Cerebral & Somatic Oximetry

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Near Infrared Spectroscopy as an index of Brain and Tissue Oxygenation

Jobsis, 1977: first reported that the high degree of transparency of myocardial and brain tissue in the NIR range enabled real time non invasive detection of tissue oxygen saturation using transillumination spectroscopy

Ferrari & colleagues, 1985: reported some studies on humans, using NIRS

FDA approval, 1993 / INVOS 3110c first introduced by Somanetics

Reflectance Near Infrared Spectroscopy

NIR light can be used to measure regional cerebral tissue oxygen saturation (rSO2). Using Optical spectroscopy and the fact that biological material, including the skull, is relatively transparent in the NIR range.

Because of the poor signal to noise ratio, due to the low intensity of transmitted light, most devices use reflectance mode NIRS in which detector optodes are placed ipsilateral to the transmitter . Photons will traverse elliptical path. Depth of penetration is proportional to transmitter and receiver optode separation. INVOS consider skull thickness,CSF area and Hb conc.and substraction algorithm for compensation.
So extrcranial tissue oxygenation had a negligible influence on values recorded using NIRS.

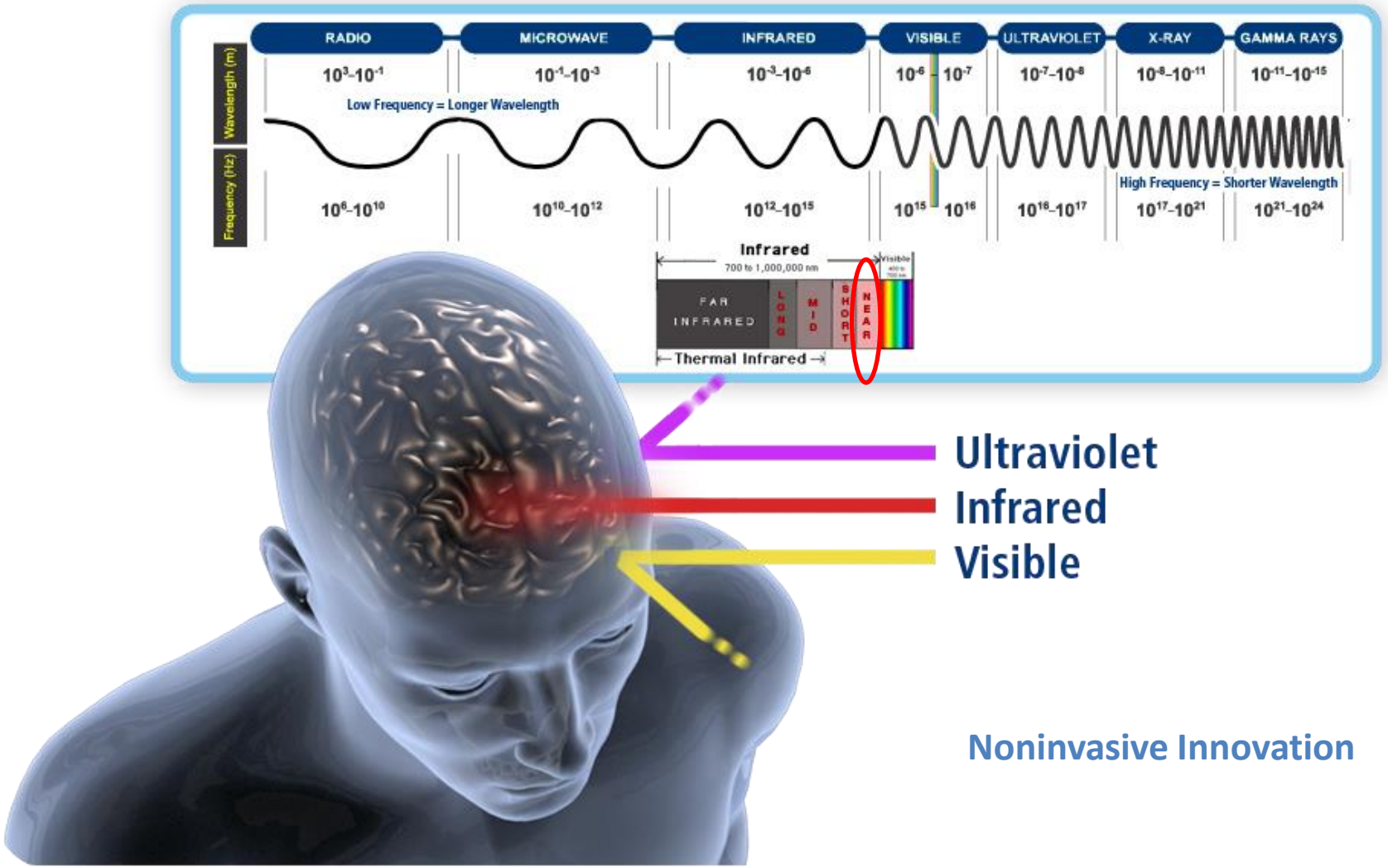
Near Infrared Spectroscopy – cont.

• Different wavelengths of light have differing penetration into human tissue. Wavelengths in the near infrared range and larger easily penetrate bone and tissue.

• We use wavelengths 730 and 810 nanometers which penetrate the bone, skin and dura, and are not absorbed by biologic tissues other than oxy and deoxy hemoglobin

• The behavior of energy at these wavelengths is similar to that used in pulse oximetry. The difference is the *site of measure – the microvasculature in tissue*.

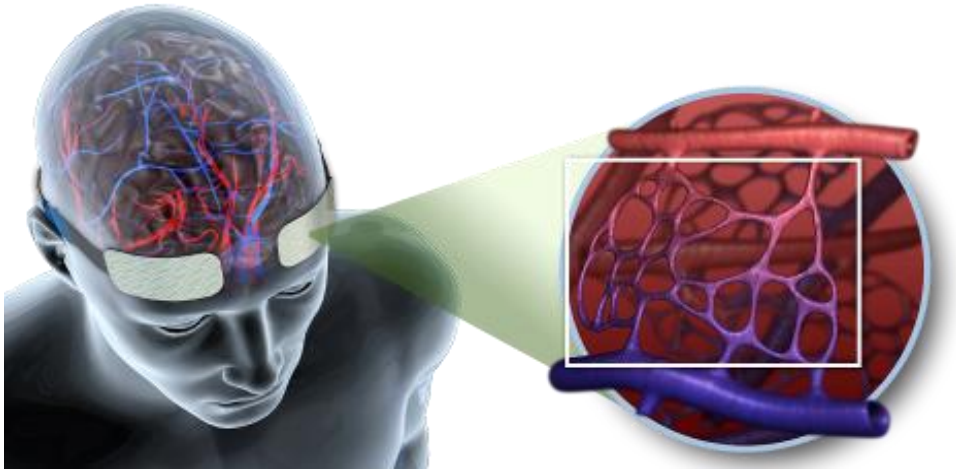
Optical Technology

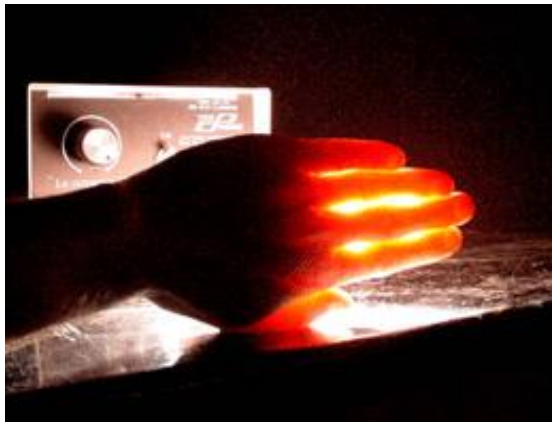


Noninvasive Innovation

Clinically Unique Data

Near infrared light easily penetrates the skull and surface tissue to reflect ***perfusion adequacy*** of the microvasculature beneath the sensor.



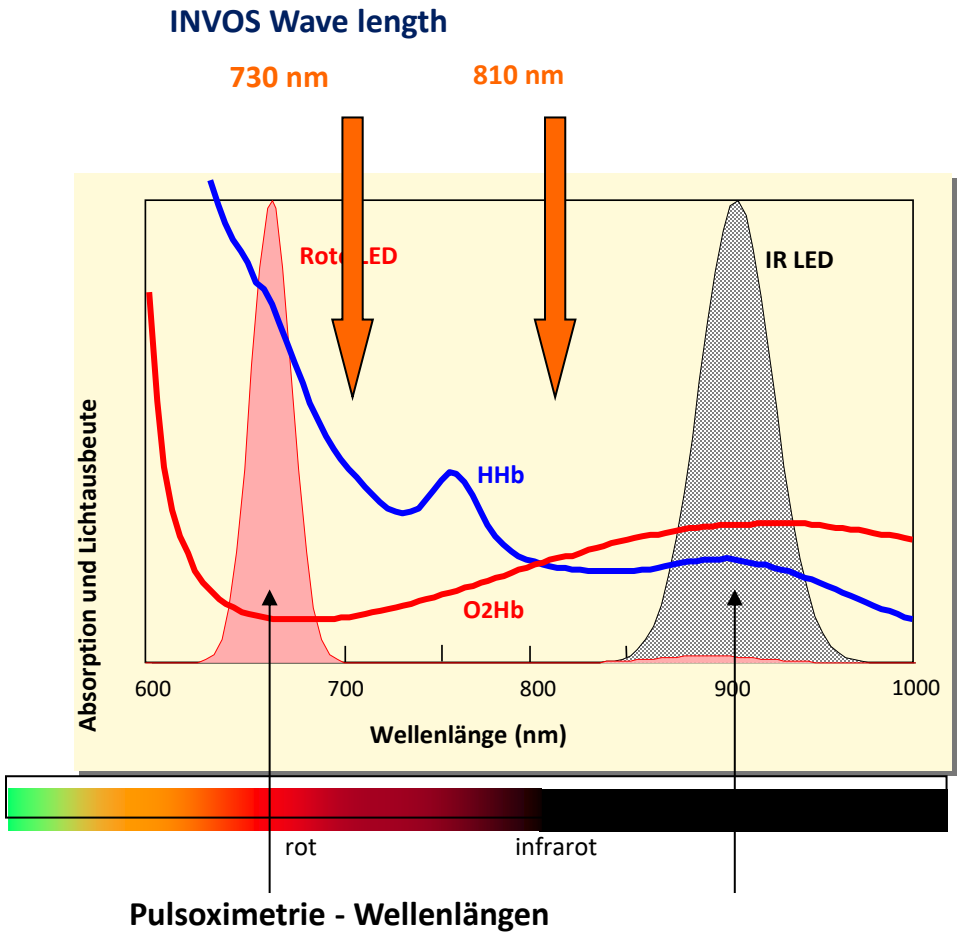


INVOS™ wavelengths

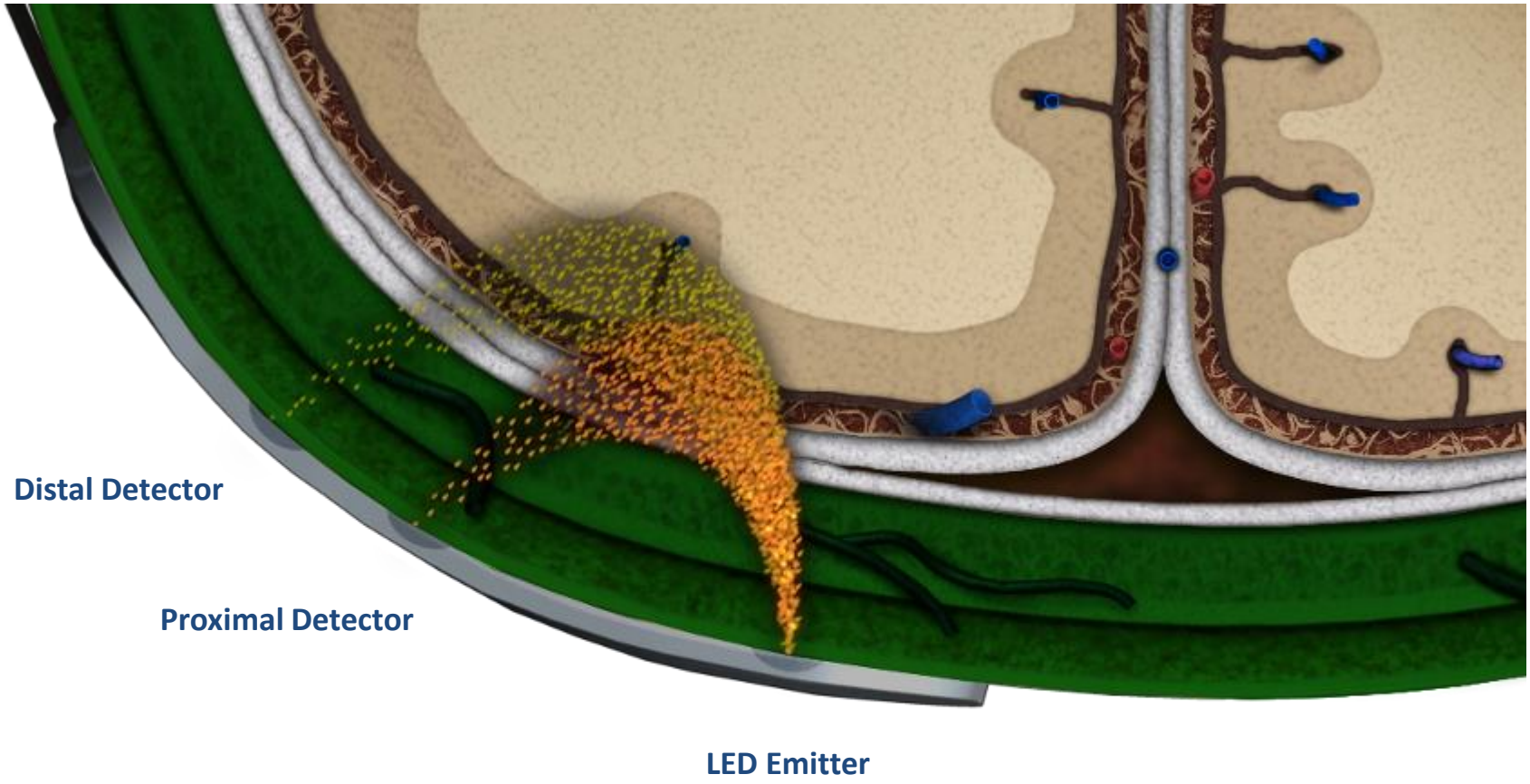
Invos:
Red spectrum = 730 nm
Infrared spectrum = 810 nm

Pulsoximetry:
Red spectrum = 660 nm
Infrared spectrum = 920 nm

Isobestic point for HB/HBO2 to measure total tissue HB concentation



NIRS using Reflectance-mode



Signal from surface tissues are subtracted out

Hongo K, Kobayashi S, Okudera H, Hokama M, Nakagawa F. Noninvasive cerebral optical spectroscopy: Depth-resolved measurements of cerebral haemodynamics using indocyanine green. *Neurol Res.* 1995;17(2):89-93.

The INVOS™ System

Two Channel Near-Infrared Spectroscopy System

The INVOS™ System

Four Channel NIRS Monitoring

Beer Lambert Law

In optics, the **Beer–Lambert law**, also known as **Beer's law** or the **Lambert–Beer law** or the **Beer–Lambert–Bouguer law** (named after August Beer, Johann Heinrich Lambert, and Pierre Bouguer) relates the absorption of light to the properties of the material through which the light is traveling.

$$A = -\log_{10}\left(\frac{I}{I_0}\right)$$

Clinical Challenges

Adult CVS

Prevalence of CVS Complications

- Despite improvement in *survival* rates, *complications* in CV surgery remain common

- Neurological Impairment: 6.1%
  - Stroke, stupor, coma, deterioration in intellectual function, memory deficit or seizures

- Post-Op Delirium: 10%-60%
  - Depending on patient age and type of surgery
  - These patients have a length of stay of 20-25 days vs. 10 days for patients with no adverse outcomes

Prevalence of CVS Complications

- Major organ morbidity or mortality (MOMM): 13.4%
  - Based on 503,478 records in the Society of Thoracic Surgeons (STS) database
  - MOMM is a cumulative score of:
    - Death within 30 days
    - Renal failure requiring dialysis
    - Permanent stroke
    - Reoperation for any reason
    - > 48 hours ventilation
    - Mediastinitis/deep sternal infection
- INVOS™ System monitoring drops MOMM to 3%

Prevalence of CVS Complications

- Cognitive Decline: 24%-53%
- Prolonged Ventilation (Greater than 48 hours) 5.96%
- *Despite increased patient acuity and inherent complications we expect patient outcomes to continually improve*

Newman MF, Kirchner JL, Phillips-Bute B, et al; Neurological Outcome Research Group and Cardiothoracic Anesthesiology Research Endeavors Investigators. Longitudinal assessment of neurocognitive function after coronary artery bypass surgery. *N Engl J Med*. 2001;344(6):395-402.
Shroyer AL, Coombs LP, Peterson ED, et al; Society of Thoracic Surgeons. The Society of Thoracic Surgeons: 30-day operative mortality and morbidity risk models. *Ann Thorac Surg*. 2003;75(6):1856-1864.

Why use cerebral Oximetry?...Neuroprotection

- Raise neuroprotection to a higher level
  - Neuromonitoring studies demonstrate that cerebral desaturations are common

    but with the NIRS, we can correct them
    - ''Ganzel CABG study; 67% desat rate (53/78 cases, with successful interventions in 94% of cases)
    - Murkin CAB study; 56% desat rate (56/100 cases, with successful interventions in 80% of cases

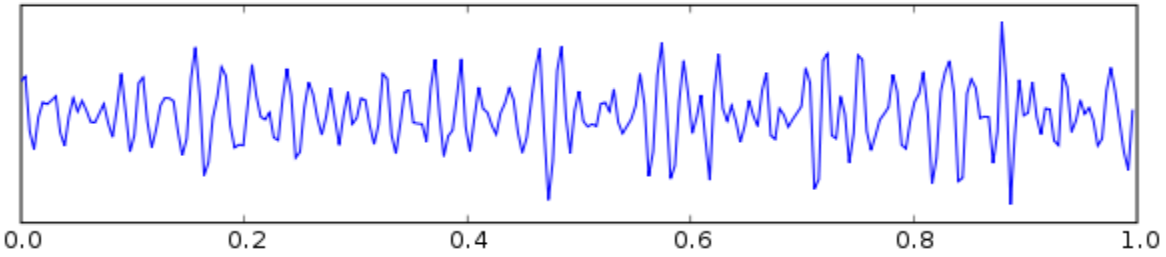
Improve Neuroprotection – cont.

What is traditionally used monitoring in the OR ?:

- Jugular Bulb O_2 Saturations ($SjvO_2$) – no prospective, randomized evidence of benefit; plus it's invasive

- Pulse Oximetry (SpO_2) – its prospective, randomized trial found no difference in complication rates with and without pulse oximetry; plus systemic oxygenation values only

- Electroencephalogram (EEG) – no prospective, randomized study showing improved outcomes



Improve Neuroprotection – cont.

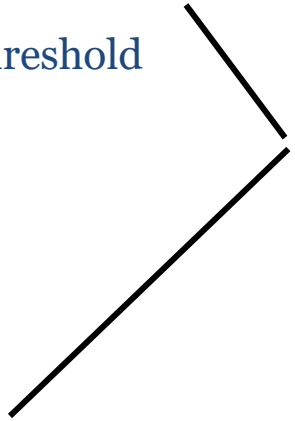
Neuro dysfunction is not always embolic – so detect and correct other factors

"Cerebral hypoxia may be caused by any or a combination of the following conditions:"

Hypotension below the autoregulation threshold

Arterial oxygen desaturation

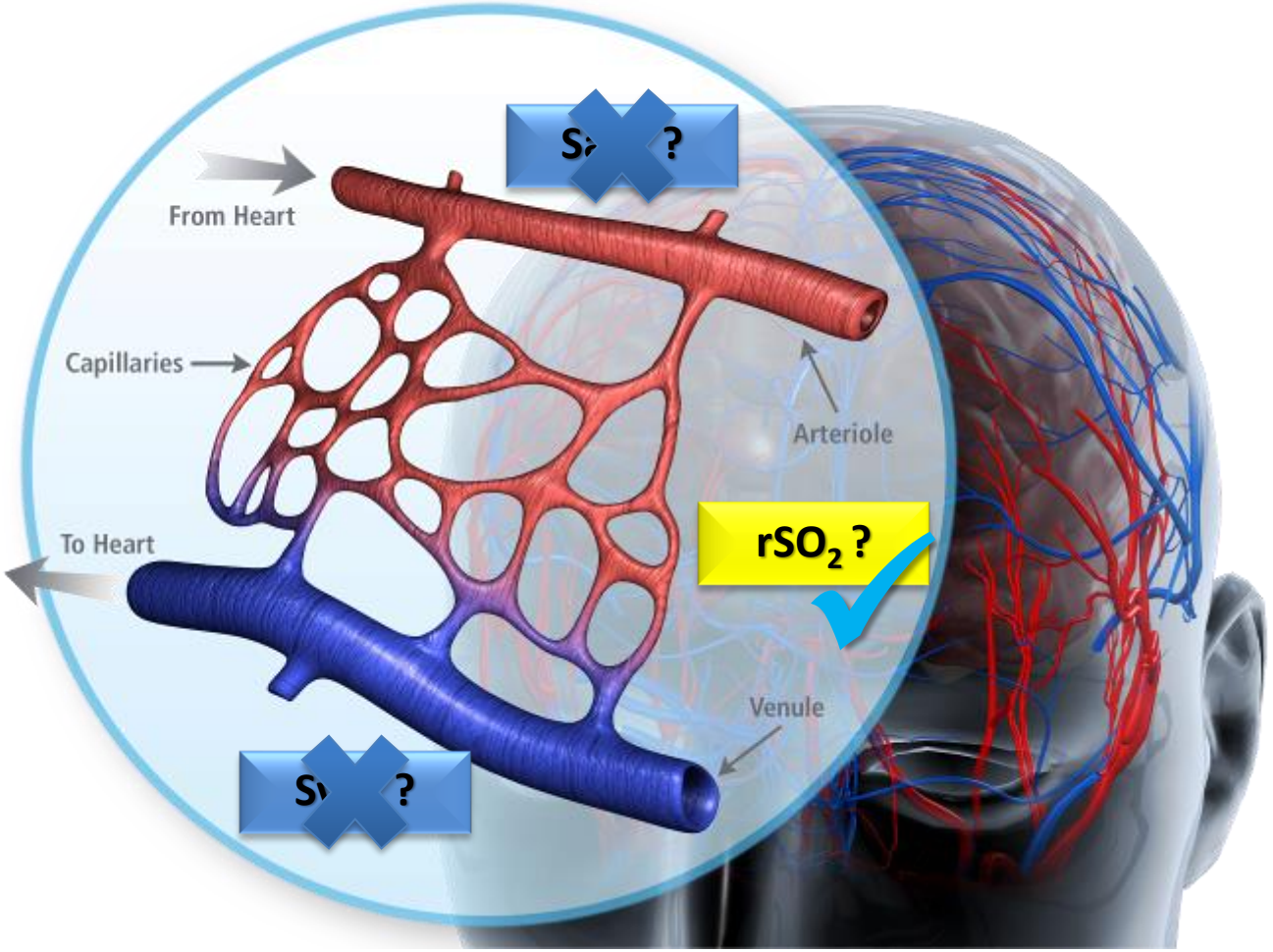
Cerebral vasoconstriction



The NIRS System can help manage these

Yao FSF, et al. J Cardiothorac Vasc Anesth. 2004 Oct;18(5):552-8.

What are we measuring when we placed INVOS Sensor on the forehead?



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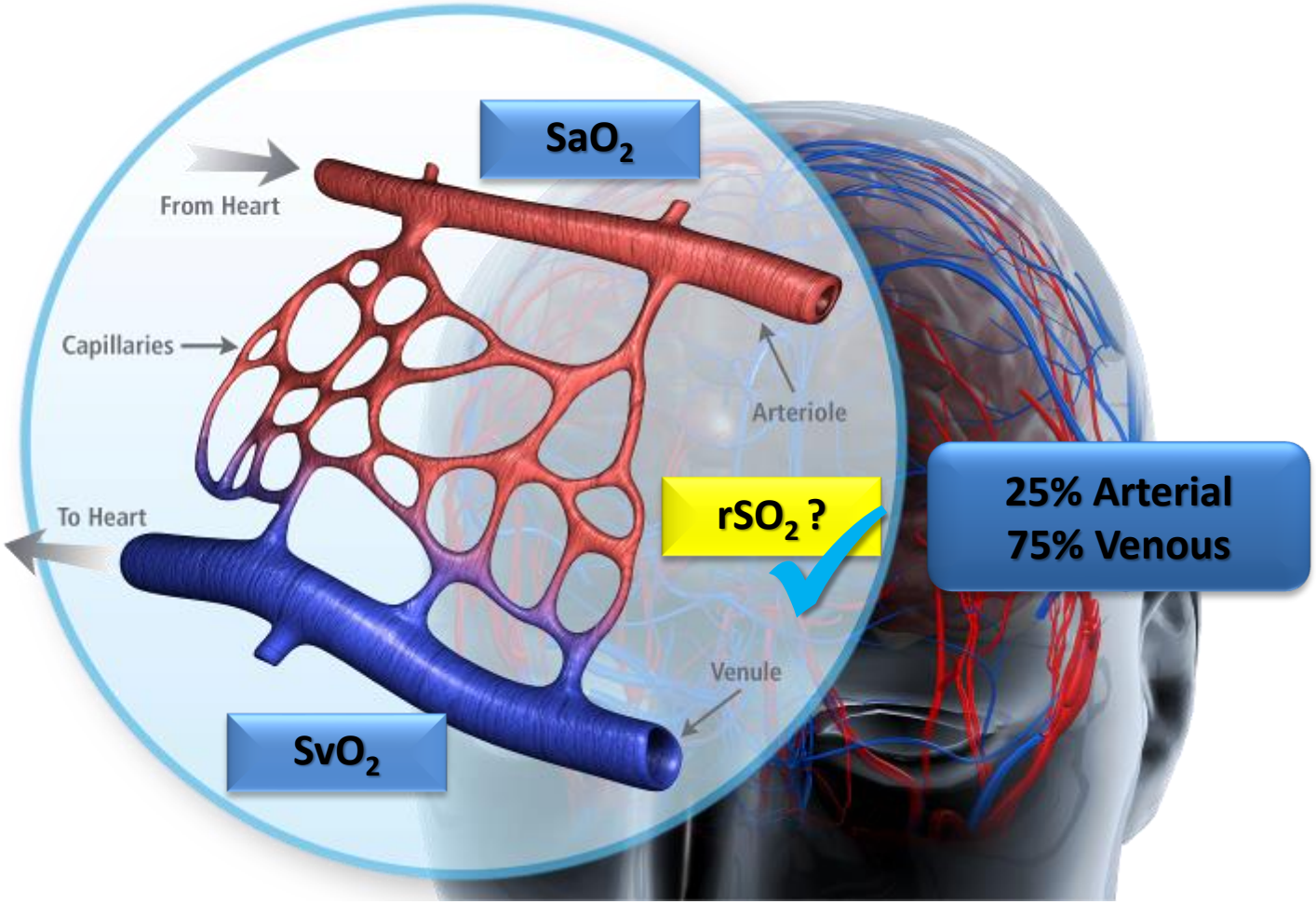
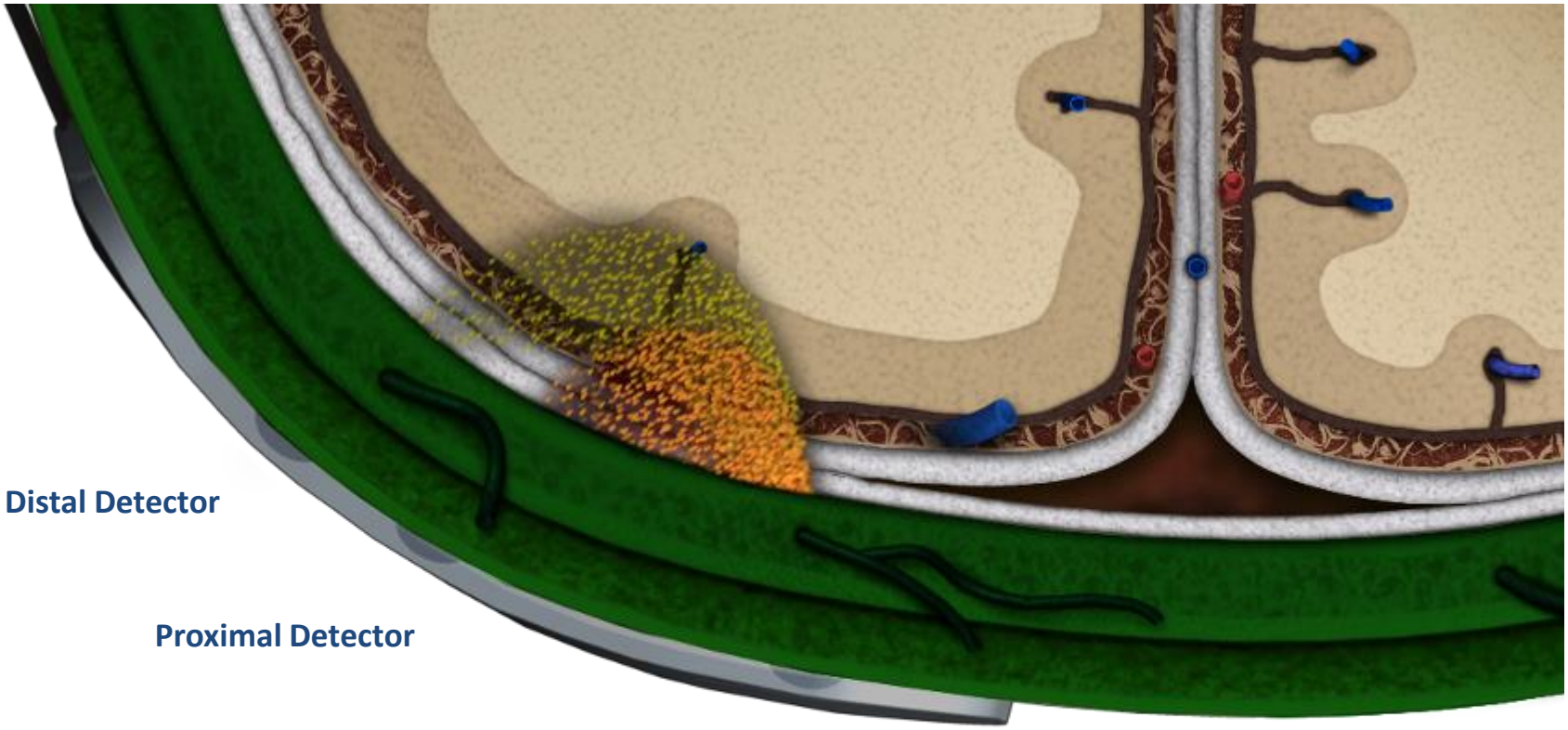


What can we correlate rSO2 value to?

- No gold-standard for rSO2 value comparison
- Performed validation studies to sjvO2 / jugular bulb measurements which is the closest approximation

Empirically Validated in Human Subjects



Signal from surface tissues are subtracted out

Hongo, et al. Neurological Research, 1995, Vol. 17, pp 89-9

VALIDATION

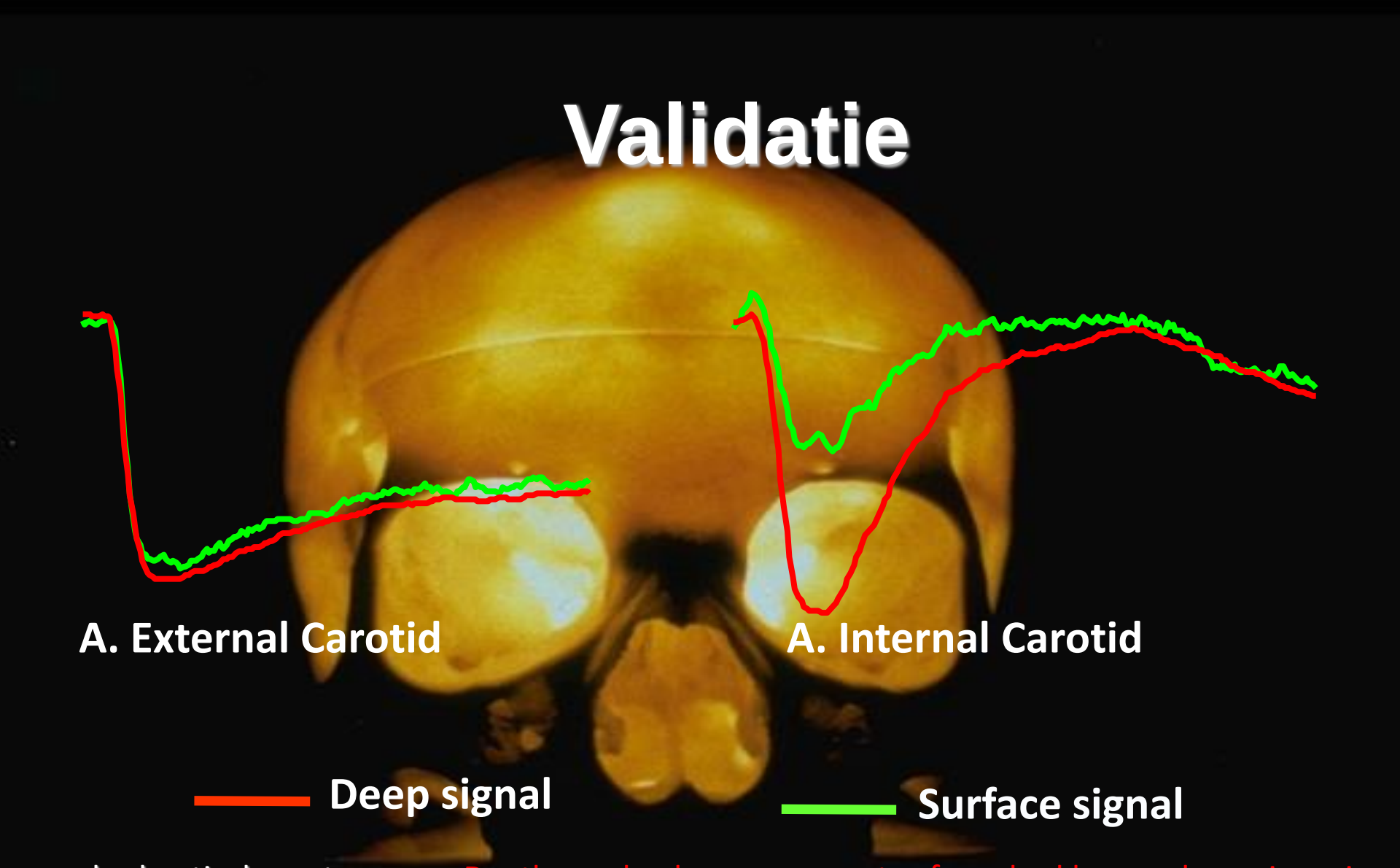
HONGO 1995

- Indocyanine green injected in the int. and ext. carotid
- Finding the best distance to put the detectors
- 30 mm and 40 mm

KIM 2000

- 42 subjects
- rSo2 compared to arterial and venues jugular saturation
- 1 : 3 ratio

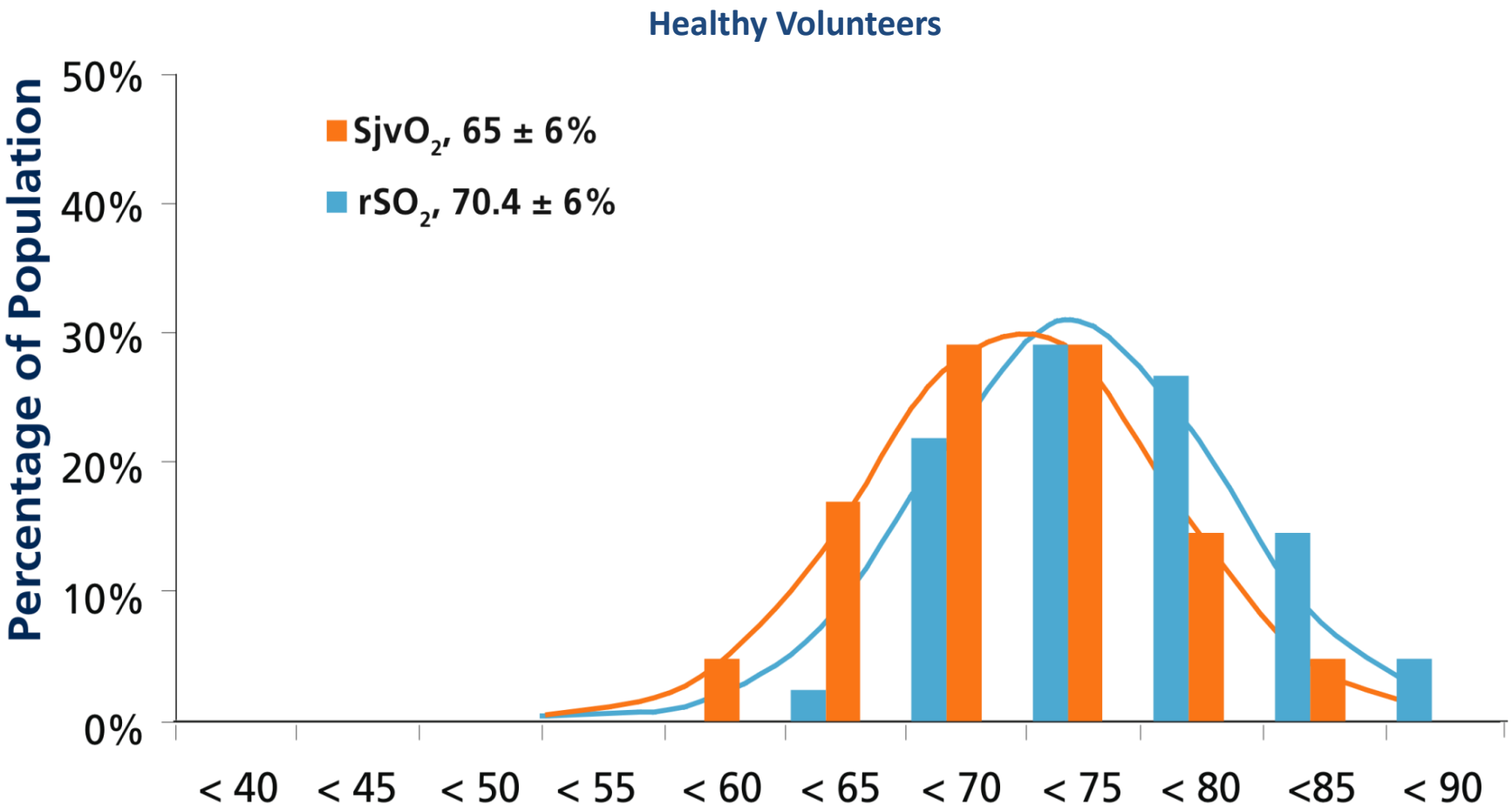
Validatie



ve cerebral optical spectroscopy: Depth-resolved measurements of cerebral haemodynamics using
ne green.

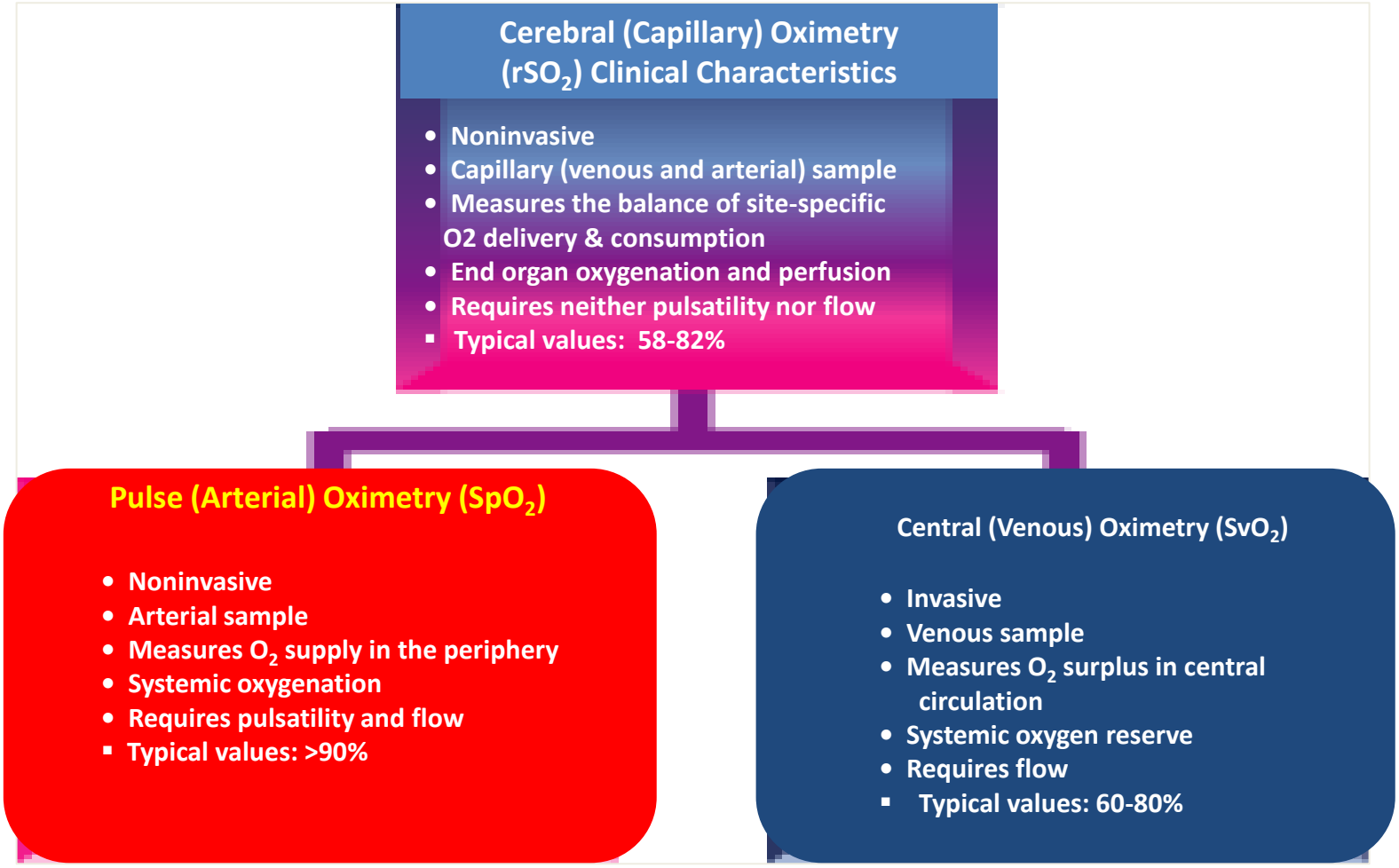
Neurological Research, 1995, Vol. 17, pp 89-93.

Validation: Distribution Comparison to Jugular Bulb



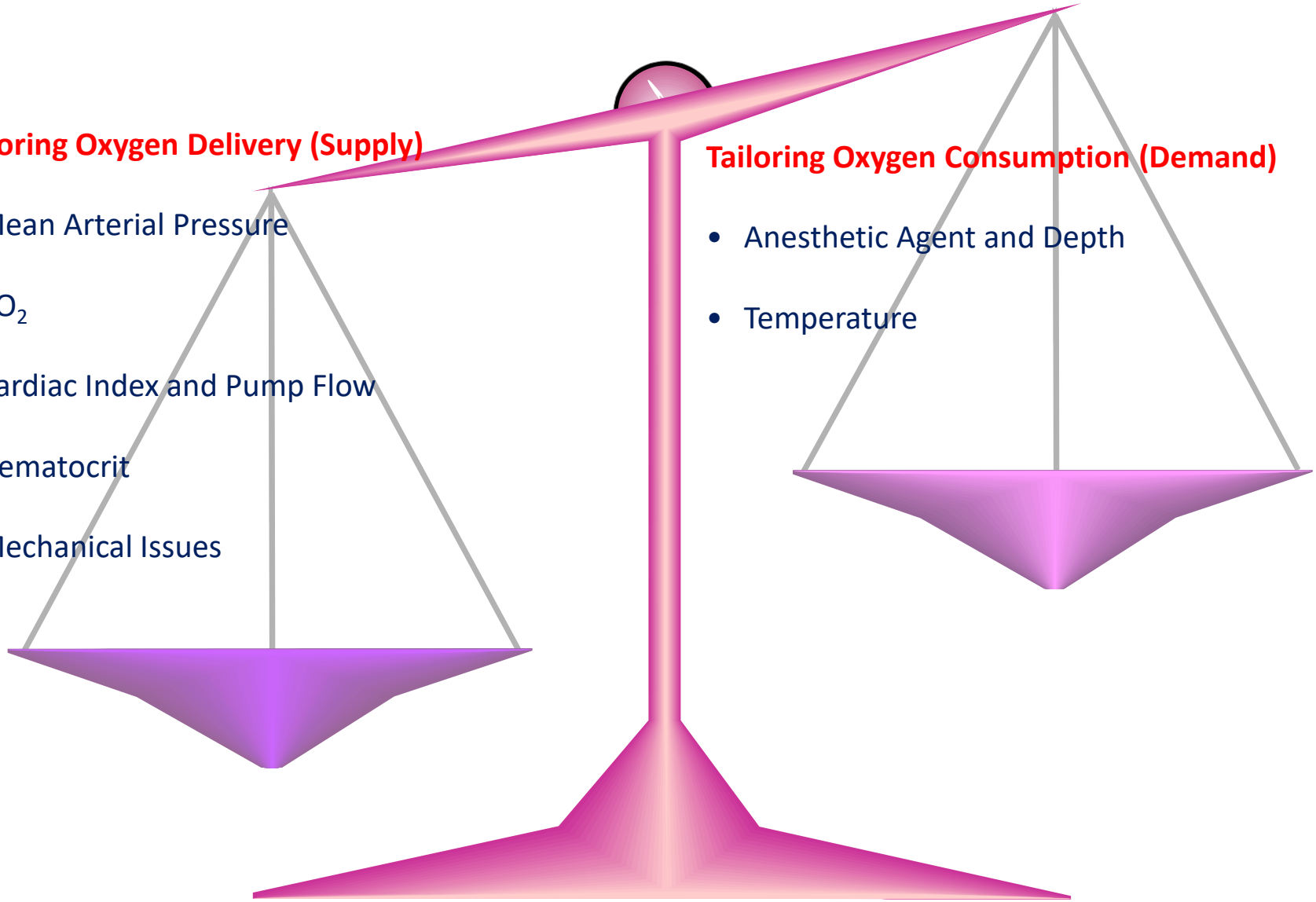
Kim M, Ward D, Cartwright C, Kolano J, Chlebowski S, Henson L. Estimation of jugular venous O2 saturation from cerebral oximetry or arterial O2 saturation during isocapnic hypoxia. *J Clin Monit Comput.* 2000;16(3):191-99.

Regional Oximetry vs. Other Oximetry



Kim MB, et al. J Clin Monit Comput. 2000;16(3):191-

Factors Affecting Blood Oxygenation



Tailoring Oxygen Delivery (Supply)

- Mean Arterial Pressure
- CO_2
- Cardiac Index and Pump Flow
- Hematocrit
- Mechanical Issues

Tailoring Oxygen Consumption (Demand)

- Anesthetic Agent and Depth
- Temperature

Corrective Interventions to NIRS Value

Demand Changes

- Cooling & Warming
- Seizures
- Anesthetic Level
- Pain / Analgesia

Increase Supply (Oxygen Delivery)

- Increase blood pressure
- Increase FiO_2
- Increase cardiac output (pump flow)
-

Decrease Demand (Cerebral Metabolism)

- Increase anesthetic
- Decrease temperature

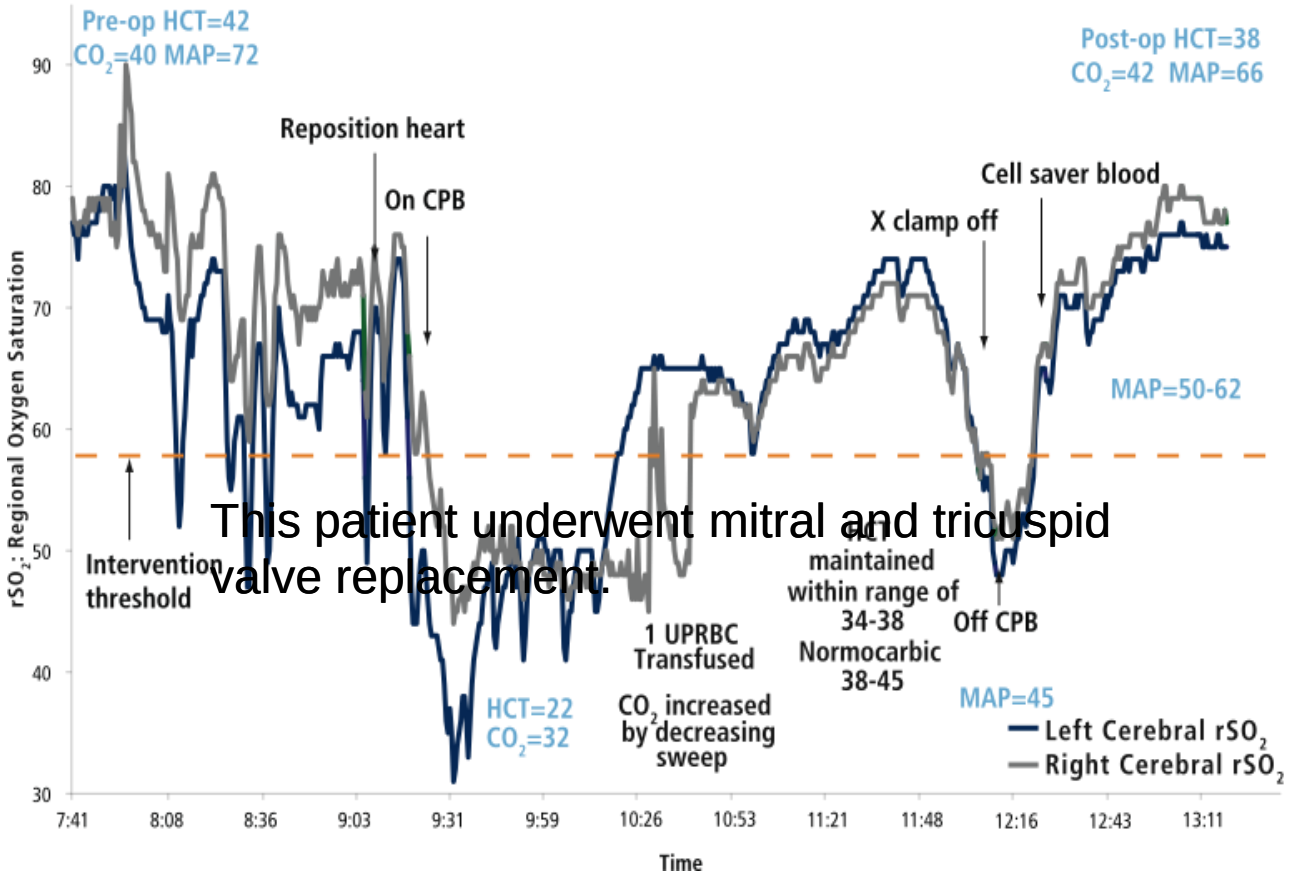
Outflow Issues

- Head & Heart Position
- Venous Congestion *(OPCAB)*
- Venous Obstruction
- Cannula Kinking

Rule out Mechanical Cause

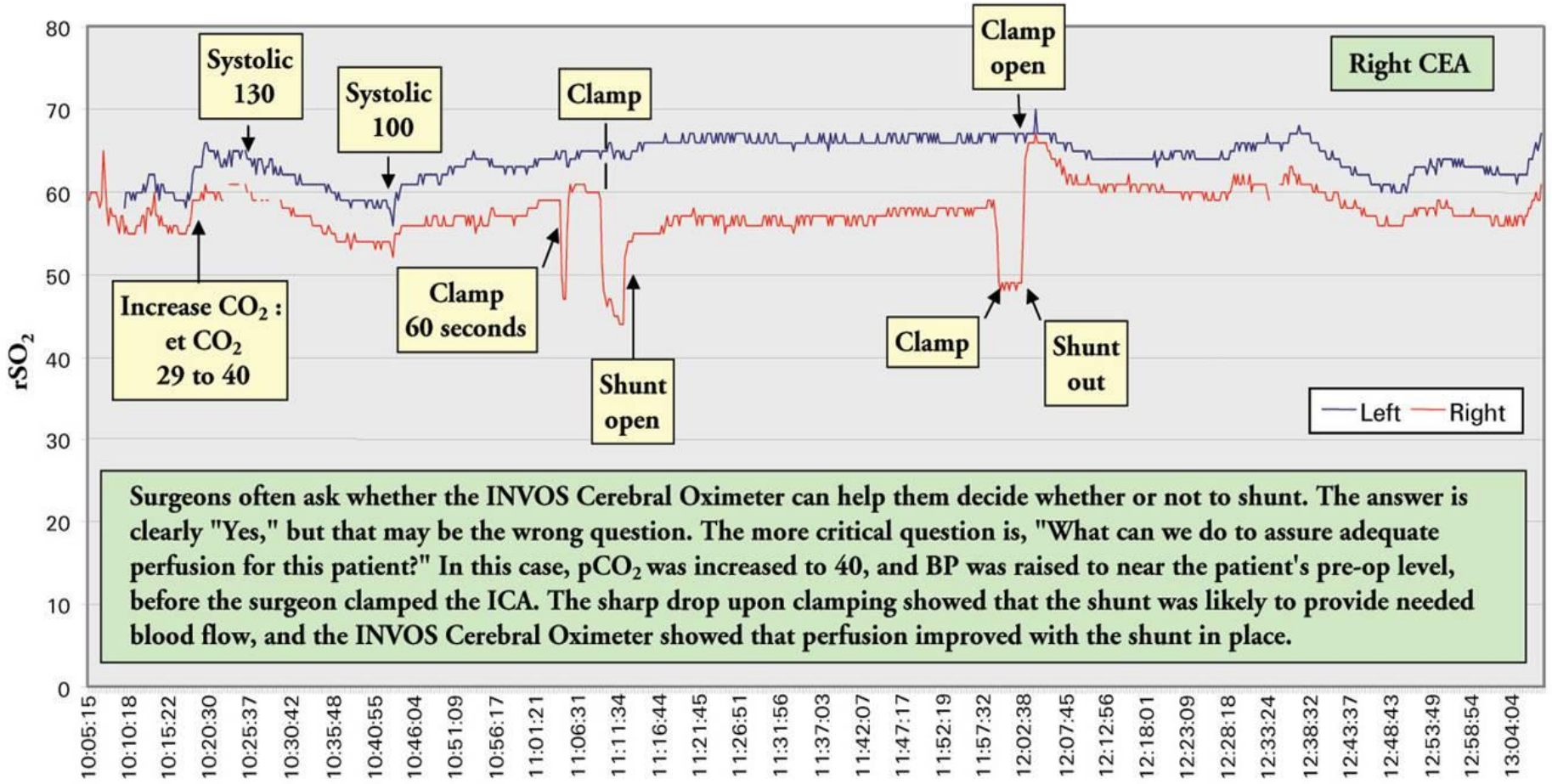
- Head or heart position
- Cannula position

rSO_2 Provides First Alert of Hemodynamic Changes



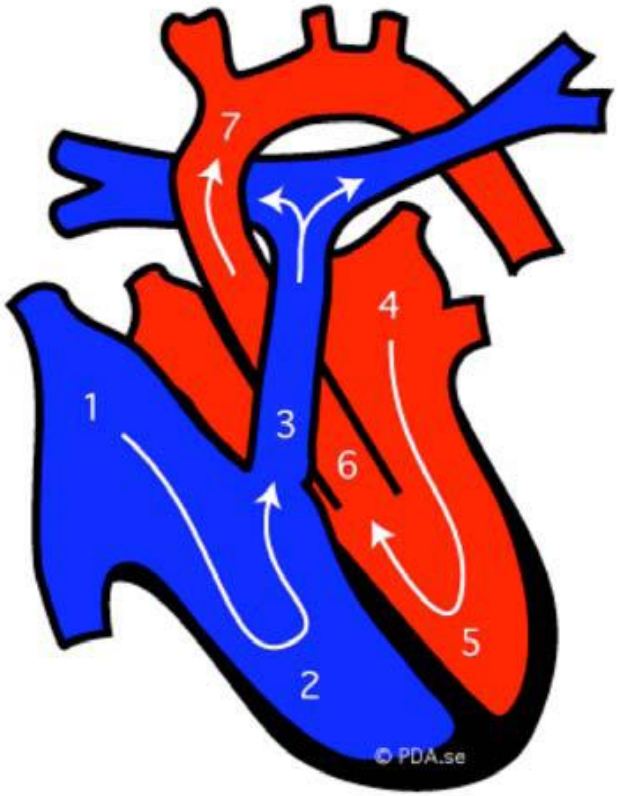
This patient underwent mitral and tricuspid valve replacement, baseline rSO_2 set prior to induction, was adequate at 77L and 79R. Upon initiation of CBP, the patient experienced a dramatic decrease in rSO2 bilaterally to the critical threshold. This decline persisted for approximately one hour , patient was given one unit of packed RBCs , rSO_2 increased to above the intervention threshold . Off CBP, MAP dipped to 45 and rSO_2 again decreased below threshold.

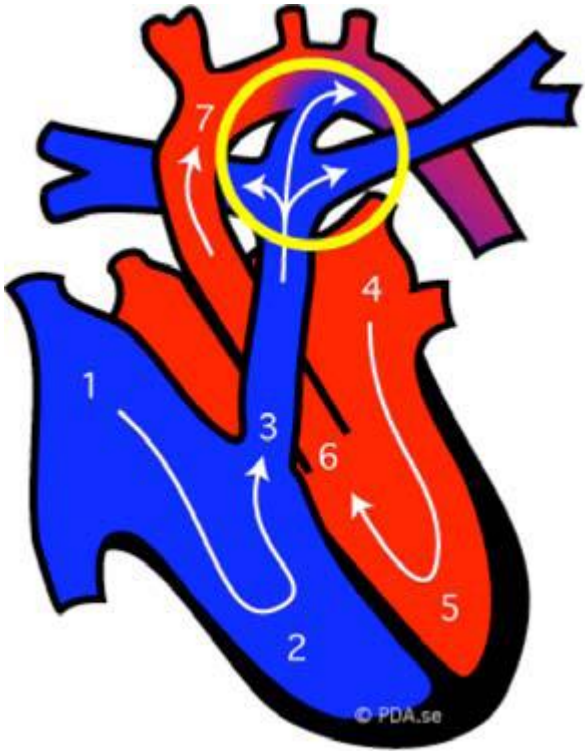
Proven Clinical value - CEA



Surgeons often ask whether the INVOS Cerebral Oximeter can help them decide whether or not to shunt. The answer is clearly "Yes," but that may be the wrong question. The more critical question is, "What can we do to assure adequate perfusion for this patient?" In this case, pCO_2 was increased to 40, and BP was raised to near the patient's pre-op level, before the surgeon clamped the ICA. The sharp drop upon clamping showed that the shunt was likely to provide needed blood flow, and the INVOS Cerebral Oximeter showed that perfusion improved with the shunt in place.

PDA





NIRS Measurements During PDA

- Hemodynamic changes due to PDA blood flow have been reported in retrograde flow within the pulmonary artery [(1)], the descending aorta [(2)] and ***a lower diastolic flow rate in the anterior cerebral artery*** [(3)].

- ***How does this reduced blood flow through the Aorta manifest itself in the gut or renal perfusion?***

1) Stevenson JG , et al . *Cathet. Cardiovasc. Diagn* . 1980 ; **6** : 255 – 63 .
2) Serwer GA , et al . *J. Pediatr* . 1980 ; **97** : 394 – 9 .
3) Perlman JM , et al . *J. Pediatr* . 1981 ; **99** : 767 – 71

So Somatic Tissue Perfusion is Affected by an Open PDA

- Most Neonatologists diagnosis an open PDA by Cardiac ECHO.

- There are questions a Neonatologist has to answer:

  1) Do I need to do something about this PDA?

  2) What information do I need to decide if I need to close this PDA?

- Should we close the PDA with Medicines or Surgery? Or should we watch and wait. ***Somatic Tissue perfusion with NIRS gives us a valuable new tool to help answer that question.***

PDA

- Current decisions look at:

  1) Overall Clinical Picture (are they getting worse on the Ventilator, or not tolerating feeds)

  2) Cardiac ECHO: size measurements of the PDA

- The End result is none of the data are great; and there are real long term risks, especially for surgical closure of the PDA.

NEC

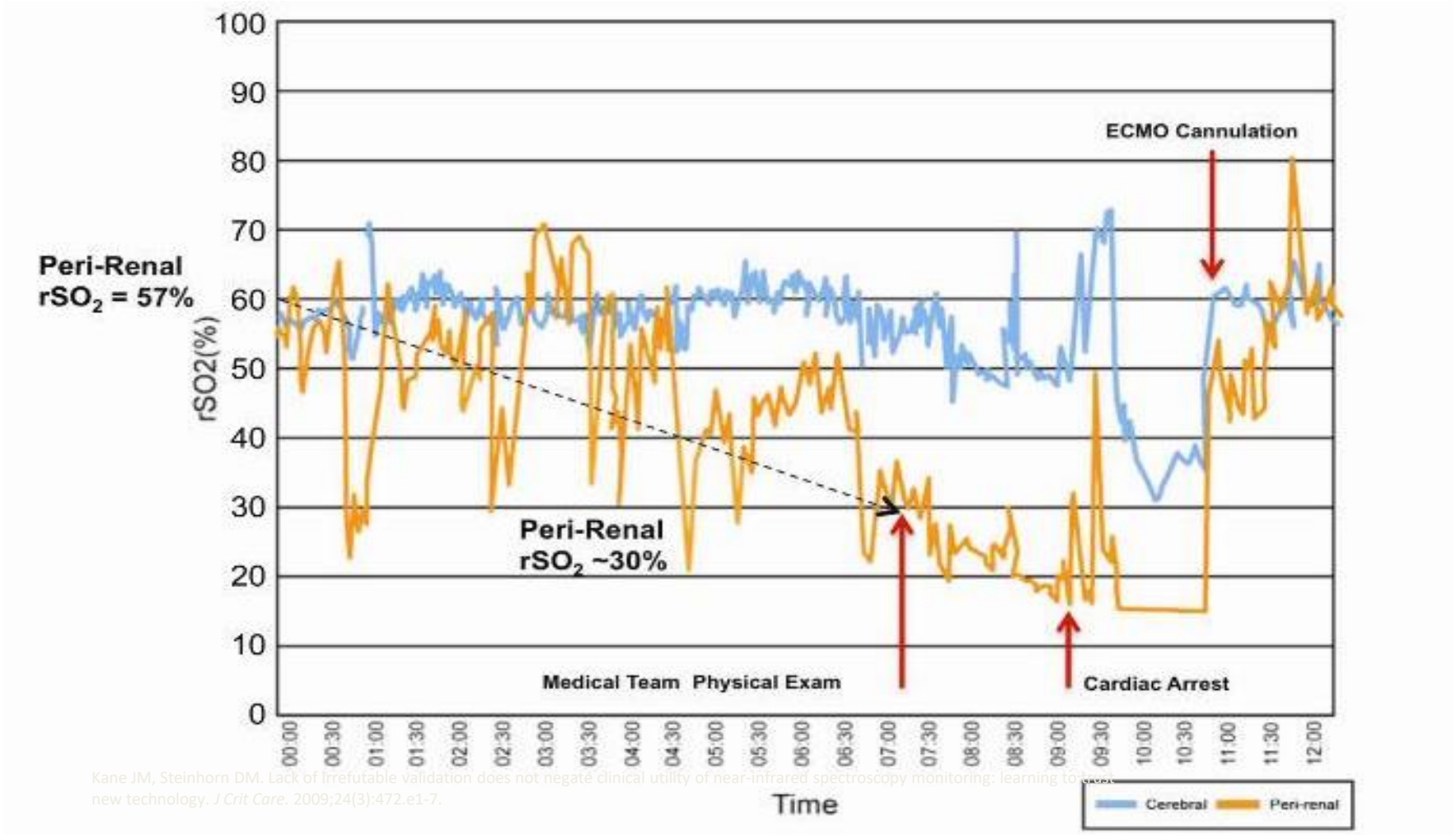
- **Necrotizing enterocolitis** (NEC) is a medical condition primarily seen in premature infants, where portions of the bowel undergo necrosis
- Necrotizing enterocolitis (NEC) is the most common surgical emergency occurring in neonates.

Understanding the gravity of the problem

- Abdominal Perfusion data appears to be different in babies with NEC compared to babies who are sick with something else (ex. Shock).

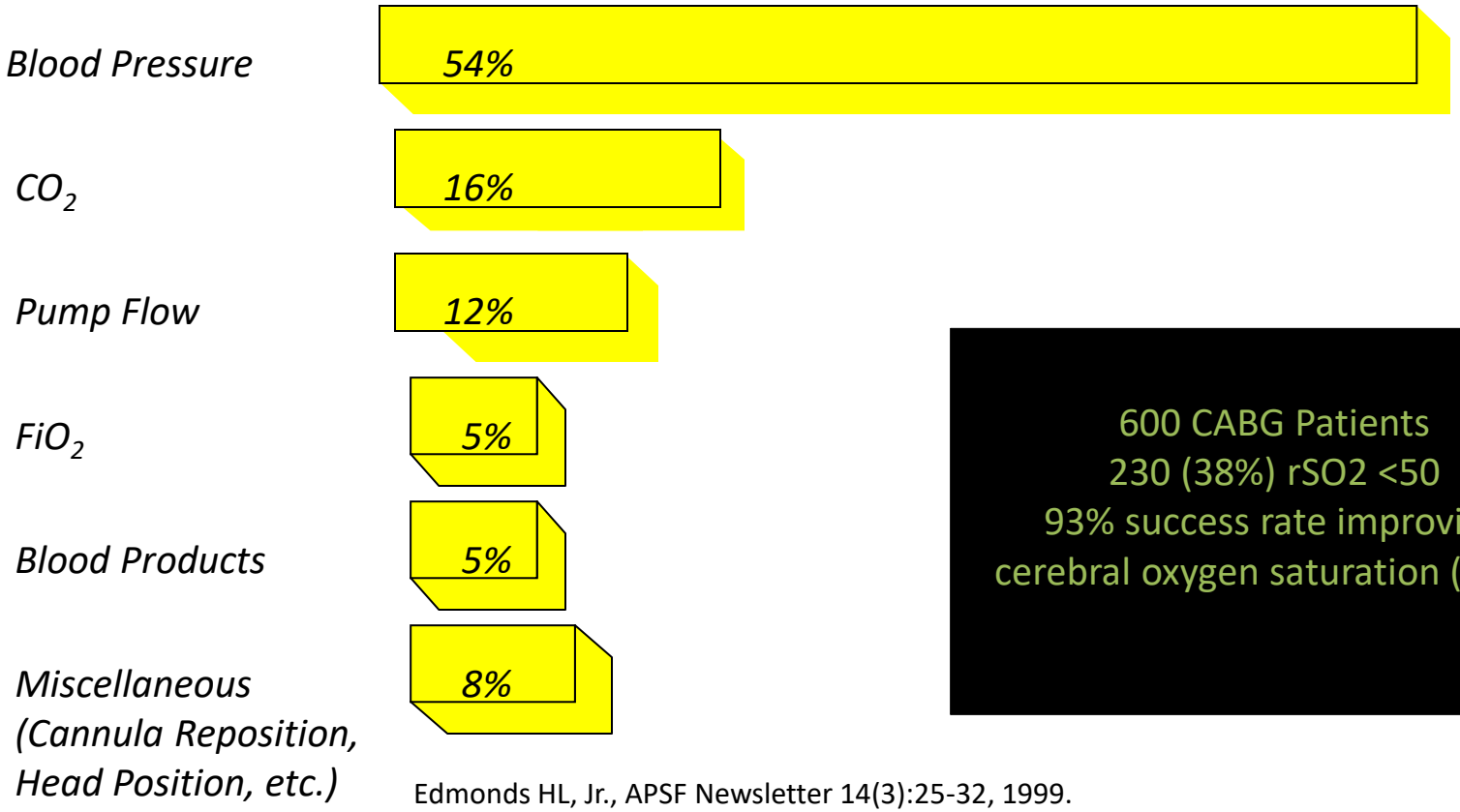
- Your surgeon doesn't want to operate because there is no "free air" indicating a perforation yet. ***But NIRS says part of the intestines may have died,*** and get surgery done quicker.

Early Detection of Ischemia



Kane JM, Steinhorn DM. Lack of irrefutable validation does not negate clinical utility of near-infrared spectroscopy monitoring: learning to use new technology. *J Crit Care*. 2009;24(3):472.e1-7.

Common Successful Interventions to Correct a Declining rSO_2



600 CABG Patients
230 (38%) rSO2 <50
93% success rate improving
cerebral oxygen saturation (rSO2)

Edmonds HL, Jr., APSF Newsletter 14(3):25-32, 1999.

3 Randomized Controlled Trials

- **Murkin study**
- **Slater study**
- **Goldman study**

MURKIN Study

Anesthesia & Analgesia in January 2007; 200 coronary artery bypass patients (prospective and randomized)

Hypothesis:

By using the brain as an index organ, interventions to optimize cerebral perfusion have a similarly beneficial effect on systemic tissue perfusion and clinical outcomes

Murkin JM, et al. Anesth Analg. 2007 Jan;104(1):51-8.

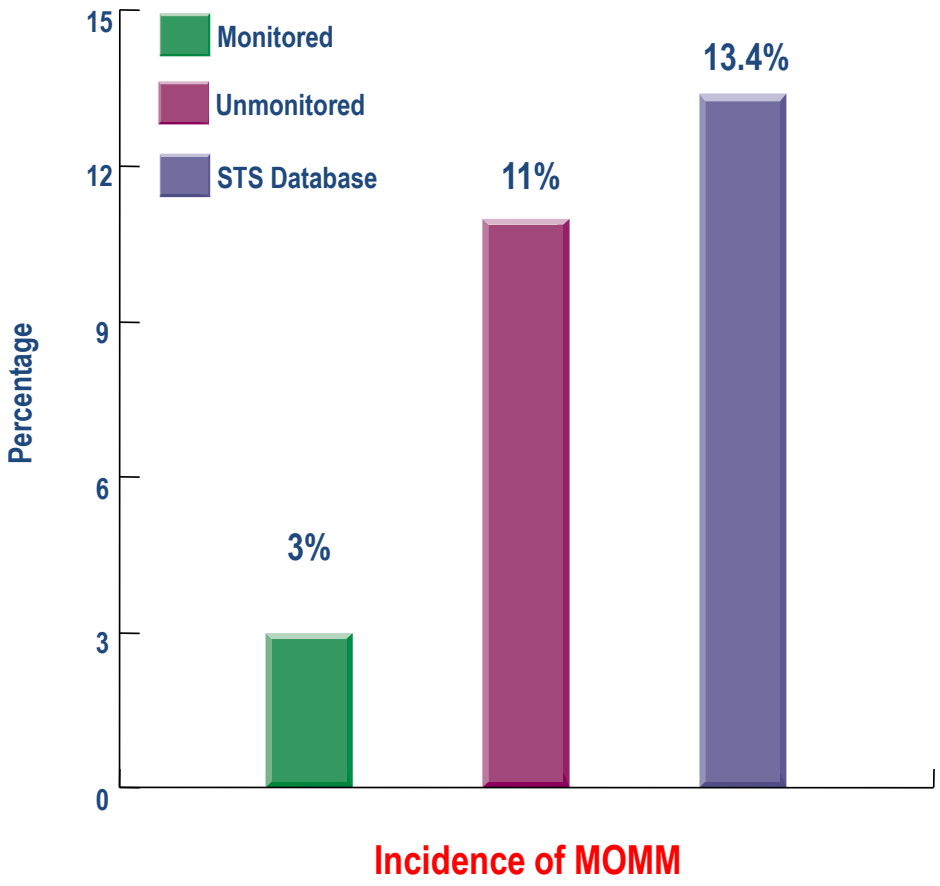
Improved Outcomes

	Unmonitored		Monitored	
	Metric	Standard Deviation*	Metric	Standard Deviation*
Length of Stay (Days)	6.9	±5.5	6.1	±4.4
ICU Duration (Days)	1.87	±2.67	1.25	±.84
ICU > 2 Days	12		5	
Ventilation Time (Hours)	14.7	±23.3	11.4	±9.3
New Onset Stroke	4		1	
> 48 Hours Ventilation	4		1	

*Differences in standard deviation demonstrate the reduction in outliers between the groups.

Murkin JM, et al. Anesth Analg. 2007 Jan;104(1):51-8.

Improved Outcomes

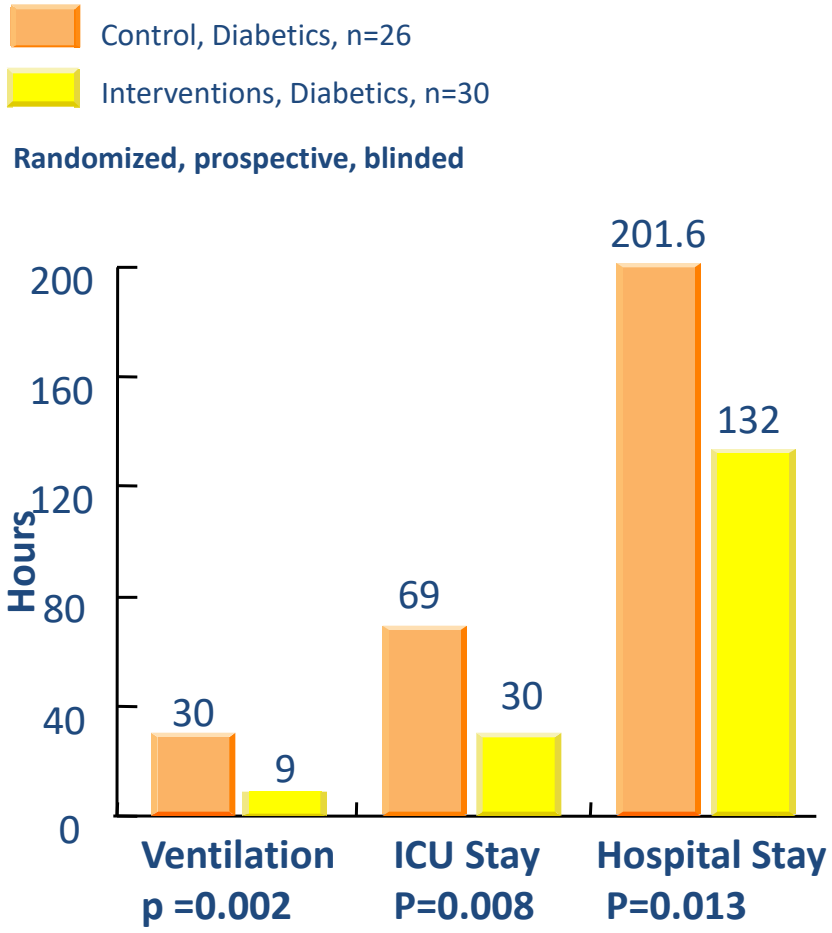


There was a statistically-significant reduction in major organ morbidity or mortality (MOMM)

- Death within 30 days
- Permanent stroke
- > 48 hours ventilation
- Renal failure requiring dialysis
- Re-operation for any reason
- Mediastinitis/deep sternal infection

Murkin JM, et al. Anesth Analg. 2007 Jan;104(1):51-8.
Shroyer AL, et al. Ann Thorac Surg. 2003;Jun:75(6):1856-64.

Leveling the Playing Field for Diabetics



Diabetic cardiac surgery patients monitored with the INVOS System showed statistically-significant improvements over unmonitored diabetic patients.

Murkin JM; Iglesias I; Bainbridge D; Adams S; Schaffer B; et al. Anesth Analg 2005;100:SCA101.

Goldman study

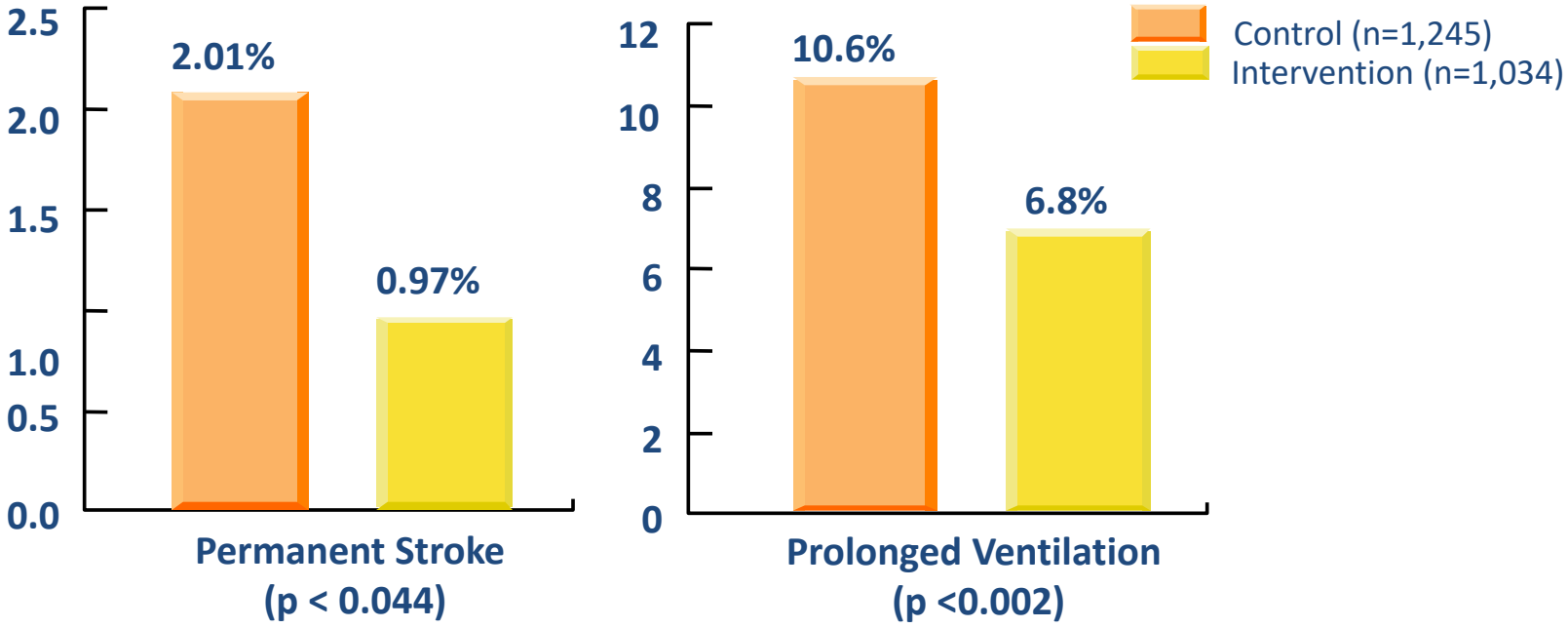
- Goldman S, et al. Heart Surg Forum 2004;7:E376-E378
- Retrospective study! 2000 patients
- Goal:

  Optimizing the cerebral oxygen delivery variables by using non-invasive cerebral oximetry could reduce the incidence of **stroke**
- Method:
  - All cardiac surgery patients during 18 months
  - Compared to 18 months before

Results (Goldman Study)

- INVOS System used on cardiac surgery patients reduced permanent stroke, pulmonary complications and length of hospital stay
- Statistically-significant decreases were achieved despite the INVOS System group having a higher acuity than the control group (64.1% in NYHA class III and IV vs. only 30.7%)

Goldman S, et al. Heart Surg Forum 2004;7:E376-E378.



Thank You