An examination of carboxyhemoglobin levels in a community blood bank was undertaken to ascertain the human carboxyhemoglobin burden in relation to stored blood. Smoking histories were obtained from 198 volunteer blood donors. Carboxyhemoglobin determinations were made at the time of donation and at the time of recipient transfusion of the donor unit. T-test for repeated measures demonstrated no significant difference (p < .05) in carboxyhemoglobin levels between donation and recipient transfusion, and between inhaling and non-inhaling cigarette smokers. This author suggests that all banked blood be prominently labeled with carboxyhemoglobin content.

A variety of habitual and environmental factors can impact upon the quality of donor blood. The donor's physical condition, nutritional status, erythropoietic system, exposure to environmental pollutants (such as carbon monoxide), and changes that occur during blood storage influence the suitability of the blood for recipient transfusion. Carbon monoxide (CO) is a by-product of cigarette smoking and is known to bind 210 times more readily with hemoglobin than oxygen, forming the carboxyhemoglobin (CoHb) complex. Smoking provides a ready source of CO. While non-smokers have measurable levels of CoHb from endogenous production and environmental exposure, the CoHb levels of inhaling smokers are significantly higher and may approach 18%.2

In a national survey, Stewart et al. found that the mean CoHb levels for smoking blood donors exceeded 5% in most locales, and that increased levels were in part due to the contribution of community exposure to CO.8 Davis and Ganter examined 16,649 donor units and found that 39% of the donor population engaged in cigarette smoking on the day of donation, with 17% exhibiting CoHb levels in excess of 5%.4 Shields compared CoHb levels in smoking and non-smoking blood donors under 40 years of age with those of patients over the age of 40 from a medical or pulmonary disease clinic.9 A post-hoc comparison demonstrated higher CoHb levels from the group of donors over age 40 who had known medical and pulmonary disease histories.

Is the smoking individual a quality blood donor? It would appear that if a recipient were transfused with donor blood containing significant levels of CoHb, the recipient would receive blood with additional biochemical alterations. It would be unwise to administer banked blood containing high levels of CoHb to recipients with seriously compromised cardiovascular reserves, when the primary purpose is to improve oxygen transport. The
fact that the biological half-life of CO in donor blood is five hours following recipient transfusion would indicate that the administration of banked blood with increased CoHb levels is clinically relevant.\textsuperscript{3}

The following hypotheses were used to elucidate whether the smoking individual is a quality blood donor, and to quantify the CoHb levels in the community blood bank studied to ascertain the human CoHb burden in relation to stored blood:

1. There is no difference in the CoHb levels between individuals who smoke less than one pack per day, those who smoke one to two packs per day, and those who smoke greater than two packs per day.

2. There is no difference in the CoHb levels of donor blood at the time of donation as compared to the time of removal for recipient transfusion.

3. There is no difference in CoHb levels between individuals who smoke less than five cigarettes within eight hours of donation and those who smoke more than five cigarettes within eight hours of donation.

4. There is no difference in CoHb levels between individuals who inhale and those who do not inhale while smoking.

5. There is no difference in CoHb levels between individuals under 40 years of age and those over 40 years of age.

### Methodology

Institutional review and approval of the human subjects committee of the university through which this study was performed were obtained. The subjects numbered 198 informed volunteer blood donors, male and female ages 18-75 years, who participated via a convenient sampling technique over a one-month period. The tool was a closed-ended, balanced scalar questionnaire used to obtain smoking histories (Table I). Medical histories were obtained by blood bank personnel, and a screening hematocrit was obtained to ensure a value of at least 39% for females and 41% for males. A total of 3 ml of venous blood was allowed to flow into a sodium heparinized green-top tube (Vacutainer\textsuperscript{®}, Becton Dickinson) and sealed following completion of blood donation. The samples remained at 22-25° C until analyzed at day's end.

It has been demonstrated that the CoHb moiety in blood stored at 4.5° C and at 22° C showed no signs of deterioration for periods up to six weeks in refrigerated samples, and up to two weeks in non-refrigerated samples.\textsuperscript{6} This author verified this stability in an earlier pilot study, finding that the CoHb levels did not vary over an eight-hour period at 22° C.

Thirty-five \(\mu\)l of the whole blood sample were used to determine the CoHb concentration using heparinized glass capillary tubes and a Radiometer OSM 3 Hemoximeter\textsuperscript{®} (Radiometer, Copenhagen, Denmark). Calibration standards were used for initial machine set-up and following the analysis of every 10 samples. Results were recorded, and the units were followed to two area hospital blood banks. All donor units contained the preservative CPD-A and were stored at 0-4° C.

At the time of recipient transfusion, one "pigtail" section of donor tubing was obtained for CoHb determination. Storage duration, in days from the time of donation, was recorded. The "pigtail" samples were allowed to warm to room temperature, and mixing was facilitated by rolling the sample between hands for one minute to ensure a uniform sample. Repeat CoHb determinations, as previously described, were made to compare and

### Table I

**Questionnaire used to obtain smoking histories**

Please answer the following questions by circling the appropriate response, or by writing your answer to the question as indicated.

1. Do you smoke?
   (a) cigarettes
   (b) pipe
   (c) cigars
   (d) do not smoke

   **If you do not smoke, do not complete this questionnaire.**

2. Have you smoked within the past two weeks?
   (a) yes
   (b) no

3. How many packs of cigarettes do you smoke per day?
   (a) less than one
   (b) one to two
   (c) two or more

4. Do you inhale when you smoke?
   (a) yes
   (b) no

5. How many cigarettes have you smoked within the past eight (8) hours? __________

6. How many years have you smoked cigarettes? __________
predict the impact of the blood banking process on the CoHb level.

Step-wise multiple regression analysis was employed to measure the predictor ability of the multiple independent variables (sex, age, and smoking history) on the dependent variable (CoHb). A T-test for repeated measure was utilized for the analysis of the CoHb level throughout the storage period. A T-test analysis was also used to determine the significance (p < .05) of the inhaling versus the non-inhaling smokers, as well as the significance of the CoHb levels of those individuals under the age of 40 and those over the age of 40.

Table II
Stratification of banked units by carboxyhemoglobin levels

<table>
<thead>
<tr>
<th>CoHb %</th>
<th>Number of units</th>
<th>% total units</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-1.3</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>1.4-2.0</td>
<td>73</td>
<td>39.2</td>
</tr>
<tr>
<td>2.1-3.0</td>
<td>81</td>
<td>43.5</td>
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<tr>
<td>≥3.1</td>
<td>4</td>
<td>2.1</td>
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<tr>
<td>≥4.0</td>
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</tr>
<tr>
<td>≥7.0</td>
<td>3</td>
<td>1.6</td>
</tr>
<tr>
<td>≥8.0</td>
<td>6</td>
<td>3.2</td>
</tr>
<tr>
<td>≥9.0</td>
<td>2</td>
<td>1.0</td>
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<tr>
<td>Total</td>
<td>186</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Repeat CoHb Determination

<table>
<thead>
<tr>
<th>CoHb %</th>
<th>Number of units</th>
<th>% total units</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-1.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.4-2.0</td>
<td>29</td>
<td>30.5</td>
</tr>
<tr>
<td>2.1-3.0</td>
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<tr>
<td>≥9.0</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Results

Whole blood samples were collected from 198 donors; 36 (18.8%) indicated cigarette smoking histories, 151 (81.2%) indicated non-smoking histories, and 10 donor cards (5%) were without a smoking preference indicated. These 10 blood samples, and two donors (1%) who indicated cigar smoking histories, were not included in the study, leaving a total of 186.

Initial CoHb determinations were made on 186 samples with repeat determinations on 95 samples. Repeat determinations were made on the locally available blood used for recipient transfusion. Table II provides the ranges of CoHb. T-test for repeated measures demonstrated no statistical significance (p < .05) between the initial and the repeat CoHb determinations.

Smoking histories identified two smoking groups: less than one pack per day (CoHb range 2.1%-8.2%), and one to two packs per day (CoHb range 4.4%-9.3%). The range of CoHb levels in non-smokers was 1.7%-3.5%. Figure 1 shows the mean CoHb levels for the smoking and non-smoking groups. Utilizing step-wise multiple regression analysis, the predictor ability of CoHb with increasing cigarette consumption was significant (p < .05). It is apparent from Figure 1 that a predictably higher mean CoHb level is associated with a greater consumption of cigarettes.

Figure 1
Mean carboxyhemoglobin by smoking history

(*) denotes significant difference at the p=.05 level.
Cigarette consumption in the eight-hour period prior to donation (up to five cigarettes, and five or more cigarettes in the eight hours prior to donation) was not significant in predicting the resultant CoHb level.

The research tool identified 27 smokers (12 male, 15 female) less than or equal to the age of 40, and 12 smokers (nine male, three female) over the age of 40. Figure 2 shows the mean CoHb levels.

There were 32 (88.9%) smokers indicating inhaling with cigarette smoking; 3 (11.1%) smokers indicated non-inhaling. Figure 3 shows the mean CoHb levels for the inhaling versus non-inhaling groups.

A total of 95 samples were examined following storage. Days of storage ranged from 2-30 days. Table I illustrates the CoHb levels on initial and repeat determinations. T-test for repeated measures demonstrated no significant difference between the initial and repeat CoHb determination (p < .05).

Discussion

Inhaled CO has been shown to cause tissue hypoxia with a resultant decrease in the p-50 and the driving pressure for tissue oxygenation.7,8 Smoking causes an increase in the CoHb levels, resulting in a leftward shift of the oxyhemoglobin dissociation curve (a decreased p-50) which represents a risk factor for cardiovascular complications.9 In addition, CO alters the respiratory cell enzymes and impairs the cells’ ability to metabolize oxygen aerobically. The primary organ systems affected by CO toxicity are the central nervous system and the myocardium.10 A decreased ability in cerebration has been demonstrated by Shulte.12 CO increases the incidence of arrhythmias and has a negative inotropic effect in animals and humans.11 Approximately 30% of all persons in the U.S. who are 18 years of age or older smoke cigarettes on a regular basis.13 This study identified that 18.8% of the blood donors were smokers.

The methodology limited the participants to volunteers who made the effort to donate at the blood bank facility. These individuals are probably “health conscious” and thus a smaller representative population would be engaged in smoking. If sampling had occurred during “bloodmobile” visits to the workplace, the smoking population may have approached the 30% representative of the population at large.

The elimination of CO (specifically CoHb) is important when discussing its effects upon the smoking donor. The major factors favoring CoHb dissociation are an increase in alveolar ventilation and a high inspired oxygen partial pressure.8,14 Shields examined blood donors using pure oxygen inhalation and exercise, two factors which have been independently shown to decrease the CoHb levels.5
Pre-donation exercises such as these add to the time commitment of the donor and blood bank personnel. Smoking abstinence over a 12-hour period has been demonstrated to significantly decrease the CoHb levels from 6.55% to 1.06% and return the p-50 towards a normal value of 26.4. Based upon the study by Kambam, donors should be educated to abstain for 12 hours prior to donation.

It is difficult to inform donors to abstain from smoking for a 12-hour period, and there are problems with compliance prior to donation. Other methods to predict donors with increased CoHb levels may be more helpful and efficient. This study demonstrated the significance of cigarettes consumed in packs per day: those individuals who smoked one to two packs per day demonstrated higher CoHb levels than those who smoked less than one pack per day.

The effect of the blood banking process on the resultant CoHb level was examined, demonstrating no significant difference in the CoHb level from the time of donation through storage ranging from 2-80 days. Thus the donor with an elevated CoHb level at the time of donation is providing blood with additional biochemical changes which may impact upon the recipient. Poulton attempted to downplay the hazards associated with the CO pollution of banked blood, yet this author found his argument specious and agrees with Aronow, who considers the indiscriminate transfusion of blood with high levels of CoHb to be "inadvisable". The recipient of a donor unit from a heavy tobacco smoker may have an increase in total body CoHb level. Neonates receiving exchange transfusions may have increases in CoHb of seven-fold (1.21%, 7.43%), with post-transfusion recipient levels approaching those of the donor. This highlights the repercussions of the indiscriminate transfusion of banked blood containing high levels of CoHb.

Elevated intraoperative CoHb levels have been reported, with a predictable reduction in hemoglobin available for oxygen transport. Anesthesia providers currently lack the technology to non-invasively measure CoHb levels intraoperatively. The pulse oximeter estimates arterial hemoglobin saturation by measuring light absorbances of perfused tissue. However the pulse oximeter cannot discriminate between reduced hemoglobin, oxyhemoglobin and CoHb. Barker and Tremper have demonstrated that the pulse oximeter overestimates the arterial saturation of hemoglobin in the presence of CoHb. The resultant shift of the oxyhemoglobin dissociation curve, with the resultant hypoxia, would be undetectable without invasive laboratory testing.

It would appear to be inadvisable to transfuse susceptible patients with blood containing high levels of CoHb, particularly when multiple transfusions are required. Labeling of donor units with the CoHb content in banked blood would prevent multiple transfusions of units with increased CoHb levels. This author suggests that CoHb content be determined for all blood designated for recipient transfusion, and that this measurement be noted prominently on all units. An alternative (though an inferior one) would be to label donor units with pack-per-day cigarette consumption to aid in the prediction of CoHb content.

The half-life elimination of CoHb in non-smoking subjects at rest was found to be four hours. This study examined the influence of cigarette consumption within two elimination half-lives of donation (eight hours). The consumption of cigarettes themselves within eight hours of donation does not significantly influence the CoHb level. This is probably reflective of the stability of the CoHb level throughout a 24-hour period in smoking individuals.

This study identified three smokers who denied inhalation with cigarette smoking. The finding of no significant difference in CoHb levels among inhalers and non-inhalers has clinical significance. Most anesthetists have obtained a smoking history from a patient who emphasized, "I don't inhale." Such individuals is this study demonstrated CoHb levels of 2.2%, 5.3%, and 8.7%. Figure 3 shows that the resultant CoHb levels are not statistically different between inhaling and non-inhaling smokers. There appears to be no difference in the CoHb levels of inhaling and non-inhaling smokers.

This study examined the quality of donor blood from the cigarette smoking individual. A total smoking population of 18.2% was identified. The CoHb levels of these individuals persist during storage providing additional biochemical alteration in banked blood. The transfusion of this blood may lead to increased CoHb levels in the recipient with the resultant negative physiological changes.

The CoHb levels of inhaling versus non-inhaling cigarette smokers are identical. Thus donors who state that they smoke but do not inhale are providing the same quality donations as inhaling smokers. The consumption of cigarettes prior to donation should be discouraged, with an abstinence period preceding donation of at least 12 hours. This study refutes the post-hoc comparison by Shields, which demonstrates higher CoHb levels.
in individuals over the age of 40 years. In this donor population there exists no statistical difference.

Conclusion

It is concluded that the smoking donor may donate blood with significant contamination by CoHb. To facilitate the optimal use of donor blood in the clinical setting, it is recommended that all banked blood be prominently labeled with CoHb content.

REFERENCES

(6) Baretta ED, Graff SA & Donohoo KK. Analysis of carbon monoxide in the blood and breath of man. Unpublished data.


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