Suprasternal Doppler ultrasound for assessment of stroke distance

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Abstract

An assessment of a non-invasive technique for measurement of stroke distance was made using a portable Doppler ultrasound machine. The aim was to determine the measurement error of repeated stroke distance measurements (within-observer variability) and to assess measurement agreement between two operators (between-observer variability). The measurement error (within-observer variability) for both operators was similar at approximately 2 cm. However, the measurements of the two operators (between-observer variability) did not agree well. Using the mean (SD) of three readings by each operator, the mean difference between the operators was −0.21 cm (1.96) giving a 95% confidence interval for the differences of −4.0 to +3.6 cm. There were significant positive and negative correlations between stroke distance and a variety of variables (age, height, weight, heart rate), but the relations were weak. The results indicate that the Doppler ultrasound technique for measurement of stroke distance would best be used to study trend changes in an individual patient, or subject, by a single operator.

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There are a number of circumstances, including trauma and serious illness, which result in a fall in circulating blood volume and a mismatch between cardiac output and the body's requirements for oxygen. For example, a fall in intravascular volume is an inevitable consequence of severe burns.[1] Fluid resuscitation to restore intravascular volume is essential in patients with burns, but without invasive cardiovascular monitoring it is difficult to assess progress. The problem for clinical management is that the advantages of being able to measure cardiac output with flotation pulmonary artery catheters (Swan Ganz) must be weighed against the risk of infection and sepsis when invasive monitoring is sited through burnt (and even unburnt) tissue.[2] As a result, most resuscitation is managed without a reliable assessment of cardiac output.

For the burnt child without pre-existing cardiac anomalies, non-invasive monitoring of cardiac output at the bedside holds great promise for the future of clinical management, not only for detecting the early loss of intravascular volume but also for detecting the later changes in cardiac output, which rises to meet the demands of the healing wound. When invasive monitoring of cardiac output is contraindicated, stroke distance can be calculated by non-invasive Doppler ultrasound monitoring.[3] Stroke distance can be used as an index of stroke volume; however, some indication of the variability of repeated measurements by individual users as well as agreement of measurements between users was needed and this has been assessed in a large group of healthy children acting as a control group for future patient studies.

Methods

DOPPLER ULTRASOUND TECHNIQUE AND EQUIPMENT

Stroke distance cannot be measured directly but can be calculated using Doppler ultrasound. In this study the Deltex (Deltex, Chichester, UK) portable Doppler monitor was used. The measurements were made with a 2 MHz continuous wave ultrasound probe. A piezoelectric crystal within the probe emits a continuous, pure tone ultrasound signal, and a second adjacent crystal detects the reflected Doppler shift frequencies from moving blood cells. The velocity of blood flow in a vessel can be calculated from the change in frequency of ultrasound waves after hitting the moving blood cells. Because blood cells travel at different velocities it is logical that there will be a range of Doppler shift frequencies. A spectral analyser within the portable Doppler monitor produces an instantaneous estimate of the spectrum of Doppler shift frequencies,[4] and this gives a velocity *v* time plot (cm/second × second).[5] The velocity *v* time plot (or waveform) contains the different velocities corresponding to the Doppler shift frequency signals during each heart beat. The area under the curve is equal to the systolic-velocity integral,[6] and this is equal to stroke distance. Stroke distance (cm) can be explained simply as the distance a column of blood moves during each heart beat, from the aortic valve to a point on the arch of the aorta.

We used the portable Doppler monitor to measure the velocity of blood flow in the arch of the aorta. Correct positioning of the ultrasound beam is important. The probe is placed over the suprasternal notch and rotated towards the inferior angle of the left scapula. In this position the ultrasound beam can be directed across the arch of the aorta towards the descending aorta. To detect the optimum signal the operator listens for a crisp "whooshing" sound and looks for a strong dark triangu-

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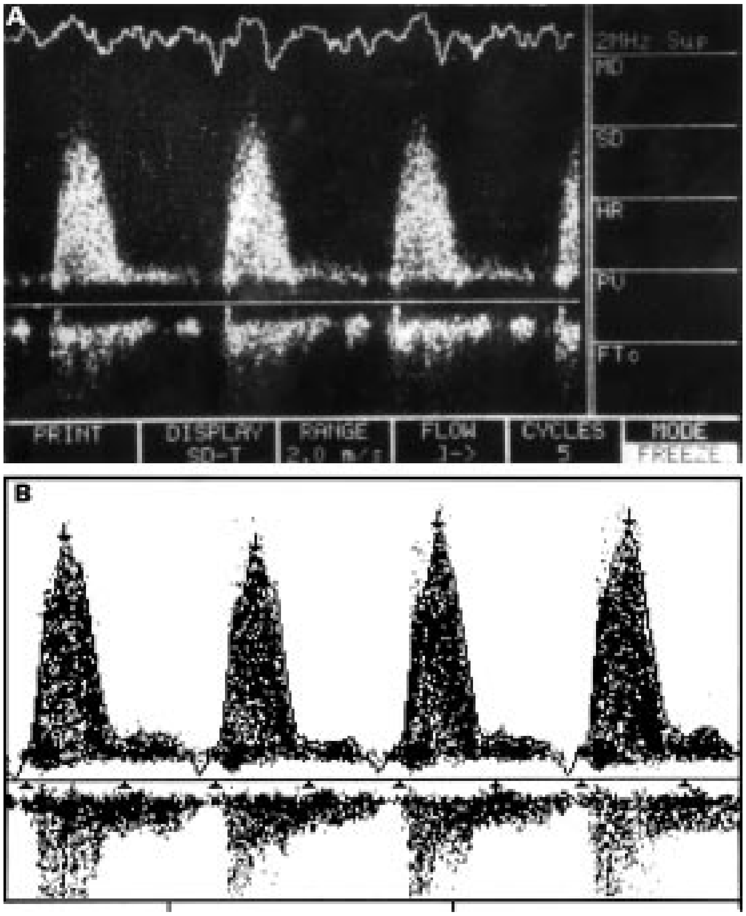

Figure 1 (A) On screen appearance of the systolic-velocity waveform. When the path of blood flow is in line with the ultrasound beam a clear, well defined, dense triangular waveform is displayed. (B) Hard copy printout of the best possible systolic-velocity waveform from a child lying supine and at rest. Arrows (at the tip of the triangle) indicate peak velocity of blood flow, arrows at the start and end of each triangle indicate the area under the velocity-time curve upon which calculations of stroke distance are made.

lar waveform on the screen (fig 1A). The portable Doppler monitor screen displays each systolic velocity-time waveform with spectral density shown by degrees of darkening—that is, the darker the waveform the greater the number of red blood cells moving at a given velocity.

Stroke distance was calculated and stored for each heart beat. The value shown on the screen is the average of the stroke distance for the previous five heart beats. Figure 1B shows a hard copy of an "on screen" waveform.

REPEATED MEASUREMENTS

The measurements of stroke distance were made by two operators (O1 and O2). Although the technique was new to both, initial training ensured a comparable level of competence. Both had used the instrument regularly over a period of three weeks. Six measurements were made for each child, three by operator 1 and three by operator 2. The ultrasound probe was repositioned between each measurement. For each child the order of measurements between the operators was randomised using a random allocation chart. During the measurements the researchers were blinded to the stroke distance value.

SUBJECTS

Two groups of healthy children were studied. The first group of schoolchildren was recruited from a primary school in the Rochdale area of Lancashire. A second group of healthy children was recruited from a nursery school in the Bolton area of Manchester.

After approval to conduct the study was given by the headteachers, written information about the nature of the study, including a consent form, was sent to the parents of the children.

A small room was reserved for the study and children were released from class by their teacher in pairs, usually pairs of friends, and accompanied by one of the researchers.

MEASUREMENTS

Height and weight

After checking the child's personal details from the consent form, height and weight were measured. The children were asked, or helped to remove shoes and outer clothing for a brief period so that an accurate weight could be obtained. The children then re-dressed for the rest of the study.

Children were given (appropriate for their age) an explanation of the equipment, and measurements were taken on one child while the other watched. After the first series of measurements the children changed places and the measurements were repeated on the second child.

BLOOD PRESSURE

Each child was asked to lie supine on a low makeshift bed and made comfortable. A blood pressure cuff was applied (Medi-Cuff; Johnson and Johnson, Medical Inc, Berkshire, UK) to the upper right arm. The cuff was left in place throughout the measurement period and the automatic sphygmomanometer (Critikon; Johnson and Johnson) was set to operate at three minute intervals.

STROKE DISTANCE

The children were encouraged to lie quietly for about five minutes before the measurements started. After selecting the direction of blood flow, in this case away from the left ventricle, a small amount of coupling gel was placed on the transducer and the ultrasound probe was placed over the suprasternal notch (fig 2) and adjusted slightly until the maximum velocity curve had a well defined outline with minimal artefacts. The microprocessor of the portable Doppler monitor calculates stroke distance under the area of the curve and, to ensure an accurate measurement of stroke distance, the curve follower must be positioned to fit neatly around the waveform. The curve follower was repositioned for each new subject.

STATISTICAL METHODS

Repeated measurements of stroke distance, as done here, may vary either because of biological variations in the subject or because of difficulties in the measurements owing to repositioning of the probe between each measurement. All ultrasound techniques in-

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Figure 2 Correct positioning of the suprasternal ultrasound is towards the inferior angle of the left scapula. (Photograph published with permission of the child's parents.)

volve an element of skill. We wanted to establish how variable stroke distance measurements were for two different operators (O1 and O2). The within-subject SD of repeated measurements can be calculated to give measurement error.[7] We have calculated the within-subject SD for O1 and O2. We also wanted to determine whether the measurements between O1 and O2 were in agreement.[8]

The Spearman's correlation coefficient (r_s) was used to give the strength and direction of the relations between stroke distance and the various clinical variables.

Statistical analyses were made using the statistical package for the social sciences (SPSS).

ETHICS

Approval for the study of the subjects was given by the local ethics committee.

Results

WITHIN-OBSERVER VARIABILITY

Seventy two children aged 4.3–11.5 years (median 7.33), of whom 39 were girls, were studied. In all but two cases six measurements of stroke distance were made on each child—a total of 429 measurements.

The mean (SD) values for all first, second, and third recordings made by O1 and O2 were very similar (table 1). All first measurements in the 72 children were normally distributed as were those of the second and third measurements and this was the case for each operator. The within-subject SD (described also as within-observer variability) or measurement error[7] for the children studied was similar for both operators at about 2 cm (2.1 cm for O1 and 1.9 cm for O2) which is probably satisfactory for the clinical measurement of stroke distance. A repeated measures analysis of variance revealed no significant ordering effect of the stroke distance recordings.

Table 1 First, second, and third readings of stroke distance for operators 1 and 2 (n = 72 children)

Measurements	Mean (SD) readings of O1 (cm)	Mean (SD) readings of O2 (cm)
1	24.37 (4.44)	24.66 (3.70)
2	24.26 (3.75)	24.55 (4.00)
3	24.41 (3.94)	24.28 (3.99)

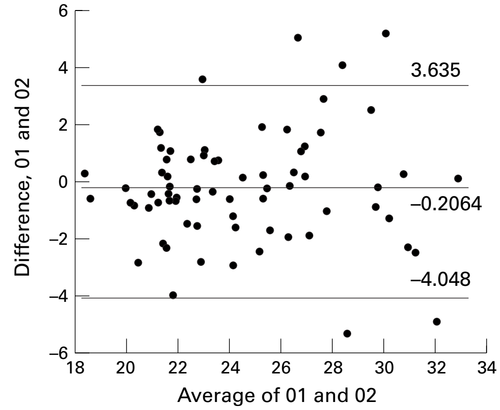

Figure 3 Average stroke difference values for O1 and O2 plotted against the differences (see reference[8]). The mean difference = −0.2064 cm with the upper limit of agreement (95% confidence interval) of 3.635 cm and lower limit of agreement of −4.048 cm. Although the measurements are in good agreement, the scatter of differences range from −5.33 to 5.23 cm. These data show that for a single stroke difference measurement the agreement between the two operators is variable.

BETWEEN-OBSERVER VARIABILITY

When using a portable Doppler monitor in clinical practice it is important to know if the measurements made by one operator will agree with those of a different operator (between-observer variability). The mean stroke distance for each operator for each child was used to study this; as expected the two observers' mean values were highly correlated.

The differences in the measurement of stroke distance between O1 and O2 were fairly evenly scattered, albeit widely throughout the range of stroke distance measurements (fig 3).

The mean difference between the measurements of O1 and O2 was −0.21 cm. The SD of the stroke difference for O1 and O2 was 1.96 cm. This means that the 95% confidence interval for a single difference of the means of three stroke difference readings ranges from −4.048 to +3.635 cm and the overall range was −5.33 to +5.23 cm (fig 3), which is rather large relative to the average reading of 24.45. A stroke difference measurement of 20 cm made by O1 could—for example, be as much as 5 cm above or 5 cm below the measurement of O2.

STROKE DISTANCE AT DIFFERENT AGES

To construct a range of stroke distance measurements in children of different ages a further group of 71 children was studied. An additional 35 schoolchildren (21 girls) aged 6.5–10.3 years (median 8.67 years) and 36

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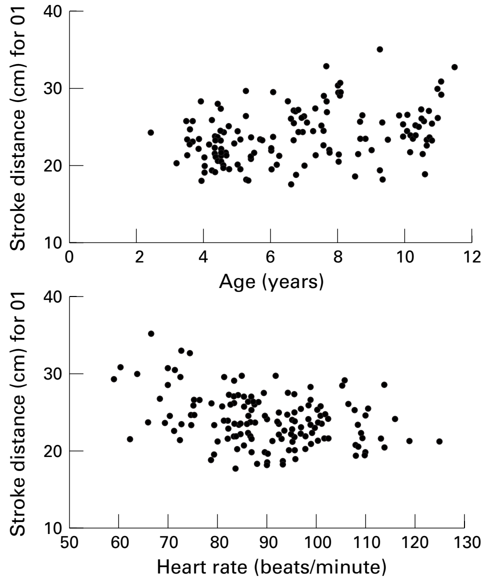

Figure 4 Mean of the three stroke distance measurements made by O1 with respect to age (r_s = 0.33) and heart rate (r_s = 0.29). In each case there is a significant, but weak, linear relation (r_s = Spearman's correlation coefficient). The range of stroke distance measurements at a given age ranges from approximately 20 to 30 cm.

preschool aged children (18 girls) aged 2.4–4.7 years (median 4.25 years) were recruited.

The mean of three stroke distance measurements made by O1 for all 143 children in this study (78 girls; aged 2.4–11.5 years) was used to assess the relation between stroke difference and five physiological variables: age, weight, height, heart rate, and mean arterial pressure.

There were positive, significant correlations ($p < 0.0001$) (fig 4) between stroke distance and age, weight, and height but not mean arterial pressure. The correlation between stroke distance and heart rate was negative and significant (stroke difference with age, $r = 0.33$; stroke distance with weight, $r = 0.33$; stroke distance with height, $r = 0.36$; stroke distance with heart rate, $r = -0.35$). From fig 4 it can be seen that stroke distance in children between the ages of about 2–12 years ranges from approximately 20–30 cm, but there is considerable variation at each age or heart rate.

A stepwise multiple regression to predict stroke distance from heart rate, age, height, weight, and sex produced an equation containing only two significant variable coefficients, those for height and heart rate. Unfortunately, these variables accounted for only 25% of the variability of stroke distance.

Discussion

The greatest advantage of the suprasternal Doppler technique for measurement of stroke distance is that it is non-invasive. There are, of course, other advantages that are listed by the manufacturer and by those who have used the technique.[9] These include speed and ease of measurement, and any difficulties inherent with the method are considered minimal if training is given. The length of training remains unspecified, however.

In this study a series of daily measurements over a three week period was considered to be sufficient training. Both operators, however, felt more at ease with the technique after a few days of intensive measurements during the first week of the study, but we do not have evidence that this reduced the measurement error or narrowed the differences between users.

We have shown that in the hands of an experienced operator one stroke distance measurement is likely to vary by about 2 cm from the next measurement. We would therefore recommend that for clinical assessment of stroke distance an experienced operator could practically make three stroke measurements with a relatively small measurement error of about 8%. This is comparable with other studies that have assessed the reproducibility of the measurement of stroke distance.[10] Some variability will be present for repeated measures as biological variability alone, albeit from one day to the next, has been reported to be 4.4%.[11]

Perfect agreement between the measurements of two different operators might be an unrealistic expectation but in this study the scatter of differences between the two operators was often rather wide. Although some measurements of O1 and O2 agreed quite well (fig 1) in the worst case one could expect the measurements of O1 to be 5.3 cm above or below the measurements of O2. One has to accept that the differences between the measurements of the two operators will be difficult to predict. We would recommend that at its current stage of development the portable Doppler monitor should be restricted to use as a clinical research tool. A particularly valuable use of the portable Doppler monitor in patients would be for serial measurements to be made over time by a designated operator because there will always be differences between operators on the optimum position and angle of the probe as judged by sound and appearance of the waveform.

It is always useful when patient measurements are made to have a control range for comparison. The range of stroke distance of all children studied was constructed from the measurements made by O1. Although there were significant correlations between stroke distance and—for example, age, weight, height, or heart rate, there was a considerable spread of values. The scatter of stroke distance measurements—for example, at any given age was rather wide and in the range of 20–30 cm. This means that small deviations from normal might not be picked up. On the other hand, gross changes would probably be detected.

Despite the difficulties, this study of healthy children suggests that it is worth persisting with this non-invasive technique. It is worth remembering that there is no gold standard for clinical measurement of cardiac output and this includes the thermodilution technique. Even this invasive, and generally considered accurate, technique can have a variability of up to 15%.[12]

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help with the manuscript. Stephen Goldring was awarded the CP Lapage prize for his presentation of the data of within-observer and between-observer variability.

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