Laser Doppler Flowmetry- Technological application for diagnosis and therapeutics in medical sciences

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Abstract: Laser Doppler flowmetry is a technological investigative method; which is considered non-invasive for investigating vascular/micro-vascular blood flow. It is used to diagnose various complicated conditions in medical sciences. Different devices are available pertaining to the need to diagnose and plan a therapy. All the technical aspects of various applications and devices are explained. The clinical applications of Laser Doppler Flowmetry is an advanced protocol but it has certain limitations which needs to be worked upon for advancements to help achieve a better quality of life for mankind.

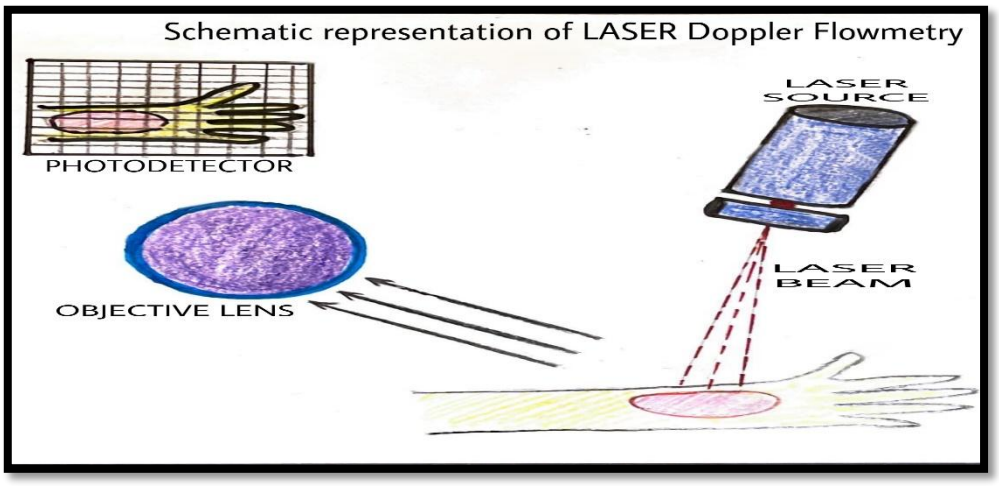
Index Terms— LDF, Micro circulation, Laser, Doppler effect. (key words)

I. INTRODUCTION

Laser Doppler flowmetry (LDF) is a technological investigative method; which is considered non-invasive for investigating vascular/micro-vascular level of flow of blood or other body fluids like the cerebrospinal fluid. The laser, developed in the middle of the last century, soon found its way into medicine, where it has been frequently used both in therapy and diagnostics. The word "laser" is an acronym for Light Amplification by Stimulated Emission of Radiation. Two characteristics of the light radiated by this stimulated emission are that it is monochromatic and coherent. The coherency is central in Laser Doppler Flowmetry (LDF).

It is used for the purposes of diagnosing several problems associated in the different fields of medical sciences. Doppler shift of the laser beam is the carrier of information, which is acquired from such an investigative methodology. Reliable correlation is found between LDF and other investigative methods for microcirculation assessment. [1-4] LDF monitors and records sudden changes in the microcirculation; which provides a reproducible parameter (Figure - 1) of sympathetic vasomotor control.[5]

Figure-1: Schematic representation of Laser Doppler Flowmetry



II. DEVICES

Figure-1: Schematic representation of Laser Doppler Flowmetry Laser Doppler flowmetry is used in medicine to diagnose various complicated conditions in diabetes, rheumatology and in dentistry. It is also used in scientific research Laser Doppler flowmetry owes the increase in its medical application to a number of studies on the correlation of blood perfusion oscillations with physiological processes. A number of works showed that LDF can be used to measure endothelium-dependent and endothelium-independent rhythms, micro-vessel muscle activity, and blood flow fluctuations associated with cardiac and respiratory activities.[6]

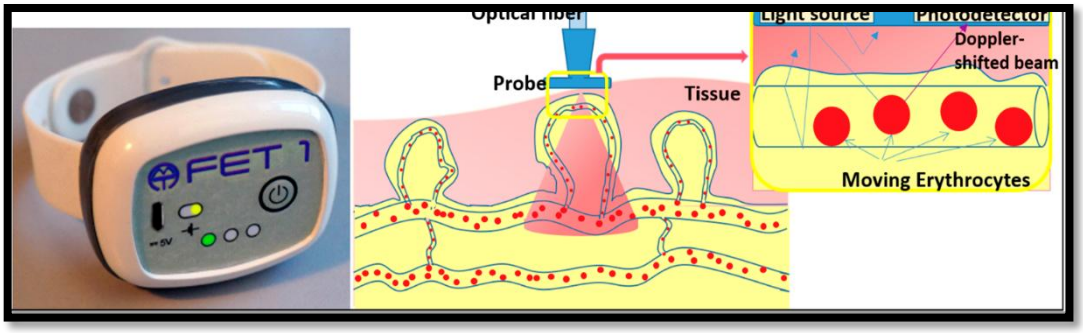
Available laser Doppler flowmeters use techniques for power spectrum processing within a wide range of power spectrum distribution over Doppler broadening frequencies (for example, 20_12000 Hz), which leads to the loss of potentially useful diagnostic information. This distribution carries important physiological information about local and systemic processes that affect microcirculation. The newer method is sufficiently accurate to provide correct classification of subjects into groups according to the state of microcirculation. Further development of the method will involve additional research into the diagnostic value of the power spectrum distribution over the Doppler broadening frequencies and, in particular, the substantiation of new diagnostic criteria based on the frequency distribution of perfusion oscillations.[4,6]

Wearable Laser Doppler Flowmetry Monitor

These devices have three similar channels for recording blood perfusion, skin temperature, and movements provide measurement

at any desirable point of the human body. The system also comprises a wireless data acquisition module. Mou Saha et al quotes that every wearable sensor in the system uses a VCSEL chip (850 nm, 1.4 mW/3.5 mA, Philips, The Netherlands) as a single-mode laser source to implement fibre-free direct illumination of tissue.[7] The fibre probe movements can cause high-frequency intensity fluctuations due to speckle movement. The intensity fluctuations can themselves produce an apparent Doppler shift, which will highly disturb the initial data acquisition creating faulty conclusions (Figure - 2). Fibre-free solution and direct illumination of tissue by the laser diode make it possible to decrease these artefacts which are common in fibre-based LDF systems, as well as to avoid fibre coupling losses.[7] To find a correlation between the changes in the registered blood perfusion and actual body movements the integral accelerometer has been embedded.

Figure – 2: Wearable LDF monitor



III. Working Principle

LDF measures capillary blood profusion parameters like blood flow, volume and its velocity in real time. Probes are used to direct the laser light of wavelength 640-720 nm through a fiber-optic cable. It penetrates 1.5 mm into the tissue to cover an area of 1 mm^3 to include red blood cells and tissue cells. The laser light emitted while activation is randomly scattered by these cells (Figure - 3). Photons are Doppler-shifted In the moving cells and the scattered light is collected by fibers in the cable. They are then coupled to a photo detector and get converted to electronic signal to produce outputs proportional to the blood flow. A Thermistor (Thermodynamically heated probe) is connected to the LDF, which raises the tissue temperature to 45° C. G. C. Zografos et al in their research concludes that the above statement holds true to cause local vasodilatation and increases the blood flow to theoretical values by eliminating the environmental factors thereby increasing the sensitivity of the system.[8]

Figure – 3: Working principle of LDF

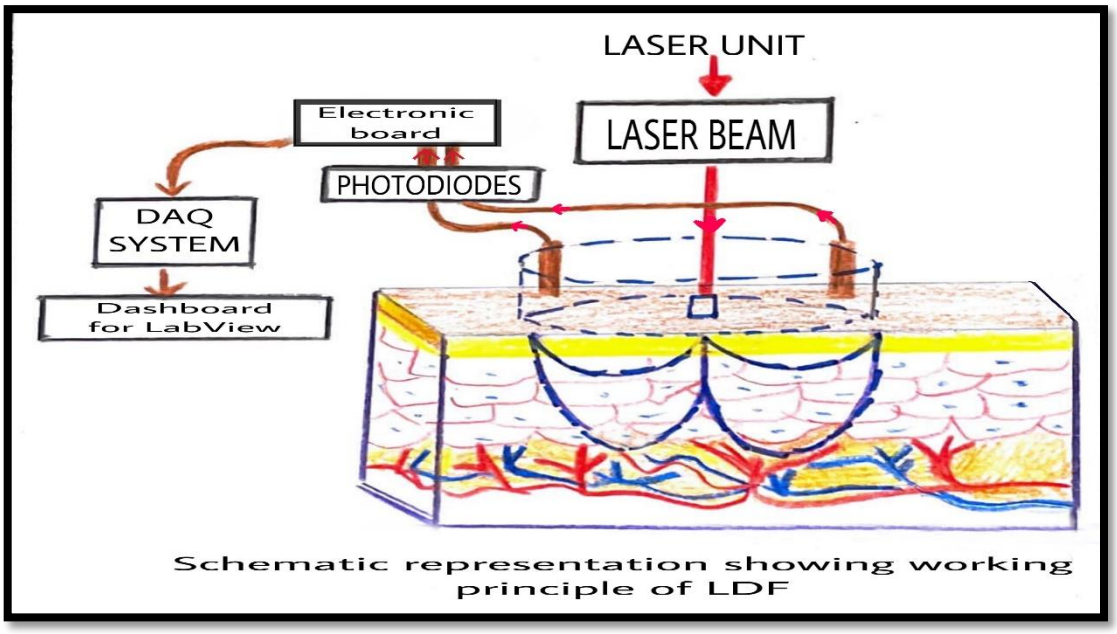
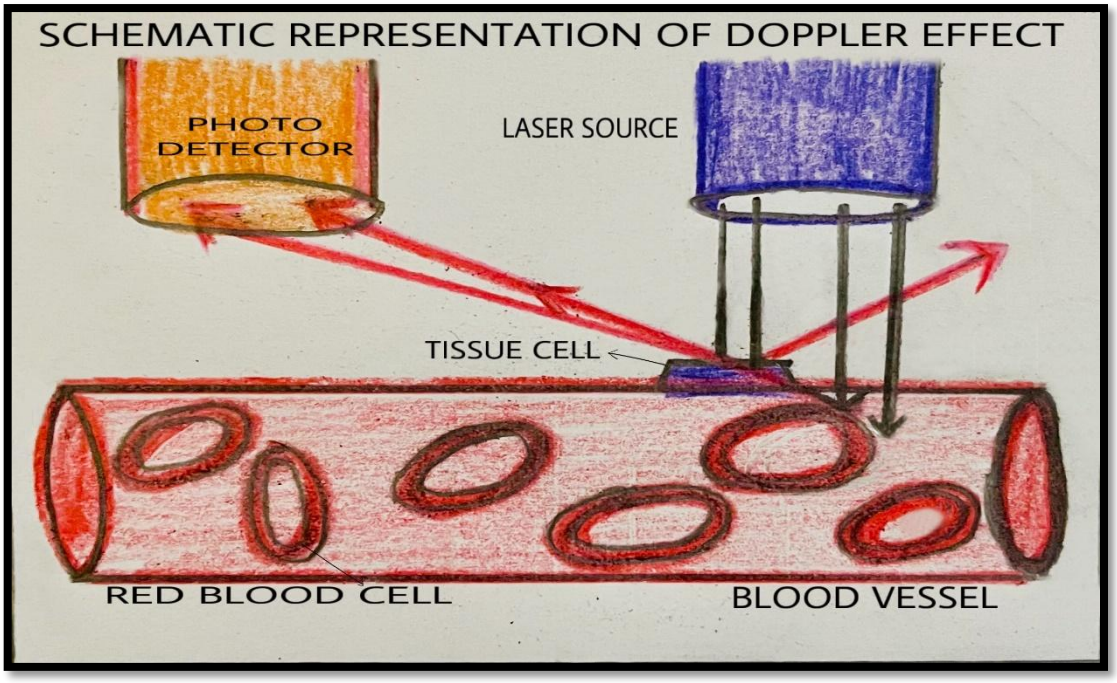


Figure – 4: Doppler effect



Procedure

In LDF, light that has been backscattered from tissue is analyzed to retrieve information about the blood flow in the microcirculation. A fraction of the backscattered light has been scattered by moving red blood cells and undergone one or several Doppler shifts. The backscattered light interferes on the detector to cause the detector current to fluctuate depending on the Doppler shifts of the backscattered light. The detector current is analyzed to give information about the local microcirculation, conventionally summarized into a single perfusion value that scales to the tissue fraction and velocity of the moving red blood cells in the examined tissue volume (Figure - 4). Both single point (laser Doppler perfusion monitoring, LDPM) and imaging (laser Doppler perfusion imaging, LDPI) systems exist.[9]

Single Doppler shift: The Doppler effect, i.e. the frequency shift of sound or light when emitted, reflected, scattered, or detected by a moving object, was first described by Johan Christian Doppler, that impinges the detector will interfere, under the assumption of equal polarization direction. When the light is coherent, the interference gives rise to a speckle pattern and due to the small frequency differences within the light, caused by the Doppler shifts, this speckle pattern will move and change intensity rhythmically and it seams to beat.[9] This beating leads to amplitude variations in the detector current; which can be analyzed by looking at the power spectral density of the signal, called the Doppler power spectrum.

Hardware realizations: Single point (LDPM) and imaging (LDPI) LDF systems are in the field for various purposes. The special characteristics of these systems, as well as a newer type of imaging systems based on fast CMOS cameras, noise reduction and typical calibration procedures are available in the research archives. In single point systems, optical fibers are typically used to guide the light from the laser source to the tissue and from the tissue to the detector. Most often separate fibers are used, but a single fiber can also be used when a very small measurement volume is wanted.[9]

The source-detector distance in probes is 0.25 mm. Short source-detector distances have been preferred to limit the measurement depth, and to avoid a high degree of multiple Doppler shifts leading to severe non-linearities in the conventional CMBC and perfusion measures. In a fiber-based system, the detector fiber illuminates the detector at a certain distance between the fiber tip and the detector. Another type of LDPM systems, not based on fibers, also exists, where the optics and electronics are built on a single chip that is in direct contact with the tissue.[9] These systems are less sensitive to movements and can therefore be used under less controlled situations, but at low perfusion levels, the SNR is lower due to the shorter coherence length of the lasers used. In a conventional imaging system, a laser beam is scanned over the tissue of interest to form an image. In each scanning position, the perfusion value is calculated and transformed into a pixel value, and the scanning procedure lasts for a couple of minutes to form an entire image. The detector is typically placed some 20-30 cm above the tissue surface. In some systems a lens focuses the light on the detector. The backscattered light from the impinging laser beam escapes the tissue from a spot centered in the point of injection, with a radially decaying intensity.

Therefore, the calculated perfusion value is inversely proportional to r2 for a system without a lens. For a system with a light focusing lens, the solid angle is determined by the dimension and position of the lens and is thus independent on the spot size. However, as the lens focuses the light on the detector, the illuminated part of the detector will depend directly on the size of the spot, under the assumption that the entire spot is imaged on the detector. Therefore, the “active” detector area will depend on r2, and the calculated perfusion value is inversely proportional to r2 also for a system with a lens.[9]

Noise: Various types of noise influence the Doppler power spectrum. Some of this noise originates from variations in background light intensity and other common mode noise. To get rid of this type of noise, a differential detector technique is often used for IAC, that simply calculates the difference between the light falling on two adjacent detectors. By calculating the difference, common noise is cancelled out, whereas the statistical properties of the two separate realizations of IAC are kept.

Other types of noise are not removed by this technique.[9] The amplitude of shot noise, which is a variation in the photoelectron emission rate of the detector, is linearly dependent on the total detector current IDC, whereas thermal noise is constant as long as

the temperature is held constant.

The biological zero: In LDF, a phenomenon called biological zero (BZ) has long been known and debated. The BZ signal is the recorded non-zero perfusion signal that still remains when the flow is obviously arrested, and it is believed that the signal originates from Brownian motion of trapped blood cells and maybe other moving constitutes in the tissue.[9]

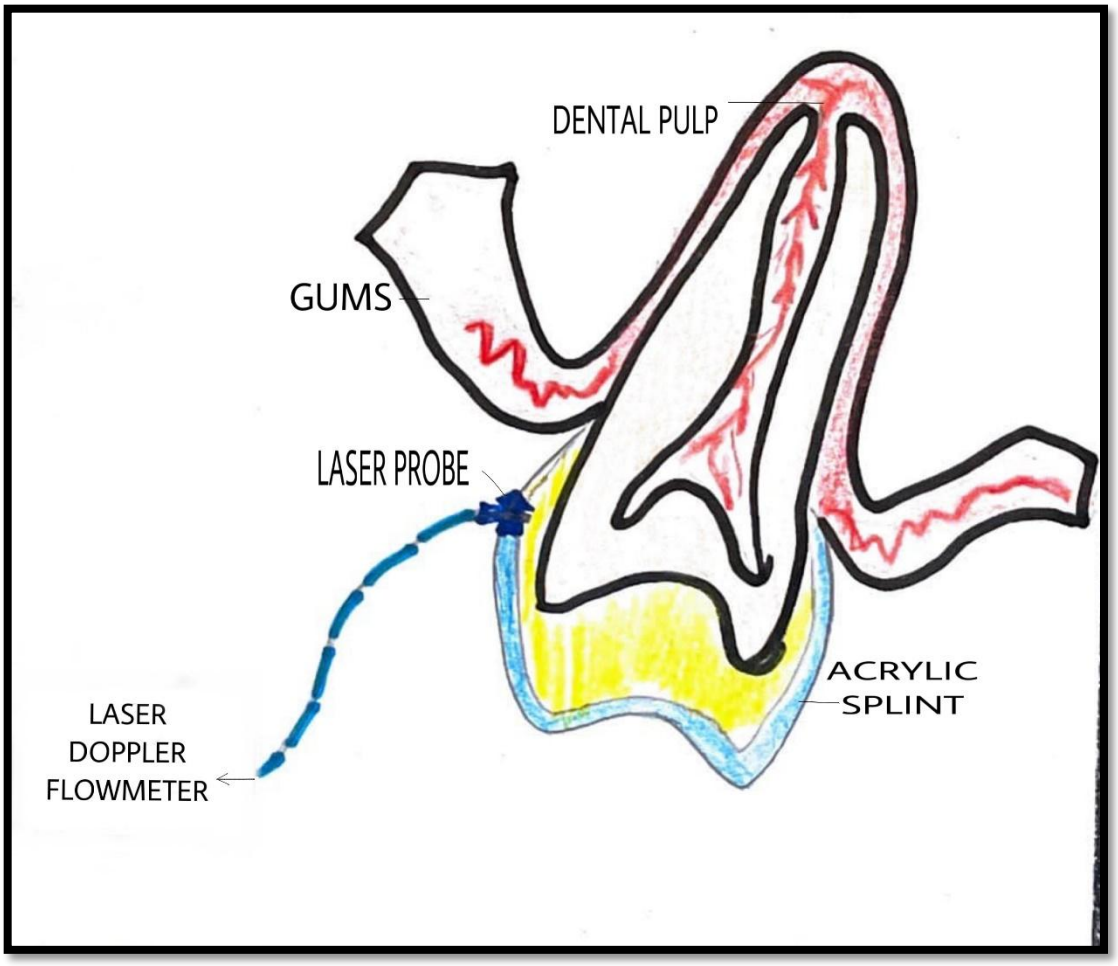
er in 1842. The size of this frequency shift in the case of light scattered by a moving object, for example an RBC, is given by a mathematical formula or an expression.

IV. CLINICAL APPLICATIONS

There are important clinical applications and clinical usefulness for LDF. It is considered a dependable method in order to ascertain microcirculation of blood. Blood flow can be assessed for wound healing, in smokers, in cardiac functioning tests, lungs, liver, skin, scalp and Diabetes.[3,5,7,8]

Dental pulp: LDF application provides dentists with fundamental benefits in terms of an early and precise investigation of pulpal blood flow. [9] In addition, LDF is a useful monitoring tool for revascularization of traumatized teeth and reliable objective diagnostic indicator of pulp vitality (Figure - 5).

Figure – 5: LDF of dental pulp



V. ADVANTAGES

The techniques for measuring perfusion by laser Doppler instruments have made great progress since their introduction. The improvements in laser technology and fiber optics, and in signal processing, have made LDF into a reliable and user-friendly technology. The introduction of the imaging technique opened up clinical research applications where non-contact measurements are a necessity and where perfusion information within an area of tissue is required. The emerging full-field laser Doppler imaging technique has the potential to overcome motion artifacts and the slow scanning speed of conventional scanning imagers. [10]

VI. LIMITATIONS

CMOS:

The big drawback with these systems is that the cameras used are not yet fast enough.

A normal Doppler power spectrum has frequency components of significant power up to about 15 kHz. The sample frequency thus has to be at least 30 kHz to collect the entire frequency content of the Doppler signal, and to avoid aliasing.[9]

The limitations of the technique were thoroughly addressed by the researchers, enabling them to make many improvements. However, some of the more fundamental limitations given in this review still demand a revisit, and measuring perfusion in absolute units remains a scientific challenge.[6] The problem of multiple Doppler shifts remains unresolved as well. The velocity-resolved perfusion measurements cited by a few authors need more research before being applied to real tissue. Also, the problem of the tissue's optical properties should be addressed in the case of scanning field laser Doppler perfusion imagers. In full-field laser

Doppler imaging technique, the influence of optical properties on the number of coherence areas will be less, because of the use of a full-field beam. Regardless of all these limitations, laser Doppler methods remain a highly sought after technique for microcirculatory blood flow measurements. [10]

VII. SUMMARY AND CONCLUSION

Laser Doppler Flowmetry can be termed an opportunity for technological world and a boon to the medical fraternity to derive a better quality of life for the needy. With immense potential, LDF truly lives up to the current needs in the medical field for not only diagnostic purposes but also with therapeutic value. Research is on-going in this area, which can bring larger contribution from scientists of the future in order to help mankind.

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