EFFECT OF THE ZETA-POTENTIAL ON INTRAVASCULAR BLOOD CLOTTING

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Experiments on rabbits have demonstrated a direct relationship between the zeta-potential and local hemocoagulation. With an increase in magnitude of the zeta-potential, a tendency toward hemocoagulation is observed, and vice versa.

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Recent work has shown that the state of hemocoagulation depends not only on the ratio between procoagulants and anticoagulants, but also on the electrochemical characteristics of the blood cells and the vascular wall [8, 10, 12-15]. Some workers consider that changes in the potential of the vessel wall are an important factor in the etiology of intravascular thrombosis, and they have even gone so far as to classify thromboses on this basis [3]. During movement of the blood along the blood stream, an electrokinetic potential develops on the internal wall of the blood vessel [1, 5-7]. Besides potentials of flow, sedimentation, electroosmosis, and so on, the total electrokinetic potential also includes the zeta-potential. This arises directly on the endothelium of the vessel wall [1, 5-7].

The object of the present investigation was to study the relationship between local hemocoagulation and the magnitude of the zeta-potential in various blood vessels.

EXPERIMENTAL METHOD

Acute experiments were carried out on 26 rabbits weighing 2.5-3 kg. The blood vessels to be investigated were first exposed under intravenous urethane anesthesia (10 ml of a 20% solution) and carefully separated from surrounding tissues. In the course of the investigation the region of the blood vessel and the tissues surrounding it were moistened with physiological saline at 37°. The amplitude of the zeta-potential was determined by Smolukhovskii's equation, which takes into account all factors exerting a significant influence on the zeta-potential. Smolukhovskii's equation has the form:

$$\xi = \frac{4\Pi\eta KV}{DP},$$

where ξ represents the zeta-potential (in mV), η the dynamic viscosity of the blood (in P), D the dielectric constant (120 for blood), K the specific constant of electrical conductivity ($1.07 \cdot 10^{10}$) for blood), P the blood pressure (in dynes/cm^2), and V the difference of flow potentials (in mV).

It follows from Smolukhovskii's equation that the most important constant is the difference of flow potentials. To measure them, glass microelectrodes with a tip 5 μ in diameter were used. The microelectrodes were filled with 2.7 M KCl solution and connected through a salt bridge (2.7 M KCl solution) with Ag–AgCl electrodes [15]. The microelectrodes were inserted into the blood stream in the blood vessel to be investigated, immediately next to the internal wall, by means of a micromanipulator and MBS-1 microscope. The distance between the microelectrodes was 10 mm, and their resistance was between 10 and 20 MΩ. The difference of flow potentials was determined by a type LPU-01 laboratory pH-meter, which was used as dc amplifier. The input resistance of the instrument was 150 MΩ. The flow potentials were recorded graphically on a type ÉPP-09 automatic electronic potentiometer. The blood viscosity was measured with a Hess viscosimeter. The blood pressure was recorded in the carotid artery by a mercury manometer. The state of hemocoagulation was judged by measuring the plasma recalcification time and by studying the thrombo-

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TABLE 1. Zeta-potential of Rabbit's Blood Vessels

Blood vessels	Difference of flow potentials (in mV)	Viscosity of blood (in P)	Zeta-potential (in mV)
Abdominal aorta	25,6±0,8	0,021±0,0008	42,6±3
Inferior vena cava	12,7±1,17	0,0246±0,004	24,7±5
P	<0,001	<0,001	<0,001
Femoral artery	18,2±1,1	0,0238±0,0006	31,5±3
P	<0,001	<0,02	<0,01
Femoral vein	15,1±0,38	0,023±0,002	27,5±1,2
P	<0,001	<0,001	<0,001
Renal artery	22,9±2,1	0,02±0,0008	36,6±5,2
P	0,2	>0,05	0,5
Renal vein	31,4±0,4	0,025±0,0015	63,1±3,3
P	<0,001	<0,001	<0,001
Portal vein	10,8±1,06	0,029±0,001	23,3±5,1
P	<0,001	<0,001	<0,001

Note. Significance of differences (P) determined relative to abdominal aorta.

elastogram [4]. Blood for investigation of the viscosity and clotting parameters was taken directly from the vessels examined. The numerical data were subjected to statistical analysis [3].

EXPERIMENTAL RESULTS

The difference of flow potentials investigated in the rabbit's blood vessels in vitro was recorded within a few seconds after insertion of the microelectrodes into the blood stream and was stable in character. The polarity of the flow potentials was always negative, and their amplitude did not exceed 35 mV. An I-01 simulator of the electrode system was used to check the amplitudes and polarity of the flow potentials obtained. Furthermore, at the beginning and end of the experiment the potential difference, which should always be zero,was measured in Tyrode solution.

As Table 1 shows, the difference of flow potentials was greatest in the renal vein and least in the portal vein. The highest blood viscosity was observed in the portal vein and the lowest in the abdominal aorta and renal artery. Corresponding to the amplitude of the flow potentials, the highest zeta-potential was recorded in the renal vein and aorta. Measurement of the plasma recalcification time of blood in the vessels where the difference of flow potentials and blood viscosity were investigated showed that the velocity of blood coagulation differed in the different vessels. The longest recalcification time was found in the renal vein (211 sec). The recalcification time in the renal artery, abdominal aorta, inferior vena cava, femoral artery, femoral vein, and portal vein was 180.4, 203, 116, 149, 143, and 127 sec respectively. Corresponding parameters of the thromboelastogram were obtained. Of the temporal parameters of the thromboelastogram which were studied, the total clotting time, the reaction time, and the maximal amplitude showed the most marked differences in the different blood vessels. For instance, the reaction time in the abdominal aorta and renal vein was 552 ± 12 and 528 ± 36 sec respectively ($P < 0.05$), and in the portal vein and inferior vena cava it was 336 ± 18 and 294 ± 24 see respectively ($P < 0.02$).

The results indicate that hemocoagulation follows a different course in different blood vessels. The experiments showed that coagulation of the blood takes place most rapidly in the inferior vena cava and portal vein, and is slowest in the renal vein, abdominal aorta, and renal artery. These results correlate with the values of the zeta-potential measured in these blood vessels ($r = 0.902$). It may be supposed that these differences in blood clotting in the vessels investigated are due to differences in the amplitude of their zeta-potential. The velocity of movement of the fluid, the dielectric constant of the solution and surface in contact with it, the pH of the solution, and all factors known to influence the total electrokinetic potential have all been shown to have a substantial effect on the amplitude of the zeta-potential [1, 5-7]. It is certain that electrokinetic processes in different blood vessels follow their own characteristic course which is determined by metabolic activity of the vessel wall, the concentration of vasoactive substances in the flowing blood, the nerve supply to the blood vessels, and the local concentration of pro- and anticoagulants in the vessel wall and blood. All these factors have a significant effect also on the amplitude of the zeta-potential in the blood vessels. Another important factor is the local heparin concentration in the vessel wall and the blood, for according to some data heparin contains a large number of negatively charged ions and, consequently, tends to increase the zeta-potential [9-11]. The results of the present investigation show that the highest value of the zeta-potential and slow coagulation of the blood are observed in the renal vessels and

aorta. This is presumably attributable to the presence of a high concentration of heparin in these vessels, entering the aorta from the mast cells of the lung tissue and eliminated through the kidneys [2, 11]. In addition, the aorta and renal vessels are distinguished by a high velocity of blood flow and also, apparently, by a low concentration of procoagulants in the vessel wall, for in clinical practice intravascular thrombosis is observed comparatively rarely in these vessels. The high viscosity of the blood in the portal vein and the low zeta-potential found in it in the present experiments, compared with other vessels, indicate that relative hypercoagulation of the blood corresponds to an increase in its viscosity. Since the withdrawal of more than 0.5 ml of blood from the rabbit's blood vessels was accompanied by a marked decrease in the initial values of the blood pressure and flow potentials, only the recalcification time and thromboelastogram were studied, giving an indication of the general state of blood coagulation in the vessels. Besides the general features of local hemocoagulation in different blood vessels, differences in their content of pro- and anticoagulants are certainly also observed in them.

The rate of blood coagulation thus differs in different blood vessels. Vessels with slow blood coagulation have correspondingly higher values of their zeta-potential than blood vessels distinguished by rapid blood coagulation.

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