled with cerium-141, was injected. Five minutes
following the last measurement, the animals were
killed with pentobarbitone, given into the heart.

Arterial and mixed venous blood
samples were analysed for pH, \(P_{CO_2}\), \(P_{O_2}\) and oxygen saturation
(ABL 1, Radiometer, Denmark) at 37 °C. The
blood-gas values were corrected to the dog’s rectal
temperature.

Haematocrit was measured with heparinized
microhaematocrit tubes centrifuged at 8000 rev min\(^{-1}\)
for 5 min.

Cardiac output was determined by a thermodilution
 technique (Fegler, 1954), using the Swan–Ganz
catheter (model 93–117–7F, Edwards Laboratories,
S. Ana, Calif., U.S.A.) with a thermistor in its tip
(Forrester et al., 1972; Woods, Scott and Harkin,
1976) and a cardiac output computer (model 9510,
Edwards Laboratories). The thermal indicator, 5 ml
of 5.5% glucose at a temperature of 0–2 °C, was
injected into the superior vena cava. Five determina-
tions, three before and two immediately after injection of the microspheres, were performed during each period of measurement and the mean value was calculated.

Arterial \((C_{aO_2})\) and mixed venous \((C_{vO_2})\) oxygen
content were calculated as follows:

\[
C_{aO_2} = 1.34 \times Hb \times S_o_2 + 0.023 \times P_{O_2}
\]

where \(S_o_2\) = percentage saturation of haemoglobin
with oxygen; \(P_{O_2}\) = oxygen tension (kPa); 1.34 =
oxygen capacity of haemoglobin (millilitre oxygen per gram haemoglobin) and 0.023 = oxygen solubility
coefficient (ml kPa\(^{-1}\)).

Systemic oxygen transport was expressed as the
product of cardiac output and arterial oxygen content
(Nunn and Freeman, 1964).

Oxygen consumption, \(\dot{V}_{O_2}\) (ml min\(^{-1}\)) was calculated
from the formula

\[
\dot{V}_{O_2} = (C_{aO_2} - C_{vO_2}) \times CO \times 10
\]

where \((C_{aO_2} - C_{vO_2})\) = arterio–venous oxygen content
difference (ml dl\(^{-1}\)) and \(CO = \) cardiac output (litre
min\(^{-1}\)).

Calculation of distribution of blood flow. The micro-
spheres (15 ± 5 (SD) \(\mu\)m in diameter) were labelled
with the radionuclides strontium-85, ytterbium-169
and cerium-141 respectively (3M Company, St Paul,
Minn., U.S.A.) and suspended in dextran 10 ml.
Aggregation was prevented with one drop of Tween
20. Depending on the activity of the microspheres,
500 000–1 500 000 spheres were used for each
injection.

The technique and measurements of organ blood
flow were performed according to the principles of
Rudolph and Heymann (1967). Three rabbits and
one dog were used initially for assessing the technique.
Each rabbit received a single intracardiac injection of
one of the radionuclides. The kidneys and liver
were removed, frozen and their radioactivity
measured in order to determine the interference
between the three radionuclides in the chosen
gamma-spectrometer channels. The dog, prepared
with a catheter in the left atrium, received an injection
of all three differently labelled microspheres. The
infused activity, measured with the syringe in a
specially adapted, water-filled "phantom" (Ericsson,
1971) was compared with sum of the activities for
each radionuclide in the measured organs. The
activity of ytterbium-169, measured in the "phantom"
was underestimated compared with the activity of the organs and the other two radionuclides. Therefore, when calculating the injected dose of ytterbium in the experimental dogs, the measured activity was multiplied by a predetermined correction constant (1.154).

Organ radioactivity was measured (Ericsson, 1971) in pieces weighing not more than 100 g, in a lead-shielded scintillation detector with a 4×3-inch (10×7.6-cm) thallium-activated sodium iodide crystal 38 cm from the centre of the specimen. The output of the detector was connected to a gamma-spectrometer (Canberra scaler, model 818), with window settings 155–235 keV (ytterbium-169), 90–155 keV (cerium-141) and 390–550 keV (strontium-85). Blood flow in the coeliac artery, preportal area, liver and carcass were calculated from the values observed. The sum of values found for the stomach, spleen, hepatic artery, pancreas and duodenum was taken as a measure of the flow through the coeliac artery; the sum of the measurements of the splanchnic organs except the liver (hepatic artery), as the preportal value. The difference between the sum of the activities measured and the activity of the isotope injected was taken as carcass activity.

Measurement of endo-epicardial flow ratio. The canine hearts were first measured as above. In five of the dogs the anterior wall of the left ventricle between the anterior and posterior descending coronary vessels was isolated and cut tangentially into three layers of equal thickness, representing the sub-epicardium, mid-myocardium and sub-endocardium. Each layer was subsequently cut into four to nine smaller pieces, weighed and measured in a two-channel well-type scintillation counter (Nuclear Chicago, Ridge 33–13A) with a crystal size of 2×1½ inch (5×2.9 cm). The specimens were measured twice, with the window settings at 75–500 keV (169Yb-window), 200–540 keV (141Ce-window) and 450–600 keV (85Sr-window) respectively. The ratio between the sub-endo- and sub-epicardium (endo-epicardial) was then calculated for each radionuclide.

Calculations were made of the mean and standard error of the mean. The significance of the difference between two means was estimated with Student's t test for paired observations.

RESULTS

Following haemodilution

Isovolaemic exchange of 20 ml kg⁻¹ blood with dextran 70 decreased the haematocrit from 33 ±1.0 (mean±SEM) to 25 ±0.6 (mean±SEM). Despite the reduced arterial oxygen contents, systemic oxygen transport increased at measurement II, as a result of an increased cardiac output produced by an increase in stroke volume. Haemodilution did not change the calculated oxygen consumption (table I). However, the oxygen consumption was small in comparison with the findings of most workers. This may be related to the hypothermia present in the experimental animals. The changes in blood flow distribution following haemodilution are shown in table II. The fractional distribution of cardiac output to the carcass and spleen was increased at the expense of the fractions to the brain, kidneys, small bowel and

| Table I. Measurements and calculations before (I) and the mean differences after haemodilution (II) and after haemorrhage (III). Compared with measurement I: *P<0.05; ** P<0.01; *** P<0.001 |

<table>
<thead>
<tr>
<th></th>
<th>I—Control data</th>
<th>II—After haemodilution</th>
<th>III—After haemorrhage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean difference (II—I)</td>
</tr>
<tr>
<td>Cardiac output (litre min⁻¹)</td>
<td>1.6</td>
<td>0.2</td>
<td>+0.9***</td>
</tr>
<tr>
<td>Stroke volume (ml min⁻¹)</td>
<td>14</td>
<td>1.7</td>
<td>+7***</td>
</tr>
<tr>
<td>Haematocrit (%)</td>
<td>33</td>
<td>1</td>
<td>-8***</td>
</tr>
<tr>
<td>PaO₂ (kPa)</td>
<td>14.1</td>
<td>0.6</td>
<td>+0.3</td>
</tr>
<tr>
<td>PvO₂ (kPa)</td>
<td>7.1</td>
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<td>PaCO₂ (kPa)</td>
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<td>MPAP (mm Hg)</td>
<td>11</td>
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<td>0</td>
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<tr>
<td>Heart rate (beat min⁻¹)</td>
<td>112</td>
<td>6</td>
<td>+7</td>
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<td>O₂ transport (ml min⁻¹)</td>
<td>204</td>
<td>26</td>
<td>+54*</td>
</tr>
<tr>
<td>O₂ consumption (ml min⁻¹)</td>
<td>36</td>
<td>3.4</td>
<td>+4</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>35.1</td>
<td>0.3</td>
<td>-0.8**</td>
</tr>
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</table>
TABLE II. Fractional distribution of cardiac output and individual organ blood flow before (I) and after (II) haemodilution. Compared with control data (I): *P<0.05; **P<0.01; ***P<0.001

<table>
<thead>
<tr>
<th>Organ</th>
<th>Fraction (%)</th>
<th>Flow (ml 100 g⁻¹ min⁻¹)</th>
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<tr>
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<td>5.4</td>
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<td>11.0</td>
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<tr>
<td>Lungs</td>
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<td>3.3</td>
<td>328.5</td>
<td>122.1</td>
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<tr>
<td>Kidneys</td>
<td>21.6</td>
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<td>639.8</td>
<td>44.1</td>
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<tr>
<td>Hepatic artery</td>
<td>5.2</td>
<td>2.8</td>
<td>10.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Spleen</td>
<td>3.0</td>
<td>0.5</td>
<td>75.3</td>
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Derived values. Total flow (ml min⁻¹)

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Colon–rectum. No significant changes were noted for the heart, lungs, liver (hepatic artery) and stomach.

Oxygen supply (table III) to the heart, liver (hepatic artery), spleen and carcass was increased, while a decrease in the supply of oxygen to the brain was found. The endo–epicardial ratio of distribution of microspheres at measurement I, 1.46 ± 0.06 (SEM), was not changed significantly by haemodilution, although there were individual variations.

Following haemodilution and bleeding

The reduction of mean arterial pressure to 60 mm Hg (table I) was accomplished by withdrawing 26 ± 1.5 (mean ± SEM) ml kg⁻¹ of blood (i.e. about 30% of the calculated blood volume in the dog). In comparison with measurements II, there was a decrease in cardiac output (P<0.001), stroke volume (P<0.001) and heart rate (0.01 > P > 0.001). A decrease in systemic oxygen transport (P<0.001)
and an increase in oxygen consumption (0.05 > P > 0.01) produced a reduction in mixed venous oxygen tension (P < 0.001).

The blood flow distribution following bleeding as compared with the distribution in the haemodiluted dogs is shown in table IV. The fractional distribution of cardiac output to the brain and liver (hepatic artery) was increased significantly at the expense of the fractions to carcass and lungs. There was a reduction in total blood flow to all organs with the exception of the liver and brain.

The endo-epicardial ratio of distribution of microspheres, 1.06 ± 0.16 (SEM), decreased significantly (P < 0.05) following bleeding.

DISCUSSION

The animals in this study tolerated thoracotomy well and there were no signs of pleural effusion or bleeding at examination after sacrifice. However, the operation may be responsible for the rather low haematocrit value (33 ± 1, mean ± SEM) found at the start of the investigation.

The validity of the microsphere method for measurement of organ blood flow has been demonstrated in fetal sheep and goats, dogs, monkeys and rabbits (Rudolph and Heymann, 1967; Neutze, Wyler and Rudolph, 1968; Kaihara et al., 1969; Hoffbrand and Forsyth, 1971). In this study, the injection of microspheres caused no changes in cardiac output, systemic arterial pressure or heart rate. Pentobarbitone anaesthesia in the dog usually causes tachycardia and reduction in cardiac output, cerebral, splanchnic and renal blood flow (Price, 1960). Using the microsphere technique, Ericsson (1972) demonstrated a decrease in cerebral and an increase in liver fraction of cardiac output following 30 min of anaesthesia. In a previous study of dogs (our own unpublished observations) no significant changes in cardiac output, stroke volume or systemic arterial pressure were noted during 2 h of anaesthesia. This accords with the observations of Priano, Traber and Wilson (1969) who found that prolonged anaesthesia caused minimal haemodynamic changes. All measurements in this study were performed during anaesthesia.

The response to exchange of blood 20 ml kg⁻¹ with dextran 70 in this study included increases in cardiac output, stroke volume and systemic oxygen transport. These findings are in agreement with several studies of the immediate reactions to normovolaemic anaemia (Guyton and Richardson, 1961; Messmer et al., 1972; Laks et al., 1973; Restorff et al., 1975).

Following haemodilution the fractional distribution to carcass (mainly muscle, skeleton and skin) increased by 35%. Blood flow fraction to skin was found to increase by 60% following extreme haemodilution (Yoshikawa and Yamamura, 1975). In
monkeys with postoperative anaemia the fraction of cardiac output delivered to the skin was also increased significantly (Hoffbrand and Forsyth, 1971).

The blood flow fraction to the lungs is the sum of the flow through the bronchial arteries and systemic arteriovenous shunting. This shunting is known to take place during pentobarbitone anaesthesia in the dog (Kaihara et al., 1968; Ohlsson, 1971).

No significant change was found in the fractional distribution of cardiac output to the liver. This is in accordance with the observations of Yoshikawa and Yamamura (1975).

The fraction of cardiac output distributed to the heart did not change after haemodilution, and thus myocardial blood flow increased by 58%. In studies by Race, Dedichsen and Schenk (1967) and Yoshikawa and Yamamura (1975) myocardial blood flow increased by a proportionally greater amount than the cardiac output. However, these authors studied more severe anaemia, in which the increases in cardiac output were not sufficient to compensate for the reduction in oxygen content. The findings in the present study, in which systemic oxygen transport increased 34%, could be a manifestation of the mechanism described by Allela and colleagues (1955) and Bern (1964), in which coronary blood flow is regulated not so much by cardiac output as by cardiac work.

Haemodilution did not change the endo-epicardial ratio of flow measured with 15-μm microspheres. This is in agreement with the findings of Buckberg and Brazier (1975), using 8–10-μm microspheres. The ratio in this study was 1.46, compared with 1.07 in the study by Buckberg and Brazier (1975). As pointed out by Domenech and colleagues (1969) the ratio obtained with smaller microspheres is closer to that found by diffusible indicators. It may be that there is a tendency to underestimate the epicardial flow with the microspheres used in this study.

The fractional distribution of cardiac output to the kidneys decreased significantly following haemodilution. This has been reported not only in acute dilutional anaemia (Race, Dedichsen and Schenk, 1967; Grupp et al., 1972; Yoshikawa and Yamamura, 1975), but also in moderate chronic anaemia (Hoffbrand and Forsyth, 1971; Vatner, Higgins and Franklin, 1972). There is normally a large arteriovenous oxygen content difference across the renal vascular bed, which should tolerate a reduction of arterial oxygen content without necessarily impairing oxygen delivery (Vatner, Higgins and Franklin, 1972). In this study, the 6% decrease in flow to the kidneys was accompanied by a 3% reduction in renal oxygen supply.

Haemodilution has been shown to increase cerebral blood flow (Michenfelder and Theye, 1969; Paulson et al., 1973). In this study, blood flow to the brain did not change, and the fraction of cardiac output delivered to the brain was reduced. W. Stelter (personal communication), using the microsphere technique (15 μm), also found a decreased fractional distribution to the brain following haemodilution from a haematocrit of 44 to one of 33, while further haemodilution to a haematocrit of 20 increased the cerebral fraction of cardiac output. Anaesthesia should not be responsible for this change, as it has been shown that 6 h of pentobarbitone anaesthesia does not reduce cerebral oxygen consumption or blood flow (Håggendal, Nilsson and Norbäck, 1966). It was shown by these authors that changes of red cell concentration in the haematocrit range 30–60% did not influence cerebral blood flow, which increased at lower haematocrit values, and correlated with a decreased oxygen capacity. In this study, the limited reduction in haematocrit, from 33 to 25%, may have been too small to cause a significant change in cerebral blood flow.

A reduced proportion of flow to the gastrointestinal tract was found. This has been reported in moderate chronic anaemia (Hoffbrand and Forsyth, 1971; Vatner, Higgins and Franklin, 1972), while Race, Dedichsen and Schenk, (1967) noted no change and Yoshikawa and Yamamura (1975) an increased ratio of flow in extreme haemodilution.

The central haemodynamic response to withdrawal of approximately 30% of the calculated blood volume in the dog is in agreement with the reactions described in the non-haemodiluted animal by Ericsson (1971).

The increased oxygen consumption found in this study is probably caused by increased plasma catecholamine concentrations, known to occur during haemorrhage (Chien, 1967; Haddy, Overbeck and Daughterty, 1968).

The fractional distribution of the cardiac output following bleeding indicated differences in local vascular response, with an increased fraction to "vital" organs such as heart, brain and liver, but also to the gastrointestinal tract, at the expense of the carcass fraction. The reduction of the fraction to the lungs suggested that in addition to a reduction in bronchial artery flow, there was closure of arteriovenous shunts. A comparison of the fractional changes of distribution in this study with those obtained from our laboratory (Ericsson, 1972) after
withdrawal of 30% of the blood volume in dogs which were not anaemic shows the same pattern. Thus the moderately haemodiluted dog has a normal response to uncompensated blood loss. It consists of an increased oxygen extraction from the blood, and a redistribution of regional blood flow.

The decreased endo-epicardial ratio suggested a diversion of flow within the heart following bleeding. Such a change has been reported to occur in extreme haemodilution (haemoglobin concentration less than 5 g dl⁻¹) and in dogs with aortic stenosis haemodiluted to a haemoglobin concentration in the range 5–10 g dl⁻¹ (Buckberg and Brazier, 1975). As shown by Winbury, Howe and Hefiner (1969) and Winbury (1971), the sub-endocardium in resting normal dogs has more open capillaries and less arteriolar tone. This is caused by autoregulatory mechanisms elicited by a smaller oxygen tension in sub-endocardial tissue. Dilatation of arterioles following a hypoxic stimulus is, therefore, probably greater in epicardial tissue. This may be the mechanism responsible for the diversion of flow during posthaemorrhagic hypotension seen in this study. Since no control dogs were studied, it is not possible to judge the influence of anaemia on this response. However, it may be presumed that the anaemic dog, with dilated coronary vessels, is more likely to exhibit this mechanism in situations of reduced myocardial oxygen supply or increased oxygen demand, or both.

ACKNOWLEDGEMENTS

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REFERENCES


DEBIT SANGUIN REGIONAL LORS D'UNE HEMODILUTION NORMOVOLEMIQUE ET HYPOVOLEMIQUE

Étude expérimentale

On a étudié sur le chien, les effets qu'ont sur la circulation une hémodilution normovémique limitée de dextran 70 et l'hémorragie qui lui a fait suite à une pression artérielle moyenne de 60 mm Hg, à l'aide de microsphères marquées par un isotope. Après l'hémodilution, le débit cardiaque, le volume systolique et le transport d'oxygène systémique ont augmenté. La répartition de l'oxygène au cœur, au foie (artère hépatique), à la rate et au reste du corps (surtout aux muscles, au squelette et à la peau) a augmenté, alors qu'on a constaté une diminution de l'alimentation en oxygène du cerveau. Après l'hémodilution et l'hémorragie, le débit cardiaque, le transport d'oxygène systémique et la tension de l'oxygène veineux mélangé ont diminué. Le débit sanguin a été redistribué afin de maintenir les circulations cérébrale, rénale, artérielle hépatique et coronaire, surtout aux dépends du flux sanguin au reste du corps et par l'entremise de shunts systémiques arterio-veineux. Ainsi, l'hémodilution normovémique limitée n'affecte pas la réaction circulatoire normale à une hypotension hémorragique modérée.

DER ÖRTLICHE BLUTSTROM BEI NORMOVÖLÄMISCHER UND HYPOVÖLÄMISCHER BLUTVERDÜNNUNG

Eine experimentelle Untersuchung

ZUSAMMENFASSUNG


CIRCULACIóN REGIONAL DE SANGRE EN HEMODILUCIÓN NORMOVOLEMICa

E HIPOVOLEMICa

Un estudio experimental

SUMARIO

Se estudiaron los efectos ejercidos sobre la circulación por una limitada hemodilución normovémica con dextran 70 y la hemorragia subsiguiente, a una presión arterial media de 60 mm Hg mediante microesferas marcadas isotópicamente en el perro. Tras la hemodilución, aumentó el volumen-minuto cardíaco, el volumen de sangre por latido y el transporte de oxígeno a todo el cuerpo. La distribución de oxígeno al corazón, higado (arteria hepática), bazo y cuerpo (principalmente los músculos, esqueleto y piel) mientras que se descubrió una disminución en el suministro de oxígeno al cerebro. Tras la hemodilución y la hemorragia, disminuyó el volumen-minuto cardíaco, el transporte de oxígeno al cuerpo y la tensión de oxígeno venoso mezclado. La circulación de la sangre fue redistribuida para mantener las circulaciones cerebral, renal, hepática, arterial y coronaria, especialmente a expensas de la circulación de sangre al cuerpo y por medio de derivaciones arteriovenosas sistemáticas. Por lo tanto, la hemodilución normovémica limitada no afecta la respuesta circulatoria normal a la hipotensión hemorrágica moderada.