# PERFUSION MEASUREMENT BY A SURFACE THERMAL PROBE

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ABSTRACT

The purpose of this paper is to demonstrate the sensitivity of a surface thermal probe for the measurement of tissue perfusion. Measurements using isolated and *in vivo* rat livers show that the surface thermal probe is sensitive to the perfusion. Thermographic images of the liver surface have been taken of both the isolated rat liver as well as the *in vivo* rat liver. The thermographic images can be used to evaluate the spatial distribution of perfusion at the tissue surface. Perfusion is found to be nonuniform in the isolated rat liver and uniform in the *in vivo* rat liver.

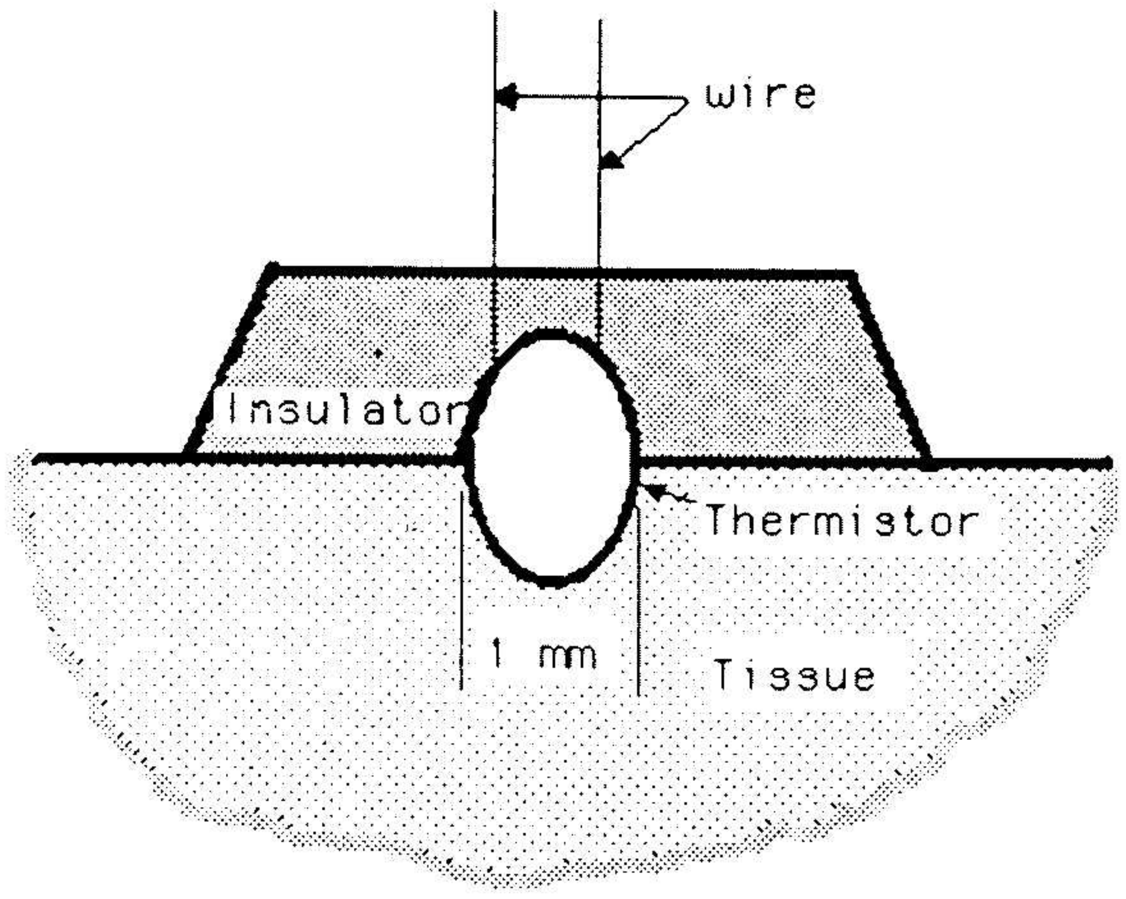


Figure 1: Surface thermal probe.

## INTRODUCTION

Knowledge of thermal properties of tissue is important for both diagnostic and therapeutic medicine. Thermal properties are required to model thermal transport phenomena in tissue. Such models allow better interpretation of heat transfer processes in thermography, hyperthermia, hypothermia, organ preservation, and peripheral vascular diseases. Tissue perfusion is a measure of the local blood flow through the capillary network of a tissue. Perfusion provides a reliable estimate of the viability of an ischemic or reimplanted tissue.

A microcomputer based instrument to measure thermal conductivity, thermal diffusivity and perfusion at the surface of a tissue has been developed. Self-heated spherical thermistors, partially embedded in an insulator, are used to simultaneously deliver thermal energy to tissue and to measure the resulting temperature rise (Figure 1).

The applied power to the self-heated thermistor is dissipated into the tissue medium. Tissue can conduct heat either by intrinsic thermal conduction or perfusion. In a perfused tissue, the intrinsic thermal properties of the tissue ($K_m$, $a_m$), the local blood flow rate, and specific heat of the blood are all physical characteristics that affect tissue heat transfer. All these characteristics can be lumped together as effective thermal properties $K_{eff}$, $a_{eff}$. The instrument simultaneously measures the applied power, and the resulting heated thermistor temperature. The temperature increase of the thermistor for a given applied power is a function of the combined thermal properties of the insulator, the thermistor and the tissue. Tissue thermal properties and perfusion can be derived from measured thermistor power and temperature using relations between these and the measurands [2]. A thermal model has been solved numerically and the parametric relations for measuring thermal conductivity, thermal diffusivity and perfusion are presented [1]. Once the probe is calibrated, the instrument accurately measures the thermal properties of tissue.

## ISOLATED RAT LIVER EXPERIMENTS

To demonstrate the sensitivity of the surface probe for the perfusion measurement, isolated rat liver experiments were conducted. An isolated rat liver apparatus was designed to achieve thermal stability, flow control, pH control, and oxygenation [1]. These factors are critical for the viability of the liver.

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Figure 2 shows that the measured $K_{eff}$ is sensitive to perfusion. Repeated measurements with the same flow demonstrated the reproducibility of the measurement.

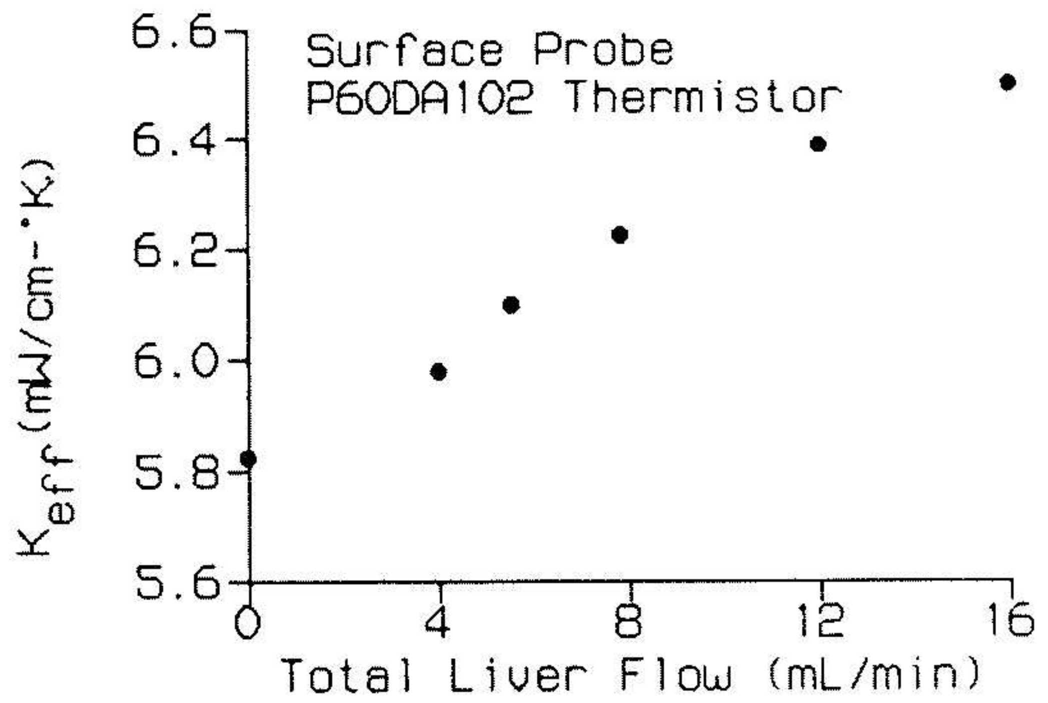


Figure 2: Measured $K_{eff}$ vs total liver flow in the isolated rat liver.

The baseline temperature stability was found to be a significant disturbing factor. When the baseline temperature varied during the measurement, the thermal properties measurements were scattered. Probe placement was a critical factor. Imperfect or poor contact between the probe and tissue surface caused widely scattered measurements even when the baseline temperature was stable. When the contact was very poor, the measurements were insensitive to perfusion.

## IN VIVO RAT LIVER EXPERIMENTS

The objective of the *in vivo* liver experiments was to demonstrate the sensitivity of the surface probe to changes in perfusion.

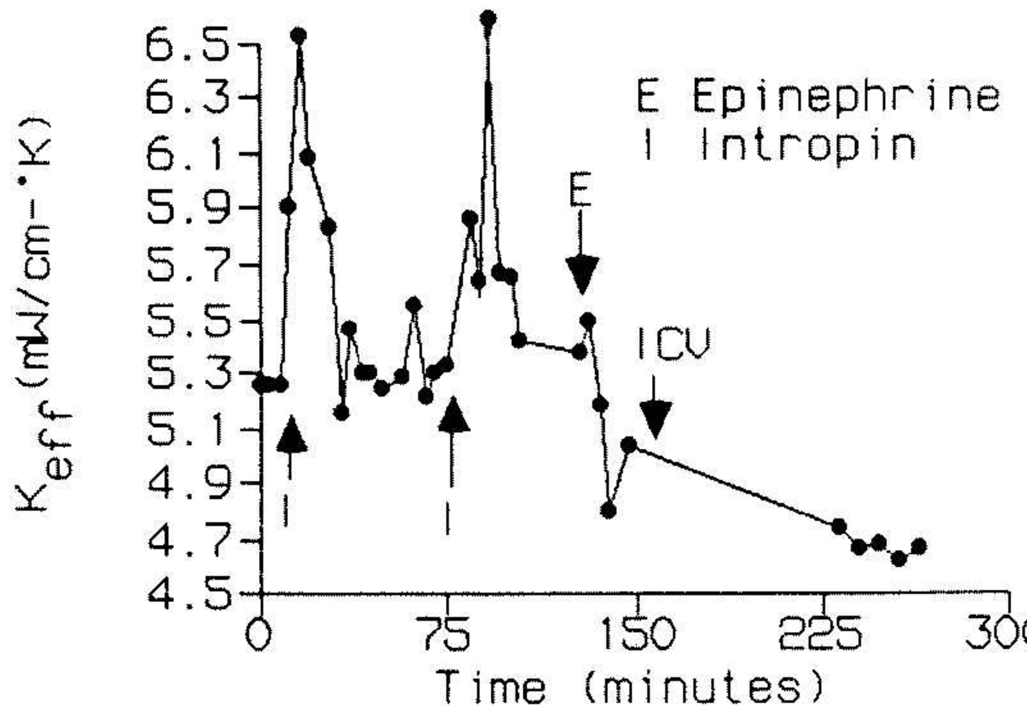


Figure 3: Sensitivity of the probe to change in perfusion *in vivo* rat liver.

Figure 3 shows $K_{eff}$ as measured by the surface probe versus time during a typical rat liver experiment. The measured $K_{eff}$ increased and decreased as expected. From the figure it can be concluded that the surface probe is sensitive to changes in perfusion.

## THERMOGRAPHIC IMAGING

Thermographic images of the liver surface have been taken and analyzed to determine the uniformity of perfusion *in vitro* and *in vivo*. For the isolated liver, a cold bolus is injected into the portal vein and thermal images of the surface are taken at four times: before injection, and 5, 11, and 28 seconds post injection. The baseline image had non-uniform temperature distribution. As the bolus is injected, the temperature of the tissue surface dropped as the cold bolus perfused through the tissue. Image at 5 second is very blotchy. Images at 11 and 28 seconds are comparetively less blothcy. The blotchs indicate that the perfusion is non-uniform at the surface of the isolated liver. For the *in vivo* liver, a cold sponge is applied to the liver surface for 3 seconds and thermal recovery is monitored. Thermal images are uniform in this case indicating that the perfusion is uniform at the surface of the *in vivo* liver. Thermographic images taken every second can provide recovery phase information at various sites on the liver surface. From the recovery, time constant can be calculated which in turn can be used to determine surface perfusion.

## CONCLUSION

Measurements using isolated and *in vivo* rat livers show that the thermal probe is sensitive to the perfusion. Thermographic images of the isolated rat liver surface have shown that the perfusion is non-uniform at the surface. However, images of the *in vivo* liver have shown that the perfusion is uniform at the surface. The temperature images can be used to evaluate the spatial distribution of perfusion. The accurate measurement of perfusion is possible only when the tissue surface is uniformly perfused.

## ACKNOWLEDGEMENTS

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## REFERENCES

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