Carbon-monoxide Monitoring
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INTRODUCTION

Carbon monoxide is one of the chief causes of poisoning morbidity and mortality in the United States. It is responsible for over 400 deaths each year in the US. This can be attributed to the fact that carbon monoxide is so hard to detect. This gas is not visible and does not have a distinct smell, making it really easy for someone to be exposed to it without even knowing it. Carbon monoxide is a byproduct of burnt fuels such as gas, oil, kerosene, wood, and charcoal. Most incidences of carbon monoxide poisoning are credited to poorly functioning or misuse of fuel burning appliances in the home. Yet, other CO poisonings are attributed to idling vehicles and house fires. When exposed to low levels of carbon monoxide one may experience shortness of breath, mild nausea, mild headache, and other long term effects to one’s health. Moderate levels of carbon monoxide exposure may cause severe headaches, dizziness, mental confusion, nausea, and syncope. High levels of carbon monoxide exposure for a long period of time can cause seizures and death. In a clinical setting it may be very difficult to detect carbon monoxide poisoning in a patient, mainly because the symptoms are very vague and nonspecific and may be passed off as a common cold. Usually, if a patient is suspected of having carbon monoxide poisoning, blood is drawn from the patient and analyzed in a lab with a co-oximeter. The co-oximeter measures the percent carboxyhemoglobin or the percentage of the blood that is saturated with carbon monoxide. Drawing blood to measure the blood carbon monoxide level is invasive and takes relatively long, something that patients sometimes don’t have much of. For this reason other noninvasive methods of measuring carboxyhemoglobin levels exist. But it is important to know whether these devices are accurate enough at measuring
carboxyhemoglobin or %COHb levels as the co-oximeter in a lab?

One such device measures exhaled carbon monoxide, which can be related to %COHb. In an experiment, Stewart et al. estimated venous %COHb by measuring the CO of exhaled breaths in 56 firemen in a lab setting and plotted it against theoretical blood COHb. The author reported that the 95% confidence interval for estimating %COHb concentrations was very precise +/- 0.5 %COHb. CO breath analyzers are usually seen in smoking cessation classes as an aid to show people how smoking adds CO to the body. ToxCO smoke analyzer, made by Bedfont Scientific Ltd, is often used for this purpose, but it has potential in being used in medical setting for quick CO analysis. Bedfont markets the device as having less than +/-5% accuracy, making it practical in clinical settings.

Another noninvasive and more common way to analyze %COHb is with a multi-wave pulse-oximeter. When CO enters the body it attaches to the red blood cell just like oxygen does, but CO has a much stronger bond with the hemoglobin. Standard pulse-oximeter uses two wavelengths of light which makes it impossible to distinguish between oxygen and CO in the blood, and thus giving inaccurate SaO2 results. Devices like the Rad-57 and the Redical-7 co-oximeters use eight wavelengths of light, which makes it possible to distinguishing CO from oxygen; thus a proper %COHb and SaO2 is read. In a study, Roth Dominik et al. evaluated the accuracy of multi-wave pulse-oximeter, in which 1,578 Emergency Department patients were studied. Each patient’s CO levels were analyzed with a Masimo Redical-7 co-oximeter and compared with the %COHb that was obtained from a blood gas analysis. The results showed good correlation between the Mesimo Redical-7 and the blood gas values, even though the
results correlated better at higher levels of $\%COHb^5$.

When a patient is presented to the ED with suspected CO poisoning there is no time to waste. A definite diagnosis is needed as soon as possible to assure better outcomes for the patient. Drawing a blood gas for blood analysis is invasive, time consuming, and not a quick enough method to form a diagnosis. This is why it is vital to have quicker means of measuring $\%COHb$. It is important not only to have quick CO measurements but it is also important to have accurate results as well. For this reason testing different CO analyzers for accuracy is critical to clinical practice.

After much research, it is believed that the Bedfont ToxCO will be more statistically accurate than the Mesimos Red-57 and Redical-7 co-oximeter in determining the CO levels in patients.

**Methods**

This study will begin on June 30th, 2014 in the Lancaster Regional Medical Center Pulmonary Function Lab. The test subjects will be regularly scheduled PFT patients for that week and possibly some volunteers, such as respiratory therapy students and department RTs will also participate. In the PFT lab each patient will have blood drawn to be analyzed by the co-oximeter and have a Red-57 and Redical-7 reading done. The only extra procedure that will be done that isn’t regularly done in a PFT lab is the breath analysis with the ToxCO. After each PFT, blood will be drawn. Then right after that a Red-57 and Redical-7 probe will be placed on the patient’s finger while being instructed to breathe into the ToxCO breath analyzer. The blood sample will be analyzed within 15 minutes to make sure the results are accurate. Any sample not analyzed within an hour will be discarded due to the possibility
of unreliable results. Another variable that will be addressed is dark nail polish on patients’ fingernails because some studies claim that dark nail polish interferes with pulse-ox results; therefore, nail polish will be removed. The breath analyzer that will be used is called ToxCO, which is made by the Bedfont Company.

The multi-wave co-oximeters that will be utilized in this study is the Red-57 model and the Redical-7 by Mesimo. The finger probe will be reusable and will be cleaned with isopropyl alcohol after every use.

The three non-invasive CO analysis (Red-57, Redical-7 and ToxCO) results will be compared to the invasive CO analysis results, which will be obtained by the Siemens RapidPoint 500 machine. Each patient will have capillary blood drawn and analyzed.
Results

The data gathering period only took three days and a total of 20 subjects were included in the study. The study included 10 male and 10 female subjects between the ages of 20 to 79. Six out of the 20 subjects were current smokers which resulted in them having higher CO levels. The data was collected all at the same time. The patient blood was drawn with a capillary stick and analyzed within 15 minutes. At the time that the blood was drawn the patient was instructed to breathe into the ToxCo and 2 finger probes were placed on the patients fingers to measure the CO levels with the Radical-7 and Red-57 devices. All the data was entered into a Microsoft Office Excel spread sheet which also included the patient’s age, sex, height, weight, occupation, vehicle driven, smoker status, and type of heating appliance at home. Some of the questions were asked to determine whether some patients are more exposed to CO than others.

<table>
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<td>Non Smoker</td>
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The data was analyzed by using the one-way Anova test and the simple T-test to determine which devices had more precision in measuring the subjects CO levels. All the non-invasive CO measurements were compared to the co-oximeter measurement which is the most precise way to measure CO levels in the blood.

The Anova test showed that the Red-57 and the Radical-7 had significantly different results than the blood co-oximeter.

The Tukey Pairwise Comparison on the above chart shows that the Co-oximenter and the ToxCo had the same grouping and the Redical-7 and Red-57 had another grouping, meaning that the CO-oximeter and the ToxCo were the same and the Masimos were statistically different.

The last test that was done is the simple T-test and the results of this test showed that the ToxCo had the most precise CO readings compared to the blood co-oximenter and the Redical-7 and the Red-57 readings were significantly different from the blood co-oximeter readings.

Also a Tukey Pairwise Comparison was done, and it also showed the same results as the on-way Anova test.
From all this statistical data it is clear that the ToxCO is a good machine that has precise CO readings and the Redical-7 and the Red-57 have statistically different readings than that of the blood co-oximeter.

Discussion

As predicted, I found that the breath carbon monoxide monitor results correlated better with the invasive co-oximeter than the multi-wave co-oximeters. The invasive co-oximeter analyzer draws blood to calculate the percent of blood that is saturated with carbon monoxide. This is why this method of carbon monoxide monitoring is the most precise. This is why I used this method as the standard to which I compared the noninvasive methods of CO monitoring. The Multi-wave co-oximetry sounded promising at first, since it is the most common way to measure CO levels noninvasively. But as the testing began with each subject it was evident that repeatedly the Redical-7 and the Red-57 displayed results that were not correlating with the invasive co-oximetry. Only at some instances the Redical-7 and the Red-57 showed results that were more precise than the Toxco.
After analyzing all the data with the Anova test and the standard T-test the results confirmed that the Redical-7 and Red-57 were both significantly different than the invasive co-oximeter and the Toxco was statistically the same as the invasive co-oximeter. Since the invasive co-oximeter was used as the standard for CO monitoring, it is safe to conclude that the Toxco is more precise than the Redical-7 and the Red-57 at measuring CO levels in the blood.

There is not much research done on carbon monoxide poisoning, but the couple of studies that were done are very informative and helpful. A study done by AJ Cunnington and P Hormbrey showed the breath carbon monoxide analyzer as a good tool to detect recent exposure to carbon monoxide. In this study a hand held breath analyzer was used to measure the carbon monoxide concentrations in 382 subjects. The study concluded that the breath analysis was quick, easy and correlated well with the reported carbon monoxide exposure. This study also showed that the Toxco breath analyzer was very easy to use and took only 15 seconds to display precise results. Out of the 20 subjects that participated in my study, not one had trouble following direction of how to use the Toxco breath analyzer.

Another study done by Usmani Z and associates compared CO breath analysis results with women’s self-reporting of smoking behaviors for identifying smoking during pregnancy. This study showed that 27% of women lied about smoking according to the CO breath analyzer (a cut-off of 6ppm of CO was used to distinguish between smoker and non-smoker). There was also a similar study done by D S Seidman and associates that used end tidal carbon monoxide measurements of the newborn to validate smoking behavior of the mothers. The results showed that newborns with higher ETCO levels (10.0 +/- 7.7) were
birthed by mothers who were smokers and newborns with lower ETCO levels (2.51+/-.1.4) were birthed by mothers who had some to no smoking history. These two studies show that the breath analyzer correlates well enough with true carbon monoxide levels in the blood to be used in other clinical setting such as the NICU and the maternal ward, which agrees with my study that shows the Toxco to be a very precise device.

The other non-invasive mode of CO monitoring that was used in this study was the multi-wave co-oximetry. The Redical-7 and the Red-57 were used. My results showed that these devices did not correlate well with the invasive co-oximetry, which was used as the standard.

My results were contradicted by a study done by Roth D and associates. In this study over 5000 patients were screened for carbon monoxide poisoning in the emergency department with the use of a multi-wave co-oximeter. It was found that the multi-wave co-oximetry measured COHb with acceptable precision. Another study also confirmed these results by measuring COHb levels in bingo players who smoked. This study showed precise results even in patients who received second hand smoke while playing bingo. The manufacturer of the devices that were used in my study (masimo) claims that their devices are very precise, and will display CO levels within +/-5% of the true CO levels.

All the studies that I found about multi-wave co-oximetry contradict the results of my study. My theory for this is that the subjects in these studies all had high COHb levels which made the measurements of the multi-wave co-oximetry more precise. In my study patients who have claimed to be smokers had higher COHb levels and their Redical-7 and Red-57 measurements were more precise than of those who were not smokers.
The subjects in my study consisted of patients who were mainly non-smokers and were not victims of a recent house fire or any CO exposure. Their COHb levels were relatively low. This is why I believe my results showed the Toxco to be more precise than the Redical-7 and the Red-57.

This is one of the limitations of my study. If my study group consisted of variety of subjects such as smokers, non-smokers, emergency patients, house fire victims, and subjects who were exposed to more CO maybe the multi-wave co-oximetry would have done a better job at measuring COHb levels with more precision. Another limitation of my study is that I had a very small study group. Although 20 subjects is enough to analyze my results, I believe that a larger study group would have been more favorable.

This study has very important implications clinically due to all the misdiagnosed CO poisoning cases. Clinically, it is always more favored to be as less invasive as possible but also to be as precise as possible. This is why it is important to study the precision of the tools that we use. In this case the Toxco proved to be the more precise, non-invasive way of measuring COHb levels. All though this device is rarely seen in the hospital setting and more in the smoking cessation programs, I believe that this study should change that.

Conclusion

All though invasive co-oximetry is the most precise way to measure COHb levels, a non-invasive way is always more favored. It is safe to say that the Toxco is a really precise device to measure COHb levels in a clinical setting. All though the Masimo Redical-7 and Red-57 were shown to be less precise in their COHb measurements, further studies should be done to see whether the precision gets better with higher COHb levels.
Citation