Renal Tissue Gas Tensions during Hemorrhagic Shock

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To evaluate the development of renal hypoxia during hemorrhagic shock, fourteen dogs were induced in this study. The animals were divided equally into a group in which mean arterial pressure (MAP) was kept at 50 mmHg (group 1), and into another where MAP was kept at 40 mmHg for 180 min (group 2). Renal tissue gas tensions were determined by a mass spectrometer. In the 50-mmHg group, renal tissue oxygen tension (Pr_{O_2}) dropped for 15 min following hemorrhage, remained constant for 90 min, then fell further for 150 min before a plateau was established. In the 40-mmHg group, the Pr_{O_2} dropped for 90 min before reaching a plateau. The second Pr_{O_2} decline occured at the same level in both the 50-mmHg group and the 40-mmHg group. The point at which the same Pr_{O_2} level occurred for each group suggests the cessation of oxygen consumption and the conditions of renal hypoxia. It is assumed that renal hypoxia occurs in 120 min at a MAP of 50-mmHg and in 60 min at a MAP of 40 mmHg.
(Key words: hemorrhagic shock, mass spectrometer, kidney, renal hyposia, renal ischemia, renal tissue gases)

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The kidney effects from hemorrhagic shock may result from disturbed autoregulation of the renal blood flow. Severe hypotension may limit renal blood flow autoregulation. Furthermore, as hemorrhagic shock and hypotension progress, renal ischemia became more marked. The latter may produce renal hypoxia and acute renal failure[1,2]. Munch et al.[3] disputed this hypothesis; they found that renal cortical capillary oxygen saturation remained around 68% in dogs during hemorrhagic shock, while the mean arterial blood pressure (MAP) was maintained around 50 mmHg. Strauss et al.[4] also disagreed with this hypothesis; they found that, when the systolic arterial BP was kept at 60 mmHg in rabits during hemorrhagic shock, the maximum decreases in tissue oxygen were only 47% in the cortex, 37% in the outer medulla, 30% in the inner medulla and 32% in the papilla.

Prevously, we[5] lowered the BP by bleeding the dogs, while measuring the tissue gas tension in the renal cortex continuously with a medical mass spectrometer. When MAP dropped from 80 to 70 mmHg, the renal tissue P_{O_2} (Pr_{O_2}) began to fall and the renal tissue P_{CO_2} (Pr_{CO_2}) began to rise; when MAP dropped from 50 to 40 mmHg, the Pr_{O_2} no longer declined and the Pr_{CO_2} no longer rose. It appeared that severe renal hypoxia occured when MAP decreased to 40 mmHg.

This study was undertaken to examine the possible effect of renal hypoxia during hemorrhagic shock, the kidney changes at MAPs of 50 and 40 mmHg and the changes in renal tissue gas tension.

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Subjects and Methods

Fourteen adult mongrel dogs weighing 11.2 ± 2.05 kg were anesthetized with iv pentobarbital (15 mg/kg) and intubated. After administering 4 mg pancuronium iv, ventilation with room air was achieved using a Harvard respirator. After cannulae insertion into the bilateral femoral arteries, arterial BP was monitored continuously on one hind limb using a pressure transducer (1280c, Hewlett-Packard, Colorado Springs, CO), A pulmonary catheter was inserted through the femoral vein into the pulmonary artery, to measure pulmonary capillary wedge pressure (WP) and mixed venous blood gas was measured spectoro-photometrically. Cannulation of the other femoral vein was used for infusion. Following midline abdominal incision, a teflon probe for tissue gas filtration was inserted into the renal cortex and connected to the medical mass spectrometer (MS-8, Scientific Research Instruments, Baltimore, Maryland) for continuous measurement of renal tissue gas tension. A probe was also inserted through a branch of the renal vein to simultaneously and continuously measure the renal venous blood gas tension. Blood samples were collected before bleeding (control) and at 15, 30, 60, 90, 120, 150, and 180 min thereafter.

One hour after insertion of the teflon probe for the tissue gas determination, 2,000 U of heparin were administered iv, and it was confirmed that no changes were seen in the tissue gas tension. After the control measurement, bleeding then began simulating hemorrhagic shock. Two methods were used for bleeding: In the first group (n=7), the MAP was lowered to 50 mmHg after which transfusion and bleeding were repeated to keep the MAP at 50 mmHg for 180 min, while in the second group (n=7), the MAP was kept at 40 mmHg with the same procedures. The data obtained were represented by mean and SEM. Statistical analysis were performed using Students' t test and differences were considered to be significant when $P<0.05$.

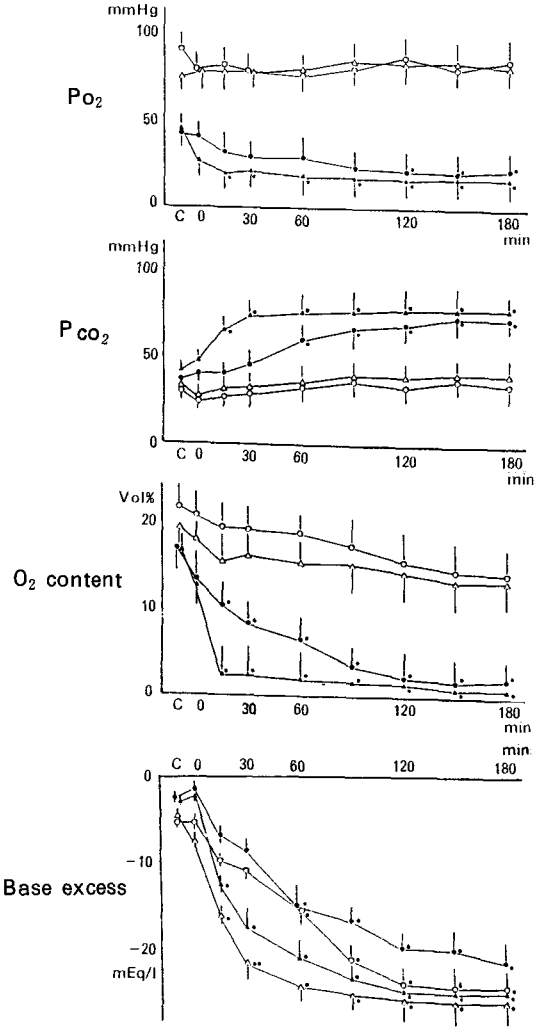

Fig. 1. Changes in arterial (open circles and triangles) and mixed venous (closed circle and triangles) P_{O_2}, P_{CO_2}, O_2 content, and base excess for 50 (circles) and 40-mmHg MAP groups (triangles), respectively.

*$P<0.05$ significant change from control.

Results

As shown in figure 1, Pa_{O_2} did not display any significant changes accompanying hemorrhagic shock in the 50-mmHg group or in the 40-mmHg group. On the other hand, mixedvenous P_{O_2} (Pv_{O_2}) dropped immediately after MAP fell and dropped significantly 15 min later. In the 50-mmHg group, the Pv_{O_2} decline continued for 120 min, after

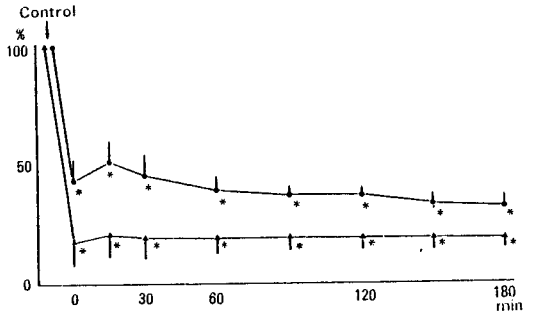

Fig. 2. Changes in cardiac output for 50 (closed circle) and 40-mmHg groups (closed triangles), respectively. Values are plotted as per cent change from control.

*P <0.05 significant change from control.

which it became negligible. In the 40-mmHg group, MAP continued to fall for 60 min and then became insignificant.

In both groups, Pa_{CO_2} exhibited slight changes accompanying hemorrhagic shock, which were not statistically significant. On the other hand, an increase was seen in Pv_{CO_2}. In the 50-mmHg group, the increase became significant ($P<0.05$) after 60 min, but stopped rising after 150 min. In the 40-mmHg group, Pv_{CO_2} rise became significant ($P<0.05$) after 15 min, but this increase stopped after 90 min.

The arterial oxygen content (Ca_{O_2}) declined during hemorrhagic shock, but in both groups this decline was not statistically significant ($P<0.1$) for 180 min. However, a significant decline in Cv_{O_2} was ovserved immediately after the fall of MAP. In the 50-mmHg group, it dropped for 120 min, but then stopped. In the 40-mmHg group, a sharp drop was seen for 15 min, but became insignificant thereafter.

In the 50-mmHg group, cardiac output (CO) declined significantly ($P<0.05$) following the MAP decrease and increased slightly in 15 min, continuing to do so for 150 min, after which it declined gradually. In the 40-mmHg group, CO declined significantly following the MAP decrease and stopped declining (fig. 2).

In the 50-mmHg group, Pr_{O_2} (figs. 3 and 4) dropped sharply following the MAP

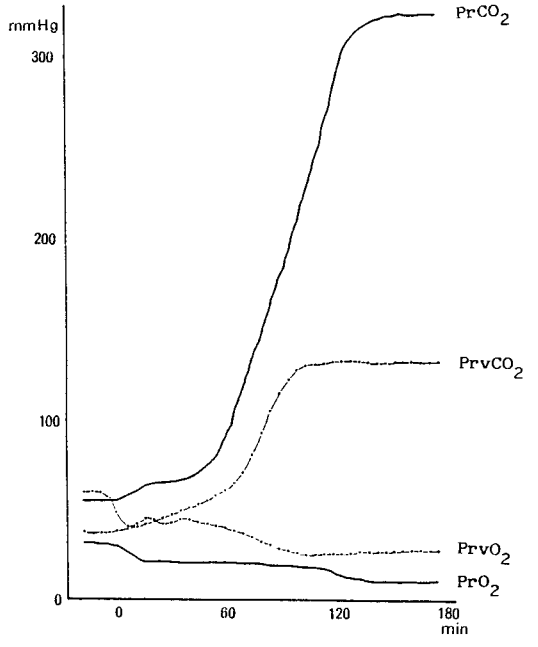

Fig. 3. Continuous recording of renal tissue gases (solid line) and renal venous blood gases (dotted line) at 50 mmHg MAP.

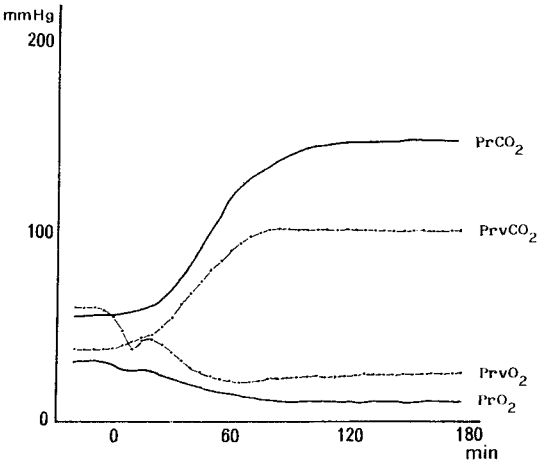

Fig. 4. Continuous recording of renal tissue gases (solid line) and renal venous blood gases (dotted line) at 40 mmHg MAP.

decrease, but stopped in about 15 min and stabilized after about 90 min. Pr_{O_2} then began to drop again and continued to do so for 150 min, after which it dropped no more, representing a plateau.

Pr_{CO_2} rose subsequent to the MAP decreases, but stabilized after 20 min. However, it began to rise again after 40 min and continued to rise sharply for 150 min; then it stopped rising, representing a plateau. Renal venous P_{O_2} (Prv_{O_2}) continued to fall with fluctuations for 100 min after the MAP decrease, but stopped at a plateau. Renal venous blood P_{CO_2} (Prv_{CO_2}) continuously rose after the MAP decrease, gradually accelerating to reach a high level, it then tapered off after 100 min and stopped at around 120 min representing a plateau.

In the 40-mmHg group, Pr_{O_2} dropped continuously after the MAP decrease and discontinued after 90 min when a plateau was reached. Pr_{CO_2} rose continuously after the MAP decrease. After a sharp 90 min rise, it stopped rising after 120 min, representing a plateau. With fluctuations, Prv_{O_2} dropped for 60 min after the MAP decrease. After that the drop was no longer observed and a plateau was reached. Prv_{CO_2} rose continuously after the MAP decrease, stopping after 80 min and reaching a plateau.

Discussion

There is no doubt that renal ischemia due to hemorrhagic shock is significantly involved in acute renal failure due to hemorrhagic shock. But it is difficult to accept the hypothesis that renal ischemia is directly connected with renal hypoxia for the following reasons: As the kidney contains much blood flow in proportion to its weight, and its oxygen consumption is enormous in proportion to its weight, the greatest part of its oxygen consumption is used for active reabsorption of sodium in the renal tubles. Therefore the oxygen consumption by the renal tissue itself is very small. Under ischemic conditions, there should be an extreme decrease in glomerular filtration rate and a noticeable decline in the oxygen consumption used for active reabsorption of sodium in the renal tubles. Accordingly, even if observations on renal ischemia during hemorrhagic shock are made based on the renal blood flow, such observations may be of little use for a hypothesis about the onset of renal hypoxia.

For this reason, the determination of the tissue gas tension is thought useful[6]. We[5] made observations on the changes in renal gas tension due to a decline in the oxygen supply to the kidney resulting from a decline in the renal blood flow accompaning hemorrhagic shock. We simultaneously observed the effects caused by a decline in the oxygen supply even though the renal blood flow was maintained by hemodilution. We[7] reported reduced renal function from dereased oxygen supply accompanying hemodilution. If the hemoglobin falls below 5g/dl with hemodilution, the renal blood flow may be maintained, but decreases presumably from decreased oxygen supply, urine excretion and renal function entirely. At that time, the onset of renal hypoxia could be suggested by the plateauing of Pr_{O_2}.

During this study, there was a significant difference in renal tissue oxygenation at an MAP of 50 or 40 mmHg. The most noticeable difference in Pr_{O_2} was in the 50-mmHg group where it dropped sharply due to hemorrhage, reaching two plateaus. Pr_{O_2} in the 40-mmHg group, however, dropped continuously before reaching a plateau. The second Pr_{O_2} plateau established in 50-mmHg group and the plateau in the 40-mmHg group displayed almost the same value, suggesting that the halt in the Pr_{O_2} decrease at that time indicates renal hypoxia. Contradictory, the conditions under which the first Pr_{O_2} drop plateaued in the 50-mmHg group were not sufficient to be diagnosed as renal hypoxia even if there was a decrease in oxygen supply to the kidney. The oxygen consumption is thought to continue. Likewise, a Pr_{CO_2} rise is attributed mainly to a decrease in the CO_2 removal, but at the same time CO_2 production is thought to be taking place. Accordingly, the stop in CO_2 production is supposed to be involved the halt in Pr_{CO_2} increase, but this occurred in the 50-mmHg group about 60 min later than in the 40-mmHg group, and the Pr_{CO_2} level in the 50-mmHg group was about twice that of the 40-mmHg group. In comparison with the 40-mmHg group, CO_2 production ac-

companying oxygen production presumably lasted longer in the 50-mmHg group. A gradual decline in Prv_{O_2} for about 100 min in the 50-mmHg group can be thought to accompany a decrease in the renal blood flow. But as Pr_{O_2} maintained a constant value during this period, the oxygen supply to the kidney is balanced specifically with the oxygen demands, despite a decrease seen in the oxygen supply. Consequently, renal hypoxia should not have occurred under these conditions. But in the 40-mmHg group, Prv_{O_2} registered a sharp decline which stopped suddenly after about 60 min, and Pr_{O_2} after dropping continuously, stopped after 90 min, representing a plateau. This may indicate conditions of renal hypoxia in which oxygen consumption is hardly observed because the renal blood flow continues to decrease in spite of the 40-mmHg MAP and because the decline has stopped both in Prv_{O_2} and Pr_{O_2}, though the decline should continue. Because of the delayed probe reaction of the teflon membrane or the medical mass spectrometer involved in these gas changes, a comparison shows that though there is a decrease in the oxygen supply to the kidney for about 120 min in the 50-mmHg group, renal hypoxia did not develop at that time, resulting in a later onset of renal hypoxia, while in the 40-mmHg group, renal hypoxia developed rapidly. According to Munch[3], this hypoxia depends upon the renal cortical capillary oxygen saturation when MAP is kept at 50 mmHg. When we take this into consideration, it demonstrated together with the time factor the condition before the development of renal hypoxia. The data of Strauss et al[4] concern the determination of tissue oxygenation when systolic arterial BP is kept at 60 mmHg. In our data also, Pr_{O_2} was kept above 50% of the value before hemorrhage for about 120 min when MAP was 50-mmHg. So it is thought that these data alone are not sufficient to refute the onset of renal hypoxia during hemorrhagic shock. As to how long the kidney can tolerate hypoxia, it is said that tissue metabolism in the renal cortex stops completely 150 min after blood flow completely stops; reports[10–12] are available about cellular changes observed at such a time.

Accordingly, at the onset of hemorrhagic shock, improving the blood flow within 3 h at a MAP of 40 mmHg and within 4.5 h at a MAP of 50 mmHg should prevent loss of renal function.

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