A Comparison of Blood Viscosity between the Adult Sheep and Newborn Lamb. The Role of Plasma and Red Blood Cell Type

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Summary

Adult sheep and newborn lamb blood viscosity (Vc) have been compared by taking into account not only the hematocrit, but also the type of the red cells (adult or fetal) in the circulation and the plasma Vc. At all shear rates studied the whole blood Vc of the adult was higher than that of the newborn. Plasma Vc was 1.58 ± 0.18 centipoises in the adult compared to 1.21 ± 0.19 in the newborn group ($P < 0.001$). The mean relative apparent viscosity (whole blood Vc/plasma Vc) was higher in the newborn although the difference was not significant.

Abbreviations

CP, centipoise
Ht, hematocrit
Vc, viscosity

In a recent study, blood viscosity of adults and human newborns was compared to determine the part played by the presence of fetal red cell and the plasma viscosity. This work showed that for the same hematocrit adult blood had a higher viscosity than that of the newborn. This was due to a higher viscosity of adult plasma (10).

Because the newborn lamb is frequently used as an experimental model for fetal and neonatal circulatory (5) as well as metabolic studies (8) and the results are extrapolated to humans, it was considered of utmost importance to obtain data on rheologic properties of adult and newborn blood in this species.

MATERIALS AND METHODS

Viscosity studies were carried out on blood samples taken from adult sheep and newborn lambs younger than 48 h of age. Bard *et al.* (1) have shown that at this early age the blood contains over 75% of fetal hemoglobins. In both instances venous blood was collected into plastic syringes that had been flushed with sodium heparin. A total of 28 adult and 32 newborn samples were collected. They were centrifuged ($4000 \times g$ for 10 min) and the cells resuspended in plasma in order to obtain hematocrit levels varying from 30–71%. Manipulations and measurements were completed within 2 h of sampling. The variations in the number of data points are due to the fact that on a few samples there was some blood loss during the manipulations, thus viscosity could not be obtained at all of the shear rates.

Vc was measured with a Wells-Brookfield cone-plate viscometer (model LVTcp). The shear stress of the samples was determined at shear rates of 11.5, 23, 46, 115, and 230 sec^{-1} . Vc was calculated as described by Wells *et al.* (13) and Rand *et al.* (9). The whole blood Vc was first measured in relation to blood Ht at the shear rates previously mentioned. The rate of change of Vc of adult and

newborn blood in presence of change in Ht was studied by plotting the logarithm of Vc against Ht. The statistical analysis of the regression lines were performed according to the methods outlined in Snedecor and Cochran (11). A preliminary test of the residual variances about the regression lines was done when these tests were not significant, it was then possible to assess the equality of the two slopes. If these tests were not significant the common values of the slopes were estimated, and the intercepts were calculated. The equality of the two intercepts could then be assessed. The Vc of adult and newborn blood in relation to the shear rate was also compared at three Ht ranges: 30–40, 50–60, and 60–70%. The Vc found for each sample was divided by the Vc of its plasma to obtain the relative apparent Vc (2). This ratio reflects the rheologic properties of the erythrocyte suspension. Unpaired Student's *t* test was used for statistical analyses unless specified otherwise.

RESULTS

The influence of Ht changes on the apparent Vc of neonatal and adult blood at four different shear rates is shown in Figure 1. In all instances Vc increases with a rise of Ht, and at a given Ht the Vc decreases with increasing shear rates. Absolute values of adult blood appear to be higher than those of the newborn lamb. The comparison of the rate of change of the Vc of adult and newborn blood in presence of change in Ht is shown in Figure 2. The tests for the equality of variances were not significant at the 0.05 level. The tests of the equality of the slopes were also not significant at 0.05 level. All the tests of the equality of the intercepts were highly significant ($P < 0.001$) for all shear rates studied. Figure 3 A, B, and C show the quantitative comparison between the two types of blood at three different ranges of Ht. The apparent Vc of adult blood is consistently greater than that of the newborn. This difference is significant ($P < 0.01$) at Hts ranging from 50–60% irrespective of the shear rate studied. At the Ht range of 30–40% the difference was significant ($P < 0.01$) only at shear rate of 115 and 230 sec^{-1} .

Plasma Vc averaged for the newborn 1.21 ± 0.19 cp and for the adult 1.58 ± 0.18 cp. The difference was significant ($P < 0.001$). Relative apparent Vc (whole blood Vc divided by the plasma Vc) was plotted against the shear rate for the same three Ht ranges as shown in Figure 3 (Figure 4). In all instances and for all shear rates, the relative Vc of the adult blood was lower than that of the newborn blood, although the differences were not statistically significant.

DISCUSSION

This study demonstrates that at a given Ht, whole blood Vc of adult sheep is significantly higher than that of the newborn lamb. As observed with human blood, the difference between adult and newborn blood Vc is due to the plasma Vc, which is more elevated

Fig. 1. Comparing the relationship of hematocrit changes on whole blood viscosity of adult and newborn blood at different shear rates: (A) 11.5; (B) 46; (C) 115; and (D) 230 sec^{-1} .

Fig. 2. Influence of hematocrit changes on whole blood viscosity expressed in logarithm values at different shear rates of (A) 11.5; (B) 46; (C) 115; and (D) 230 sec^{-1} .

in the adult blood (10). Plasma Vc is primarily related to the fibrinogen concentration (14). Kisker *et al.* (6) have shown that in the newborn lamb, fibrinogen concentration at birth averages 117 mg/dl, which is 60% of the adult sheep level. Although the direct effect of fibrinogen has not been demonstrated in the present study, it can be speculated that the lower plasma Vc of the newborn lambs may be due, at least in part, to the lower fibrinogen concentration. Chien *et al.* (4) have also shown that fibrinogen affects whole blood Vc at low shear rates by inducing red cells aggregation.

Several comparative hemorheologic studies have revealed that various mammalian species have erythrocytes with different properties (3, 12). For example, at low shear rates, in the presence of plasma proteins (fibrinogen, macroglobulins) adult sheep erythrocytes do not form large aggregates like those observed in the human. Also, adult sheep erythrocytes were found to be more rigid than the adult human cells. Furthermore, deformability could be different according to the type (adult or fetal) of the red

Fig. 3. A comparison of fetal and adult blood based on the relationship between whole blood viscosity and shear rates at three different ranges of hematocrit: (A) 30-40%; (B) 50-60%; and (C) 60-70%. The lines join the mean and a S.D. The N values (number of viscosity studies) for (A) adult, 12 and newborn 11; (B) adult, 5 and newborn, 7; and (C) adult, 12 and newborn, 16.

Fig. 4. A comparison of fetal and adult blood based on the relationship between relative viscosity and shear rates at three different hematocrit ranges (A) 30-40%; (B) 50-60%; and (C) 60-70%. Relative viscosity is the ratio of whole blood and plasma viscosity. The lines join the mean and a S.D. N values for (A) adult, 5 and newborn, 5; (B) adult, 5 and newborn, 9; and (C) adult, 7 and newborn, 13.

cells in the same species. This is seen in the human being where fetal red cells are less deformable than adult red cells and thus contribute to the increase in Vc at higher shear rates (7, 10). In spite of these differences, it is of interest to report that the absolute values of whole blood Vc found in the present study are similar to that found in human blood (10).

All these different factors should always be taken into account when applying Vc studies on ovine blood to human being, especially during the perinatal period.

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