USE OF THE MASIMO RAINBOW NONINVASIVE HEMOGLOBIN MEASUREMENT TECHNOLOGY FOR CHILDREN WITH SICKLE CELL DISEASE

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USE OF THE MASIMO RAINBOW NONINVASIVE HEMOGLOBIN MEASUREMENT TECHNOLOGY FOR CHILDREN WITH SICKLE CELL DISEASE

by

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DISSERTATION

Presented to the Faculty of the Medical School

The University of Texas Southwestern Medical Center at Dallas

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF MEDICINE WITH DISTINCTION IN RESEARCH

The University of Texas Southwestern Medical Center at Dallas

Dallas, Texas

March, 2011

ABSTRACT

USE OF THE MASIMO RAINBOW NONINVASIVE HEMOGLOBIN MEASUREMENT TECHNOLOGY FOR CHILDREN WITH SICKLE CELL DISEASE

Landon Farris

The University of Texas Southwestern Medical Center at Dallas, 2011

Supervising Professor: Peter Szmuk, M.D.

Purpose of Study: Until recently, pulse oximeters have been limited by the fact that they use two wavelengths of light to measure oxygen saturation. The use of only two wavelengths often resulted in serious errors, especially in patients with hemoglobinopathies. Although multiwavelength pulse oximeters have been the subject of research in the past, the first multiwavelength instruments did not reach the commercial medical market until 2005. More recently, the new 'Rainbow Technology' pulse oximeters developed by Masimo Corp., which also use multiple wavelengths, have permitted the

noninvasive measurement of total hemoglobin. To further evaluate the accuracy of this new technology, we intended to test the hypothesis that the total hemoglobin as measured by the Masimo Rainbow Radical correlates with laboratory data in children with sickle cell anemia as measured by the Sysmex Automated Hematology Analyzer.

Methods Used: Hemoglobin measurements were taken at Children's Medical Center in Dallas from patients under the age of 18 with a diagnosis of sickle cell anemia. In addition, the study limits enrollment to patients which are scheduled for routine hemoglobin measurements as part of their clinical course. A single use, flexible probe is applied on the middle finger of the hand from which blood is drawn, and the monitor is allowed to run for 3-5 minutes until the readings are stabilized. Only the readings taken at the time of the blood draw are recorded as SpHb values and used for subsequent analysis. .

Summary of Results: 150 patients were enrolled, and the device completed measurements on 133 of the patients. The Masimo Rainbow Radical recorded a total hemoglobin measurement an average of 17 minutes from when blood was taken for laboratory analysis. The hemoglobin values as measured by the Radical (SpHb) and the Sysmex Automated Hematology Analyzer (Hb) differed by an average absolute value of 1.26 g/dL. Additionally, when the SpHb measurements are plotted against the Hb values, the Pearson Correlation Coefficient is 0.69. The mean bias was 0.8 g/dL with a standard deviation of 1.3 g/dL and limits of agreement of -1.8 to 3.4 g/dL. SpHb.

Conclusions: The bias and precision of SpHb to Hb in our patients was higher than that found in healthy volunteers. This might be due to the different sensors used in adults and

children, or may be due to the presence of sickle hemoglobin in our patients. Further studies are needed to clarify this issue. However, at this preliminary stage, the correlation between the Rainbow Radical and Hematology Analyzer suggests that the multiwavelength technology could be used as a substitute for routine screening hemoglobin measurement by blood draw.

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PRIOR PUBLICATIONS & PRESENTATIONS

Landon Farris, Oral Presentation (2011). Use of the Masimo Rainbow Noninvasive Hemoglobin Measurement for Children with Sickle Cell Disease. American Federation for Medical Research Southern Regional Meeting, New Orleans, LA.

Landon Farris, P. S. (2011). "Use of the Masimo Rainbow Noninvasive Hemoglobin Measurement for Children with Sickle Cell Disease." Journal of Investigative Medicine 59(2): 520.

LIST OF FIGURES

CHAPTER ONE:
INTRODUCTION – OXYGEN ASSESSMENT IN SICKLE DISEASE

Sickle Cell Disease is a chronic hemolytic anemia that usually presents in early childhood. The disease is caused by a mutation that leads to a hydrophobic amino acid substitution in its protein product. This protein product of the sickle hemoglobin gene allele (HbS) is associated with instability and a lower red blood cell half-life. With each cell lasting less time, a state of hemolytic anemia usually ensues. In addition, the HbS is predisposed to polymerize upon deoxygenation. The polymers then can bundle into rods and deform the red blood cells into a sickle shape, which can accumulated and clog the small vessels of the microcirculations in the body.

The fact that HbS tends to polymerize upon deoxygenation is exacerbated because patients with sickle disease have lower arterial oxygenation saturation even under normal gas exchanging conditions. This stems from two main facts, the first being that with a high 2,3-Diphosphoglyceric acid level and an inherent reduced affinity of the HbS for oxygen, the HbS follows a right-shifted oxyhemoglobin dissociation curve. This is shown in the below figure (Figure 1). The second predisposing fact is that as part of the disease process, there are chronic episodes of pulmonary infiltration.[1] This pulmonary infiltration increases ventilation-perfusion mismatch and leads to hypoxemia.

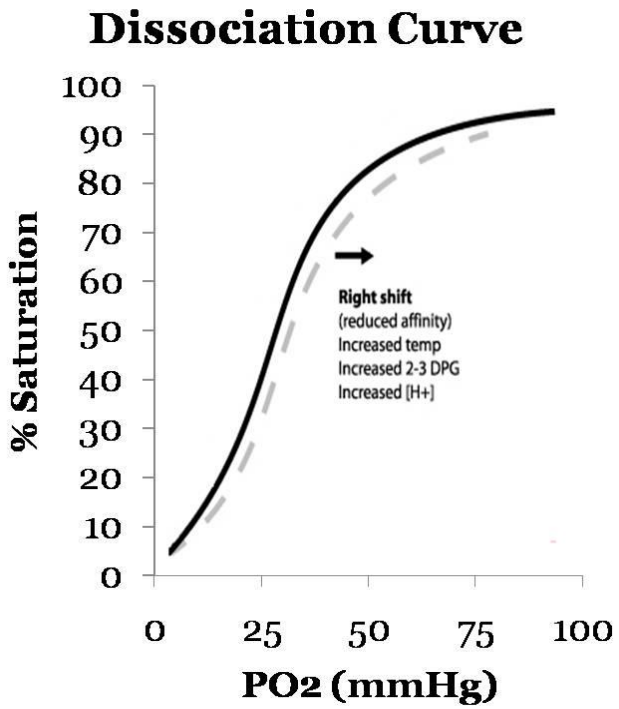

Figure 1. Two of the four causes of a shifted hemoglobin curve are present with sickle cell disease.

To summarize, those with sickle disease are predisposed to enter a cycle in which chronic deoxygenation leads to sickled cells in microcirculation. These cells occlude the circulation and undergo hemolysis, causing more ischemia and feeding back on worse deoxygenation. Eventually, this results in end organ damage or vaso-occlusive crisis.

Thus, the detection of arterial hypoxemia is of great importance in the management of sickle cell disease.

CHAPTER TWO:
BACKGROUND – HISTORY OF MEASURING HEMOGLOBIN WITH MULTIWAVELENGTH PULSE OXIMETERS

Assessing hypoxia requires measuring two main variables, oxygen saturation and the concentration of hemoglobin. Oxygen saturation is generally measured at the clinic by a pulse oximeter. However, measuring the concentration of hemoglobin is done using a variety of technologies, the most popular of which include laboratory devices (CO-oximeters and coulter counters), point-of-care devices (HemoCue®), and the most recently developed multiwavelength pulse-oximetry devices (Masimo Rainbow Radical).

The ability to measure hemoglobin with pulse oximetry has been attributed to the addition of more wavelengths, which allows one to accurately measure more types of hemoglobin. For example, older pulse oximeters use only two wavelengths and thus must assume that all the absorbed light is absorbed by either oxyhemoglobin or deoxyhemoglobin. This is not a valid assumption because, as can be seen in Figure 2, methemoglobin and carboxyhemoglobin also exist and absorb light over a large range of wavelengths (Figure 2). As a result, the old pulse oximeters could not measure the hemoglobin, but could only report the ratio of oxyhemoglobin to deoxyhemoglobin in the form of oxygen saturation. In contrast, with the use of more wavelengths, the multiwavelength pulse oximeters can measure different forms of hemoglobin and

thus can sum them to obtain a total hemoglobin concentration.

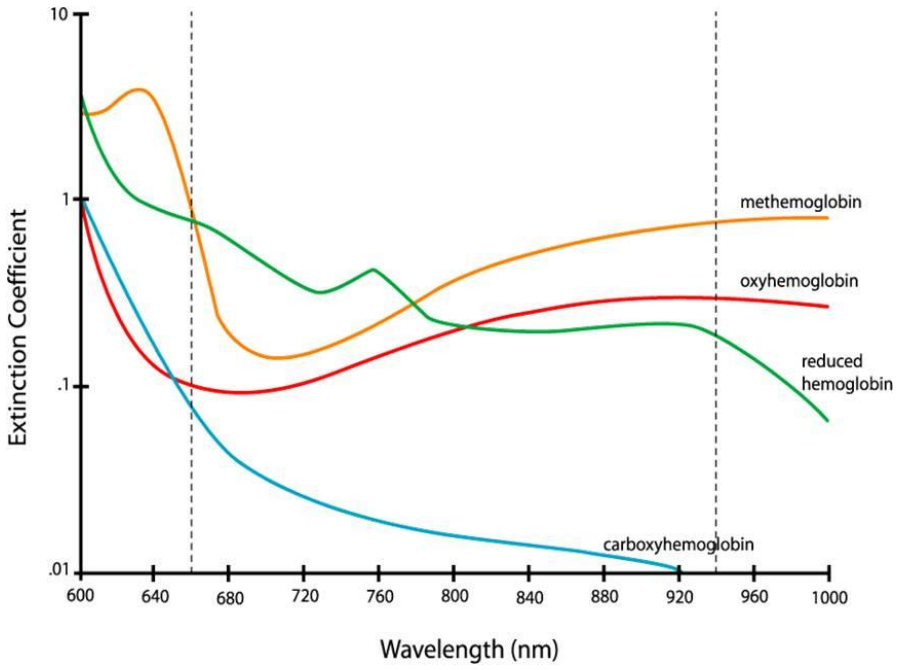

Figure 2. Different chemical structures absorb light at a range of wavelengths.

Ideally, one would use the most rapid, non-invasive, and accurate method to measure hemoglobin. Measuring hemoglobin with either laboratory devices or point-of-care devices requires drawing blood. From this aspect, the use of these devices requires an invasive protocol, and the repetitive needle sticks can reduce quality of life in the pediatric population. By contrast, the use of multiwavelength pulse oximetry requires no blood draw and is therefore non-invasive. In addition, because blood drawing and transportation protocols are eliminated with pulse oximetry, the time required to obtain a hemoglobin measurement is reduced.

The third criteria of accuracy, however, has not been so straight forward to measure

in pulse oximeters in the sickle cell population. It should be noted that the accuracy of using multiwavelength pulse oximetry to measure hemoglobin in sickle cell patients has not yet been performed. In fact, even evaluating its accuracy in normal patients has proved problematic. The first obstacle is that the variability within the gold standard devices (laboratory devices and point-of-care devices) is quite high. There is a standard deviation of up to +/- 1.18 g/dL[3] when the same sample of blood is repeatedly measured with the same model of system.[2] Also, as can be seen below, there is much variability between systems (Figure 3)[3]. To further complicate matters, even the characteristics of the blood draw itself like blood source[4-5], site[6-7] and time[7] of the blood draw, patient body position[8], and "pushing out" during a capillary draw[6] have been shown to influence the measured hemoglobin concentration. Thus, because of these mentioned points, it has been difficult to interpret the measured accuracy of hemoglobin measurements against the gold standards in the past.

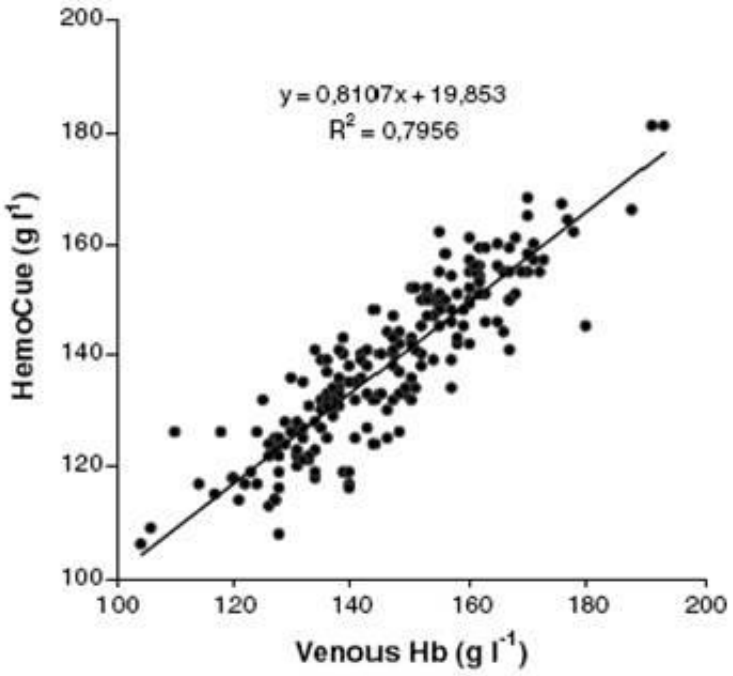

Figure 3. Comparison from Gomez-Simon et al. of HemoCue and Fluorescent Cytology

Despite these difficulties, Macknet el al. concluded that when measured against a laboratory CO-oximeter over a range from 4.4 g/dL to 15.8 g/dL in a non-sickle cell population, the Masimo Rainbow multiwavelength pulse oximeter was accurate within 0.03 +/- 1.12 g/dL.[9] The comparison is seen below (Figure4).

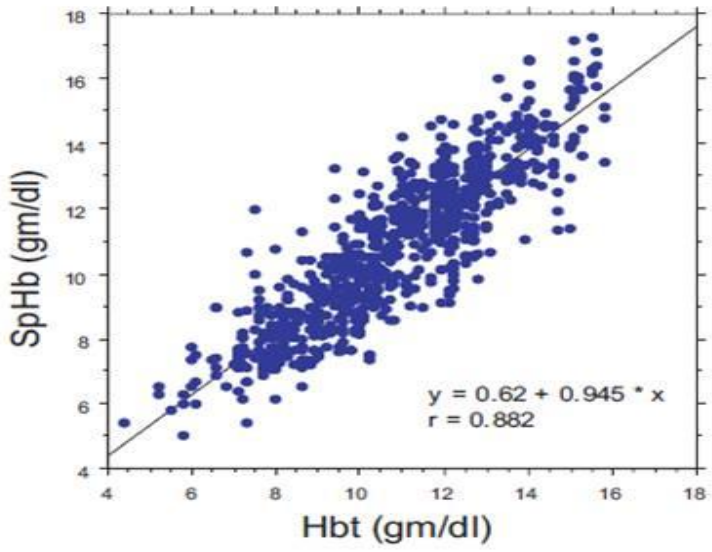

Figure 4. In non-sickle cell patients, the measured values and reference values are modeled by linear regression.

Unfortunately, past inaccuracies with pulse oximetery in the setting of sickle cell patients may suggest that these values are not generalizable to sickle cell patients. Specifically, in the past, pulse oximeters have shown greater inaccuracy when measuring oxygen saturation in sickle cell patients than normal patients. Some studies have shown that the oximeters to overestimate[10], underestimate[11], and even measure accurately[12-13]. While the reasoning for these discrepancies is not absolutely certain, some believe that either reduced peripheral blood flow or an inherent change in the absorption of light are indeed responsible. At this time it is uncertain whether these same discrepancies will also cause inaccuracy of the multiwavelength pulse oximeters in measuring total hemoglobin concentration in sickle disease patients.

CHAPTER THREE:
METHODS

In this trial, it was hypothesized that the total hemoglobin as measured by a Masimo Rainbow Radical-7 Pulse CO-Oximeter, sv 7604 (Masimo Corp, Irvine, CA) multiwavelength pulse oximeter would correlate with the laboratory data in children with sickle cell anemia as measured by a Sysmex XE Series Analyzer (Sysmex America, Inc., Mundelein, IL) (fluorescent cytology).

To evaluate the hypothesis, a convenient sample of one hundred and fifty outpatients at the Children's Medical Center in Dallas Center for Cancer and Blood Disorders were enrolled in a trial. Data collected from each patient included demographic data like race and skin tone; morphometric data like gender, weight, and height; genotypic data like the type of sickle cell anemia; and hemoglobin measurements by both a multiwavelength pulse oximeter and a fluorescent cytology analyzer.

To be included in the trail, patients must have been outpatients scheduled for hemoglobin measurements as part of their clinical course, below the age of eighteen, and with either HbSS or HbSβ0 genotypes. In addition, patients were then excluded if they had acrylic or painted nails, were smaller than the design specifications for the measuring probe (finger diameters below ten millimeters or total body mass below ten kilograms), or could not be measured with the multiwavelength pulse oximeter within an hour of the

blood draw for comparison measurement. A measurement probe is shown in below (Figure 5).

Figure 5. The probe for the system is disposable and fits a variety of children.

First patients or guardians were consented, and the blood was drawn and measured by a fluorescent cytology analyzer as part of the normal clinical course. Then, within an average of seventeen minutes before or after the blood draw, the patient's hemoglobin (Hb) values were measured using the oximeter. The measurement process began by attaching a single use probe to the middle finger of the hand from which blood was drawn, as can be seen below (Figure 6). The monitor was then allowed three to five minutes until the readings stabilized. The readings were recorded as SpHb values. Finally, all statistical analysis was performed in Microsoft Excel. Notably, in our calculations, bias was defined as the mean difference between the SpHb and Hb data pairs, and precision was defined as one standard deviation of the bias.

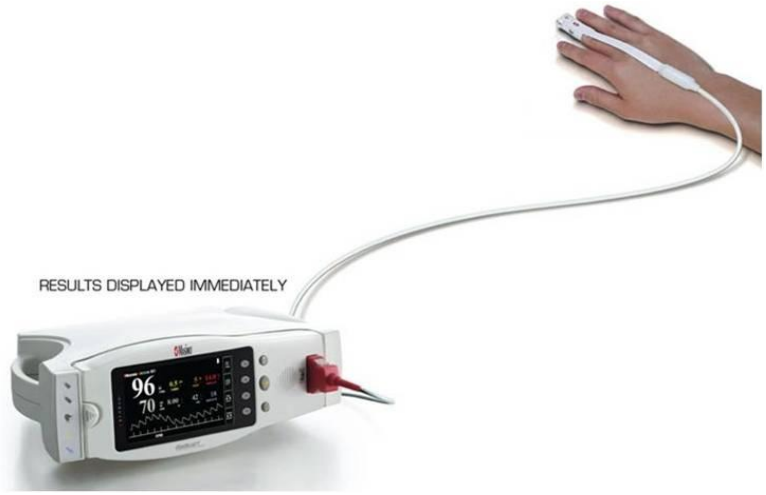

Figure 6. The multiwavelength pulse oximetry system is easy and quick to set up.

CHAPTER FOUR:
RESULTS

The machine produced stable measurements on one hundred and thirty-three of the patients. 59% (88/150) of the patients were male. The mean SpHb was 9.1 g/dL (range 4.2-13) and mean Hb was 8.2 g/dL (range 5.6-12.4).

The values taken from the oximeter correlate within 1 g/dL forty-six percent of the time, and within 1.7 g/dL 76% of the time. The average root mean square difference between the multiwavelength pulse oximetry measurement and that of the gold standard is 1.26 g/dL. As can be seen in Figure 7, the multiwavelength readings were plotted against the reference measurements, and the best fit linear trendline is represented by the equation:

$$y = 0.96x + 1.09$$

The R2 value is 0.47, which corresponds to a Pearson Correlation Coefficient of 0.69 (Figure 7).

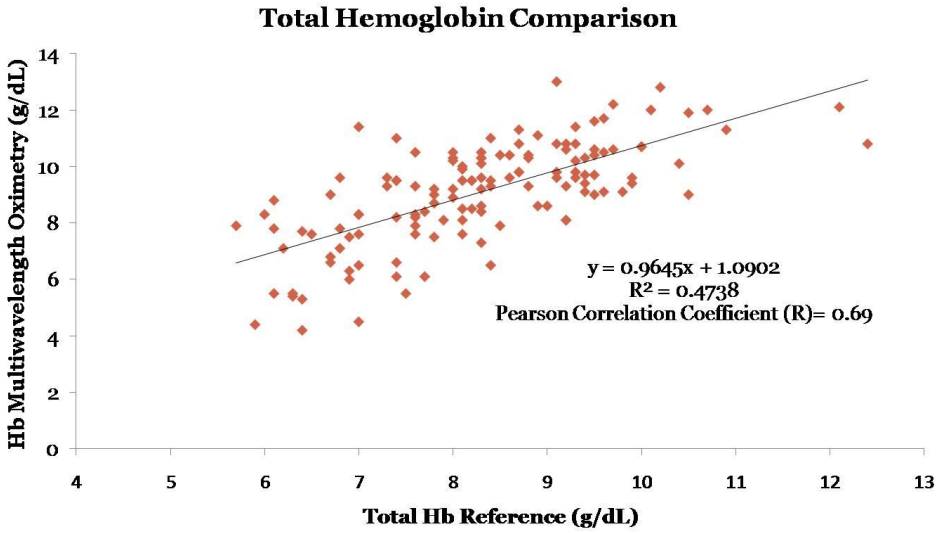

Figure 7. In a sickle cell population, the measured values and reference values are modeled by linear regression.

To place the model in context, a Pearson Correlation coefficient of 1.00 would indicate that all of the points were along the trendline and a coefficient of 0 would indicate a random placement of points.

Next, as shown in Figure 8, the errors between the Multiwavelength oximeter readings and the reference measurements were plotted against the reference measurements (Figure 8). This is often referred to as a Bland Altman plot. Analysis of the error revealed a standard deviation of 1.30 g/dL, a bias of 0.8 g/dL, and and limits of agreement of -1.8 to 3.4 g/dL. When 40 paired measurements associated with low SIQ (a SpHb signal quality indicator), were removed from the data set, the bias and precision were similar.

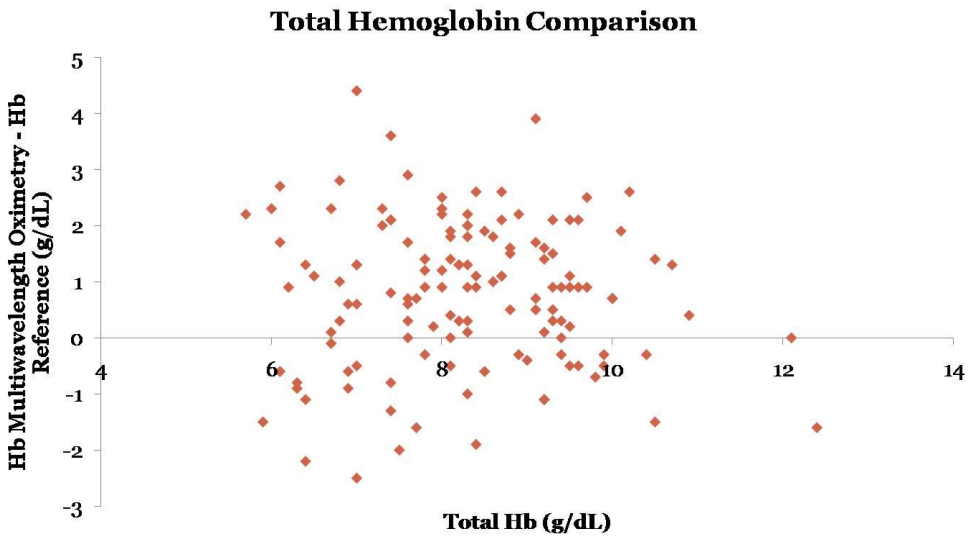

Figure 8. The error is plotted as a function of the hemoglobin.

CHAPTER FIVE:
DISCUSSION

When the data from this experiment is compared against a similar study in a non-sickle disease population by Macknet et al., interesting deductions can be made. The accuracy and standard deviation of the multiwavelength pulse oximeter in a non-sickle cell patient population is 0.03 +/- 1.18 g/dL as compared to 0.8 +/- 1.30 g/dL in the sickle cell population. Therefore both the accuracy and precision of the device is better in a non-sickle cell population.

Despite the less accurate and precise measurements, after considering that laboratory devices and point of care devices have a standard deviation of up to +/- 1.18 g/dL when repeatedly measuring the same sample of blood, one can conclude that the accuracy is sufficient enough to merit controlled clinical use. For example, it would be reasonable to use this device to routinely screen sickle cell patients with a high pretest probability of having a hemoglobin level more than 2.1 g/dL over the transfusion limit. Using the device in such a manner would minimize the number of needle sticks, the measurement time, and any errors large enough to affect treatment decisions.

Finally, although we did not reproduce the accuracy found in non-sickle cell patients, we were not able to explain this discrepancy. This might be due to the different sensors used in adults and children, or may be due to the presence of sickle hemoglobin in our

patients. It would be beneficial to measure the absolute concentration of HbS and the percentage of hemoglobin that is HbS from blood in future studies. These values could be measured by performing electrophoresis analysis on the drawn blood. The composition of HbS could then be correlated with the error in hemoglobin measurement. From this, it may become clear if a physical property of the sickle hemoglobin itself is responsible for the discrepancy.

CHAPTER SIX:
CONCLUSIONS

This study of one of the first available non-invasive multiwavelength pulse oximeters concluded that its accuracy and precision are 0.8 +/- 1.30 g/dL when compared to a laboratory fluorescent cytology blood analyzer. This accuracy suggests that the multiwavelength pulse oximetry could be a substitute for routine screening of hemoglobin measurement by blood draw.

The bias and precision of SpHb to Hb in our patients was higher than that found in healthy volunteers. This might be due to the different sensors used in adults and children, or may be due to the presence of sickle hemoglobin in our patients. Further studies are needed to clarify this issue.

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APPENDIX: ESTROGEN REDUCES PANCREATIC INFLAMMATION PROCEEDING SEVERE BURNS IN RATS

By

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The University of Texas Southwestern Medical Center at Dallas, 2011

ABSTRACT

ESTROGEN REDUCES PANCREATIC INFLAMMATION PROCEEDING SEVERE BURNS IN RATS

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The University of Texas Southwestern Medical Center at Dallas, 2011

Supervising Professor: Jane Wigginton, M.D.

Purpose of Study: Multisystem and remote organ failure following burn injuries remains a significant cause of death each year. The mechanisms relating such organ failure to the burn injury are currently not fully understood. However, it is known that the systemic and remote effects of severe burns are at least in part driven by an increase in inflammation. This post-burn inflammatory response is regulated by certain factors which are released from the burn site; these factors include tumor necrosis factor α (TNF- α), interleukin 1β (IL-1β), interleukin 6 (IL-6), and prostaglandins. In an effort to blunt the inflammatory response following injury, administration of estrogen in animal models has resulted in both decreased levels of circulating inflammatory cytokines and in various remote organs, as well as a decrease in mortality. Previous humans studies have

demonstrated that pancreatic function is negatively affected following remote burn injuries. More specifically, a decrease in beta-cell function and an increase in plasma levels of IL-1 have been correlated with increased patient mortality. It is therefore hypothesized that administration of estrogen post-burn may protect the pancreas following remote burn injuries. The objective of this study is to elucidate the effect of acute estrogen treatment on IL-1β, IL-6, and TNF-α levels in the pancreas following severe burn injury.

Methods Used: In this study, male rats received 40% total body surface area burns. Fifteen minutes following burn, the animals received a subcutaneous injection of either placebo (corn oil) or 17 A -estradiol (0.5 mg/kg). The pancreas was harvested at various time points within the proceeding 24 hours, and then cytokine levels were measured using the ELISA method.

Summary of Results: Administration of estrogen significantly ($p < 0.05$) decreased the cytokine levels (IL-1β, IL-6, and TNF-α) in the pancreas compared to the placebo/burn group at multiple time points within twenty-four hours.

Conclusions: Following remote severe burn injury, single-dose estrogen significantly decreases the levels of inflammatory cytokines in the pancreas.

Appendix

PRIOR PUBLICATIONS & PRESENTATIONS

Landon Farris JG, D. Maass, J. Wingginton. Estrogen Reduces Pancreatic Inflammation Proceeding Severe Burns in Rats. Journal of Investigative Medicine. 2010;58(2):483.

Landon Farris, Oral Presenation. Estrogen Reduces Pancreatic Inflammation Proceeding Severe Burns in Rats. Paper presented at: American Federation for Medical Research Southern Regional Meeting2010; New Orleans, LA.

LIST OF FIGURES

SECTION ONE:
INTRODUCTION

As reported by the American Burn Association, in the decade preceding 2005, there were an estimated 500,000 burns victims treated annually in the U.S. Of these, 176, 311 per year were hospitalized and about 4000 had severe burns as defined by over 30% total body surface area. For those that do not die directly from the burn, multisystem organ failure is the largest cause of death.

Severe burns are characterized by an uncontrolled release of inflammatory cytokines from the burn site[14]. Most notable of these cytokines are Tumor Necrosis Factor-Alpha (TNF-α), Interleukin 1 Beta (IL-1 β), and Interleukin 6 (IL-6)[14-18]. The resulting inflammation caused by these mediators drives, at least in part, the systemic and remote effect of severe burns.

17-β estradiol is known to have protective effects. It has been shown that high levels of estrogen after trauma correlates with greater resistance to inflammatory injury, oxidant injury, and apoptotic injury in animal models. It has been proposed that such protective mechanisms are mediated by the ability to maintain mitochondrial integrity and decrease the activity of pro-apoptotic factors[17-19]. Additionally, protective factors correlated with decreased levels of inflammatory cytokines in circulation and decreased animal mortality and morbidity[20-23]. However, all past studies of severe burn models have used administration of estrogen in pre-loaded rats.

SECTION TWO:
METHODS

It was hypothesized in this study that the administration of estrogen post-burn may decrease inflammation in the pancreas following remote burn injuries. Specifically this was determined by measuring the effect of estrogen treatment on IL-1β, IL-6, and TNF-α levels in the pancreas following severe burn injury in a rodent model.

144 Adult male Sprague-Dawley rats weighing 325 to 350 g were used in these experiments. Protocols were approved by the UT Southwestern Institutional Animal Care and Research Advisory Committee and conformed to guidelines in the Guide for the Care and Use of Laboratory Animals from the American Physiological Society.

For this procedure, the rats were anesthetized with isoflurane, and loaded onto a device that isolated an area of skin on the back, as can been seen in Figures 9 and 10 (Figure 9)(Figure 10). The area isolated was estimated to be 40 % of the total body surface area. The backs were shaved and the rats were then placed in a 100 ° C water bath from 10 seconds. The burn procedure produced complete thickness burns and destruction of the underlying nerve tissue. This resulted in minimal pain to the animals. The rats were immediately given fluid resuscitation of lactated ringer (LR) solution intra-peritoneally and buprenorphine for pain.

Figure 9. The rats were anesthetized using a gas method with isoflurane.

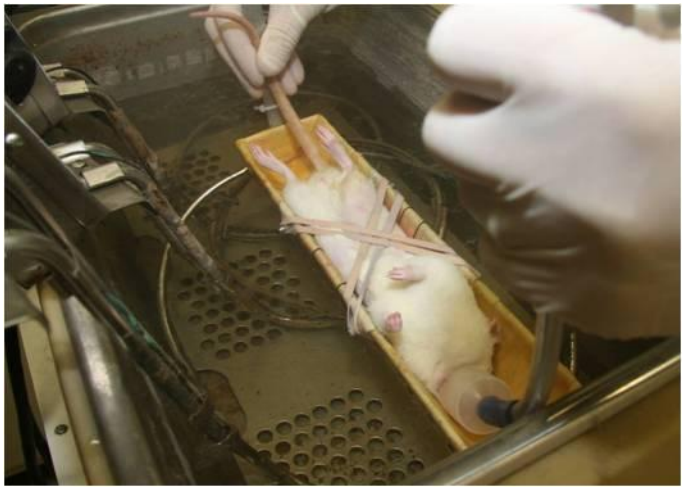

Figure 10. A controlled area was isolated and burned.

Fifteen minutes following the burn, half of the rats received a subcutaneous injection of placebo (corn oil) while the others received 17 β -estradiol (0.5 mg/kg). At 0.5, 1, 2, 4, 6, 8, 12, 18, and 24 hours after the burn, a group of eight placebo rodents and eight estrogen treated rodents were sacrificed. Controls were also sacrificed at the 24 hour time

point. Immediately following the sacrifice, the pancreas was removed and analyzed for cytokine levels.

Each pancreas was placed in 0.5 ml of lysis buffer, which allowed for the isolation of the protein. The samples were then homogenized and centrifuged for 10 minutes. Following centrifugation, the supernatant was collected and analyzed for protein concentration. Next the supernatants were diluted to equivalent protein concentrations. Finally TNF-α, IL-1β, and IL-6 cytokines were measured from the fluid using the Enzyme Linked-Immuno-Sorbent Assay (ELISA).

The data was analyzed using the student's t-test analysis. Groups were considered to be significantly different if P values < 0.05.

SECTION THREE:
RESULTS

Estrogen significantly ($p<0.05$) decreased inflammatory markers in the pancreas in the first 24 hours. This is shown with more details in Figures 11, 12, and 13 (Figure 11)(Figure 2)(Figure13).

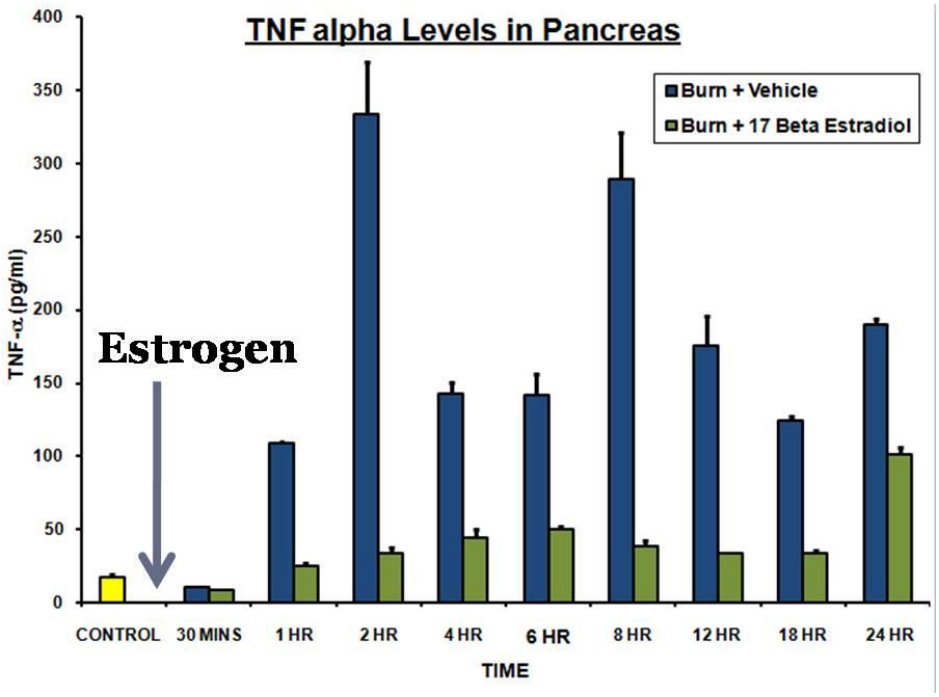

Figure 11. Control/unburned, treated, and untreated rats differ in TNF alpha levels.

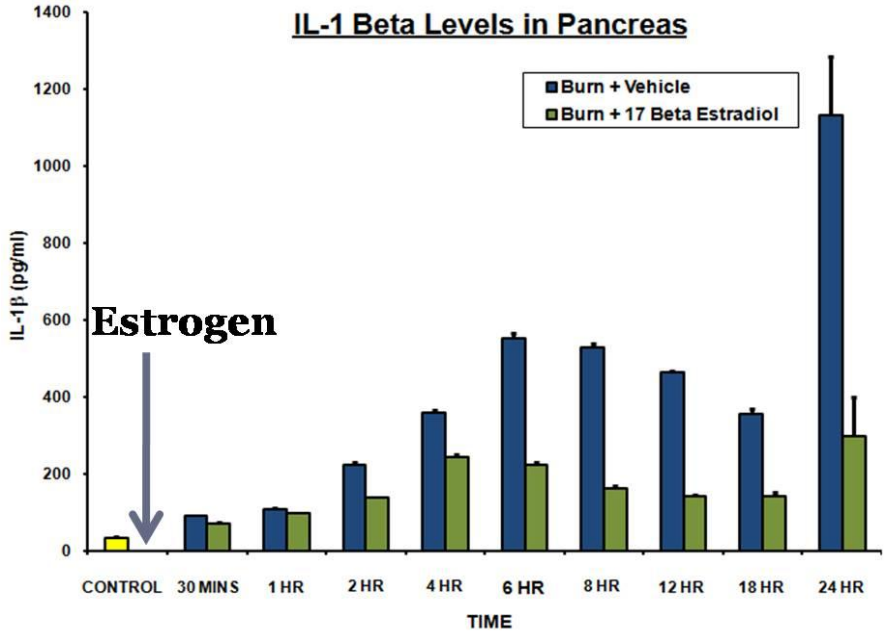

Figure 12. Control/unburned, treated, and untreated rats differ in IL-1 beta levels.

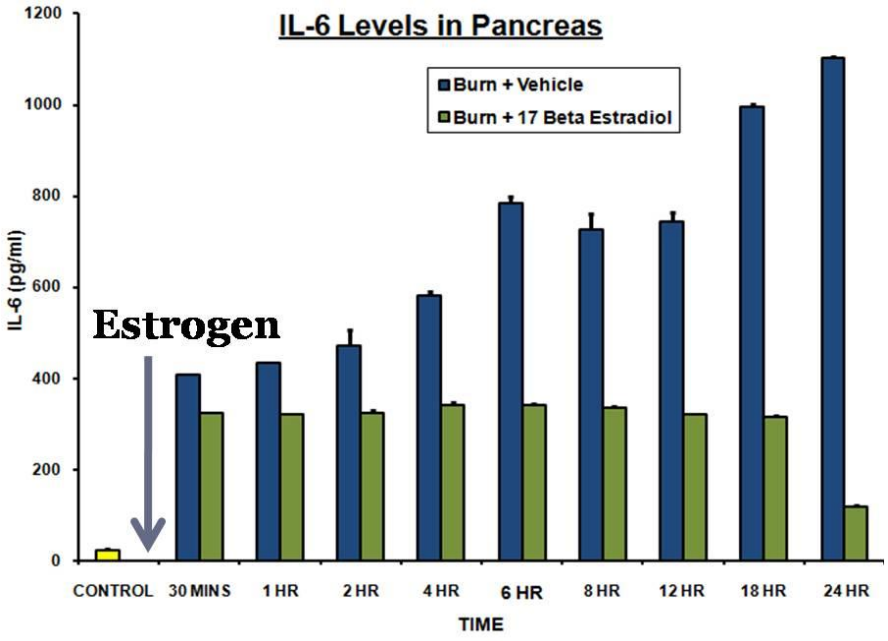

Figure 13. Control/unburned, treated, and untreated rats differ in IL-6 levels.

SECTION FOUR:
CONCLUSIONS

This study shows that in a rat model of severe burns that is not pre-loaded with estrogen, the single administration of estradiol significantly decreases inflammatory cytokines in the pancreas. Future directions for studies will correlate pancreatic function and mortality in this model. Also, because this protocol is clinically reproducible, additional studies will correlate human responses to similar dosing after severe burn.

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via suppression of interleukin-6 production. *Inflamm Res.* 2001;50(12):585-591.

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VITAE

LANDON FARRIS

Research

06/2010-08/2010 **Department of Anesthesiology at Children's Medical Center at Dallas**
Research Assistant, Peter Szmuk, M.D.
Participated in clinical trial at Children's Medical Center at Dallas, evaluating the performance of minimally invasive technology to measure hemoglobin levels in children with sickle cell disease.

05/2009-09/2009 **Division of Emergency Medicine, Department of Surgery at the University of Texas Southwestern Medical Center at Dallas**
Research Assistant, Jane Wigginton, M.D.
Trained to use animal based model to examine the effect of estrogen after severe traumatic burns
Participated in clinical trial at Parkland Memorial Hospital, investigating the effects of estrogen administration following traumatic brain injury or hemorrhagic shock in Level 1 trauma patients

05/2008-08/2008 **University of Texas M.D. Anderson Cancer Center**
2008 STEP-UP Research Intern, Alessandro Grattoni, Ph.D. and Mauro Ferrari, Ph.D.
Tested and developed a nano-channel insulin drug delivery system

05/2007-12/2007 **Applied Research Laboratories at the University of Texas at Austin**
Honors Scholar Research and Development Intern, Gene Brown, Ph.D.
Estimated performance levels of SONAR systems using digital signal processing

Publications

Medical Abstract
USE OF THE MASIMO RAINBOW NONINVASIVE HEMOGLOBIN MEASUREMENT FOR CHILDREN WITH SICKLE CELL DISEASE
Landon Farris, P. Szmuk. Use of the Masimo Rainbow Noninvasive Hemoglobin Measurement for Children with Sickle Cell Disease. *Journal of Investigative Medicine*. 59(2):520, February 2011

Medical Abstract
ESTROGEN REDUCES PANCREATIC INFLAMMATION PROCEEDING

SEVERE BURNS IN RATS
Landon Farris, J. Gatson, D. Maass, J. Wingginton. Estrogen Reduces Pancreatic Inflammation Proceeding Severe Burns in Rats. *Journal of Investigative Medicine*. 58(2):483, February 2010

Presentations

02/2001 **Oral Presentation**
USE OF THE MASIMO RAINBOW NONINVASIVE HEMOGLOBIN MEASUREMENT FOR CHILDREN WITH SICKLE CELL DISEASE
2011 American Federation for Medical Research Southern Regional Meeting

02/2010 **Oral Presentation**
ESTROGEN REDUCES PANCREATIC INFLAMMATION PROCEEDING SEVERE BURNS IN RATS
2010 American Federation for Medical Research Southern Regional Meeting

07/2008 **Poster Presentation**
12/2008 REVIEW: CLINICAL TRIALS EVALUATING THE USE OF STEM CELLS TO TREAT CARDIOVASCULAR DISEASES
Presented at the 2008 MD Anderson Cancer Center Step UP Research Presentation Symposia and at the 2008 UT Austin Department of Biomedical Engineering Research Symposium

Education

Bachelor of Science with Highest Honors, Biomedical Engineering, May 2009
The University of Texas at Austin