Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.JournalofSurgicalResearch.com

# Detection of free flap pedicle thrombosis by infrared surface temperature imaging

*Cherng-Kang Perng, MD, PhD,*[a,b,*] *Hsu Ma, MD, PhD,*[a,b,c] *Yu-Jen Chiu, MD,*[a,b] *Pei-Hsin Lin, MD, MPH, PhD,*[d] *and Chi-Han Tsai, MS*[a]

[a] *Division of Plastic and Reconstructive Surgery, Department of Surgery, Taipei Veteran General Hospital, Taipei City, Taiwan*

[b] *Department of Surgery, School of Medicine, National Yang Ming University, Taipei City, Taiwan*

[c] *Department of Surgery, National Defense Medical Center, Taipei City, Taiwan*

[d] *Rehabilitation and Technical Aid Center, Taipei Veterans General Hospital, Taipei City, Taiwan*

ARTICLE INFO

*Article history:*
Received 15 July 2017
Received in revised form
5 February 2018
Accepted 21 March 2018
Available online xxx

*Keywords:*
Free flap
Infrared thermal imaging
Pedicle thrombosis

ABSTRACT

*Background:* Reliable detection of any circulatory issue threatening flap viability after free flap surgery is essential for prompt flap salvage. Currently, the gold standard of flap monitoring is clinical monitoring. However, this method presents logistical challenges to insufficient trained personnel. Auxiliary methods are becoming increasingly vital.

*Materials and methods:* Twelve swine pedicle myocutaneous flaps were harvested and monitored using infrared cameras to investigate the developed monitoring parameters and vascular thrombosis in the free flap model.

*Results:* The mean flap surface temperature after vein or artery occlusion decreased significantly, but the differences were relatively small. As a result, the difference between recorded (flap surface temperature [$T_s$]) and predicted (estimated surface temperature [$T_{es}$]) flap surface temperature ($\Delta T = T_s - T_{es}$) was used as the parameter for pedicle thrombosis. A $\Delta T$ of $<0.86^{\circ}C$ was used as a vascular occlusion criterion; the sensitivity and specificity of this parameter were 90% and 81%, respectively. The standard deviation of the surface temperature ($SD_T$) was another indicator of vascular occlusion; the estimated sensitivity and specificity for vessel occlusion of $SD_T < 0.48^{\circ}C$ were 84% and 73%, respectively.

*Conclusions:* Infrared thermal imaging has the advantages of being noninvasive, contact-free, continuous, and able to detect the whole flap surface area. Two indicators, $\Delta T$ and $SD_T$, can be used with high sensitivity and specificity for early prediction of flap pedicle thrombosis. Further human studies are necessary to validate clinical application of infrared thermal imaging.



## Introduction

Currently, the gold standard of flap monitoring is observation of color, turgor, temperature, capillary refill, and bleeding to pin prick owing to its wide applicability.[1] However, these methods present logistical challenges to small, hour-restricted residency programs and private practices.[2] Even, well-trained medical staff cannot achieve 100% early detection of vascular obstruction. Many flap-monitoring techniques have been described to enable early detection of vessel

* *Corresponding author*. 19/F, No. 201, Sec. 2, Shipai Road., Beitou District, Taipei City 112, Taiwan. Tel.: +886 2 2871 2121x7542; fax: +886 2 2875 7041.

E-mail address: ckperng@vghtpe.gov.tw (C.-K. Perng).

0022-4804/$ – see front matter 
https://doi.org/10.1016/j.jss.2018.03.054

occlusion to improve the free flap salvage rate, such as hand-held Doppler probe,[3] surface temperature,[4] implantable Doppler detection system,[5] and infrared spectroscopy.[2,6] However, these flap-monitoring techniques have important disadvantages, such as high cost, lack of accuracy, or possible invasive injury to patients.[2] Thus, no widely accepted alternative method for early detection of vascular obstruction is currently available.

Flap surface temperature monitoring is one of the oldest and simplest methods for detecting vascular anastomosis site thrombosis after free tissue transfer surgery. Previous studies have reported that the variation of surface temperature between the flap and surrounding normal skin could detect meaningful flap blood circulation problems.[4,7,8] However, in some cases of full or partial flap necrosis following deep inferior epigastric perforator free flap breast reconstruction surgery, surface temperature changes failed to be detected before reoperation.[9] These studies provide no clinical consensus as to the applicability of surface temperature monitoring to indicate flap vascular anastomosis occlusion, and its accuracy remains doubtful. The difficulty in determining an objective indicator might be related to the fact that traditional methods measured single spot temperature, not the whole flap surface temperature, and that the surface temperature itself is affected by body temperature, room temperature, and other factors.[10]

Infrared thermal imaging devices can noninvasively, contact-freely, and continuously detect the radiation emitted from animals. With advances in infrared cameras and computer image analysis, more accurate thermal imaging analyzers can detect subtle surface temperature changes, providing representative information on surface temperature average and variation. Our study used infrared thermal imaging and constructed a simplified flap thermal model according to the heat transfer formula to develop an objective method and parameters, $\Delta T$ and standard deviation in flap surface temperature ($SD_T$), for detecting postoperative free flap vascular occlusion.

## Materials and methods

### *Swine pedicle myocutaneous flaps model setup*

Twelve male swine (weight, 10-15 kg) were anesthetized generally using intravenous isoflurane for a total of 4.5 h for data collection with infrared cameras (Spectrum 9000 MB series Digital Infrared Thermal Image System; United Integrated Services Co, Ltd, New Taipei, Taiwan) and visible light cameras (D90; Nikon, Tokyo, Japan) capturing images every 2 min. The infrared imaging system was equipped with a black box measuring room temperature; the infrared image was simultaneously recorded, and the correlation served as a reference of the skin infrared imaging to obtain the real temperature. The core temperature of the swine was recorded with a rectal thermometer (Fig. 1C).

An island pedicled pectoralis major myocutaneous flap was designed and harvested (Fig. 1A), and the pedicle vessels were dissected and controlled separately using rubber loops (Fig. 1B). The flap was sutured back to its original position and was left undisturbed. The pedicle vessels were patent, postoperatively. Two hours later, the flap surface temperature stabilized, and the blood flow in either the flap artery or vein was temporarily clamped for 2 h to simulate clinical vessel occlusion. Six swine were included in the arterial occlusion group, and another six swine were included in the venous

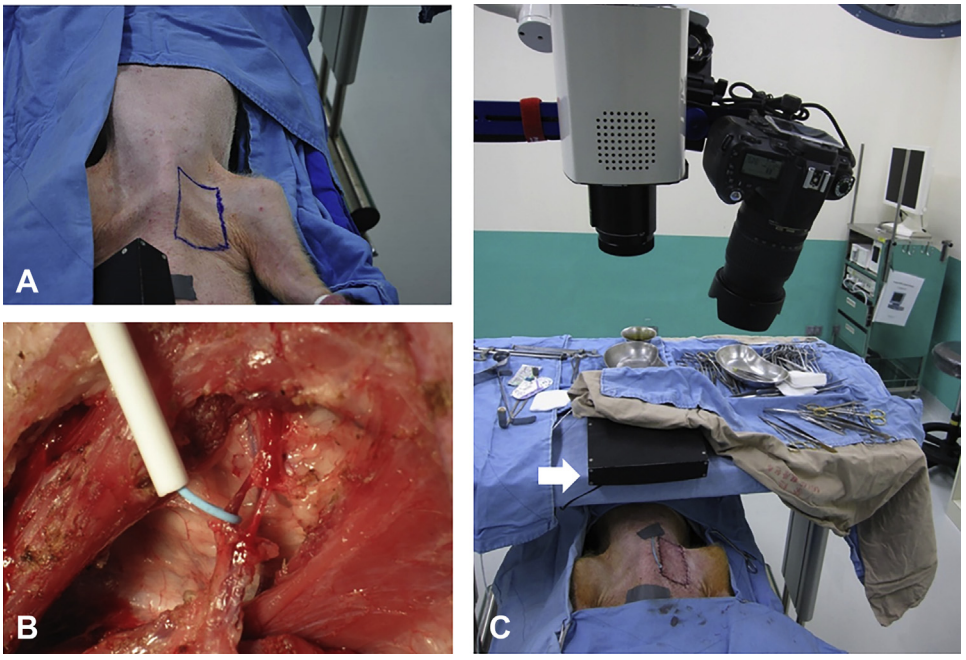


**Fig. 1 – Images of the infrared monitor system. (A) Pectoralis major myocutaneous flap was designed on a swine model under general anesthesia. (B) The pedicle vessels were controlled separately with a rubber loop. (C) The flap was sutured back to its original position, with an infrared camera and a visible light camera capturing images every 2 min. The system was equipped with a black box that measured room temperature (white arrow). (Color version of figure is available online.)**