The Doppler Necklace: a Wearable and Noninvasive Ultrasound Sensor for Continuous Monitoring of Blood Flow in the Common Carotid Artery

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Abstract The Doppler Necklace is a wearable sensor that employs continuous wave ultrasound to monitor blood flow in the common carotid artery of a patient. Piezoelectric transducers mounted at the neck target the centerline of the artery. The Doppler shift is then transmitted to a computer where the centerline blood velocity is recovered and the flow profile estimated using a novel algorithm.

Keywords: Doppler, ultrasound, carotid, flow profile.

1. The Doppler Necklace

A 24-hours patient-monitoring device called "Doppler Necklace" has been designed by the authors. An array of equally spaced small transducers mounts at the neck and allows handling the location uncertainty of the vessel with minimal skin coverage. The transducers are alternately driven and the one that yields the highest velocity reading over one cardiac cycle is considered as targeting the centerline of the vessel and is kept in emitting mode (figure 1). Transducers adjacent to it can also be excited in phase to create a wider beam if the need arises.

2. The Received Signal

The centerline velocity is recovered from the highest frequency carried in the Doppler signal (after removing the noise). In addition, under conditions of uniform insonification of an artery, the amplitude of each frequency (hence velocity) component in the signal will directly relate to the number of blood cells moving at that particular velocity. Thus, for a uniform acoustic field and a circular velocity profile given by

$$v(r) = V_o(1-(r/R)^p) \qquad (1)$$

- where r is radial position, R the radius of the vessel, V_o the centerline velocity, and p the velocity profile index that varies over the cardiac cycle - the velocity profile index p is given by [1]

$$p=2F_{mean}/(F_{max}-F_{mean}) \qquad (2)$$

where F_{mean} is the mean frequency in the signal and F_{max} corresponds to V_o. The Doppler Necklace however, is intended for continuous monitoring and cannot accommodate the power consumption and the system complexity required to create an almost uniform acoustic field. This makes equation (2) of little use and a new approach was developed. Assuming a circular cross-section for the artery and expressing the field distribution as a function of radial

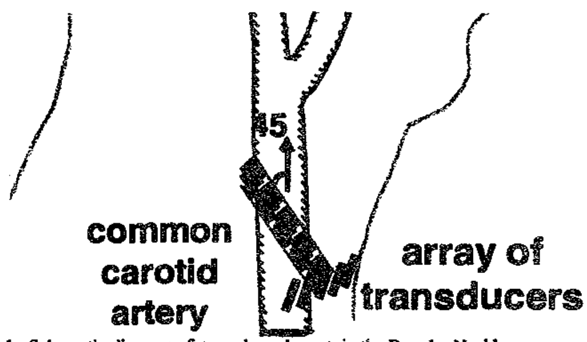

Fig 1 : Schematic diagram of transducer layout in the Doppler Necklace.

position $F(r)$, the normalized power density spectrum as a function of velocity is given by

$$S(v) = \frac{F(r)\dfrac{R^2}{pV_o}\left(1-\dfrac{v(r)}{V_o}\right)^{\frac{2}{p}-1}}{\sum_{j=1}^{N} r_j.F(r_j).\Delta r}$$

where the denominator serves to normalize the spectrum.

With proper processing, S(v) and V_o can be retrieved from the reading of the Doppler Necklace at any time. Setting p=2 during diastole will provide an estimate of $R^2F(r)$. Assuming a constant radius, this estimate can be used to evaluate p for the rest of the cardiac cycle. The assumption that flow is parabolic (p=2) during diastole is supported by published measurements of carotid flow [2].

3. Simulation Results

Computer simulations mimicking a circular artery insonified with an arbitrary field have shown that the new algorithm to estimate p was more accurate than equation (2) especially in extreme cases of field non-uniformity: the former would have an error of less than 3% while the latter error was higher than 90%.

References

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