

# MUSCLE FLAP MONITORING WITH A THERMAL DIFFUSION FLOWMETER DEVICE: A PRELIMINARY STUDY IN THE RABBIT MODEL

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## REZUMAT

Acest studiu investighează fezabilitatea flowmetriei prin difuzie termică pentru monitorizarea supraviețuirii lambourilor. Pentru studiu au fost folosiți șapte iepuri albi. A fost prelevat în bloc un lambou muscular alcătuit din vastul medial, vastul lateral și dreptul femural, pe un singur pedicul arterial și venos derivat din vasele femurale. Pentru flowmetria prin difuzie termică a fost utilizat un instrument portabil cu citire digitală a fluxului sangvin, măsurat în ml/100g/minut. Proprietățile termice ale lamboului muscular au fost măsurate după clamparea și declamparea succesivă a pedicolului, arterei și venei. Rezultatele au arătat că flowmetrul a sesizat modificările fluxului sangvin în toate lambourile. Timpul mediu pentru un răspuns complet a variat între 3,2 și 5,3 minute. Modificări semnificativ statistice ale înregistrărilor au fost observate în primele 30 secunde - 2 minute, în toate cazurile. În concluzie, acest dispozitiv este simplu, de încredere și sigur, poate înregistra date continuu și merită a fi investigat în continuare, în studii clinice.

**Cuvinte cheie:** lambou muscular, monitorizare, flowmetrie prin difuzie termică, iepure

## ABSTRACT

In this study the feasibility of thermal diffusion flowmetry for flap survival monitoring was investigated. Seven adult albino rabbits were used for the study. A muscle flap including vastus medialis, vastus lateralis and rectus femoris were elevated en bloc on a single pedicle artery and vein branching off the femoral vessels. The thermal diffusion flowmetry used in the study was a hand-held instrument with a digital read-out of blood flow in ml/100gm/min. Thermal properties of muscle flap were recorded while the pedicle, artery and vein were successively clamped and unclamped. The results showed that the thermal diffusion flowmeter responded to blood flow changes in all flaps. The average time for complete response ranged from 3.2 to 5.3 minutes. Statistically significant changes in readings were noted within 30 seconds to 2 minute in all situations. In conclusion, this device is simple, reliable and safe, and continuous data could be recorded, and deserves for further studies in the clinical setting.

**Key Words:** muscle flap, monitoring, thermal diffusion flowmetry, rabbit

## INTRODUCTION

Postoperative microsurgical flap monitoring is a source of constant debate and endless study. A very reliable means of monitoring flaps with skin components has been utilized at medical centers.<sup>1,2</sup> However, there has not yet been developed a reliable and widely accepted means of monitoring muscle flaps and buried flaps.

The traditional gold standard for flap monitoring is clinical examination. This method includes various

bedside manipulations such as capillary refill test, muscle stimulation, and flap bleeding.<sup>3,4</sup> These skills are experience-dependent and may have significant lag time from the onset of complications.<sup>5</sup> Ultrasound Doppler of the pedicle is a common method as well, but is susceptible to false negatives from non-pedicle vessels and to delayed diagnosis of venous problems.<sup>6,7</sup>

Fluorescein clearance has been used with success in cutaneous flaps, but is less effective in pigmented skin and muscle flaps, and unusable in buried flaps.<sup>2,8,9</sup> An increasingly popular monitoring device is the laser Doppler. There have been some encouraging studies but there have also some disappointing reports.<sup>10-14</sup> Some problems that have been reported include motion sensitivity, the lack of a true zero, and occasional false positives.<sup>5,15-17</sup> Other seldom used or clinically unproven forms of monitoring include temperature probes, thermocouple probes, pulse oximetry, reflection plethysmography, impedance plethysmography, pH monitoring, and isotope clearance.<sup>18-27</sup>

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Thermal diffusion flowmetry was originally developed for surface monitoring of brain cortical blood flow by utilizing the Peltier effect.<sup>28</sup> The device uses a neutral plate and an electronically heated active plate to continuously record the thermal conductivity of tissue. The difference in temperature between the two plates is inversely proportional to the thermal conductivity of the tissue. Experimental study has demonstrated that the thermal conductivity is a linear function of blood flow.<sup>29,30</sup> Previously a preliminary study has been performed for skin, but not for muscular tissue. This study was undertaken to investigate the feasibility of transferring this technique to flap monitoring.<sup>16,31</sup>

## MATERIALS AND METHODS

Seven adult albino rabbits weighing 3 kg were used for the study. The National Research Council's guidelines for the care and use of laboratory animals were followed. Combination anesthesia with acepromazine, xylazine and ketamine was used for all animals.

The thermal diffusion flowmetry used in the study was a hand-held instrument with a digital read-out of blood flow in ml/100gm/min (Flowtronics, Inc., Phoenix, AZ). (Fig. 1) The device is factory calibrated to the thermal capacity of tissue. The probe used was a silastic disposable cerebral blood flow sensor.



**Figure 1.** The thermal diffusion flowmetry.

Via a transverse groin incision, the vastus medialis, vastus lateralis and rectus femoris were elevated en bloc on a single pedicle artery and vein branching off the femoral vessels. All accessory veins were carefully ligated or cauterized. The perfusion to this composite muscle flap was confirmed with direct arterial dye

injections. A total of twelve flaps were tested.

The thermal diffusion flowmeter probe was carefully positioned in the intermuscular planes. This particular device was calibrated to the thermal properties of neural tissue, which was different from the property of muscle. Therefore, for this study, the numbers were recorded as arbitrary units rather than true blood flow readings.

The wound edges were closed loosely while allowing continued access to the pedicle. The pedicle was then clamped and the device was zeroed. The blood flow was reestablished. The pedicle, artery and vein were then successively clamped and unclamped. Readings were recorded at 30 second intervals.

The readings for each scenario were combined for an average monitor reading at each time interval. Each time interval was then compared with the baseline reading using Student's t-test. This identified the first statistically significant change in readings after initiation or cessation of vessel insult.

## RESULTS

The thermal diffusion flowmeter responded to blood flow changes in all flaps. The average initial baseline reading was  $6.6 \pm 3.1$ . The amplitude of the initial reading appeared to correlate with the extent of dissection trauma and subject condition. Interruption of blood flow in any pedicle vessel initiate a change in reading within 15 seconds.

The average time for complete response ranged from 3.2 to 5.3 minutes. (Table 1) Figures 2, 3 and 4 illustrate the average response curves to the clamping and unclamping of pedicle, artery and vein. Statistically significant changes in readings were noted within 30 seconds to 2 minute in all situations. (Table 2)

**Table 1.** Average total response time (minute).

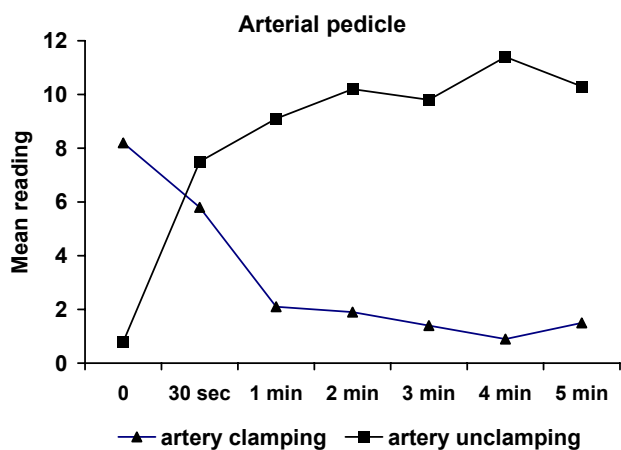
Vessel	Clamping	Unclamping
Artery	5.3	3.9
Vein	4.7	3.2
Pedicle	3.9	4.0

## DISCUSSION

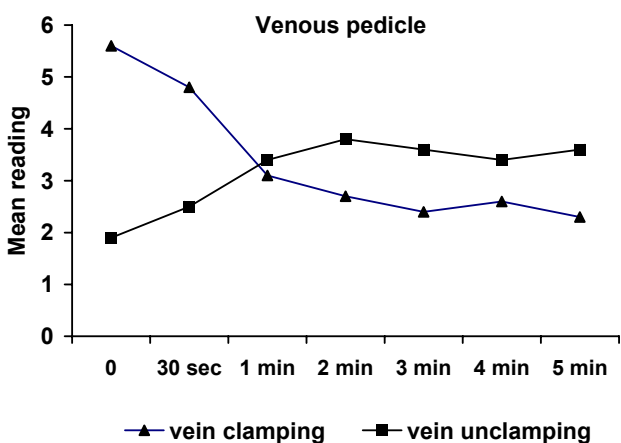
The ideal monitoring system should rapidly and continuously generate objective, reproducible data with good accuracy and specificity. The device should be simple, reliable, affordable, and safe, and be as equally effective with buried flaps as with superficial flaps.<sup>1,32</sup>

**Table 2.** p-values (comparison of interval readings to baseline, t-test).

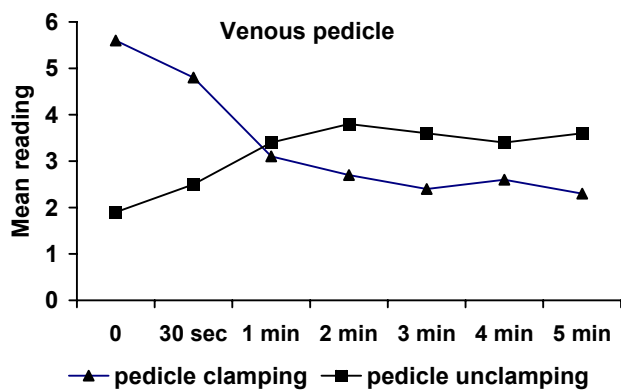
Time	Artery clamping	Artery unclamping	Vein clamping	Vein unclamping	Pedicle clamping	Pedicle unclamping
30 sec	0.015	0.0009	0.076	0.035	0.153	0.041
1.0 min	0.006	0.0001	0.019	0.016	0.065	0.023
2.0 min			0.005	0.019	0.035	0.014



**Figure 2.** The average response curve to the clamping and unclamping of artery.



**Figure 3.** The average response curve to the clamping and unclamping of vein.



**Figure 4.** The average response curve to the clamping and unclamping of whole pedicle.

The thermodiffusion system measures blood flow by monitoring the thermal conductivity of the tissue. Increased blood flow increases the thermal conductivity of the tissue in a linear fashion. The system generates a temperature differential between to an active probe and a passive probe incorporated in a single implantable unit. The original thermal diffusion transducers were hampered by the averaging effect in the capillary bed. The Peltier element of these probes allows a greater and more isolated temperature gradient which is less affected by alterations in the ambient temperature.<sup>28</sup>

The system tested is a simple device with a single and constant numeric reading. The probe is a thin, pliable silastic ribbon comparable in size and shape to the average penrose drain. We envision this device serving the added function of passive drainage of the surgical wound.

This study investigated the feasibility of using this monitoring device in buried muscle flaps. The results showed reproducible and rapid responses to vascular pedicle compromise. There was not a discernable difference between responses to arterial and venous insults. The numbers generated by the device were not taken as objective quantitative data, but rather as quantitative readings. The thermal capacity of muscle is likely different than that of brain tissue, and the device will ultimately need to be recalibrated to match muscle tissue.

The thermodiffusion device is limited in its depth of measurement to between 1.25 to 3 mm.<sup>16,28</sup> In addition, Tamura in a previous study of both laser Doppler and thermal diffusion monitoring suggested that both methods may be susceptible to variations in numeric reading secondary to the variable special distribution of vascular units in the tissue.<sup>16</sup> That is, depending on the location on the probe, the circulation of the particular region immediately beneath the probe will have different numbers of vessels and thus have subtle variations in thermal conductivity.

Overall, we found that the device responds consistently and rapidly to changes in flap perfusion. The device is simple, reliable and safe, and continuous data could be recorded. Future studies will evaluate the performance of device in the clinical setting, and concomitant xenon clearance studies will be needed to calibrate the device to muscle tissue.

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