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Review Article

REVIEW ARTICLE

Tissue oxygen tension monitoring of organ perfusion: rationale, methodologies, and literature review

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Abstract

Tissue oxygen tension is the partial pressure of oxygen within the interstitial space of an organ bed. As it represents the balance between local oxygen delivery and consumption at any given time, it offers a ready monitoring capability to assess the adequacy of tissue perfusion relative to local demands. This review covers the various methodologies used to measure tissue oxygen tension, describes the underlying physiological and pathophysiological principles, and summarizes human and laboratory data published to date.

Key words: monitoring, intraoperative; monitoring, intensive care; monitoring, oxygen; oxygen, tissue

Editor's key points

- The authors explore the concept of tissue oxygen tension and describe the utility of its measurement and the methods available.

Tissue oxygen tension (tP_{O_2}) is the partial pressure of oxygen within the interstitial space of a particular tissue. It represents the balance between local oxygen delivery and consumption at any given time.[1] The tP_{O_2} varies between different organs in resting healthy subjects and animals, and this relates to both the organ's metabolic activity and its blood flow. Of note, the tP_{O_2} within an individual organ remains reasonably comparable across species, allowing for methodological variations (Fig. 1, Supplementary Table S1). Likewise, there may be intra-organ differences, depending on regional variations in organ flow and activity, of which the kidney is a prime exemplar. The tP_{O_2} increases if oxygen delivery increases in excess of consumption and decreases if local oxygen requirements cannot be met. Matched increases or decreases in local oxygen delivery and consumption will thus not impact upon the tP_{O_2}.

Tissue oxygen tension monitoring offers the capability of continuous assessment of the adequacy of regional perfusion. Apart from indicating the local situation in the organ bed being monitored, it may serve as a surrogate for perfusion adequacy in other organ beds, particularly if such an organ can be accessed readily and safely. Such a technology is not in routine clinical use at present but, if shown to be reliable, offers significant utility in the critically ill or in patients undergoing high-risk surgery. We are shortly to embark upon a clinical study exploring the clinical utility of bladder tP_{O_2} monitoring. It is thus timely to review the available methodologies, the underlying (patho)physiological principles, and the prior literature in both patients and laboratory models, and to address any implicit challenges.

In vivo measurement methods

Tissue oxygen tension may be measured by polarographic or dynamic fluorescence quenching methods, or using electron paramagnetic resonance (EPR) oximetry.

The Clark polarographic technique (Fig. 2) consists of electrodes that generally contain a platinum cathode and a silver anode linked by a salt bridge.[6] As oxygen is reduced at the cathode surface, more oxygen diffuses through the oxygen-permeable membrane to be reduced at the cathode surface. Upon doing so, the circuit is completed, and this generates a current proportional

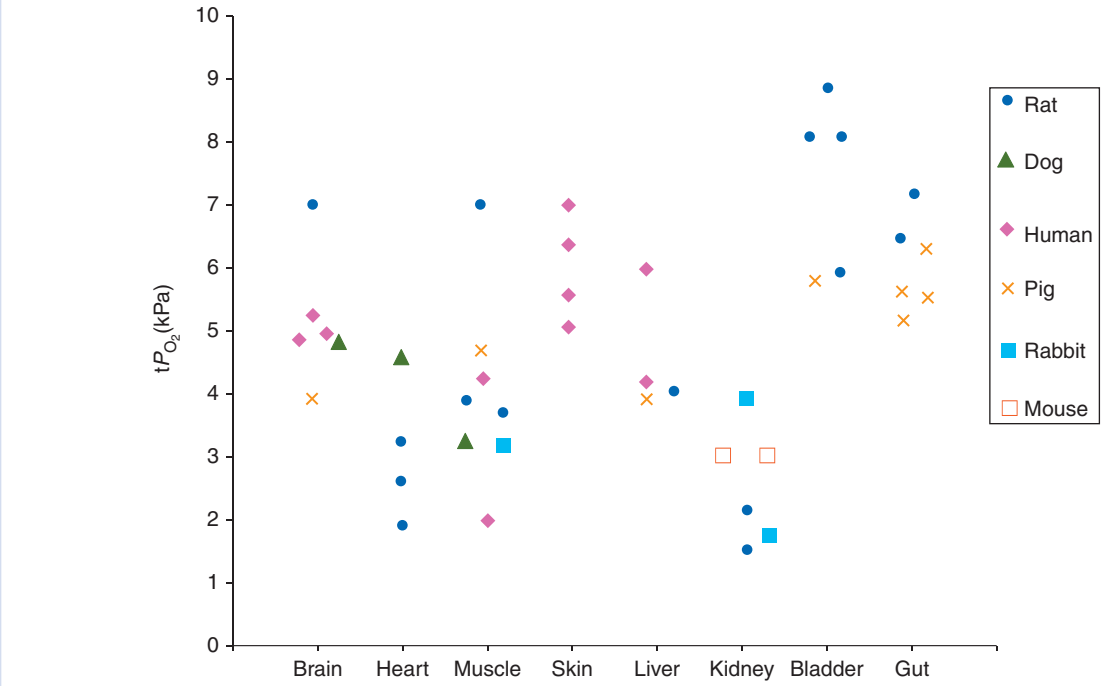

Fig 1 Tissue oxygen tension (tP_{O_2}) values measured in different organs in different species. Only studies in which the inspired O_2 fraction was reported to be 0.21 are included. Ranges for human brain P_{O_2} are reported as 3.4 (SD 0.2) kPa,[2] for muscle 3.8 (0.8) kPa,[3] for skin 7.2 (3.3) kPa, and for liver either 6.1 (5.8)[4] or 4.1 (range 2.6–5.4) kPa.[5]

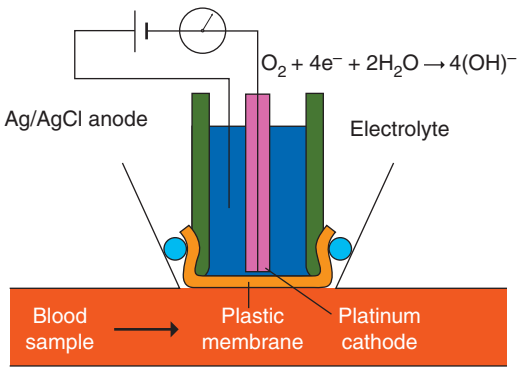

Fig 2 The Clark polarographic technique.

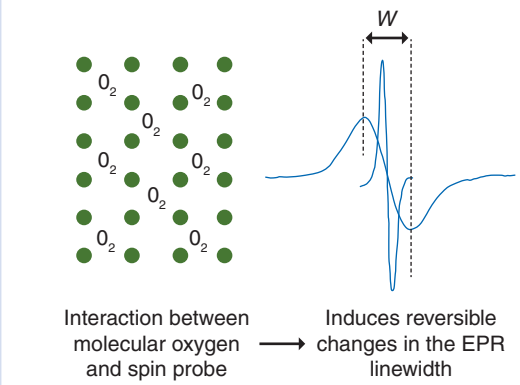

Fig 3 Principle of electron paramagnetic resonance (EPR) spectroscopy. W, linewidth.

to the oxygen content at the measurement site. Such electrodes consume oxygen, and this may potentially be disadvantageous when tP_{O_2} values are very low.

Electron paramagnetic resonance spectroscopy and imaging can provide structural and dynamic information on materials with unpaired electrons. Excitation of the material or tissue provides characteristic EPR spectra for different free radical species. Indeed, molecular oxygen is a naturally occurring triplet radical; however, there are no stable free radicals occurring naturally *in vivo* at either adequate concentration or biological half-life. Injection or tissue implantation of an external spin probe consisting of paramagnetic material in either particulate (solid) or soluble form will, however, enable tissue oxygen monitoring.[7] The EPR spectrum width is broadened by an interaction between molecular oxygen and the spin probe, permitting quantification of local oxygen concentration (Fig. 3). Electron paramagnetic resonance oximetry can monitor for long periods of time with no loss of sensitivity, but this methodology is expensive, requires a high level of knowledge and user expertise, and is not applicable to human study. *In vivo* studies have been performed in animal models using injection of gloxy, a paramagnetic component of certain coals, either i.v. or directly into the organ under study.[8 9]