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Preliminary experiences with laser Doppler velocimetry for the determination of amputation levels

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Abstract

Laser Doppler velocimetry is a newly available technique for the continuous and non-invasive measurement of capillary perfusion. The technique is presented and preliminary results of its use in the evaluation of amputation levels in 16 patients discussed.

Introduction

A large number of amputations are performed worldwide each year, exceeding 100,000 in the United States alone. Decisions as to when to amputate and at what level have become an important surgical problem. Most of the amputations are being carried out for atherosclerotic ischaemic vascular disease of the lower limb in an ageing population.

The success of rehabilitation following an amputation in this population is related to many factors but certainly among the most important is the level at which the amputation is performed. The lower the level, the greater the chance of successful rehabilitation and independent living. It therefore becomes of great importance to be able to accurately assess the level at which the least destructive surgery can be carried out.

Experience with present methods

Over the years, a multitude of methods to predict the success or failure of a given level of amputation have been advanced and applied Burgess and Matsen (1981) in a recent review have discussed this problem and concluded that none of the methods have proven ideal. Evaluation of clinical symptoms and signs has been the standard way of evaluating a limb for the presence or absence of vascular disease, and if an amputation was indicated, what would be the most satisfactory level for healing. Clinical signs however are heavily subjective, and are frequently of value only in experienced hands.

Beginning in the late nineteenth century and continuing to the present a variety of techniques have been introduced to evaluate the viability of a limb using more objective techniques and technologies. These have included measurement of various aspects of blood flow, blood pressure, and delivery or removal of metabolic substances. Some of these have become more standardly used than others. Venous occlusion plethysmogaphy has become more or less the physiological standard for measuring volumetric blood flow in a limb (Summer, 1982). This technique however is cumbersome clinically and cannot be utilized on all locations where one might wish to measure blood flow. There is also the question as to whether the inflation and deflation of cuffs on the limb causes changes in the blood flow being measured. A second technique is that of segmental blood pressure (Yao and Takaki, 1982). It is now well known however that in both diabetics and nondiabetics the major arteries may be calcified and stiff and cannot be compressed giving an artificially high pressure at that level. Radioisotope clearance has also been used fairly extensively but is both invasive and requires exposure to radiochemicals although frequently relatively minimal. Again, evidence suggests that the blood flow being measured is altered by the technique (Holloway, 1980). More recently the partial pressure of oxygen has been measured at the skin surface as an indicator of the oxygen level in the capillary system (Matsen et al, 1980). This system has proved of some value although it is limited by the fact that it cannot be used on every surface, and tha the skin must be heated before a value can be obtained.

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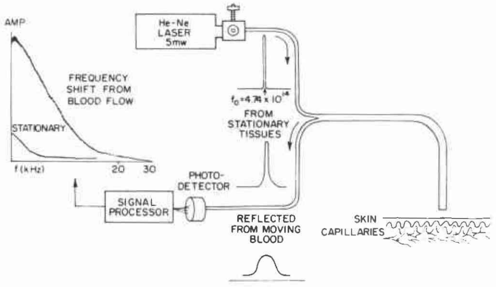

Fig. 1. Block diagram of laser Doppler system. See text for detailed explanation.

It is the purpose of this paper to review an additional technique, laser Doppler volocimetry (Stern et al, 1977; Watkins and Holloway, 1978; Nillson et al, 1980) for its potential use in evaluating ischaemic vascular disease and amputation levels. As it is noninvasive, continuous, and has a small sample volume, its consideration for use in evaluation of ischaemia and amputation levels appears warranted.

Laser Doppler principles and methods

Laser Doppler velocimetry is a technique which uses the Doppler principle much as the ultrasonic Doppler does, but uses light instead of sound. A simplified block diagram is shown in Figure 1. A low power laser provides the source of monochromatic (single frequency) light which is led to the skin surface through a small glass optical fibre. As the light impinges on the skin surface it is backscattered as two components as indicated in Figure 2. The first is light backscattered from the non-moving structures in the surface layers of the skin and is therefore not Doppler shifted. The second component is backscattered from moving red blood cells in the superficial capillaries in the skin and is Doppler shifted in frequency in accordance with the velocities of the red blood cells. Both of these components are returned from the skin surface through a second optical fibre to a photodetector. Both the Doppler shifted and non-Doppler shifted components mix together on the surface of the photodetector and constructively and destructively interfere. The frequency at which this interference occurs is the Doppler shift frequency. However as the light is backscattered from many different red cells moving at different velocities, a single frequency is not present, in fact a spectrum of frequencies is observed. The electronic signal carrying these frequencies is then processed with the output of this circuit being a single number which has been shown to vary directly with flow as measured by other "standard" methods. This output is then displayed either on a panel meter or a strip chart recorder. The actual probe containing the two optical fibres is simple and light in weight and can be either set upon the skin surface or more tightly attached using double sided cellophane tape. With the probe on the skin surface a continuous and noninvasive measure of capillary blood flow in a sample volume of approximately one cubic millimeter is made. Figure 3 shows the instrument in use.

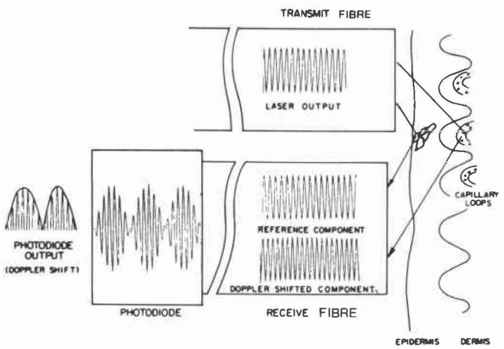

Fig. 2. Diagram of laser Doppler optical mixing process. "Reference" light from non-moving tissues is mixed on the photodetector with Doppler shifted light scattered from moving red blood cells. The interference pattern produced is seen in the envelope of the photodetector output, and is the Doppler shifted frequency.

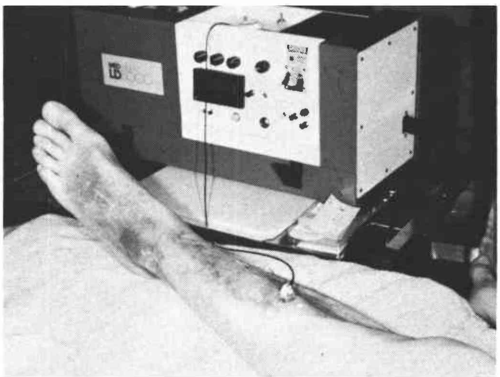

Fig. 3. Laser Doppler velocimeter in use. (With permission from Holloway, G. A. (1983) Laser Doppler measurement of cutaneous blood flow. In: Rolfe, P. (ed) Non-invasive Physiological Instrumentation, Vol. II. London, Academic Press. (in press). Copyright, Academic Press Inc. (London) Ltd.

Comparison with other methods

Laser Doppler velocimetry has been compared with several other methods for the measurement of blood flow. It is important to realize however that the sample volumes and the quantities being measured in these other methods all differ to some degree. Firstly laser Doppler velocimetry has been compared to the clearance of the radioisotope xenon on several occasions (Stern et al, 1977; Watkins and Holloway, 1978). These comparisons have shown a linear relationship between the two techniques but with a fair amount of variance. The methods differ in that the sample volume from the xenon clearance is in the order of one cubic centimeter and the technique is only valid during the rapid clearance phase of xenon. It also appears to be influenced by the method used to apply the xenon (Holloway, 1980).

The laser Doppler technique has also been compared to flow as measured by microsphere deposition. Stern et al (1979) measured flow through the renal cortex using both laser Doppler and radioactively labelled microspheres as well as an electromagnetic flow meter on the renal artery. The laser Doppler instrument used had a slightly different processing algorithm than present instruments but showed a generally linear relation to flow as measured by either microspheres or electromagnetic flow meter but a tendency to underestimate flow in high flow states. These studies using microspheres have not been repeated in the skin, and no studies have been done comparing laser Doppler instruments with the newer processing techniques with microspheres.

Two recent studies have been done in the gastrointestinal tract comparing laser Doppler velocimetry with measurements made using an electromagnetic flow meter placed on the mesenteric artery to that segment (Feld et al, 1982; Shepherd and Riedel, 1982).

When the laser Doppler was placed on the mucosal surface, changes in total blood flow as measured with the electromagnetic flow meter correlated well with local mucosal flow changes as measured by the laser Doppler system. It is important again to note that the laser Doppler, microsphere technique, and electromagnetic flow meter are all measuring different quantities. Thus although the correlation between the techniques is good one cannot calibrate the laser Doppler as a measurement of capillary flow against these other methods. There is in fact no model system for a capillary network as appears in the skin which will permit callibration of the laser Doppler in absolute flow. On the other hand work by Bonner and Nossal (1981) has suggested that the laser Doppler does indeed provide a quantitative measure of instantaneous microvascular blood flow in optically accessible tissues.

Clinical experience

As the laser Doppler instrument has only been recently available clinical experience in patients with ischaemic vascular disease in the determination of amputation levels has been limited. Our experience has been limited to sixteen patients undergoing twenty amputations; eight were diabetic and eight nondiabetic. The amputations performed were: one Raye, one transmetatarsal, four Syme, eight below-knee (BK) and six above-knee (AK). The first studies were done with a prototype laser Doppler instrument but subsequently a new commercially available instrument with a slightly different processing algorithm has been used.* As the algorithms are different, the flow values scale differently and thus values from one machine cannot be well compared with those from the other. In addition only partial data is available on some of the patients. The patients have varied in age from 29 to 94. The protocol used evaluated both resting and heated flow as well as transcutaneous Po_2 at the dorsum, BK, and AK levels. Heating was performed to test for flow reserve with the heated flow value being measured in the centre of the area where the transcutaneous oxygen heater had been at 44°C for ten minutes.

Of the 20 amputations performed, all fourteen performed at either BK or AK levels healed satisfactorily and primarily. The Raye, transmetatarsal and two of the Syme amputations failed. In the failed Raye and both Syme amputations resting flow was about the same as in normals, but heated flow increased only minimally and to a level less than one third of that seen in normals. Transcutaneous Po_2 values were highly variable in all three. The transmetatarsal amputation had good values for

* The laser Doppler velocimetry instrument used was the LD5000 Capillary Perfusion Monitor manufactured by MEDPACIFIC Inc., 6701 6th Ave. So., Seattle, Wash. 98108. List price: $13,500.

both resting and heated flow as well as transcutaneous Po_2. This amputation was performed for pressure induced ischaemic ulcers and was healing relatively well at that level but a nonhealing ulcer eroding down to the Achilles tendon made it clinically advisable to revise it to a BK level. All of the patients having amputations at the BK or AK level in whom technically adequate flow readings were obtained showed a significant increase in the heated flow value as compared to the resting level, although less than seen in normals.

Our initial data would therefore support the continued trial of the laser Doppler velocimeter in the evaluation of amputation levels for ischaemic vascular disease. Although the resting values are in the same range as those for normals, values after heating to 44°C for ten minutes showed markedly diminished hyperemic response as compared to normals, especially in those patients who failed to heal their amputations primarily. It has not yet been determined what levels define the cutoff between amputations which heal and those which do not. It is felt that now the instrumentation is being better standardized and when more patients are evaluated, critical flow levels will be able to be indentified.

Acknowledgements

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