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

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(Submitted for publication November 16, 1953; accepted January 22, 1954)

In view of the well recognized differences be-
tween 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 com-
plaints. 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 resi-
dents of Johannesburg.

Method: Arterial blood was drawn directly into hepari-
nized syringes. Twelve ml. samples were equilibrated in
tonometers of approximately 90 ml. capacity for 20 min-
utes at 37° C. with gas mixtures containing nitrogen, car-
bon 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 ap-
proximately 34 mm. Hg which is the average normal
alveolar CO2 tension for this altitude 1 (5). After equili-
bration the blood samples were stored in syringes at
approximately 4° C. until they were analyzed on a Van
Slyke-Neill manometric apparatus. Analyses were com-
pleted in duplicate within ten hours of drawing the sam-
ple 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 nomo-
gram of Keys, Hall, and Barron (6) was derived. Cor-
rection 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
pO2 so corrected was plotted against the correspond-
ing 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 pO2 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 cal-
culations 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 pO2 for Hb =
HbO2 at the cell pH of blood in the tonometers uncor-
tected to a cell pH of 7.1.

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1 5780 feet above sea level.

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**TABLE I**

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Sickle cell anemia</th>
<th>Sickle cell trait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cases</td>
<td>10</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>HbO2 vols. % (Mean)</td>
<td>18.95</td>
<td>12.55</td>
<td>19.95</td>
</tr>
<tr>
<td>pCO2 in tonometers (Mean)</td>
<td>32.6</td>
<td>36.9</td>
<td>34.2</td>
</tr>
<tr>
<td>Calculated cell pH (6) (Mean)</td>
<td>7.18</td>
<td>7.00</td>
<td>7.08</td>
</tr>
<tr>
<td>pO2 for Hb = HbO2 at cell pH of blood in tonometers (Mean)</td>
<td>25.7</td>
<td>42.6</td>
<td>28.6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>±1.10</td>
<td>±5.08</td>
<td>±.97</td>
</tr>
<tr>
<td>pO2 for Hb = HbO2 at cell pH of 7.1 (Mean)</td>
<td>26.0</td>
<td>40.0</td>
<td>28.1</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>±.42</td>
<td>±4.82</td>
<td>±.97</td>
</tr>
</tbody>
</table>
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).
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 coworkers (11) produced evidence to show that in pernicious anemia there was certainly a relative alkalosis of the serum and probably relative acidosis 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 pO₂ for Hb = HbO₂ of sickle trait hemoglobin was significantly different from the mean normal pO₂ for Hb = HbO₂ (p > 0.01). When this case is included, the scatter of results makes the difference of no statistical significance (p = 0.2 to 0.1). 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 (pO₂ for Hb = HbO₂ 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 (15, 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.

ACKNOWLEDGMENTS

Our thanks are due to Professor G. A. Elliott in whose department the blood gas studies were carried out and for his helpful criticism of the text, to Dr. E. Cluver, Director of the South African Institute for Medical Research, for facilities given, and to Dr. A. Zoutendyke who made available the sickle cell trait blood for study. All electrophoretic studies were performed by Dr. C. J. Anderson of the South African Institute for Medical Research, and he very kindly put us in touch with three of the cases studied. Medical Officers of various Reef Mine Hospitals assisted in giving facilities for study of individual cases, and Dr. G. H. Soni of Johannesburg kindly allowed us to study three of his patients.

REFERENCES

O₂ DISSOCIATION CURVES IN SICKLE ANEMIA AND TRAIT


