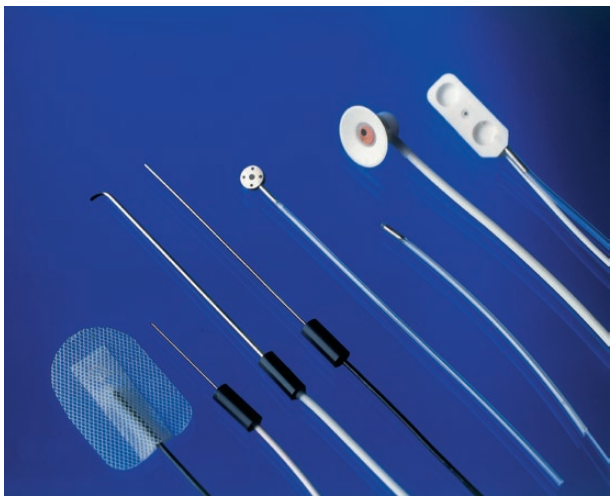
Blood flow imaging – Missing links, Robot Wars and how to get colour images from a black and white camera…

We hope you have enjoyed the first two articles to help gain an insight into Moor Instruments and to help celebrate our 30th year in business. Article 1 focussed on our founding and range of laser Doppler monitors and Article 2 focussed on how we developed the Burn Assessment system and market (www.moorclinical.com). In this, Article 3 (of 4) we focus on the expansion of our product range from monitoring into imaging.

Laser Doppler Monitoring

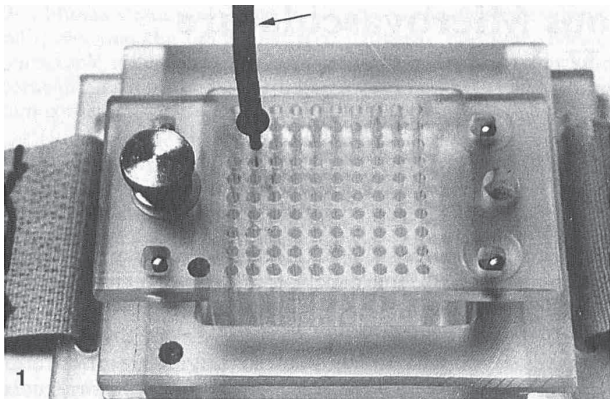
Whilst the laser Doppler monitor was our founding product and still offers unique advantages that make it relevant today, the technique always requires a probe in contact with tissue to generate a measurement of blood flow in a very discrete sample volume. The strength of the monitoring technique is in looking at changes in blood flow over time, usually due to a provocation (e.g. pressure cuff, vasoactive drug delivery, tissue heating etc). With a range of probes for skin, endoscopic use, muscle, teeth etc the monitor has always been versatile and able to access tissues that could not otherwise be examined easily.



However there was always an interest in spatial variations in flow – or a blood flow "map" - and without the potential influence of probe contact and the sterility issues that creates. Thus the need to develop laser Doppler Imaging...

The Missing Link…

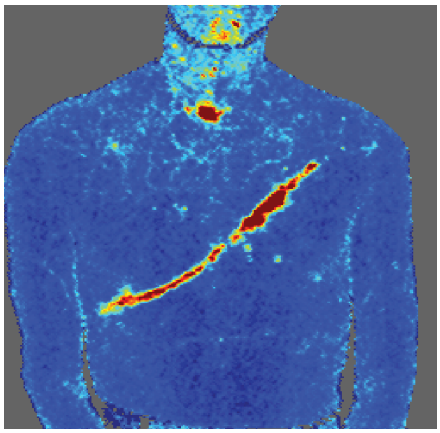
Experimentally, one crossover technique was an adaptation of monitoring by Professor Irwin Braverman in Yale, who used a perspex square with holes drilled in a grid to allow mapped placement of a laser Doppler probe reproducibly over an area, subsequently producing processed grey scale images to show areas of high and low flow. This technique still relied on tissue contact though which is less optimal for patient measurements, particularly for those who are suffering from painful wounds. But: Prof Braverman was amongst the first (if not the first) to generate blood flow images and could clearly identify ascending arterioles for example. Simple, but very clever. Monitoring? Yes. Imaging? Yes Also! We would later have the pleasure of meeting Prof Braverman and showing him our imager, moorLDI, on its first US promotional tour.



Around this time, a system was produced and commercialised in Sweden by Lisca Development that used a laser beam, directed onto the tissue by two moving mirrors and stepped motors to move the beam in a raster pattern across the tissue – emulating Bravermans model and thus becoming the first mechanical laser Doppler imager. For a short time Moor became the UK distributor of the system although the early feedback was that the system was very slow in use, required semi-darkness and only offered 64 x 64 pixels covering a small, hand sized area in ~5 minutes. It became obvious this unit would not gain clinical acceptance so we started work on our own, based on a patented technology transfer prototype from Newcastle (refer to article 2 for more information).

moorLDI

We subsequently launched the moorLDI which offered flexibility up to 256 x 256 pixels – 16 x the number of pixels of the Swedish. The moorLDI could map an area up to 50 x 50cm with clinically useful resolution in a relatively modest 2 minutes. The faster, larger, high resolution scan was made possible with a patented continuously moving beam and a large single mirror design that was used both to direct the beam onto the tissue and also to collect reflected light from the tissue which was focussed onto photo detectors with a lens system. The improved optical design enabled the system to be used in normal room lighting, finally enabling practical use in a hospital environment, on human subjects. The system was made easy to use with the use of Windows based software designed to run on the Microsoft 3.1 platform bypassing DOS (for those of us who remember what that is!) altogether. For the first time we could start to think of clinical applications for the imaging technology (refer to article 2 to learn about Burn Assessment).



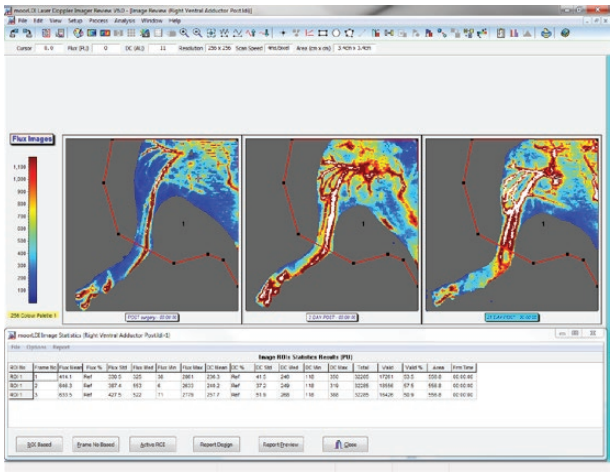
moorLDI2

The moorLDI became a key financial success for us and enabled continued expansion and with profits ploughed back into the business, we could soon consider the replacement for moorLDI. Aesthetically the system left a little to be desired so we engaged external consultants to design a new, moulded case with built in handles to ease positioning. We also found customers in the clinical setting were interested in colour photographs of what they were imaging – so we incorporated a colour CCD camera which not only provided the additional documented information but also allowed us to offer automatic distance measurement so we could correct measured flow values to a common calibrated scale (perfusion units) regardless of whether small (close up measurement) or large area (distant measurements). Infection control also became an issue, so the open window design was replaced with a suitable glass window which would allow the system to be “fogged” in the theatre environment.

Variations…

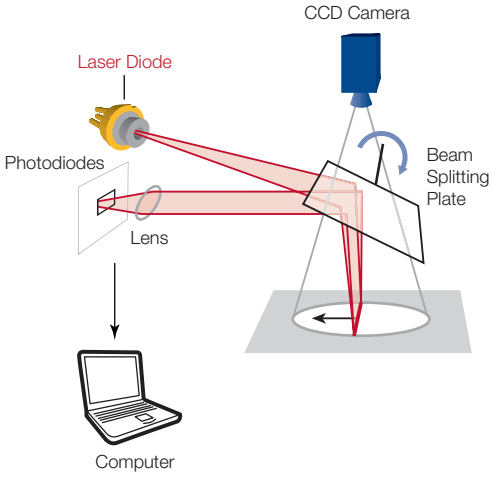
A handful of customers had quite exacting needs and unique requirements and over the years we produced a number of variants, using different wavelengths to access different tissue beds, even incorporating two lasers in one system to scan from different beds at the same time (moorLDI2-SIM). Although functionally it was one of the most advanced options, looking back now, aesthetically it wouldn't have looked out of place on robot wars.

One variant that really gained momentum was the moorLDI2-HIR (High resolution). This was specifically designed for the hind limb ischemia model and featured a longer, 830nm wavelength and focussed optical design for superior penetration to allow visualisation of collateral vessel formation. We also include fine pitch encoders to limit the scan area from 2.5 x 2.5cm to 5 x 5cm (although larger areas are possible). This variant remains popular to this day offering 100 micron resolution.



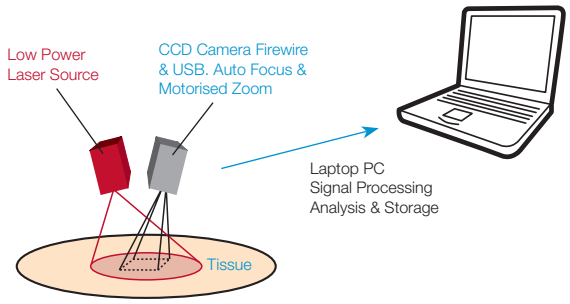
Line scanning with moorLDLS

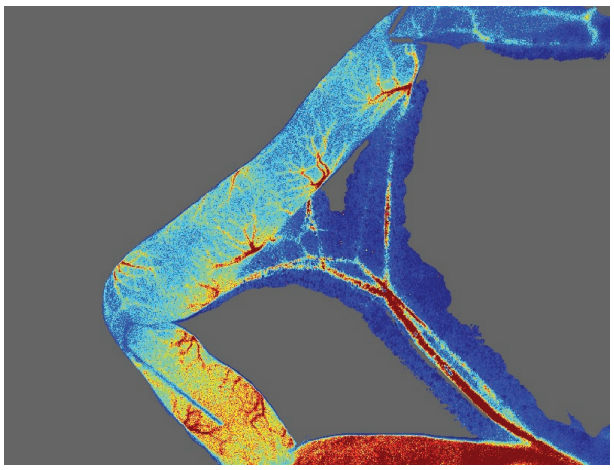
There was still a clinical need for faster scanning, despite moorLDI2 being relatively fast so our engineers embarked on a novel patented solution. Instead of a single beam scanning back and forth, building up the image pixel by pixel, line by line, we decided to project a laser line onto the tissue and capture the entire image in one sweep, with a series of photodetectors. This made total image acquisition possible in just 6 seconds as the line swept across the tissue making it ideal for burn assessment of paediatrics and the elderly, two groups who we learned found it hard to pose stationary for a regular image. The scan head was smaller and we could offer a smaller mobile stand, with self contained PC and battery backup.



Laser Speckle – moorFLPI

Laser Doppler monitoring and imaging had served us very well, but looking at what could be the next imaging step, laser speckle contrast (AKA LASCA and Full field perfusion imaging) became an obvious choice to develop. This technique illuminates an area with low power laser light and uses a black and white CCD camera to pick up changes in the random speckle pattern that is generated. The changes in contrast can be processed in various ways to generate flow images very quickly, with very high resolution. The first prototype took just 6 weeks to develop (although the production version, moorFLPI would take much longer!). Very quickly the potential became obvious. For the first time we could see “blood flow videos” enabling the study of variations in flow, both spatially and temporally. Using a zoom lens meant we could study large and small areas with one system. Laser Doppler had become so well published and established that it took a little while for customers to adopt the new technique, but both moorLDI and moorFLPI still offer unique advantages that make them both relevant today.

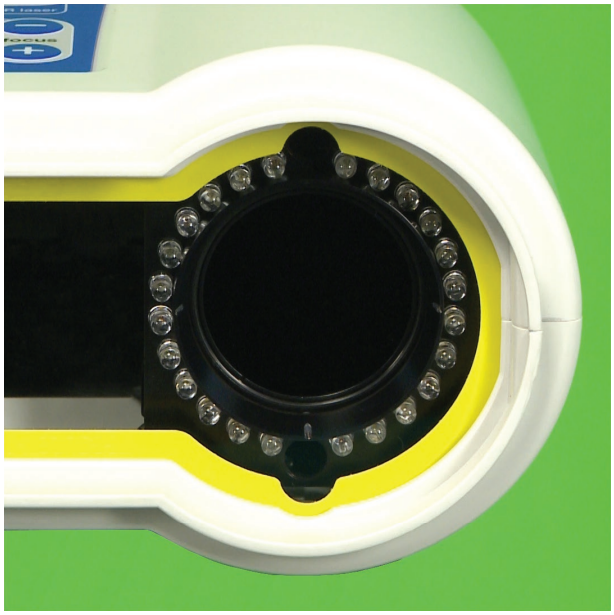




To the present…

We still sell moorLDI2 today, although we have refined the electronics considerably. With a new clinical mobile stand this unit forms the basis of our burn assessment system. The HR variant we developed has become one of the mainstream offerings for hind limb ischemia, where larger animals or a deeper penetration is needed. The Swedish laser Doppler never caught up and is discontinued so we have become sole providers of laser Doppler imaging globally. The moorLDLS has also been refined again, with a more compact electronic design. This has become stablemate to the moorLDI2-BI enabling us to offer a dedicated burn assessment solution for adults and children alike. We also offer moorLFPI2 – a much improved version of moorFLPI. This unit offers a motorized zoom and auto focus for small and large area imaging from one model. With a unique RGB area illumination of the scan area, we can produce a composite colour photo from the same black and white CCD camera that is used for measurement – clever stuff indeed!

Over the years we have established ourselves as global experts in blood flow imaging, and with a core offering of 5 imagers we will have an optimal solution and the widest application experience for you.



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