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NON-CONTACT MEASUREMENT OF CAROTID ARTERY PULSEWAVE VELOCITY: NECK PHANTOM AND PRELIMINARY IN-VIVO RESULTS

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INTRODUCTION

Aortic pulse wave velocity (PWV), measured from the time delay of the pulse between carotid and femoral measuring sites, is a powerful prognostic indicator for cardiovascular disease (CVD). Currently, no tools are available to measure PWV to screen large populations for CVD risk factors, because all commercially available devices require skilled operators and most are prone to movement artefacts. As part of a larger consortium, we aim to build a non-contact device to measure (PWV) between the carotid and femoral arteries as well as measuring PWV in the carotid artery itself by detecting movement of the skin due to the underlying pressure pulse. Our immediate objective is to prove the principle that PWV can be measured in a simple model (phantom) of the neck containing a tissue mimicking gel, using a commercially available dual-beam laser Doppler vibrometer (LDV). The LDV measures displacement at the surface of the model at two sites a known distance apart. Displacement of the surface is due to the passage of a pressure pulse wave in a compliant tube embedded within the model.

A secondary aim of this work is to test the hypothesis that the same equipment can detect low-amplitude displacement of the skin (amplitude ≈ 1μm, frequency range 100 - 1000 Hz) due to disturbed flow distal to a stenosis [1]. The data from the model measurements provides input for computational models, currently under development, of the processes by which energy is transferred from the flowing blood to the arterial wall and thence, through soft tissue, to the skin.

Finally, we report the results of preliminary measurements of carotid artery pulse transit time in healthy volunteers, confirming an earlier report [2] that a LDV can be used to detect the pulse wave at two sites in the carotid artery and thus measure carotid artery PWV.

METHODS

The model consists of a cuboidal acrylic container, open at the top, filled with a soft-tissue-mimicking viscous gel (Aquasonic, Parker Labs, Fairfield, NJ. Length 400, width150, height 100 mm), with an embedded latex tube (i.d. 6.5mm, wall thickness 0.25 mm) representing the common carotid artery (depth below gel surface 10 mm). The upper surface of the gel is covered with a thermoplastic polyurethane sheet 0.1mm thick, (Platilon, Epurex Films, Bomlitz, Germany), to mimic the skin. The system is water-filled, pressurized from a header tank and pulsatile flow is imposed with an in-house programmable piston pump. Pressure in the tube is measured with 2 catheter-tip manometers (6f gauge, Gaeltec, Dunvegan, Scotland) and surface movement, with a dual beam laser-Doppler vibrometer (SIOS Meβtechnik, Ilmenau, Germany) and/or up to 6 miniature 3-axis MEMS accelerometers (ADXL 337, Analog Devices, Norwood MA.) to provide an independent measure of skin movement and to map the displacement field.

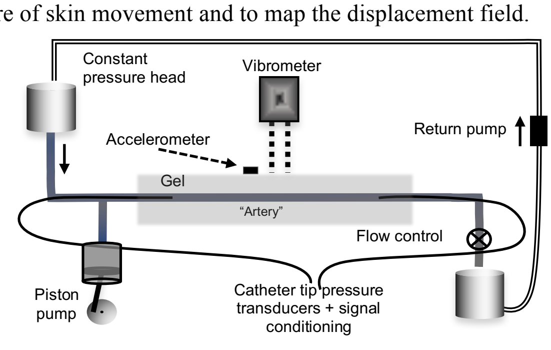

Figure 1: Pulsatile flow rig. Retroreflective patches on gel top surface return LDV beam. Fixed spacing between beams, 25mm

The in-vivo measurements were conducted on subjects lying supine with the LDV beams directed onto the skin overlying the right common and external carotids (figure 4).

Data were sampled at 10kHz (Powerlab 16/35, AD Instruments, Oxford, UK), typically for 10 seconds and displayed in real time with associated *Labchart* software. Pulse wave transit time between measurement sites was calculated by cross correlation of the surface velocity from the first derivatives of the paired LDV or pressure signals and from the first integral of paired accelerometer signals.

RESULTS

Under pulsatile flow, LDV displacement measurements normal to the surface (≈100µm) at two sites 25 mm apart, gave PWV values in the range 4-10 ms^{-1}, agreeing well with those obtained from pressure measurements within the embedded tube. Typical pressure and displacement signals are shown in figure 2. The mean PWV (±SD) for a typical run of 10 pulses was 6.00 ± 2.56 for pressure and 5.68 ± 0.91 for displacement.

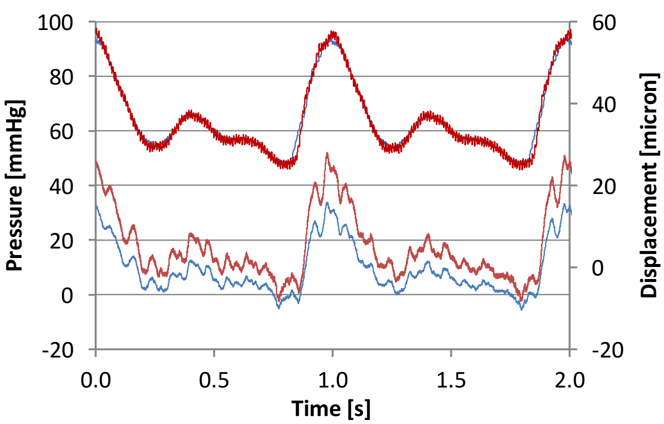

Figure 2. Pressure within embedded tube (upper 2 traces) and displacement of phantom's surface (lower 2 traces) when subjected to pulsatile flow.

In a stenosed tube (70% by area), the frequency spectra of the surface movement measured with accelerometers showed peaks in the range 100 – 600 Hz. At frequencies above 150 Hz the magnitude of the peaks increased with mean flow rate, although in some cases this increase was not monotonic (figure 3).

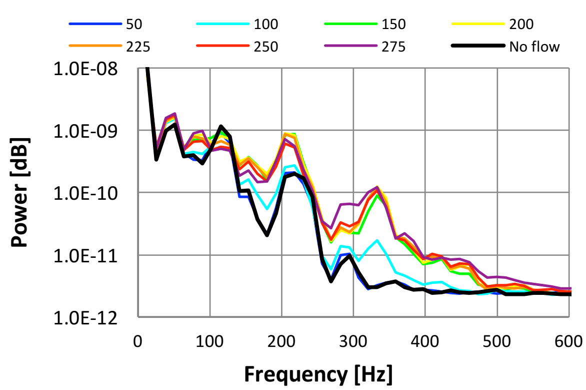

Figure 3. FFT spectrum for a range of mean flow rates of accelerometer placed on phantom surface 20mm downstream from stenosis exit. Flow rates in ml/minute. LDV measurements on this system in progress.

We have carried out in-vivo measurements of skin displacement over the carotid artery in 10 subjects ranging in age from 23 to 70 with the set up in figure 4 and obtained pulsatile waveforms with similar characteristics (figure 5) to those derived by, for instance, tonometry [3], although this depended critically on the beam position, with the most repeatable signals being obtained from the more proximal positions. PWV values in the range 4.6 to 10.1 ms^{-1} were recorded with the older subjects having the higher values, as expected.

Figure 4. Set up for carotid artery PWV measurement. LDV in foreground, laser-subject distance ≈ 400 mm, beam separation, 25 mm. Array of retro-reflective patches to map displacement field.

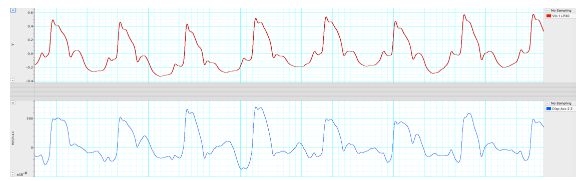

Figure 5. LDV signal from mid neck region (upper trace) and displacement derived from accelerometer at same position (arbitrary units).

DISCUSSION

We have shown that in a simple neck phantom containing an embedded compliant tube representing the common and external carotid arteries, measurements of surface displacement allow reliable estimation of PWV in the tube. Currently, the phantom does not include other structures, so their effect on signal strength shape and timing remains to be assessed. Furthermore, the 'artery' is simply a uniform tube of constant diameter and does not yet include the internal/external carotid bifurcation. A 40% by volume glycerol/water solution will shortly replace the water to more closely mimic blood viscosity.

We have also observed that low amplitude acoustic signals in the frequency range 100 – 500 Hz are associated with the presence of an axisymmetric stenosis at mean flow rates similar to those seen in the carotid artery [4]. We have also shown that, in-vivo, plausible values of carotid artery PWV may be obtained, requiring no direct contact with the subject, and that the shape and timing of displacement signals derived from accelerometers are similar in shape and timing to those from the LDV. Repeatability measurements are in progress. Other consortium members are developing miniaturized optics and electronics to build a multi-beam hand-held device which will be used in a forthcoming clinical validation trial.

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REFERENCES

[1] Semmlow, J. & Rahalkar, K. *Ann Rev Biomed Eng, 9*:449-469, 2007.

[2] De Melis M. et al., *Am J Hypertens*, 21:1280-1283, 2008.

[3] Chen C-H et al. *Hypertension,* 27:168-175, 1996

[4] Likittanasombut P. et al. *J. Neuroimag,* 16:34-38, 2006