THE EFFECT OF pH AND BLOOD GAS CORRECTION ON DPG AND PLASMA POTASSIUM CONTENT OF STORED BLOOD

CHARLES L. WALTEMATH*

THE SERUM POTASSIUM content of CPD preserved blood increases, reaching values above 20 mEq/L after 21 days of storage. This is due to a slow loss of potassium from intact red cells, and to a lesser extent from destruction of formed elements. Any treatment to decrease plasma potassium of stored blood must involve re-uptake by intact red cells. Eurenus and Smith¹ recently reported that warming of stored blood to 37° C does not reduce the plasma potassium. Bank blood is also acidotic, hypercarbic and hypoxic. These defects are corrected by the recipient after the blood has been transfused.

A close relationship of red cell potassium and 2,3-DPG was demonstrated in three subjects by Valeri and Hirsch.² Red Cell DPG content decreases during blood storage, but no direct relationship of potassium and DPG changes have been found.

The purpose of our *in vitro* study was twofold: first, to determine the effect on plasma potassium and 2,3-DPG of stored blood when blood gas and pH are returned to normal; and second, to subject fresh blood to the blood gas and pH conditions of blood storage and examine the effect on plasma potassium.

METHODS

The stored blood was taken from 36 transfusion units being administered to surgical patients. The blood bags were gently agitated to ensure complete mixing and the samples were taken after the blood had passed through a dacron-wool filter and had been warmed to 37° C in a coil. Six 3 ml samples were obtained in syringes without added anticoagulant and without passing the blood through a needle. The P_{O_2} , P_{CO_2} , pH, and plasma potassium were determined on one of the six samples.† Two others were subjected to open circuit tonometry at 37° C with humidified gas mixtures listed for flasks 1 and 2 in Table I. Tonometry was limited to 30 minutes, since longer periods result in red cell destruction. In one of these two samples blood gases would be in the physiological range, but the other would be hypoxic in the presence of a normal P_{CO_2} . Following tonometry, P_{O_2} , P_{CO_2} , pH and plasma potassium were measured in these samples. The remaining three samples were centrifuged in the syringes in such a manner that the red cells were impacted against the plunger and the plasma remained near the hub. This allowed 0.075 ml of $NaHCO_3$ (2.5 mEq/ml) to be added to the plasma phase. The samples were then gently remixed. Two of these buffered samples were subjected to tonometry with the gases as described above. The remaining buffered sample was

*Department of Anesthesiology, University of Oregon Medical School, Portland, Oregon 97201.

†Radiometer A/S., Copenhagen, Denmark.

TABLE I
TONOMETRY GASES (IN PERCENT)

Gas	Flask 1	Flask 2	Flask 3
Oxygen	20.78	<10	<10
Carbon Dioxide	6.94	6.78	20.75
Nitrogen	72.28	93.22	79.25

allowed to incubate in the syringe for 30 minutes at 37° C. The P_{O_2} , P_{CO_2} , pH and plasma potassium were then determined on these three samples. Any reduction in potassium or DPG due to dilution by the added buffer (0.075 ml in 3.0 ml) would be less than 2.5 per cent.

In cases in which gross haemolysis was apparent the plasma haemoglobin was measured. Red cell indices, DPG and total blood potassium were measured on samples from each group, the enzymatic method being employed for DPG estimation.

Additional paired heparinized venous samples were obtained from six surgical patients. After plasma potassium had been determined, the samples were centrifuged as described above and 0.2 ml of 0.1 N HCl was added to the plasma. The samples were remixed and then subjected to tonometry for 30 minutes with the humidified gas listed for flasks 1 and 3 in Table I. This resulted in one sample with metabolic acidosis, normocarbia and normal oxygen tension, and the other with hypoxia and both metabolic and respiratory acidosis. The P_{O_2} , P_{CO_2} , pH and plasma potassium of each of these samples was then determined.

All data comparisons are by parabolic curve fitting.

RESULTS

During storage of CPD preserved blood, there is a progressive decrease in red cell DPG and blood pH with a simultaneous increase in plasma potassium. These changes are summarized in Tables II and III and in Figures 1 and 2.

Correction of acidosis, with or without blood gas correction decreases plasma potassium (Table II). There is a close inverse correlation between pH and plasma potassium (Figure 1). But only in blood stored less than five days does plasma potassium return to the normal range after pH and gas correction.

Correction of blood gases and pH increases red cell DPG (Table III). There is a highly significant inverse correlation ($r = 0.9891$ by parabolic regression) between red cell DPG and plasma potassium as the pH is corrected (Figure 3).

Table IV lists potassium changes in fresh blood induced by addition of HCl, by hypercarbia and hypoxia. Neither metabolic acidosis nor combined acidosis and hypoxia increase plasma potassium.

No control samples were grossly haemolyzed. Three of the samples with more than 21 days of storage showed evidence of haemolysis after tonometry, but in none was plasma haemoglobin above 80 mg%. This represents 0.5 per cent haemolysis and would have increased plasma potassium by only 0.2 mEq/L and would

TABLE II
pH AND PLASMA POTASSIUM CHANGES IN STORED BLOOD AFTER BUFFER AND/OR GAS CORRECTION

Blood Gas Correction	NONE (Blood Bag Contents)	Normal O ₂ Normal CO ₂ No buffer		Normal O ₂ Normal CO ₂ Buffer Added		Low O ₂ Normal CO ₂ No buffer		Low O ₂ Normal CO ₂ Buffer Added		Low O ₂ High CO ₂ Buffer Added								
		K ⁺	pH	K ⁺	pH	ΔK ⁺ †	K ⁺	pH	ΔK ⁺	K ⁺	pH	ΔK ⁺	K ⁺	pH	ΔK ⁺			
0-5	Storage Age (days)	6.8 ±1.5	6.93 ±0.07	6.0 ±1.3	7.13 ±0.8	14	5.5 ±0.9	7.48 ±0.9	19	6.0 ±1.2	7.0 ±0.16	14	5.5 ±1.4	7.40 ±0.06	19	5.9 ±1.3	7.07 ±0.05	13
		12.6 ±2.8	6.78 ±0.04	11.4 ±2.3	6.99 ±0.05	9	10.2 ±2.0	7.41 ±0.07	19.5	11.6 ±2.4	7.04 ±0.05	8	10.2 ±2.3	7.45 ±0.07	19.5	10.5 ±1.7	7.07 ±0.12	17
11-15		14.7 ±2.4	6.72 ±0.02	13.7 ±2.0	6.97 ±0.04	7	12.5 ±2.1	7.46 ±0.11	15	13.8 ±2.2	7.03 ±0.04	6	12.2 ±1.8	7.55 ±0.11	17	11.5 ±0.9	7.20 ±0.15	22
16-21		16.6 ±2.8	6.69 ±0.03	16.1 ±2.5	6.92 ±0.03	3	14.3 ±2.4	7.48 ±0.08	14	15.8 ±2.5	6.98 ±0.03	5	14.5 ±2.5	7.48 ±0.10	13	14.4 ±1.5	6.95 ±0.04	14
22+		22.3 ±1.9	6.61 ±0.2	21.3 ±0.2	6.78 ±0.04	4	17.4 ±1.4	7.48 ±0.03	22	20.4 ±2.2	6.60 ±0.04	9	17.3 ±1.6	7.38 ±0.03	22	16.3 ±1.6	7.17 ±0.06	27

*(mEq/L).

†Change in K⁺ in per-cent. In all cases this is a decrease in K⁺.

TABLE III
2,3-DPG* CHANGES AFTER GAS/AND BUFFER CORRECTION

Storage Age (Days)	Blood Bag Contents	Normal O ₂ Normal CO ₂ No Buffer	Normal O ₂ Normal CO ₂ Buffer Added
0-7	15.32	15.58	16.08
8-14	7.57	9.43	10.20
14+	5.57	7.00	7.62

* $\mu\text{M/gm}$ Hemoglobin.

FIGURE 1. Relationship of plasma potassium and pH (from the data listed in Table II). The age listed is days of storage. The curves are lines of best visual fit. In each group the solid symbol is the sample which was buffered without gas correction.

not have changed DPG. There was no significant change in mean corpuscular volume in any sample.

In six samples with more than 21 days of storage, the mean plasma potassium was 22.3 mEq/L and the mean total blood potassium was 48.8 mEq/L.

DISCUSSION

Recently, Schweizer and Howland³ have reviewed the marked metabolic changes that occur in blood preserved in CPD and stored for transfusion. How-

FIGURE 2. Relationship of plasma potassium and duration of blood storage. The open circle data point represents blood stored for 22-30 days.

FIGURE 3. Relationship of red cell DPG and plasma potassium.

ever, they did not mention the significant increase in plasma potassium. After two weeks of storage plasma potassium is likely to be more than 15 mEq/L, and at three weeks to be above 20 mEq/L (Figure 2).

Transfusion recipients usually correct the metabolic lesion of stored blood. However, patients who receive rapid, large volume transfusions often develop signs

TABLE IV
EFFECT OF ACUTE METABOLIC AND RESPIRATORY ACIDOSIS AND
HYPOXIA ON PLASMA POTASSIUM

	PO ₂ (torr)	PCO ₂ (torr)	pH	K ⁺ (mEq/L)
Control	—	—	—	3.7 ± 0.6
Metabolic Acidosis	132 ± 10	36 ± 2	7.2 ± 0.05	3.4 ± 0.5
Combined Metabolic and Respiratory acidosis and Hypoxia	<10	113 ± 4	6.86 ± 0.04	3.6 ± 0.7

of cardiac failure. This is usually associated with prolonged hypotension, decreased peripheral perfusion and decreased renal function. In addition these patients tend to be acidotic and hyperkalaemic. It is likely that the acid and potassium load from the stored blood contributes to these problems.

Normally less than 10 per cent of total blood potassium is in the plasma. After 21 days of storage, the ratio between intracellular and plasma potassium approaches 1:1. This implies a loss of the mechanism which binds potassium within the cells or prevents its diffusion across the cell membrane. Benesch and Benesch⁴ have suggested that ion transport in red cells may be controlled by the level of free organic phosphates, such as 2,3-DPG. DPG decreases during blood storage⁵ and slowly regenerates after transfusion.² However, no direct relationship between decreasing DPG and loss of red cell potassium has been proven. It may be that each is dependent on normal red cell metabolic activity and corrects itself as this is re-established.

Increasing the pH of stored blood decreases plasma potassium and increases red cell DPG. These changes are closely correlated (Figure 3) and in proportion to the increase in pH. The mechanism of this relationship could not be determined, but considering the known relationship of DPG and pH⁶ one may postulate an initial increase in DPG which in turn causes potassium uptake by the red cells.

The regeneration of DPG by stored red cells begins immediately after transfusion, but is not complete for several days. For this reason, it is possible that longer equilibration of the blood would have resulted in greater change of DPG and potassium. However, tonometry longer than 30–45 minutes leads to increasing haemolysis. It is unlikely that the changes reported are due to movement of water between red cells and plasma, as mean red cell size did not change.

SUMMARY

During storage of CPD preserved blood, red cell DPG decreases and plasma potassium increases, the changes becoming more marked with increasing duration of storage. Correction of the blood gas and pH alterations of stored blood decreases plasma potassium and increases red cell DPG, but they do not return to normal except in blood stored less than seven days. There is a highly significant correlation between increasing red cell DPG and decreasing plasma potassium as the pH and blood gases of stored blood are restored to physiological range.

RÉSUMÉ

Les taux du potassium plasmatique augmentent et ceux des DPG cellulaires diminuent dans le sang de banque en solution CPD et ces changements deviennent plus marqués avec la durée du storage.

La correction des gaz et du pH du sang de banque permet de diminuer les modifications ci-haut mentionnées. Cependant ces paramètres ne demeurent normaux que sur du sang conservé moins de sept jours.

La corrélation entre l'élévation des DPG cellulaires et l'abaissement du potassium plasmatique consécutives à la restauration des gaz sanguins et du pH à des valeurs normales est hautement significative.

REFERENCES

1. EURENIUS, S. & SMITH, R.M. The effect of warming on the serum potassium content of stored blood. *Anesth.* 38: 482 (1973).
2. VALERI, C.R. & HIRSCH, N.M. Restoration *in vivo* of erythrocyte potassium ion, and sodium ion concentrations following the transfusion of acid-citrate-dextrose-stored human red cells. *J. Lab. and Clin. Med.* 73: 722 (1969).
3. SCHWEIZER, O. & HOWLAND, W.S. 2,3-Diphosphoglycerate levels in CPD-preserved bank blood. *Anesth. and Analg.* 53: 516 (1974).
4. BENESCH, R. & BENESCH, R. Oxygenation and ion transport in red cells. *Science* 160: 83 (1968).
5. BUNN, H.F., MAY, M.H., KOCHOLATY, W.F., *et al.* Hemoglobin function in stored blood. *J. Clin. Invest.* 48: 311 (1969).
6. BELLINGHAM, A.J., DETTER, J.C., & LENFANT, C. Regulatory mechanisms of hemoglobin oxygen affinity in acidosis and alkalosis. *J. Clin. Invest.* 50: 700 (1971).