Design of a visible-light spectroscopy clinical tissue oximeter

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Introduction

Analysis Software

1. Tissue oximetry, unlike pulse oximetry, is sensitive to the inadequacies in local blood flow.

2. Hypothesize that a limiting factor in the clinical adoption of tissue oximetry is the very use of near-infrared spectroscopy NIRS itself.

3. Development of a quantitative clinical tissue oximeter suitable for use in small, locally acting probes, catheters, and needles, that is based on visible light spectroscopy VLS.

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Methods

VLS Oximeter Design

Quantitative microvascular hemoglobin oxygen saturation measurement

The ability to operate embedded into therapeutic catheters

Clinical ease of use

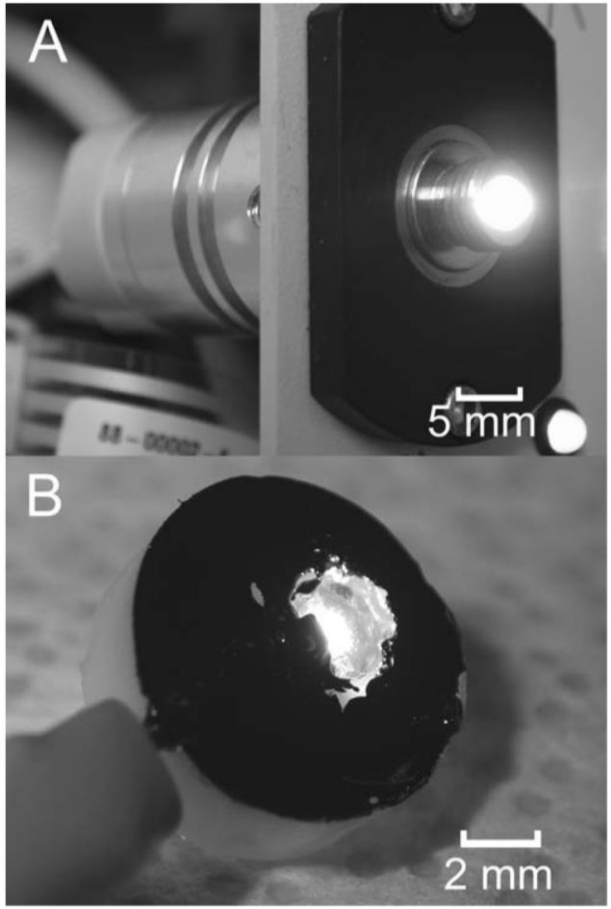
Fast response times facilitating interventional procedures.

Analysis Software

1. Spectral standards were provided in software-readable Windows® INI files.

2. Standards were then used to solve for the concentration of each standard spectrum in the tissue using a scatter-corrected least-squares matrix fit on native or differential measured spectra.

3. Iterative feature stripping allowed for complex analysis.



Light sources developed

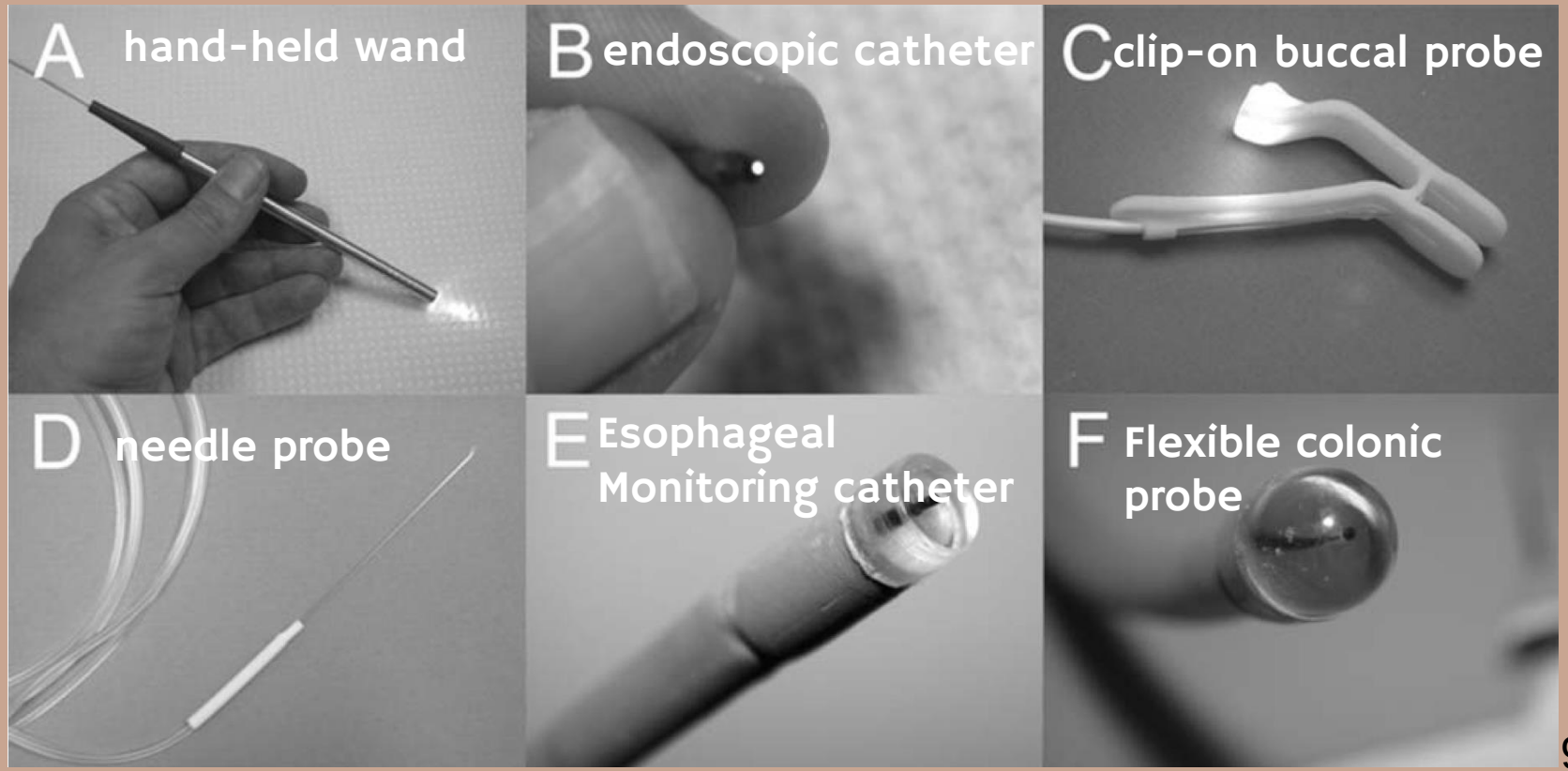
- A:

A small but intense light source

- B:

A broadband, low thermal-transfer LED light source

Clinical probes used in human trials



Calibration Standards

Hemoglobin standards.

- We compared published spectra to spectra we measured in vivo and in vitro
- Differences between these spectral sets were not significant under differential analysis

Calibration sets

- We developed calibration caps of known optical characteristics for each probe
- The reflectance, stability, flatness, and reproducibility of these standards were measured and compared

Ex Vivo Methods

Dye concentration tests

Data were analyzed for the effect of scattering on apparent dye absorbance, and for the variation between actual and calculated dye concentrations

Hemoglobin solution

Hemoglobin concentration was estimated by transmission spectrophotometry

Deoxygenation of free hemoglobin

Saturation was calculated and compared to published sigmoidal hemoglobin oxygen binding curves.

In Vivo Methods

The goal of these in vivo tests was to demonstrate that the expected VLS spectral features were seen in living subjects

- Surface oximetry
  - skin
- Mucosal oximetry
  - The inner surface of the gastrointestinal tract
- Buccal oximetry
  - The inner surface of the cheek

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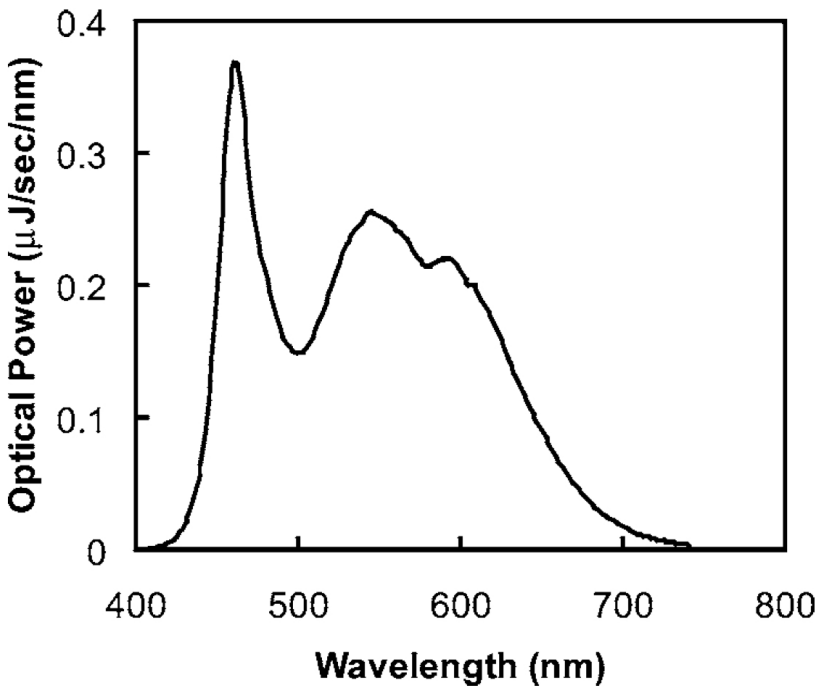
Results

Light source performance

- Halogen lamp source visible light
  - ➢ Inside the bulb and close to the filament, allowed for a 10 to 45 fold improvement in light collection
- The cool LED light
  - ➢ Despite a much lower light density of the LED source, due to the larger effective aperture achieved through direct illumination

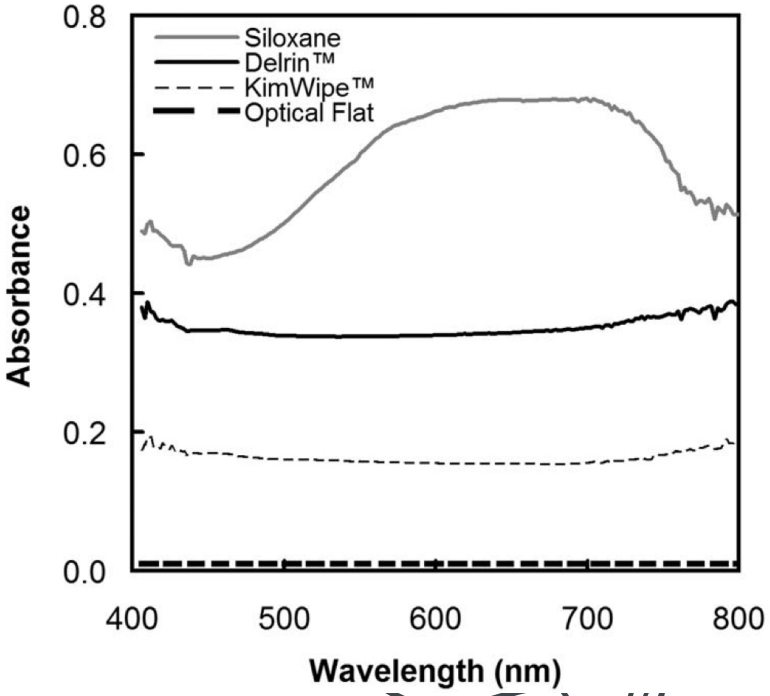


Output of the phosphor-coated blue LED

Reflectance standards and probe calibration

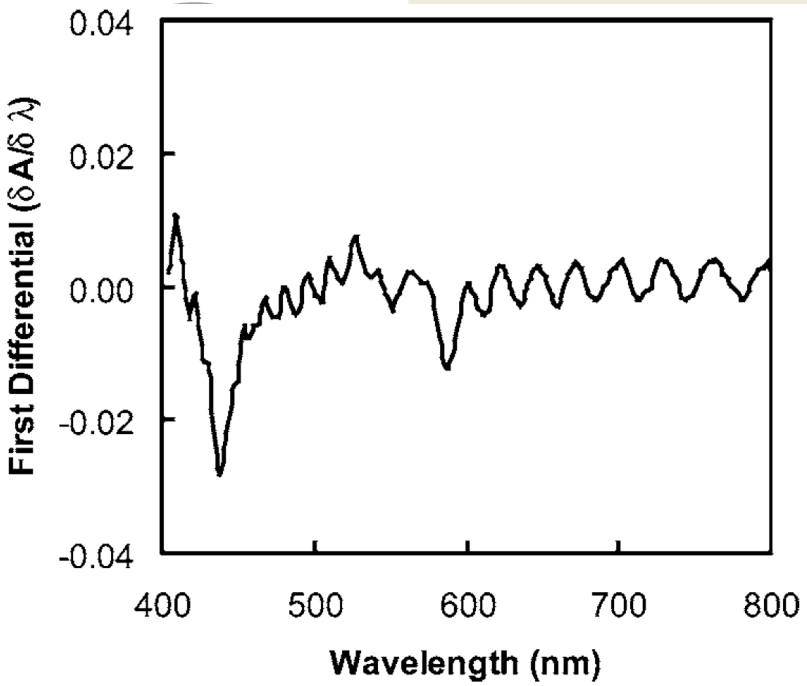
- The spectral flatness and total reflectance of the tested standards
- The noncontact and surface contact probes were best calibrated using dully surfaced diffuse reflectance materials, which reduced specular reflections
- The invasive needle probes, demonstrated large variations in coupling to solid standards

The spectral flatness of the reference materials tested



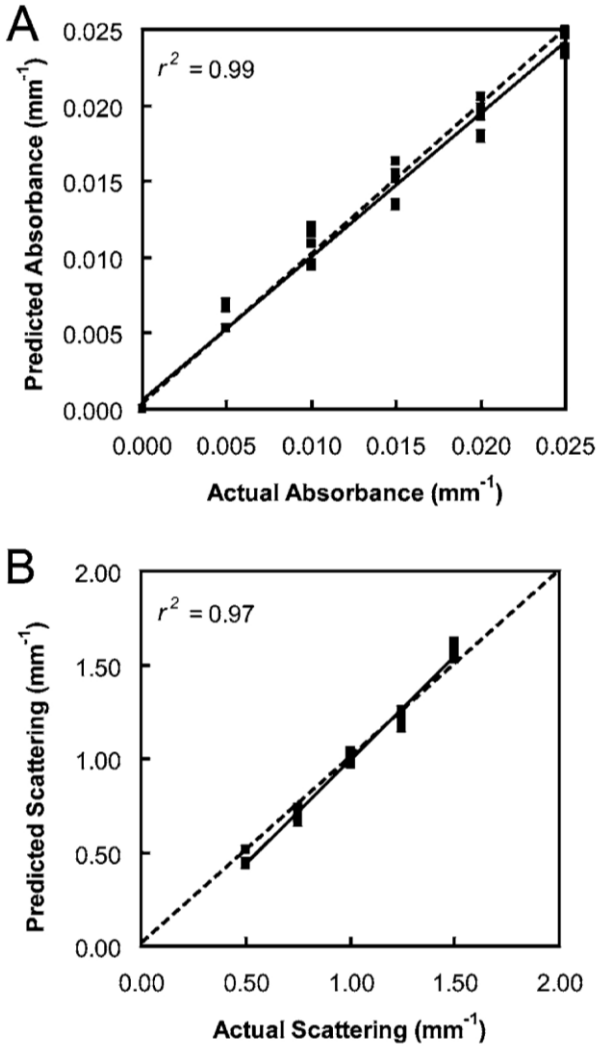
Oscillations from liquid Intralipid-based standards

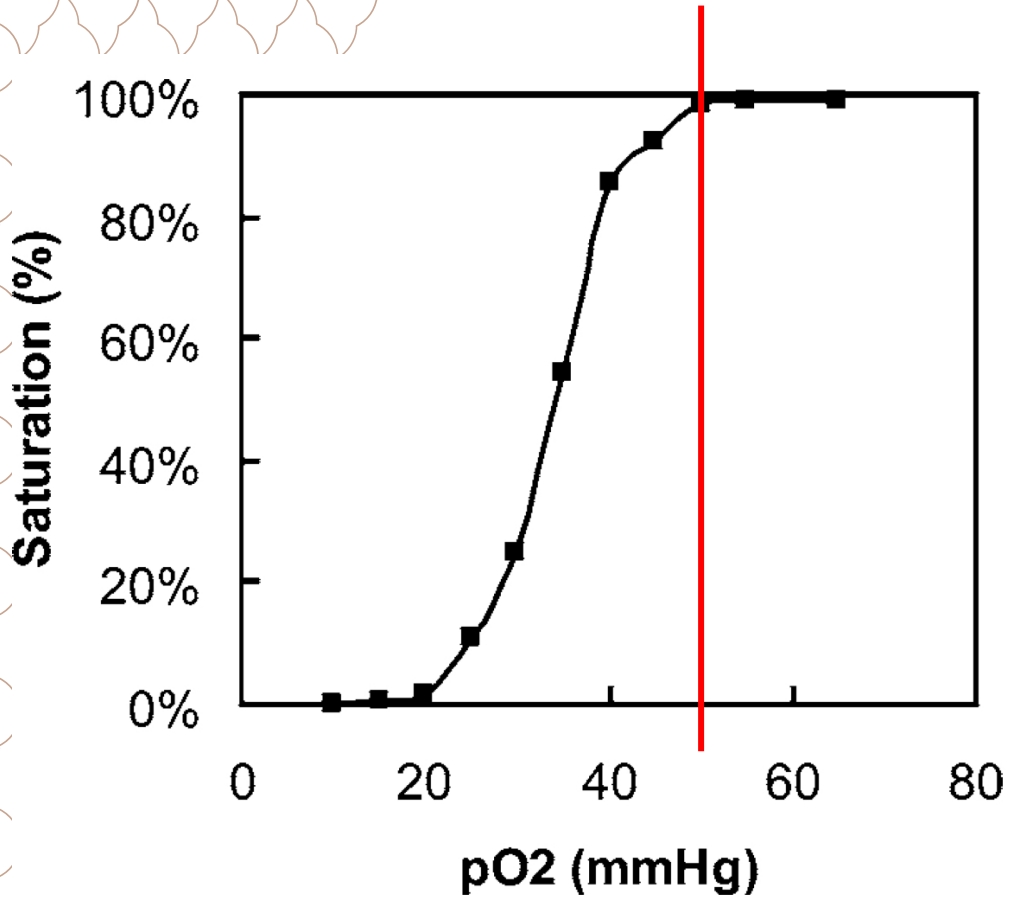
Lipid-based aqueous standards also produced unpredictable wavelike variations in the reference curves, especially after the lipid samples were left standing



Predicted versus actual absorbance and scattering plots.

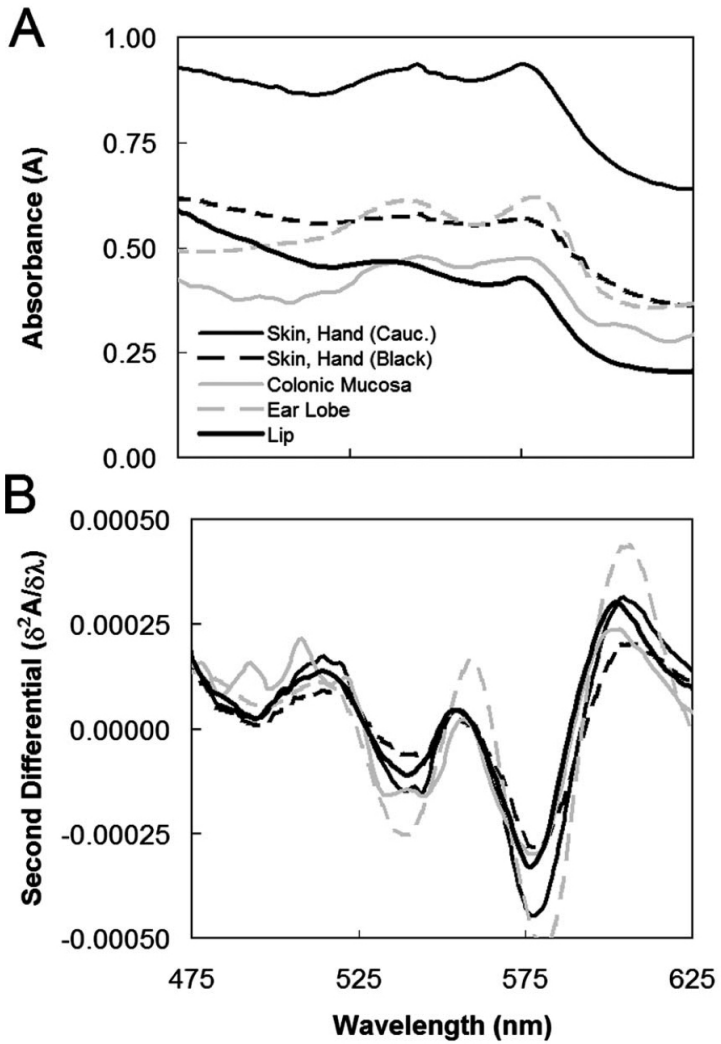
- The spectral effects introduced by scattering were reduced by use of differential spectroscopy.
- Emphasizes nonlinear effects over the baseline offset and exponential effects induced by scattering and variations in the coupling.





Deoxygenation binding curve as measured using VLS

- The measured spectra of oxygenated and deoxygenated hemoglobin compare well to published values.
- A plot of calculated hemoglobin saturation versus measured electrode pO2 demonstrates an oxygen dissociation curve with the expected sigmoid shape



Differential spectroscopy applied to in vivo spectra

- The spectral signals recorded from noninvasive measures on the hand of a Caucasian subject, the dorsal hand of an African American subject, on the ear lobe of a Caucasian subject, the lip of a Caucasian subject, and the colonic mucosa of a human subject undergoing endoscopy.

Percent up time of T-Stat® oximeter versus pulse oximeter during cardiac surgery

Bypass surgery clinical period	T-Stat® oximeter up-time (%)	Pulse oximeter up-time (%)
Start	100%	89%
Cooling	100%	32%
Cardiac arrest	100%	2%
Warming	100%	49%
Closing	99%	78%
End	100%	70%

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Discussion

VLS vs. NIRS

1. A major advantage of VLS over NIRS is that it enables highly stable, small volume oximetry measurements in tissue

2. The use of VLS allows clinical oximeter probes to be formed into small probes, clips, internal catheters, or needles and deployed in vivo.

3. VLS measures small, subsurface tissue volumes while NIRS measures larger, deeper volumes of tissue, VLS can answer different clinical questions than NIRS, and may in fact be complementary to NIRS.

Thanks