Title: TRANSTRACHEAL DOPPLER: A NEW METHOD OF CONTINUOUS CARDIAC OUTPUT IN HUMANS

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Introduction. Transtracheal Doppler is a new method of measuring total, continuous cardiac outputs in intubated patients. The technique unites endotracheal intubation with Doppler ultrasound to ensonify the ascending aorta and obtain aortic diameter and blood velocity proximal to the origins of the aortic arch vessels. The endotracheal tube used includes several novel features. First, an ultrasound transducer is placed at the tip. Second, a separate, narrow diameter lumen is provided for electrical leads. Third, a trapezoidally shaped balloon is employed to ensure atraumatic acoustic contact with the tracheal wall. We verified the feasibility of the technique in humans by measuring aortic diameter and blood velocity with the transtracheal method and compared them to independently obtained echocardiographic aortic diameter and thermodilution.

Methods. From aortic diameter and blood velocity, cardiac outputs may be calculated by the well known relations:[1, 2]

$$\bar{v} = \frac{c \, \Delta f}{2 \, f_o \cos \vartheta};$$

$\bar{v}$ = average velocity
c = velocity of ultrasound in tissue
Δf = Doppler shift
f_o = ultrasound carrier frequency
ϑ = angle of ultrasound beam with respect to blood velocity vector

$$Q = \bar{v} A;$$

Q = volume flow rate
A = cross-sectional area

To determine cardiac output from these equations, Δf, ϑ and A must be measured. Δf was obtained by comparing the frequency of reflected ultrasound to the carrier frequency. The angle ϑ was obtained in the following manner: 1) The distance between the aortic near and far walls, d, at an unknown angle with respect to a line perpendicular to the aortic wall, was obtained by range gating. 2) An independent aortic diameter, m, was determined by echocardiography. 3) An angle, α, was obtained from the relationship, $\alpha = \arccos(m/d)$. 4) The angle ϑ is $90^\circ - \alpha$. A, the cross sectional area, was obtained by assuming the cross section to be a circle. Using an average angle $\bar{\alpha}$, d', the measured diameter, is: $d' = d \cos \bar{\alpha}$. The area A, is then: $A = \frac{\pi}{4} d'^2$. With informed consent and approval of the Institutional Review Boards of United Hospitals, St. Paul, and the Univ. of Minnesota, Mpls., nine different patients were used to determine these variables. Cardiac outputs were calculated and were reproducible.

Results. Determination of Δf, ϑ and A, are shown in Table I. Averages for the angles, α and ϑ are also shown. The angle $\bar{\vartheta}$ was used for calculation of the cardiac outputs. An example of excellent correlation with both thermodilution and with cardiac bypass pump flow is shown in Table II.

Discussion. Doppler shift is a sensitive correlate of blood velocity and may be obtained with good signal to noise characteristics via transtracheal Doppler. Transtracheal Doppler measurements of aortic diameter, using the angle $\bar{\alpha}$, correlate well with independently obtained echo diameters. The use of a circle to approximate the area, A, allows calculation of cardiac outputs that correlate with both thermodilution and cardiac bypass pump flows. We conclude that transtracheal Doppler measurements can provide continuous, total cardiac outputs in intubated patients with no additional risk.

References.
1. Baker DW: Pulsed ultrasonic Doppler blood-flow sensing. IEEE transactions on sonics and ultrasonics. SU 17:170-185, 1970
2. Hartley CJ, Cole JS: An ultrasonic pulsed Doppler system for measuring blood flow in small vessels. J Applied Physiol 37:626-629, 1974

Table I

Patient Number	Δf sec^{-1}	Range mm	Echo diameter mm	α°	ϑ°	Calculated diameter $d \cos \bar{\alpha}$ mm	A area cm^2	CO l/min
1	800	33.0	27.0	35.1	54.9	25.6	5.15	6.06
2	1050	29.0	22.0	40.7	49.3	22.5	3.98	6.15
3	740	30.0	22.5	41.4	48.6	23.2	4.27	4.61
4	840	40.0	29.0	43.5	46.5	31.0	7.55	9.33
5	910	34.0	24.7	43.4	46.6	26.4	5.43	7.27
6	700	33.0	26.3	37.2	52.8	25.6	5.15	5.30
7	550	37.0	30.0	35.8	54.2	28.7	6.47	5.24
8	1040	28.5	23.0	36.2	53.0	22.1	3.84	5.88
9	521	40.0	31.0	39.2	50.8	31.0	7.55	5.79

$\bar{\alpha} = 39.2 \pm 3.2$ $\bar{\vartheta} = 50.8 \pm 3.2$

Table II

Time	Transtracheal Doppler Cardiac output l/min	Thermodilution Cardiac output l/min	Pump flow rate l/min
1020	5.44	4.71	
1131	7.90	8.09	
1133	4.27		4.70
1150	5.30		5.60
1202	3.76		3.80
1230	4.58		4.60
1303	6.00		6.07
1338	8.94	8.40	
1423	7.46	7.50	