ORIGINAL RESEARCH

A comparison of pulse oximetry and laser Doppler flowmetry in monitoring sequential vascular occlusion in a rabbit ear model

Geoffrey G Hallock MD[1], David C Rice BS[2]

GG Hallock, DC Rice. A comparison of pulse oximetry and laser Doppler flowmetry in monitoring sequential vascular occlusion in a rabbit ear model. Can J Plast Surg 2003;11(1):11-14.

The ultimate success of any free flap transfer depends not only on the experience of the given surgical team, but also requires constant vigilance in the perioperative period to assure continued anastomotic patency. Clinical acumen remains the 'industry' standard, but adjunctive monitoring devices are important to reinforce these subjective evaluations. We routinely use laser Doppler flowmetry in spite of known drawbacks, including expense. On the other hand, we know that pulse oximetry is a possible and readily available alternative.

The efficacy of these two monitoring systems was directly compared in a New Zealand white rabbit central artery and vein ear model. Arterial occlusion was immediately recognized by a precipitous drop in flow and oxygen saturation (SaO_2). A rapid drop in flow after venous occlusion with a trend to zero was also noted with laser Doppler flowmetry. The SaO_2 had a very slow but steady gradual decline, but values remained in the range of normoxemia for a prolonged time. Because a minimum threshold of SaO_2 for predicting venous occlusion was elusive, the usefulness of pulse oximetry for monitoring microsurgical composite tissue transfers is limited.

Key Words: *Free flap monitors; Laser Doppler flowmetry; Pulse oximetry*

Une comparaison entre l'oxymétrie pulsée et la fluxmétrie Doppler à laser dans la surveillance de l'occlusion vasculaire secondaire dans un modèle d'oreille de lapin

RÉSUMÉ : La réussite complète de toute greffe libre repose non seulement sur l'expérience de l'équipe chirurgicale mais aussi sur une vigilance constante en période périopératoire dans le but d'assurer la perméabilité anastomotique. L'acuité clinique demeure la norme dans «l'industrie » mais les dispositifs de surveillance d'appoint sont également importants pour préciser ces évaluations subjectives. Nous utilisons communément la fluxmétrie Doppler à laser malgré ses inconvénients connus, y compris son coût. D'autre part, nous savons que l'oxymétrie pulsée constitue une solution possible et accessible.

L'efficacité de ces deux systèmes de surveillance a fait l'objet d'une comparaison directe réalisée sur une artère et une veine centrales d'oreille de lapin blanc de Nouvelle-Zélande. L'occlusion artérielle a été immédiatement décelée par une chute précipitée du débit d'oxygène et de la saturation du sang en oxygène (SaO_2). Une chute rapide du débit après une occlusion veineuse avec tendance vers le zéro a également été décelée par la fluxmétrie Doppler à laser. La SaO_2 présentait une baisse graduelle très lente mais constante, cependant les valeurs sont demeurées longtemps près de la normoxémie. Le seuil minimal de SaO_2 pour la prédiction de l'occlusion veineuse étant imperceptible, l'utilité de l'oxymétrie pulsée pour la surveillance des greffes composées microchirurgicales se trouve donc limitée.

Although outright failure of a free flap transfer has become an increasingly uncommon event, occasional anastomotic complications inevitably occur and can be catastrophic (1). Prompt awareness of such events allows for early re-exploration and revision, and the best chance for flap salvage (1,2). Detection requires constant vigilance in the perioperative period, and clinical acumen remains the predominate monitoring technique, relying on assessment of colour, capillary refill, surface temperature and pinprick bleeding, if indicated (1-4). Nevertheless, adjunctive monitoring devices are also used frequently and have proved to be invaluable, even with experienced recovery personnel (2). The ideal monitor should be objective, provide a continuous recording of perfusion and show immediate recognition of anastomotic occlusion, and all events must be easily interpretable (1,5). These data must be reproducible, accurate, reliable, applicable to all types of flaps and obtainable by a noninvasive means that is preferably inexpensive (1,2,5).

Doppler ultrasound or laser Doppler flowmetry have universally become the most commonly used complements to conventional monitoring (2). We use laser Doppler flowmetry to monitor all of our microsurgical composite tissue transfers, beginning intraoperatively, to prevent kinking or stretching of the vascular pedicle, or excessive tension in flap closure. However, the required probe and cable attachments may sometimes be awkward to affix to the patient, their fibreglass cords are fragile and are often accidentally broken by the patient or staff, and they are relatively expensive in this day of reduced reimbursements.

We continue to seek the perfect objective monitoring device, and pulse oximetry piqued our interest as a potential inexpensive device that is ubiquitous in most institutions for anesthesia and critical care observation. Others have successfully adopted this concept to routinely monitor replants (6) and digital transfers (3,7), but free flap monitoring has been

[1]*Division of Plastic Surgery;* [2]*Advanced Clinical Technologies Department, The Lehigh Valley Hospital, Allentown, Pennsylvania, USA*
Correspondence: Dr Geoffrey G Hallock, 1230 South Cedar Crest Boulevard, Suite 306, Allentown, Pennsylvania 18103, USA.
Telephone 610-435-7555, fax 610-770-6390, e-mail pbhallock@cs.com

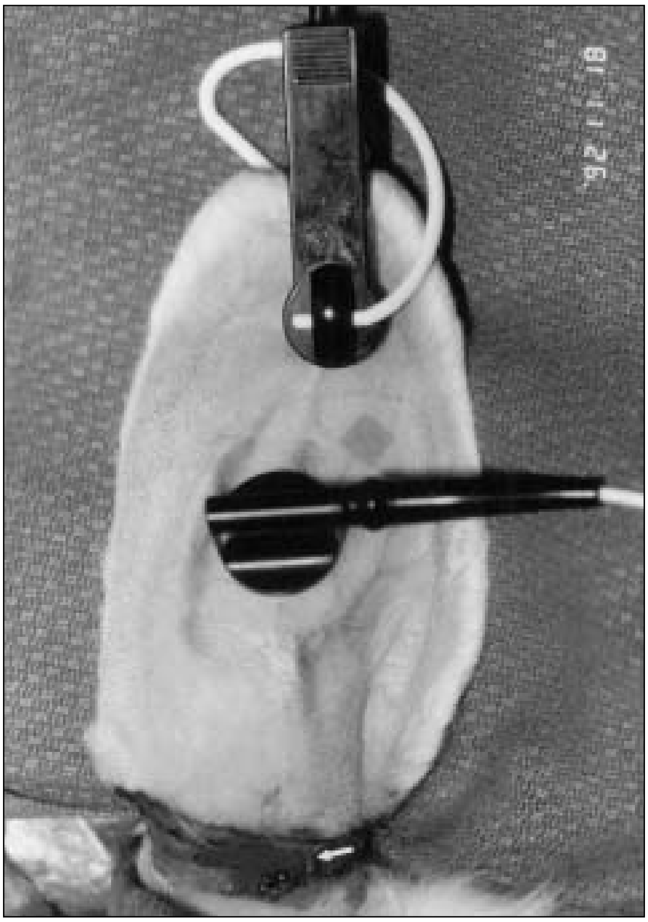

Figure 1) *Rabbit ear model with auricular vessels isolated at base (arrow). A digital pulse oximeter probe has been clipped onto the tip, with the laser Doppler surface probe attached proximally*

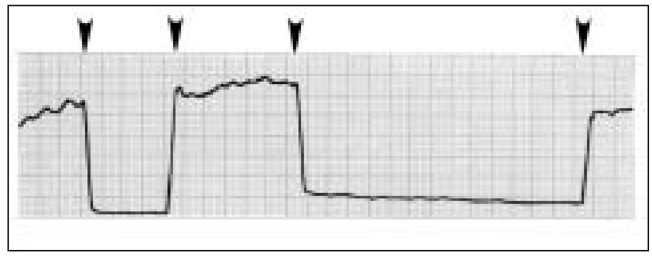

Figure 2) *Graphic display of laser Doppler flowmetry, with flow (ordinate [arbitrary units]) versus time (abscissa [10 squares = 1 cm = 1 min]). In this rabbit tracing, starting at left, the first arrow corresponds to the onset of arterial occlusion with immediate flow decrease; the second arrow indicates microclamp release with flow overshoot and return near baseline; the third arrow shows the placement of the venous clamp and corresponding drop in flow; and the last arrow indicates the removal of the latter with the return of flow to baseline*

limited (8,9). The relationship of oxygen saturation (SaO_2) as measured by pulse oximetry to arterial and venous occlusion in this context must first be better defined. We have attempted this in a rabbit central ear artery and vein model (10), with simultaneous comparison of all observations to our present standard of laser Doppler flowmetry.

THEORY

Laser Doppler flowmetry allows a noninvasive indirect estimation of tissue perfusion (11). A 5 mW laser diode with an emission wavelength of 780 nm is used as the light source (12). The Doppler shift of this reflected laser light is related to the number and velocity of moving red blood cells in the specific target region (13,14). The accrued data are calibrated to provide real time measurements of tissue perfusion that can be displayed in numerical format or as a trendline. The units of measurement with our equipment correspond to flow (mL/min/100 mg tissue) (15).

Pulse oximetry is based on the principles of photoplethysmography, and both pulse rate and SaO_2 can be recorded (7). A transducer emits both a visible red (660 nm) and infrared (940 nm) light that transilluminates the tissue, to be received by a photodiode receptor (7,8). The ratio of absorption characteristics of these wavelengths by oxygenated (oxy-Hb) and reduced hemoglobin (Hb) allows the calculation of a 'functional' SaO_2 (oxy-Hb/total Hb) (16,17). This percentage of SaO_2 is related to the partial pressure of oxygen (PaO_2) by the oxygen-hemoglobin dissociation curve, and a direct correlation between SaO_2 as measured by oximetry and arterial PaO_2 has been calibrated without the need for repeated invasive blood gas measurements (16). For example, normoxemia is considered to have an SaO_2 range of 95% to 100% (17). Determination of these values requires the pulsation of arterial blood under the sample area, which negates any effect of skin colour, tissue thickness or venous pooling, which become constant variables (17).

METHODS

The New Zealand white rabbit was selected as a good laboratory model for pulse oximetry studies because the rabbit ear is a large appendage, which simplifies the attachment of the commercially available probes. All aspects of this project were done in a United States Department of Agriculture approved laboratory under the auspices of the Institutional Animal Care and Use Committee. Anesthesia was routinely induced in these rabbits using an intravenous infusion of acepromazine maleate, and was maintained with periodic intramuscular injections of ketamine hydrochloride and xylazine. One hundred per cent oxygen was delivered via mask. All hair was shaved from one ear only, which was meticulously scrubbed using antimicrobial soap. Strict sterile techniques including the use of surgical drapes were always observed.

Surgical preparation required that the auricular artery and vein be isolated at the basal portion of the ear. The remaining skin was then circumferentially incised around the ear, down to cartilage, with careful hemostasis. The avascular cartilage was left intact to prevent kinking of the now tenuous vascular pedicle due to the weight of the monitoring probes that would be applied.

A clip-on digital oximeter probe was placed on the given ear (Figure 1) and attached to an Ohmeda 3740 pulse oximeter (Ohmeda Medical, USA) and a Cole-Parmer model 8376-30 strip chart recorder (Cole-Palmer Instrument Company, USA). Just proximal to this, a Vasamedics right angle flat surface laser Doppler probe (P-430) (Vasamedics, USA) was affixed by adhesive discs, and it, in turn, connected to a model BPM flowmeter (Vasamedics, USA) In random sequence, microclamps totally

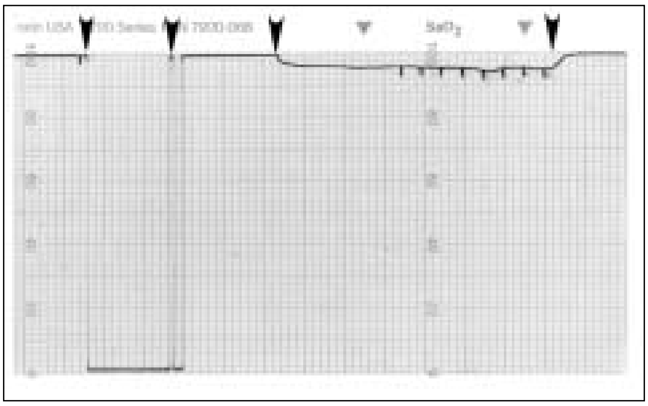

Figure 3) *Per cent oxygen saturation (SaO_2) (ordinate) versus time (abscissa [10 squares = 1 cm = 1 min]) as measured by pulse oximeter. Arrows correspond to the time and events, as in Figure 2. Arterial occlusion resulted in a drop of SaO_2 to zero. Venous occlusion resulted in slow, steady drop in SaO_2, but during this timeframe the drop was to levels still considered to be normoxemic*

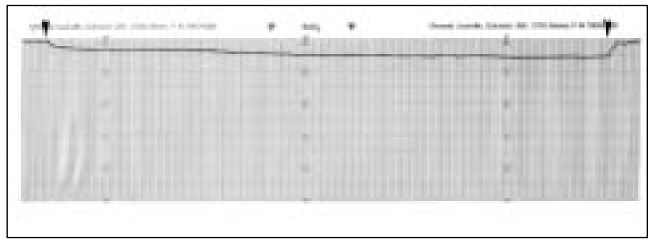

Figure 4) *In a separate but more prolonged period of venous occlusion (left arrow), oxygen saturation (SaO_2) dropped from a baseline of 100% to a minimum of 89% after 28 min when the microclamp was removed (right arrow). Ordinate = SaO_2, abscissa = time (10 squares = 1 cm = 1 min)*

occluded the artery or vein, and the effect on SaO_2 and blood flow respectively recorded. All values were allowed to return to baseline before proceeding with further vessel occlusion.

RESULTS

Arterial clamping resulted in an immediate and precipitous drop in inflow as noted by laser Doppler flowmetry (Figure 2). After a few seconds, a similar drop in SaO_2 to zero occurred with an absent pulse rate (Figure 3). Upon release of the microclamp, a rebound or overshoot of flow due to a hyperemic response was observed by laser Doppler flowmetry (14,18), and SaO_2 as measured by pulse oximetry returned to baseline. Although not as precipitous, venous occlusion resulted in a rapid drop in flow below what many consider the critical index of 50% of baseline flow (13,19) (Figure 2). Unlike this more abrupt change noted by laser Doppler flowmetry, the SaO_2 had a slow but steady downward trend in saturation (Figure 3). This reached only as low as 89% after 30 min of occlusion, due to the large capacitance of the venous system (14), presumably a result of the persistent infusion of oxygenated blood from the patent arterial side (Figure 4).

DISCUSSION

The ‘fear of failure’ remains the proper impetus for seeking the ‘ideal objective monitor’ for free tissue transfers. The pulse oximeter, as such, deserves evaluation because it is readily available in most institutions, and its display of pulse rate and SaO_2 are easily comprehended. Interpretation must be adjusted for any situation in which arterial pulsation is reduced (eg, hypotension, hypothermia), hemoglobin content is diminished (eg, anemia), or dyshemoglobinemias (eg, carboxyhemoglobinemia) where light absorption is altered and SaO_2 is incorrectly estimated by the apparatus (16,17). In previous clinical reports of the use of pulse oximetry as in our model, the cessation of arterial pulsation always obviously resulted in no pulse rate. The dilemma has been assessing the onset of venous occlusion, as a reduction in SaO_2 tends to be gradual and not instantaneous (6,20), as we have also shown (Figures 3 and 4). Jones and Gupta (7), for what appear to be arbitrary reasons, stated that the SaO_2 threshold for indicating venous occlusion should be 90% to 93% (7), but the time interval was not given. Buncke et al (20) stated that pulse oximetry is unreliable as an adjunctive monitor due to the significant delay and gradual onset of the manifestation of venous occlusion.

Laser Doppler flowmetry also has numerous known limitations. Absolute flow is not measured directly by this device and positive flow values have been observed even under ‘no flow’ conditions (21). The critical threshold for the prediction of flap viability of flow equal to 50% of the baseline (19) may actually be too high (22), and, thus, low values measured without venous obstruction could inadvertently be considered a false-positive unless a longer trendline is observed, similar to that which is necessary for pulse oximetry, rather than relying on any isolated perfusion values (5,12,14). The major problem we have dealt with is more practical than theoretical in that the fiberoptic cables are constantly being crimped by inexperienced personnel and are difficult to keep in stock due to their great expense, considering our budgetary constraints.

Nevertheless, laser Doppler flowmetry continues to be our ally, especially for noncutaneous flaps in which clinical assessment is more difficult. Transillumination of most flaps, technically essential to consider pulse oximetry, would be problematic (8). However, the pulse oximetry probes, unlike the bulky and awkward laser Doppler probes, are superior for attachment to digits. This may become the former’s unique niche as a microsurgical monitor once we gain more comfort in assessing the clinical threshold for venous occlusion.

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