

Using Noninvasive Pulse CO-Oximetry to Help Improve Patient Safety, Reduce Costs, and Increase Hospital Revenue

Healthcare institutions are under increasing pressure to improve the quality and safety of patient care while improving efficiencies and decreasing costs.^{1,2} Managing these two challenges is important in operating productive hospitals and protecting revenues.

Diagnostic laboratory measurements drive key clinical decisions for hospitalized patients, but require invasive blood draws, can reduce efficiency, and are only available on clinician order at intermittent frequencies.

Point-of-care lab testing methodologies have gained clinical momentum in recent years due to their ability to speed diagnostic and treatment decisions, but they still require a blood draw, clinician time, and are not available continuously.³

One of the most common lab variables measured in the hospital is total hemoglobin (Hb). While less frequently measured today than Hb, carboxyhemoglobin (COHb) and acquired methemoglobin (MetHb) are two dyshemoglobins present in some hospitalized patients that can significantly impact patient outcomes. This paper conveys the findings from a

recent study conducted by Capgemini to analyze potential financial gains from Pulse CO-Oximetry™ (Rainbow SET®, Masimo Corporation, Irvine, CA), the first technology to noninvasively and continuously measure total hemoglobin (SpHb™), carboxyhemoglobin (SpCO®), and methemoglobin (SpMet®) in the blood.⁴⁻⁶

Hospital respondents identified multiple potential benefits of Pulse CO-Oximetry including aiding faster diagnosis, improved detection of critical conditions, prevention of harmful interventions, increased patient throughput, and reduced costs, risks, and discomforts of invasive testing.

After comparing the financial benefits with the capital investment and operational expense to incorporate Pulse CO-Oximetry, the study found that there is a positive business case to incorporate Pulse CO-Oximetry into a hospital's clinical standards and care pathways for noninvasive, continuous, and immediate assessment of SpHb, SpCO, and SpMet.

The research indicates that surveyed hospitals and clinicians believe Pulse CO-Oximetry has the strong likelihood

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of improving the quality, safety, and efficiency of healthcare delivery.

Study Methods

A three-part methodology was used to evaluate and quantify the potential financial benefits of Pulse CO-Oximetry: 1) understand the current process of care and identify the potential clinical and financial benefits; 2) quantify the benefits into financial models; 3) verify findings and refine the model through prospective surveys and peer-reviewed literature.

Hospital inputs were first evaluated through in-depth one-on-one interviews with clinicians and other decision-makers at 15 acute care hospitals distributed evenly across the U.S. (Appendix A). Respondents represented community and teaching hospitals, HMOs, and smaller care institutions, ranging in size from 300 to 900 beds with annual revenues from \$700 million to \$3 billion.

The interviews were designed to allow data collection from a cross-section of hospital departments as well as executive management and included questions about clinical efficiency, patient safety, “do no harm” initiatives, and the noninvasive detection of blood constituents that have been directly linked to increased morbidity and mortality when undetected and untreated.

In total, 70 in-depth interviews were performed by Capgemini researchers with professionals in: Anesthesiology, Emergency Medicine, Intensive Care, Neonatal Intensive Care, Gastrointesti-

nal Labs, Cardiology, Pulmonary, Respiratory Care, Finance, Purchasing, Materials Management, and Biomedical Engineering. Capgemini analysts have completed a portfolio of like business strategy studies and business cases for healthcare and life science institutions (www.capgemini.com).

Initial findings related to clinical and financial benefits were reviewed and quantified through a follow-on survey of 200 hospital-based physicians throughout the U.S. who did not partic-

Rapid intervention for out-of-range Hb, COHb, and MetHb levels was viewed by respondents as a clinical imperative, as treatment delays have been shown to increase morbidity and mortality.

ipate in the initial interviews.⁷ Participating physicians included surgeons, anesthesiologists, intensivists, and emergency medicine physicians. Respondents from a variety of geographic regions and 38 states were included.

Technology Impact on Efficiency and the Process of Care

Hospitals surveyed for this study rated clinical efficiency and safe patient throughput of paramount importance to attaining favorable clinical and financial outcomes. Noninvasive Pulse CO-Oximetry was perceived by clinicians and administrators alike to have clinical and financial benefits across multiple hospital departments.

For SpHb, respondents indicated that most patients could benefit and those

care areas viewed as having the largest benefit were surgery, intensive care, and the emergency department. The emergency department was also seen as a high impact area for SpCO, while the endoscopy, bronchoscopy, and transesophageal echocardiography procedure labs, as well as neonatal intensive care, were the areas that would most benefit from SpMet.

Traditional methods to obtain Hb include lab CO-Oximeters, hematology analyzers, and blood gas analyzers, while COHb and MetHb could only be obtained through a CO-Oximeter. All lab methods require invasive blood draws and processing time to turn around test results that delay clinical decisions, and they are only

available intermittently after a clinician has ordered the test.

Turnaround time for lab tests was recorded at two to three hours for a regular in-house lab, and as fast as 15 minutes for a “stat” test for emergency and surgery patients.

While all hospitals interviewed in phase one of this study owned an on-site lab CO-Oximeter and blood gas analyzer, it is estimated that only half of U.S.-based hospitals have an onsite CO-Oximeter that can measure COHb or MetHb levels.⁸ In these facilities, this means that when the measurement is needed, they must send blood samples to off-site lab facilities with an average turnaround time of 15 hours.

Rapid intervention for out-of-range Hb, COHb, and MetHb levels was viewed by respondents as a clinical imperative, as treatment delays have been shown to

increase morbidity and mortality.^{9,10}

Respondents viewed noninvasive Pulse CO-Oximetry as having multiple clinical performance advantages over traditional lab methods that possess inherent delays in patient care with attendant safety compromises.

As shown in Table 1, Pulse CO-Oximetry was viewed by respondents as offering improved patient care and safety with demonstrable impact on the cost of care, overall efficiency gains, and patient safety.

Both clinicians and hospital administrators favored the ability to assess SpHb, SpCO, and SpMet in real time and viewed Pulse CO-Oximetry as having the ability to improve hospital throughput by facilitating earlier and better diagnosis, leading to quicker and improved therapeutic interventions. These actions were seen as being likely to enhance patient outcomes and free clinicians to see more patients.

Patient comfort and safety were also cited by clinicians as a potential benefit of noninvasive and immediate Pulse CO-Oximetry measurements.

Clinicians also desired the ability to make critical decisions faster without having to “stick” patients, with the attendant cautions around sharps hazards and biohazardous waste handling and

associated costs. This was seen as especially beneficial for neonates, the elderly, and trauma patients.

Specific Clinical and Financial Value: Total Hemoglobin

Anemia is defined as a low Hb level, which may occur acutely during blood loss or chronically due to internal bleeding or dietary insufficiency.

Anemic status is considered a critical driver of diagnosis, prognosis, and treatment decisions, so lab-based Hb assessment is one of the most common tests performed in hospitals.¹¹ It is often measured as part of a complete blood count (CBC) which also provides white blood and platelet count in addition to Hb.

Respondents indicated that many CBC tests were primarily for Hb and stated that they could significantly benefit from the ability to noninvasively, immediately, and continuously assess a patient’s anemic status.

Another potential benefit identified was the ability of noninvasive Pulse CO-Oximetry to save time related to ordering and waiting for tests.

Clinicians and hospital administrators projected efficiency gains for clinicians

such as anesthesiologists and emergency room physicians, where creating even a ten minute savings per clinician was seen as beneficial in improving the process of care.

Given the volume of testing associated with Hb, conversion of some traditional invasive Hb tests to noninvasive SpHb monitoring was also seen as saving time and potentially reducing load and costs on hospitals labs.

Surgery

In surgery, as many as one in five inpatients receives a blood transfusion.¹¹ Blood is a precious commodity and has a high cost to collect, test, store, and manage.¹² Unfortunately, inappropriate transfusions are a costly contributor to health care. In one large meta-analysis, the risk-adjusted increase in intensive

A recent Joint Commission report on blood transfusions estimated the total cost to transfuse one unit of blood to be \$500 to \$1,000.

Table 1. Potential Financial Benefits of Pulse CO-Oximetry

Process of Care Benefits	Increased Revenue / Patient Throughput	Decreased Costs
Reduce time needed to collect and process lab tests	●	
Avoid unnecessary lab and diagnostic testing due to delay in results	●	●
Avoid hazards and complications from invasive testing		●
Enable earlier diagnosis and treatment of life-threatening conditions	●	●
Avoid wrong treatment due to lack of real-time information		●
Avoid unnecessary treatment from misdiagnosis		●
Avoid liability from misdiagnosis and complications		●

care length of stay was between two and five days for patients receiving a transfusion,¹³ and use of a restrictive Hb trigger reduced transfusions by 40%. In the CRIT randomized trial of restrictive transfusion practices, each transfusion of 1-2 units equated to an increased hospital length of stay by 3 or more days.¹⁴ In another study, risk-adjusted nosocomial infection rate was significantly higher in patients receiving transfusions.¹⁵

Many hospitals have already initiated clinical pathways to both prevent unnecessary transfusions in patients who do not need them as well as to better identify patients who could benefit from earlier blood transfusions, both of which can have significant impact on patient morbidity and treatment costs.¹⁶ A recent Joint Commission report on blood transfusions estimated the total cost to transfuse one unit of blood to be \$500 to \$1,000.¹⁷

In our study, noninvasive SpHb was seen as having a positive impact on blood transfusion management. The majority of surgeons and anesthesiologists stated that SpHb monitoring would both enable earlier transfusion in some patients and help avoid unnecessary transfusions in others.

To quantify the potential direct and indirect cost savings from avoiding unnecessary transfusions, anesthesiologists and surgeons were asked to estimate how many blood loss surgeries

they would need to monitor with SpHb to prevent one unnecessary transfusion in one patient.

The majority of anesthesiologists and two-thirds of surgeons stated that SpHb monitoring would prevent at least one unnecessary transfusion in every ten surgical cases on which it was used.

Intensive Care

Internal bleeding is a significant risk factor for many patients in the post-surgical and intensive care environment and leads to significantly increased cost of treatment.¹⁸

While traditional vital signs do not reliably predict Hb levels, low Hb has been shown to quickly identify almost nine out of ten internal bleeding patients.¹⁹ Intermittent lab testing eventually identifies significant drops in Hb which initiate rapid assessment for the source of bleeding and intervention to prevent further bleeding, but detection of Hb changes can occur hours after bleeding begins.

When combined with decreased red blood cell production and bleeding, frequent blood draws for lab tests over multiple days often induce anemia. As many as 95% of intensive care patients have a below-normal Hb level by day three and 35% experience acute bleeding.²⁰⁻²²

In addition, an estimated 80% of pa-

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tients in intensive care for a week or more receive a blood transfusion, despite evidence showing unnecessary transfusions hurt patient outcome and increase the cost of care.^{22,23}

The majority of intensivists in our study stated that SpHb monitoring would allow them to both identify internal bleeding sooner and decrease unnecessary blood transfusions. To quantify the potential direct and indirect cost savings from SpHb monitoring, intensivists were asked to estimate how many intensive care patients would need to be monitored with SpHb in order to reduce intensive care stay by one day.

The majority of intensivists stated that SpHb monitoring would reduce intensive care length of stay by at least one day for every fifteen or fewer patients on which it was used.

Emergency Department

The emergency department is the most frequent user of Hb tests, typically as part of a CBC.²⁵ Ruling out anemia as a cause of symptoms is a frequency requirement, and also enables identifica-

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tion of anemia for proper treatment as either an inpatient or outpatient.

While less frequent, in trauma situations emergency physicians are often forced to make blood transfusion decisions without the aid of the otherwise-required Hb test, potentially leading to unnecessary transfusions.²⁶

Wait times for lab tests are known to fuel the emergency department overcrowding problem, and also increase the number of patients who leave without being seen.²⁷

Therefore, it is not surprising that decreasing the turnaround time for lab measurements has been identified by the American College of Emergency Physicians as a solution to increase emergency department efficiency.²⁸ The large majority of emergency physicians stated that SpHb spot-testing would help them evaluate anemic status more rapidly and would decrease the number of required clinician interactions with the patient. To quantify the potential direct and indirect cost savings from SpHb spot testing, emergency physicians were asked to estimate how many additional patients the efficiency gains from SpHb would allow the ED to evaluate per day.

Over three fourths of emergency physicians stated that SpHb testing would increase efficiency enough to allow their emergency department to increase patient throughput by three or more patients per day.

Specific Clinical and Financial Value: Carboxyhemoglobin

Exposure to carbon monoxide results in elevated COHb levels in the blood. The Centers for Disease Control reports that carbon monoxide poisoning accounts for an estimated 50,000 emergency department visits and at least 500 unintentional deaths in the U.S. each year.²⁹

Over three quarters of emergency physicians stated that SpHb testing would increase efficiency enough to allow their emergency department to increase patient throughput by three or more patients per day.

Common indications for testing include symptoms along with one of the following: use of portable generators, exposure to gas-powered furnaces, chemical leaks at manufacturing plants, extended inhalation of vehicle or motorboat exhaust, and fire-related exposures. When clinical suspicion is high, invasive lab CO-Oximetry tests are traditionally ordered to measure circulating COHb levels.

Recent evidence indicates that elevated COHb levels are much more common than previously thought in symptomatic patients, such as those with a headache.³⁰ Delays in carbon monoxide poisoning diagnosis have also been linked to significant increases in cardiac and neurological complications, including premature death.³¹⁻³³

A recent study in the emergency department using Pulse CO-Oximetry for noninvasive SpCO testing identified 60% more carbon monoxide poisoning cases than the traditional approach and estimated that as many as 11,000 carbon monoxide poisoning cases per year in the U.S. were being missed.³⁴

In addition to assessing environmental carbon monoxide poisoning, elevated COHb levels have shown an association with hemolysis, a dangerous blood condition which can occur during infection, sepsis, dialysis, and surgery.³⁵

Reports also demonstrate the potential for carbon monoxide poisoning through anesthesia devices with desiccated soda lime, referred to as the “Monday morning phenomena”.³⁶

About one third of respondents stated carbon monoxide poisoning is a common or somewhat common occurrence with the majority of extreme poisonings seen in the emergency department, although more cases are being recognized in other acute care settings.³⁷ The number of severe carbon monoxide poisoning cases per hospital in the study averaged 24 patients annually.

Many respondents felt CO poisoning could be significantly underestimated because of their inability to screen for it due to a time-consuming and costly invasive test it has required. Respondents in the study indicated awareness of the potential impact of a misdiagnosis of carbon monoxide poisoning for flu or some other condition—with potential for a disastrous result of the patient returning to the toxic environment.

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In cases of confirmed carbon monoxide poisoning, respondents ranked the ability to “follow the data” with real-time trending as a desirable feature of Pulse CO-Oximetry and believed it was likely to lead to improved clinical management of the patient.

Specific Clinical and Financial Value: Methemoglobin

MetHb is another dysfunctional form of hemoglobin that prevents the blood from carrying necessary oxygen. Reduced oxygen can lead to eventual organ damage or death, and is especially a risk in cardiac patients who are already compromised.

Methemoglobinemia is defined as an elevated MetHb level and is acquired through exposure to over 30 drugs commonly prescribed in the acute care and hospital outpatient setting such as topical anesthetics (benzocaine, lidocaine, articaine, prilocaine), antibiotics (dapson, trimethoprim, sulphonamides), aniline dyes, and compounds containing nitrates.³⁸ The most common treatment for methemoglobinemia is infusion of methylene blue.

However, methylene blue has been reported to actually induce methemoglobinemia, sometimes producing a methemoglobin rebound effect, often requiring additional treatment.³⁹ Trending MetHb clearance through con-

tinuous monitoring may help improve treatment efficacy.

Published evidence from two large hospitals over 28 months revealed 2.5 cases of methemoglobinemia per hospital per month, with one fatality and three near-fatalities.⁴⁰ These cases occurred across all care areas and patient types. The number of additional but undiagnosed cases was not estimated,

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but growing evidence and warnings by the FDA,⁴¹ Veterans Administration,⁴² and the Institute for Safe Medication Practices⁴³ indicate that elevated MetHb levels are not a rare occurrence and should be evaluated quickly if the clinical condition warrants. In the neonatal intensive care population, the use of inhaled nitric oxide (iNO) therapy, especially at higher doses, can cause

methemoglobinemia,^{44,45} and the American Academy of Pediatrics guidelines suggest clinical monitoring for toxicity in patient receiving iNO therapy.⁴⁶

Almost all surveyed hospitals reported infrequent but recurring cases of severe MetHb poisoning. Respondents reported monitoring for MetHb poisoning in endoscopy, bronchoscopy, and transesophageal echocardiography labs, as well as neonatal intensive care. These departments regularly use drugs that are known to induce methemoglobinemia.

Outside of these departments, awareness is growing but the full impact of the condition is not fully understood.

In general, respondents saw the benefit of more widespread and immediate testing of patients in care areas where elevated acquired methemoglobinemia is known to occur, and appreciated the ability to monitor the effects of therapy to avoid either over- or under-treatment.

Business Case for Pulse CO-Oximetry

Capgemini analyzed the data collected during interviews and surveys and identified potential financial benefits that noninvasive Pulse CO-Oximetry could create for hospitals.

Capgemini utilized three types of financial models in this study for each Pulse CO-Oximetry parameter:

1. Per-patient analysis within each department to model the price, cost reductions, revenue, and net savings or financial gain per patient.
2. Department analysis to model the net annual savings or financial gains and calculate the capital purchase payback period.
3. Hospital-wide analysis including all department analyses to model the aggregate net annual savings and financial gains and calculate the capital purchase payback period.

Pulse CO-Oximetry offers positive financial benefits to hospitals through a reduction in existing costs, cost avoidance through an enhanced process of patient care, and increases in reimbursement revenue.

The net cost savings and financial gains also facilitate a short capital payback period, which has become increasingly important in a capital-constrained healthcare environment.

Per-Patient and Department Financial Models for SpHb

Department-specific financial models were created for surgery, intensive care, and the emergency department. In each department, the make-up of applicable cost savings and revenue increases were significantly different. Cost reductions in surgery and intensive care were driven by reducing SpO₂ sensor use and lab tests, preventing unnecessary transfusion-related morbidity, and enabling earlier detection of bleeding. Revenue increases in the emergency department were

driven by increased throughput and SpHb procedural test reimbursement.

Surgery

In surgery (Table 2), Capgemini estimates that the net savings per patient monitored with SpHb is \$18. These benefits include savings from SpO₂ sensors, which are not necessary if SpHb sensors are used because they also include SpO₂ measurement capability, as well as reduced laboratory tests, which

especially in surgery are often done primarily for Hb.

The largest benefits in the model are driven by physician estimates that SpHb would help them prevent unnecessary transfusions, reduce transfusion-related costs (including blood), and reduce the known increase in morbidity associated with transfusions.

While estimates of the cost of transfusing one unit of blood to any patient range as high as \$1,000, we conserva-

Table 2. SpHb Monitoring in Surgery: Estimated per Patient Analysis

Price per Patient	
SpHb device price (equipment + parameter)	\$6,800
Device useful life (years)	÷ 5
Average uses per year per device	÷ 180
Amortized device price per use	\$8
SpHb sensor price per patient	+ \$95
Total price per patient	\$103
Cost Reductions per Patient	
Replacing SpO₂ Sensors	
Reduced SpO ₂ sensor cost per patient (now replaced with SpHb sensor)	\$10
Reducing Invasive Hb Testing	
Cost per invasive Hb test (direct costs only)	\$1.50
Estimated number of invasive Hb tests reduced per patient monitored with SpHb	x 4
Reduced cost per patient by reducing invasive Hb testing	\$6
Preventing Unnecessary Transfusions	
Material cost per unit of blood (direct costs plus waste)	\$250
Morbidity risk per unnecessary transfusion	5.0%
Cost per unnecessary transfusion-related morbidity (length of stay, therapeutic interventions)	x \$6,000
Weighted morbidity-related cost per unnecessary transfusion	\$300
Total cost per unnecessary transfusion (material + morbidity cost)	\$550
Estimated percent of blood transfusion cases monitored with SpHb to prevent one unnecessary transfusion	x 15.0%
Reduced cost per patient by preventing unnecessary transfusions	\$83
Enabling Earlier Identification of Bleeding	
Morbidity risk per late transfusion	5.0%
Cost per late-transfusion morbidity (length of stay, therapeutic interventions)	x \$6,000
Weighted morbidity-related cost per late transfusion	\$300
Estimated percent of patients monitored with SpHb in which bleeding is identified earlier to allow earlier intervention	x 7.5%
Reduced cost per patient by enabling earlier identification of bleeding	\$23
Total reduced costs per patient	\$121
Net savings per patient monitored	\$18

tively estimated that the cost to transfuse one unnecessary unit of blood to be \$550. Included in the total cost was the morbidity-related cost of transfusing an unnecessary unit of blood, which we conservatively estimated at \$300 assuming a 5% complication rate and a \$6,000 complication cost. Some additional benefits by enabling earlier identification of bleeding were also included.

Over the entire surgical department

purchasing 20 SpHb devices at a capital cost of \$136,000, it is estimated that by monitoring one patient every other day per device, SpHb could contribute to a \$93,600 improvement in net annual savings and pay back the capital investment in 1.5 years.

Intensive Care

In intensive care (Table 3), Capgemini estimates that the net savings per patient monitored with SpHb is \$127.

These benefits also include savings from SpO₂ sensors and reduced laboratory tests, but the largest benefits in the model are driven by physician estimates that SpHb would enable earlier identification of bleeding such that intensive care days could be reduced.

Additional benefits from preventing unnecessary transfusions in some patients through continuous noninvasive monitoring were also significant.

In an intensive care department purchasing ten SpHb devices at a capital cost of \$68,000, it is estimated that by monitoring five patients per month per device, SpHb could provide \$67,350 in net annual savings and pay back the capital investment in 1.0 years.

Emergency Department

In the emergency department (Table 4), Capgemini estimates that for each patient tested for SpHb, the net financial gain per patient is about \$31. These benefits include procedural reimbursement based on use of the existing CPT code for Hb measurement,⁴⁷ but the largest benefit is driven by physician estimates that SpHb would allow the department to improve patient throughput by not waiting for invasive Hb tests to make diagnostic and treatment decisions.

Over the entire emergency department purchasing six SpHb devices at a capital cost of \$40,800, it is estimated that by testing about four patients per device per day, that SpHb could provide a \$293,132 net annual financial gain and pay back the capital investment in 0.1 years.

Even if SpHb were only able to increase patient throughput a tenth of the estimated amount, the increased annual revenue would more than offset the capital and operational price of SpHb testing.

Table 3. SpHb Monitoring in Intensive Care: Per Patient Analysis

Price per Patient	
SpHb device price (equipment + parameter)	\$6,800
Device useful life (years)	÷ 5
Average uses per year per device	÷ 60
Amortized device price per use	\$23
SpHb sensor price per patient	\$95
Percent of ICU patients monitored that do not have an SpHb sensor from the OR	x 60%
Average SpHb sensor price per patient	\$57
Total price per patient	\$80
Cost Reductions per Patient	
Replacing SpO₂ Sensors	
Reduced SpO₂ sensor cost per patient (replaced with SpHb sensor)	\$10
Reducing Invasive Hb Testing	
Cost per invasive Hb test (direct costs only)	\$1.50
Estimated number of invasive Hb tests reduced per patient monitored with SpHb	x 4
Reduced cost per patient by reducing invasive Hb testing	\$6
Enabling Earlier Identification of Bleeding	
Cost per ICU day	\$2,000
Estimated percent of patients monitored with SpHb in which bleeding is identified earlier to enable earlier intervention and reduce ICU stay by one day	x 7.5%
Reduced costs by enabling earlier identification of bleeding	\$150
Preventing Unnecessary Transfusions	
Material cost per unit of blood (direct costs plus waste)	\$250
Morbidity risk per unnecessary transfusion	5.0%
Cost per unnecessary transfusion-related morbidity (length of stay, therapeutic interventions)	x \$6,000
Weighted morbidity-related cost per unnecessary transfusion	\$300
Total cost per unnecessary transfusion (material + morbidity cost)	\$550
Estimated percent of patients monitored with SpHb to prevent one unnecessary transfusion	x 7.5%
Reduced cost per patient by preventing unnecessary transfusions	\$41
Total reduced costs per patient monitored	\$207
Net savings per patient monitored	\$127

Per-Patient and Department Financial Models for SpCO and SpMet

Department-specific financial models were created for SpCO in the emergency department, and for SpMet in the neonatal intensive care and procedure labs including endoscopy, bronchoscopy, and transesophageal echocardiography.

In the emergency department and procedure labs, the major benefit was driven by increased reimbursement from noninvasive testing. Both SpCO and SpMet have established CPT coding (88740 and 88741) and \$7.33 payment under the 2009 Medicare Fee Schedule.⁴⁸

SpCO in Emergency

Based on receiving emergency department outpatient reimbursement on 90% of these patients tested for SpCO, it is estimated that the net revenue per patient tested will be \$6.60 and the price per patient tested (device and sensor) will be \$1.85, resulting in a net financial gain per patient tested of \$4.74.

Based on the capital investment in one SpCO device used two times per day and taking into account the annual sensor costs, it is expected that the net annual financial gain of \$4,121 could pay back the investment in 0.8 years.

SpMet in Neonatal Intensive Care

It is estimated that SpMet in the neonatal intensive care could generate up to \$10 in net savings per patient.

These potential benefits include savings from SpO₂ sensors (\$10 per patient) and reduced laboratory tests (\$3 per patient assuming infrequent MetHb lab test-

Pulse CO-Oximetry offers positive financial benefits to hospitals through a reduction in existing costs, cost avoidance through an enhanced process of patient care, and increases in reimbursement revenue.

ing today), but the largest benefits in the model are driven by the potential to prevent methemoglobinemia.

Assuming an incidence rate of 0.5% for elevated methemoglobin levels while receiving iNO therapy and a cost of methemoglobinemia treatment at

\$12,000, the per-patient cost reductions for prevention of methemoglobinemia equated to \$60. At a price per patient monitored (device + sensor) at \$63, the net savings per patient is estimated at \$10.

Based on a capital investment in two

Table 4. SpHb Testing in the Emergency Department: Estimated per Patient Analysis

Price per Patient	
SpHb device price (equipment + parameter)	\$6,800
Device useful life (years)	÷ 5
Average uses per year per device	÷ 1,500
Amortized device price per use	\$0.91
Sensor price per spot SpHb measurement	\$2.49
Total price per patient tested	\$3.40
Increased Revenue per Patient	
Increasing Procedural Reimbursement	
Reimbursement amount for SpHb testing (CPT 85018)	\$3.46
Percent of patients tested that are not admitted and are eligible to receive outpatient reimbursement	x 90%
Reimbursement per test performed	\$3.11
Increasing Patient Throughput	
Average revenue per patient seen in the ED but not admitted	\$125
Average revenue per patient admitted to the hospital through the ED	\$1,500
Percentage of ED patients admitted to hospital	10%
Weighted average revenue per patient (90% x \$125 + 10% x \$1,500)	\$262.50
Estimated increased patient throughput per day due to SpHb testing	x 3.0
Average number of SpHb tests per day	÷ 25
Effective increased ED throughput revenue per SpHb patient tested	\$31.50
Total revenue per patient tested	\$31.61
Net financial gain per patient tested	\$31.21

Under conservative estimates, Pulse CO-Oximetry could generate almost \$900 thousand per year and \$4.5 million over a five-year period in gross hospital cost reductions and revenue increases.

SpMet devices used 60 times per year per device, it is expected that the net annual savings of \$8,760 could pay back the investment in 3.4 years.

SpMet in Procedure Labs

In the endoscopy, bronchoscopy, and transesophageal echocardiography labs, topical use of benzocaine is routine and can result in methemoglobinemia. Based on receiving outpatient reimbursement on 70% of the patients tested for SpMet, it is estimated that the net revenue per patient tested will be \$5.13 and the price per patient tested will be \$2.71, resulting in a net financial gain per patient tested of \$2.42.

Based on the capital investment in one SpMet device for each department that is used two times per day and taking into account the annual sensor pricing, it is expected that the net annual financial gain of \$5,612 could pay back the capital investment in 1.8 years.

Hospital-Wide Financial Model for SpHb, SpCO, and SpMet

Capgemini also created an aggregate hospital-wide financial model for an average-sized hospital in the study (500 beds), using each of the department models for each Pulse CO-Oximeter measurement described in this study for a total of 42 Pulse CO-Oximeter devices across the hospital.

In this scenario, SpHb-enabled devices are deployed across surgery, intensive care, and emergency department, while SpCO-enabled devices are deployed only in the emergency department and SpMet-enabled devices are deployed in the endoscopy, bronchoscopy, and transesophageal echocardiography labs as well as the neonatal intensive care unit.

Under conservative estimates, Pulse CO-Oximetry technology could generate almost \$900 thousand per year and \$4.5 million over a five-year period in gross hospital cost reductions and revenue increases.

As shown in Table 5, the largest portion of these potential benefits will be derived from SpHb by preventing unnecessary transfusions, identifying in-

ternal bleeding earlier, and increasing patient throughput in the emergency department.

It is estimated that with a capital investment of \$272 thousand and \$468 thousand in net annual cost savings and financial gains when taking Pulse-CO Oximetry sensor pricing into account, that the capital purchase payback could be complete in seven months.

Multiple other sources of potential revenue increases and cost reductions were assessed but not included in any of the models, including: increased patient volume at the hospital through recognition as a hospital providing advanced monitoring and testing capabilities, increased patient throughput in the intensive care unit or surgery department, or potential savings from avoidance of liability due to complications from missed or delayed diagnosis.

If it were included, liability avoidance would have been conservatively estimated to be in the range of \$100,000 to \$120,000 over a five year period in potential benefits. Because a single liability case can significantly impact a hospital, this is an area that deserves careful review by any institution especially in consideration of recent patient safety initiatives and “do no harm” campaigns.

Table 5. Estimated Cost Reductions and Revenue Increases From Hospital-Wide Implementation of Pulse CO-Oximetry Technology (500 Bed Hospital, Conservative Estimate)

Annual Cost Reductions	
Replacing SpO ₂ sensors	\$43,200
Reducing lab testing	\$25,560
Preventing unnecessary transfusions	\$321,750
Enabling earlier identification of bleeding	\$171,000
Preventing methemoglobinemia	\$7,200
Annual Revenue Increases	
Increasing procedural reimbursement	\$40,928
Increasing patient throughput	\$287,438
Total cost reductions and revenue increases	\$897,075

Conclusion

Incorporating Pulse CO-Oximetry with SpHb, SpCO, and SpMet monitoring and testing with Pulse CO-Oximetry into the standard clinical practice of hospitals is expected to increase patient safety, reduce costs, and increase hospital revenues.

These potential benefits are primarily derived from process of care improvements including preventing blood transfusions, enabling earlier identification of bleeding, and increasing patient throughput, but are also aided by new procedural reimbursement.

As more evidence becomes available, it is possible that additional clinical and financial benefits may also be shown with Pulse CO-Oximetry.

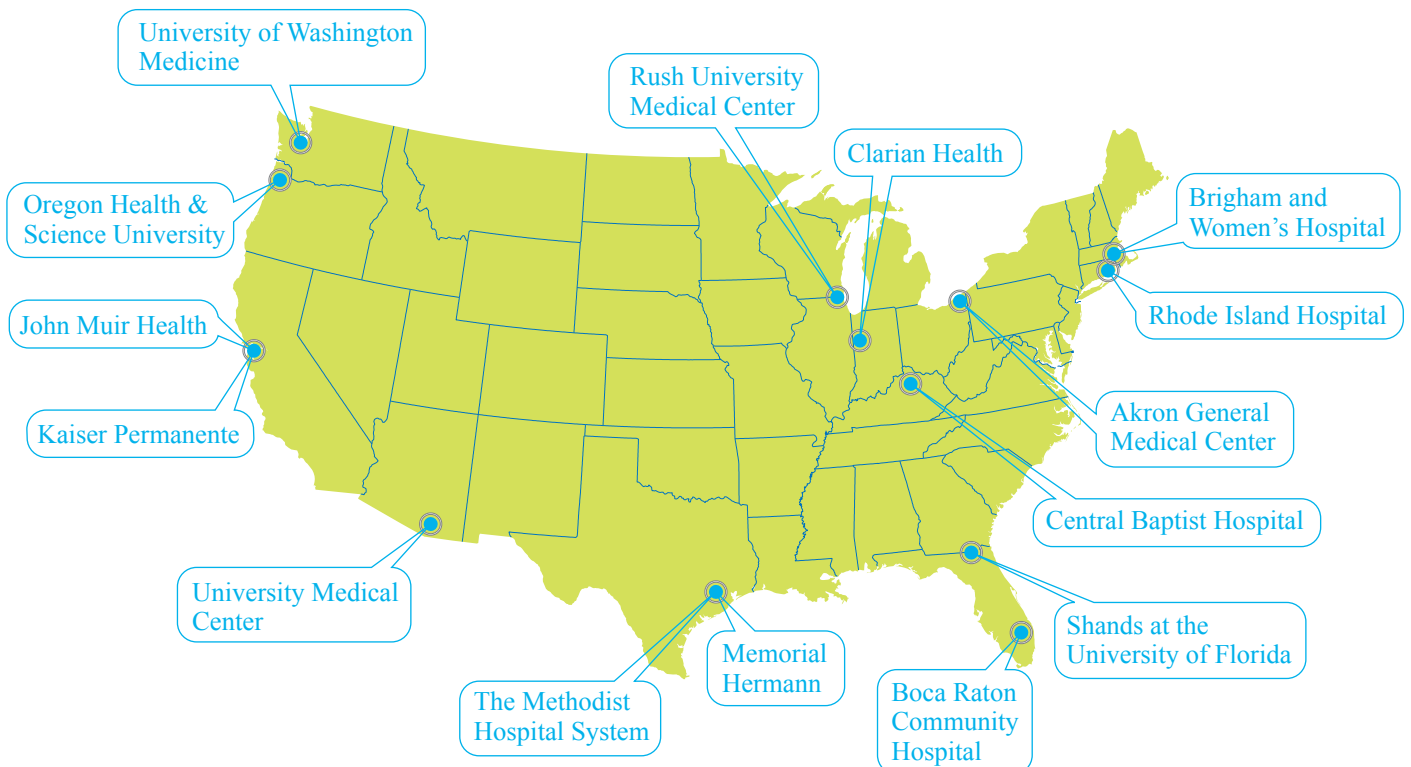
Capgemini estimates that the investment in Pulse CO-Oximetry technology has a positive business and patient

care improvement case. Whether considered on a per-patient, department, or hospital-wide analysis, there are significant clinical and financial benefits to implementing Pulse CO-Oximetry technology.

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The study was commissioned by Masimo Corporation, creator of Pulse CO-Oximetry technology, which is available as part of their Rainbow SET product platform. For a customized financial analysis based on the Capgemini models, please contact Masimo Corporation at 1-800-257-3810, or go to www.masimo.com.

Appendix A. Hospitals Participating in the In-depth Interviews



Note: Participation in the interviews does not imply an endorsement of the study conclusions.

References

- The Joint Commission: 2008 National Patient Safety Goals, Hospital Program. <http://www.jointcommission.org/PatientSafety>.
- Institute for Healthcare Improvement (IHI): Protecting 5 Million Lives From Harm Campaign. <http://www.ihl.org/IHI/Programs/Campaign>
- Price CP et al. Improving healthcare accessibility through point-of-care technologies. *Clinical Chemistry*. 2007; 53:9:1665-1675.
- Barker SJ et al. Measurement of Carboxyhemoglobin and Methemoglobin by Pulse Oximetry: A Human Volunteer Study. *Anesthesiology*. 2006; 105: 892-897.
- Barker SJ et al. The measurement of dyshemoglobins and total hemoglobin by pulse oximetry. *Curr Opin Anaesthesiol*. 2008; 21(6):805-10.
- MackNet MR et al. *Anesthesia and Analgesia*. 2007; 104:2-117.
- Contracted through HRA Research, New Jersey.
- Hampson NB et al. Carboxyhemoglobin measurement by hospitals: implications for the diagnosis of carbon monoxide poisoning. *J Emerg Med*. 2006; 31(1):13-6.
- Wolf SJ et al. Clinical Policy: Critical Issues in the Management of Adult Patients Presenting to the Emergency Department with Acute Carbon Monoxide Poisoning. *Ann Emerg Med*. 2008; 51:138-152.
- Schomaker WC et al. Resuscitation from severe hemorrhage. *Critical Care Medicine*. 1996; 24:S12-S23.
- DeFrances et al. 2006 National Hospital Discharge Survey. *Advance Data*. 2008;5:1-20.
- Shander A et al. Estimating the Cost of blood. *Best Practice & Research Clinical Anaesthesiology*. 2007; Vol. 21, No. 2:271-289.
- Hill SR et al. Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion. *Cochrane Database of Systematic Reviews* 2000, Issue 1.
- Corwin HL et al. The CRIT Study: Anemia and blood transfusion in the critically ill--current clinical practice in the United States. *Crit Care Med*. 2004; 32(1):39-52.
- Taylor RW et al. Red blood cell transfusions and nosocomial infections in critically ill patients. *Crit Care Med*. 2006; 34(9):2302-8.
- Shander A. Financial and clinical outcomes associated with surgical bleeding complications. *Surgery*. 2007; 142:S20-S25.
- A New Look at Blood Transfusion. *Joint Commission Perspectives on Patient Safety*. 2007; 1:1-12.
- Herwaldt LA. Hemorrhage after coronary artery bypass graft procedures. *Infect Control Hosp Epidemiol*. 2003; 24(1):44-50.
- Bruns B et al. Hemoglobin drops within minutes of injuries and predicts need for an intervention to stop hemorrhage. *J Trauma*. 2007; 63(2):312-5.
- Gould S et al. Packed red blood cell transfusion in the intensive care unit: limitations and consequences. *AJCC*. 2007; 16:39-48.
- Von Ahsehn N et al. Important role of nondiagnostic blood loss and blunted erythropoietic response in the anemia of medical intensive care patients. *Crit Care Med*. 1999; 12:2630-2639.
- Zimmerman JE et al. Evaluating laboratory usage in the intensive care unit: patient and institutional characteristics that influence frequency of blood sampling. *Crit Care Med*. 1997; 25:737-48.
- Corwin HL et al. RBC transfusion in the ICU. Is there a reason? *Chest*. 1995; 108:767-771.
- Hebert, et al. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. Transfusion Requirements in Critical Care Investigators, Canadian Critical Care Trials Group. *N Engl J Med*. 1999; 340:409-17.
- Nawar EW et al. National hospital ambulatory medical care survey: 2005 emergency dept. *Advance Data*. 2007;386:1-32.
- Kuhne CA et al. Emergency Transfusion Score (ETS): a useful instrument for prediction of blood transfusion requirement in severely injured patients. *World J Surg*. 2008; 32(6):1183-8.
- Weiss SJ et al. Relationship between the National ED Overcrowding Scale and the number of patients who leave without being seen in an academic ED. *Am J Emerg Med*. 2005; 23:288-294.
- ACEP Task Force on Boarding, 2008.
- CDC. Carbon monoxide--related deaths--U.S., 1999-2004. *MMWR Morb Mortal Wkly Rep*. 2007; 56(50):1309-12.
- Eberhard Mt et al. Noninvasive Measurement of Carbon Monoxide Levels in ED Patients with Headache. *J Med Toxic*. 2006; V.2, N.3.:89-92.
- Henry CR et al. Myocardial injury and long-term mortality following moderate to severe carbon monoxide poisoning. *JAMA*. 2006; 295(4):398-402.
- Weaver LK et al. Hyperbaric Oxygen for Acute Carbon Monoxide Poisoning. *N Engl J Med*. 2002; 347(14):1057-067.
- Thom SR et al. Carbon Monoxide Poisoning. Hyperbaric Oxygen 2003, Indications and results, The Hyperbaric Oxygen Therapy Committee report. Undersea and Hyperbaric Medical Society. 2003; 11-18.
- Suner S et al. Non-invasive Pulse CO-oximetry Screening in the Emergency Department Identifies Occult Carbon Monoxide Toxicity. *J Emerg Med*. 2008; 33(1):441-450.
- Hampson NB. Carboxyhemoglobin Elevation Due To Hemolytic Anemia. *J Emerg Med*. 2007; 33(1):17-19.
- Keijzer C et al. Carbon monoxide production from five volatile anesthetics in dry soda-lime in a patient model: halothane and sevoflurane do produce carbon monoxide; temperature is a poor predictor of carbon monoxide production. *BMC Anesthesiol*. 2005; 2:5(1):6.
- Hampson NB et al. Carbon monoxide poisoning: a new incidence for an old disease. *Undersea Hyperb Med*. 2007; 34(3):163-8.
- Haddad L et al. Clinical management of poisoning and overdose. 3rd ed. Philadelphia: WB Saunders; 1998.
- H. Bilgin, et al. Methemoglobinemia induced by methylene blue perturbation during laparoscopy. *Acta Anaesthesiologica Scandinavica*. 1998; 42: 594-595.
- Ash-Bernal R et al. Acquired methemoglobinemia: a retrospective series of 138 cases at 2 teaching hospitals. *Medicine*. 2004; 83:265-273.
- FDA Public Health Advisory on Benzocaine. February 13, 2006.
- VA Warning System Patient Safety Alert: Cessation of Topical Spray Benzocaine Usage to Anesthetize the Surfaces of the Nasopharynx, Oropharynx, Laryngotracheal Region and Airway <http://www.patientsafety.gov/alerts/Benzocaine-www.pdf>
- Benzocaine-containing topical sprays and methemoglobinemia: Institute for Safe Medication Practices (ISMP) Medication Safety Alert. Institute for Safe Medication Practices (Oct 3, 2002). <http://smp.org/newsletters/acutecare/articles/20021003.asp>
- Davidson D et al. Inhaled nitric oxide for the early treatment of persistent pulmonary hypertension of the term newborn: a randomized, double-masked, placebo-controlled, dose-response, multicenter study. The I-NO/PPHN Study Group. *Pediatrics*. 1998; 101(3 Pt 1):325-34.
- Taylor MB et al. Methemoglobinemia: Toxicity of inhaled nitric oxide therapy. *Pediatr Crit Care Med*. 2001; 2(1):99-101.
- Committee on Fetus and Newborn, Use of Inhaled Nitric Oxide. *Pediatrics*. 2000; 106: 344-345.
- Communication from the American Medical Association CPT Education and Information Services. July 28, 2008.
- CMS Lab Fee Schedule for 2009. Accessed at www.cms.hhs.gov



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