OXYGEN DISSOCIATION CURVES IN SICKLE CELL ANEMIA 
AND IN SUBJECTS WITH THE SICKLE CELL TRAIT

BY MARGARET R. BECKLAKE, S. B. GRIFFITHS, M. MCGREGOR, H. I. GOLDMAN,
AND J. P. SCHREVE

(From the Cardiopulmonary Unit of the Council for Scientific and Industrial Research, 
Department of Medicine, University of the Witwatersrand and from the South African
Institute for Medical Research, Johannesburg, South Africa)

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In view of the well recognized differences between sickle and normal hemoglobin (1, 2), it was thought that a comparative study of the affinities of sickle and normal hemoglobin for oxygen as shown by the oxyhemoglobin dissociation curve would be of interest.

MATERIAL AND METHODS

Material: A large number of African blood donors were tested for the sickling phenomenon using the sodium hydrosulphite technique (3).

All donors were healthy mine laborers acclimatized to manual work on the Witwatersrand Goldfields. Of the seven subjects studied with the sickle cell trait, two came from Angola, two from Nyasaland and one each from Portuguese East Africa and Tanganyika. The seventh subject was a South African born Indian. One of the cases of sickle cell anemia studied has been described in greater detail elsewhere by Altmann (4). The three other cases of anemia were South African born Indian children all over 4 years of age whose grandparents came from Surat, near Bombay. Controls were selected from European hospital patients admitted for unrelated complaints. All cases of the trait studied had been resident at the altitude of Johannesburg \(^1\) for a minimum of 10 weeks. The cases of anemia were all permanent residents of Johannesburg.

Method: Arterial blood was drawn directly into heparinized syringes. Twelve ml. samples were equilibrated in tonometers of approximately 90 ml. capacity for 20 minutes at 37°C with gas mixtures containing nitrogen, carbon dioxide and oxygen in varying amounts so as to give three or four points on the dissociation curve. The carbon dioxide was maintained at a gas tension of approximately 34 mm. Hg which is the average normal alveolar CO\(_2\) tension for this altitude \(^1\) (5). After equilibration the blood samples were stored in syringes at approximately \(4^\circ\) C. until they were analyzed on a Van Slyke-Neill manometric apparatus. Analyses were completed in duplicate within ten hours of drawing the samples and were required to agree within .1 vols. per cent.

The gas samples were analyzed on a Haldane apparatus with a burette of 10 ml. capacity. The cell pH of each sample was calculated from the Henderson-Hasselbalch equation with values of cell pK taken from the nomogram of Keys, Hall, and Barron (6). The cell pK of the blood of patients with sickle cell anemia could not be derived from this nomogram but was calculated directly from the formula for cell pK based on work by Stadie and Hawes (7) from which the nomogram of Keys, Hall, and Barron (6) was derived. Correction of the position of curve according to the cell pH was carried out by use of the factor of Keys, Hall, and Barron (6) to permit comparison of curves at a constant cell pH (in this case 7.1). The logarithm of the value for pO\(_2\) so corrected was plotted against the corresponding percentage saturation and the line of the dissociation curve was drawn to fit the experimental points as closely as possible, assuming it to be parallel to the normal curve described by Dill for blood pH 7.4 (5). From the curve so obtained the pO\(_2\) corresponding to a saturation of 50 per cent was obtained for each individual case. By using these corrections it was hoped that differences in the position of the curves due to differences in cell pH could be eliminated. However, in view of the fact that the calculations of Stadie are based on observations on normal hemoglobin, it is possible that this correction for cell pH may be invalid for sickle hemoglobin. For this reason Table I includes for comparison values for pO\(_2\) for Hb = HbO\(_2\) at the cell pH of blood in the tonometers uncorrected to a cell pH of 7.1.

\(^1\) 5780 feet above sea level.

<table>
<thead>
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<th>TABLE I</th>
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<tr>
<td>Normal</td>
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</tr>
<tr>
<td>Number of cases</td>
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<td>HbO(_2) vols. % (Mean)</td>
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<td>pCO(_2) in tonometers (Mean)</td>
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<td>Calculated cell pH (6) (Mean)</td>
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<td>pO(_2) for Hb = HbO(_2) at cell pH of blood in tonometers (Mean)</td>
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<tr>
<td>Standard deviation</td>
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<tr>
<td>pO(_2) for Hb = HbO(_2) at cell pH of 7.1 (Mean)</td>
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<td>Standard deviation</td>
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$$pO_2$$ values have been corrected to a cell pH of 7.1. The normal curves for blood pH of 7.6, 7.4, and 7.2, shown in continuous lines, are taken from the work of Dill (5).

RESULTS

Results are tabulated in Table I, and are represented graphically in Figure 1 which shows the individual points from which the curves were derived.

The significance of the differences of the mean $$pO_2$$ for Hb = HbO$_2$ of normal bloods on the one hand and in cases of sickle cell trait and sickle cell anemia on the other hand has been tested using Student's t test (8). The mean $$pO_2$$ for Hb = HbO$_2$ of the sickle anemia bloods is significantly different from the $$pO_2$$ for Hb = HbO$_2$ of normal blood ($p > .01$) when considered both at the cell pH of blood in the tonometers and at a cell pH of 7.1. The curve of one of the sickle anemias studied showed much less displacement to the right than the others ($pO_2$ for HbO$_2$ at cell pH of blood in tonometers was 30.1 mm.). This case had been admitted to hospital acutely ill in a crisis and had received many transfusions in the course of treatment, so that only about 30 per cent of circulating hemoglobin at the time of study was the patient's own. This no doubt accounts for the much less significant shift in position of this curve compared to curves on the other three cases of anemia studied in whom over 98 per cent of the hemoglobin present was abnormal.

The mean $$pO_2$$ for Hb = HbO$_2$ of the cases with the sickle cell trait is also greater than the corresponding value for normal blood both at the cell pH of blood in the tonometers and at a standard cell pH of 7.1 but this difference is not statistically significant ($p = .2$ to .1).
DISCUSSION

The techniques used in this study have been criticized by Lambertsen, Bunce, Drabkin, and Schmidt (9) whose experiments, using spectrophotometric techniques, suggested that the true dissociation curve for hemoglobin at a blood pH of 7.4 lies to the left of the curve of Dill (5). Our mean normal curve (pO₂ for Hb = HbO₂ = 26.0 mm. Hg) also lay to the left of Dill's curves (pO₂ for Hb = HbO₂ = 26.3 mm. Hg) though this difference in position does not appear to be of any statistical significance. The altitude at which these studies were carried out (5780 ft. above sea level) may have been the reason for the slight shift to the left in position of our normal curve (6). However, the interest in these results lies not so much in the position of the normal dissociation curve at this altitude as in the difference between its position and that of the cases of sickle cell anemia or trait.

Only one record of the oxygen dissociation curve of whole blood from a case of sickle cell anemia was found in the literature (10). In this report the curve of the case of anemia is shown graphically to be shifted to the right of a normal curve which on scrutiny is found to be in the position of Dill's normal curve at blood pH of 7.2. It is not clear from the text if the curve of the anemia subject was corrected to the same cell pH as the normal with which it was compared. The authors concluded that the shift in the position of the curve was not peculiar to the sickle blood but was probably due to anemia and a decrease in the cell pH coincident with insufficient oxygenation.

Other workers have reported a similar shift to the right of the dissociation curve in various types of anemia even when the cell pH, carefully controlled, is comparable to that of the normal curves used in comparison (11-13). Dill and his co-workers (11) produced evidence to show that in pernicious anemia there was certainly a relative alkalosis of the serum and probably relative acidois of the cells. These changes they felt were quite sufficient to account for the shift in position of the curve which returned to a normal position when adequate treatment had led to a return to normal in the blood count.

Kennedy and Valtis (13) also found that the oxygen dissociation curve of blood of cases of Ad-
the difference in the oxygen affinities of sickle anemia hemoglobin and normal hemoglobin is apparently only demonstrable when the two types of hemoglobin are studied in their natural plasma environment. The influence of the hemoglobin environment on the oxygen dissociation curve has been previously demonstrated by Wyman, Allen, and Smith (16) who showed that the difference in the oxygen affinities of fetal and normal hemoglobin was due to dialyzable factors. An analogous situation appears to have been demonstrated here in the difference between the oxygen affinities of sickle and normal hemoglobin. The hypothesis that the hemoglobin environment is responsible for the difference in oxygen affinity demonstrated here appears to fit our findings better than the suggestion that the difference in oxygen affinity is due to differences in the inherent properties of the two hemoglobins.

The conclusions to be derived from our studies on sickle trait hemoglobin are confused by the results in one case of sickle cell trait which differed greatly from the other 6 cases. Excluding this one case the mean $pO_2$ for $Hb = HbO_2$ of sickle trait hemoglobin was significantly different from the mean normal $pO_2$ for $Hb = HbO_2$ ($p = > .01$). When this case is included, the scatter of results makes the difference of no statistical significance ($p = .2$ to $.1$). On account of the unusual results, this case was studied on three separate occasions within a period of 3 months to make certain that technical errors could not have accounted for the result obtained ($pO_2$ for $Hb = HbO_2$ was 22.8 mm.). Electrophoretic studies on the blood of this case gave results similar to those in the other cases of the sickle cell trait and consequently afforded no reason for the curve of this case being so differently placed from the curves of the other sickle trait blood examined. The rarity of the sickle cell trait in South Africa has made it not possible to determine, by the study of a larger series, if the exceptional case in the present series of 7 must be regarded as significant.

**SUMMARY AND CONCLUSIONS**

1. The oxygen dissociation curve of blood from 4 cases of sickle cell anemia studied by the in vitro tonometer method was significantly displaced to the right of the dissociation curve of blood from 10 normal subjects.

2. The oxygen dissociation curve of blood from 7 cases of sickle cell trait studied by the same method showed no such significant displacement.

3. These observations in conjunction with the work of Wyman, Allen, and Smith (16) on the oxygen affinity of dialyzed solutions of sickle and normal hemoglobin are consistent with the hypothesis that this difference in oxygen affinity is due to dialyzable factors, i.e., the serum environment of the cell rather than actual differences between the affinity of normal and sickle anemia hemoglobin for oxygen.

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**REFERENCES**


