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# Assessment of microcirculation of the skin using Tissue Viability Imaging: A promising technique for detecting venous stasis in the skin

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ABSTRACT

*Background:* : Venous occlusion in the skin is difficult to detect by existing measurement techniques. Our aim was to find out whether Tissue Viability Imaging (TiVi) was better at detecting venous occlusion by comparing it with results of laser Doppler flowmetry (LDF) during graded arterial and venous stasis in human forearm skin.
*Methods:* : Arterial and venous occlusions were simulated in 10 healthy volunteers by inflating a blood pressure cuff around the upper right arm. Changes in the concentration of red blood cells (RBC) were measured using TiVi, while skin perfusion and concentration of moving red blood cells (CMBC) were measured using static indices of LDF during exsanguination and subsequent arterial occlusion, postocclusive reactive hyperaemia, and graded increasing and decreasing venous stasis.
*Results:* : During arterial occlusion there was a significant reduction in the mean concentration of RBC from baseline, as well as in perfusion and CMBC ($p < 0.008$). Venous occlusion resulted in a significant 28% increase in the concentration of RBC ($p = 0.002$), but no significant change in perfusion (mean change −14%) while CMBC decreased significantly by 24% ($p = 0.02$). With stepwise increasing occlusion pressures there was a significant rise in the TiVi index and reduction in perfusion ($p = 0.008$), while the reverse was seen when venous flow was gradually restored.
*Conclusion:* : The concentration of RBC measured with TiVi changes rapidly and consistently during both total and partial arterial and venous occlusions, while the changes in perfusion, measured by LDF, were less consistent. This suggests that TiVi could be a more useful, non-invasive clinical monitoring tool for detecting venous stasis in the skin than LDF.



## Introduction

Venous stasis occurs as a result of partial or full occlusion of the draining veins originating from the microvascular bed. In the skin, this typically presents as a change in skin colour and edema formation due to a local accumulation of blood cells. Efforts have been made to indirectly detect these changes in the tissue by a number of non-invasive techniques such as laser Doppler flowmetry, microdialysis (Setala et al., 2006), and near infrared spectroscopy (Lohman et al., 2013). The main limitation of these techniques is that they are all one-point measurements and are therefore not able to monitor larger tissue areas. This is especially important in microvascular surgery where reconstruction with free flaps has become an essential part of the surgical care of patients with breast cancer, head and neck cancer, and tissue reconstruction after trauma. Adequate circulation is vital for flap survival. Complications like vascular occlusion, haemorrhage, or infection require reoperation in 2%–10% of patients (Bui et al., 2007; Khouri et al., 1998; Lidman and Niklasson, 2008). Venous occlusion is the most common cause of flap failure (Kroll et al., 1996). It is important to identify as it correlates with rates of salvage (Bui et al., 2007; Nelson et al., 2012; Vijan and Tran, 2007).

Laser Doppler flowmetry (LDF) is today the most widely used non-invasive technique in postoperative monitoring of free flaps, and is highly sensitive in the detection of arterial occlusions (Yuen and Feng, 2000b). LDF is, however, relatively insensitive to occlusion in the venous anastomosis (Yuen and Feng, 2000a).

Tissue viability imaging (TiVi) is a recently developed technique for the assessment of the microcirculation in the skin (O'Doherty et al., 2007). It is based on polarisation spectroscopy, and consists of a digital camera equipped with polarisation filters perpendicularly placed over

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the camera flash and lens. An image-processing algorithm produces a measure of output, the TiVi index, which is linearly proportional to the concentration of red blood cells RBC in the skin. In contrast, LDF measures perfusion, which is affected by both the concentration of RBC and their mean velocity (Fredriksson et al., 2009).

TiVi has been characterised (Henricson et al., 2009; Nilsson et al., 2009; O'Doherty et al., 2007) and compared with LDF (Farnebo et al., 2010; Petersen et al., 2010), laser Doppler imaging (Henricson et al., 2009), laser Doppler speckle imaging (O'Doherty et al., 2009), and colorimetry (Zhai et al., 2009). The technique is accurate and reproducible (Nilsson et al., 2009) and has advantages over other techniques. Like LDF, TiVi assesses the microvasculature in the papillary and reticular dermis where the capillary network is located. Unlike LDF, however, TiVi combines a high spatial (<50 μm) and temporal (exposure time ~50 ms) resolution. TiVi allows for instantaneous measurement of large areas and is easy to use. Finally, the TiVi index is far more sensitive than LDF when skin perfusion is at or below baseline, as it is during vasoconstriction tests (Henricson et al., 2009) and arterial occlusion (Tesselaar et al., 2012).

We therefore hypothesised that TiVi is more sensitive than LDF in detecting venous stasis and that it could be a valuable technique for monitoring free flaps. We compared the changes in concentration of RBC (measured using TiVi) and perfusion (measured using LDF) in healthy volunteers during exsanguination, postocclusive hyperaemia and either constant or stepwise increasing venous occlusion.

## Methods

### *Subjects*

Eighteen healthy subjects (women) mean age 28 (range 18–38) years, were included in the study after they had given written informed consent. The subjects were asked not to drink anything that contained caffeine or tea on the day of the experiment. Reasons for exclusion were cardiovascular disease, diabetes, skin diseases, regular use of nicotine or medication (except oral contraceptives) and a systolic blood pressure of >150 mm Hg or a diastolic of >90 mm Hg. Blood pressure was measured before and after the experiment. The study conformed with the Declaration of Helsinki and was approved by the regional ethics review board at Linköping University, Sweden.

### *Tissue viability imaging*

A TiVi camera system (TiVi600, WheelsBridge AB, Linköping, Sweden) was used to measure changes in the concentration of RBC in the skin. The system consists of a digital camera equipped with perpendicular polarisation filters in front of the flash and lens (O'Doherty et al., 2007). The broad-spectrum white flashlight becomes linearly polarised when passing the first polarisation filter. Reflected light from the skin consists of both linearly polarised (directly reflected) and randomly depolarised ("subsurface") light. A perpendicularly placed polarisation filter in front of the lens prevents any directly reflected light from reaching the photo-array in the camera. The RBC in the microcirculation absorb light in the green wavelength region (about 500–600 nm) to a much higher extent than light in the red wavelength region (about 600–700 nm). By comparison, the surrounding dermis absorbs less light, and this absorption is not as wavelength-dependent as that of the RBC. An image-processing algorithm uses this difference in absorption and produces a TiVi image, of which the pixel values, or unitless TiVi-indices, are linearly proportional to the local of RBC in the skin. The system is relatively insensitive to the oxygenation of RBC (O'Doherty et al., 2007).

Images were analysed using TiVi analysis software (TiVi Version 2.1, WheelsBridge AB, Linköping, Sweden) and customised software (Matlab R2007b, The Mathworks Inc., Natick, MA). The images contained the complete volar aspect of the lower forearm from the elbow to the wrist. A mean TiVi index was calculated from the same area of skin in each subsequent image, giving the change in the mean local concentration of RBC over the duration of the experiment.

### *Laser Doppler flowmetry*

A PeriFlux system 5000 Laser Doppler Perfusion Monitoring unit (Perimed AB, Järfälla, Sweden) with a thermostatic laser Doppler probe (Probe 481-1, Perimed AB, Järfälla, Sweden) was used to measure changes in skin perfusion (in perfusion units, PU), the concentration of moving blood cells (CMBC; in concentration units, CU) and skin temperature (in °C) (Wardell et al., 1994). The bandwidth of the system is 15 kHz, and the sampling frequency is 33 Hz. The probe used in the current study has a fibre separation of 0.25 mm and collects data about perfusion at a depth of about 0.5 mm (Fredriksson et al., 2009).

### *Experiments*

Subjects rested semisupine in a room with a controlled temperature of 22 (0.5) °C. Lighting was kept low by closing blinds and turning off lights, but there was usually enough light for reading. A pressure cuff was attached around the right upper arm. The forearm was kept at heart level with the volar site upward and supported by a pillow. The TiVi camera was mounted on a camera stand positioned 30 cm above the volar forearm so that images were captured at a 90° angle. The LDF probe was placed on the volar forearm (Fig. 1). Subjects were asked to keep still during the experiments.

**Experiment 1.** Exsanguination, reperfusion, and venous occlusion

This experiment involved 10 subjects (4 women), mean age 28 (range 18–38) years, and the aim was to measure changes in the concentration of RBC in the skin and the changes in skin perfusion during


**Fig. 1.** Diagram showing the placement of the LDF probe and region of interest for TiVi analysis (ROI).