

Transcutaneous Doppler ultrasound measurement of superior mesenteric artery blood flow in man

M I QAMAR, A E READ, R SKIDMORE, J M EVANS, AND P N T WELLS

From the Department of Medicine, University of Bristol and Department of Medical Physics, Bristol and Weston Health Authority, Bristol

SUMMARY A duplex scanner which consists of a real time two dimensional scanner and a pulsed Doppler flowmeter was used to measure superior mesenteric blood flow in 70 healthy subjects. By processing the Doppler shift signals, the instantaneous average Doppler shift frequency and then the instantaneous average velocity of the flow rate were calculated. Both diameter of the vessel and angle between vessel and beam were measured from real time imaging. The mean (\pm standard error of the mean) of the superior mesenteric blood flow was 517 ± 19 ml/min. There was neither significant difference in flow between sexes, nor correlation between flow and age ($r=0.042$). The mean of coefficients of variability were 6.8% over the short term, and 8.2% in long term studies.

The superior mesenteric artery supplies blood to the duodenum – except for its superior portion – and also to the whole of the small bowel and the right half of the colon. Little information is available concerning superior mesenteric artery blood flow (SMABF) in man. It is mainly based on approximations from animal studies and from human studies carried out using invasive techniques. The development of a dye-dilution technique to estimate the SMABF in humans¹ was a considerable step forward. Its invasiveness, however, remains a major obstacle to its use. Clinical methods of measuring SMABF currently used are the spill-over angiographic reflux method,² and the video-dilution technique.³ Both are angiographic and require arterial catheterisation.⁴

Transcutaneous measurement of blood flow in humans using Doppler ultrasound techniques has been accomplished in a number of peripheral and deeply situated blood vessels such as the brachial artery,⁵ carotid arteries,⁶⁻⁸ aorta,⁹ and fetal blood vessels.¹⁰

The use of Doppler ultrasound in measuring blood flow in the major gastrointestinal arteries was proposed¹¹ and attempted¹² in 1982. The aim of this study was to measure SMABF volume in normal individuals at rest using a non-invasive ultrasonic Doppler technique.

Methods

SUBJECTS

We used a duplex scanner¹³ (ATL 500, Squibb Medical Systems). It consists of a real time two dimensional ultrasonic imager with associated 3 MHz pulsed Doppler flowmeter and video tape recorder. Real time imaging was used to localise the artery and hence to allow the placement of the Doppler flowmeter at any desired point within the blood vessel. In our study the flowmeter was placed in the first part of the SMA near its origin from the aorta (Fig. 1). After the ultrasonic Doppler interrogation of the artery, Doppler shift signals were obtained (Fig. 2) which, together with real time images were stored on video tape. On a second occasion the Doppler shift signals were displayed and analysed using a microprocessor based dual channel spectrum analyser (Radionics Medical Model 800) and a computer (Apple).

Assuming that the blood vessel was isonated uniformly the instantaneous average Doppler shift frequency over the cardiac cycle was calculated. According to the Doppler equation: $f_{av} = 2f V_{av} \cos \gamma / c$ where f is the transmitted ultrasound frequency, V_{av} the instantaneous average velocity of the target (blood in this case), c the velocity of sound in soft tissue, γ the angle of inclination of the ultrasound beam to the direction of flow of blood, and f_{av} the instantaneous Doppler shift frequency.¹⁴ The instantaneous average velocity is related to the instan-

Address for correspondence: Professor A E Read, Department of Medicine, Bristol Royal Infirmary, Bristol BS2 8HW.

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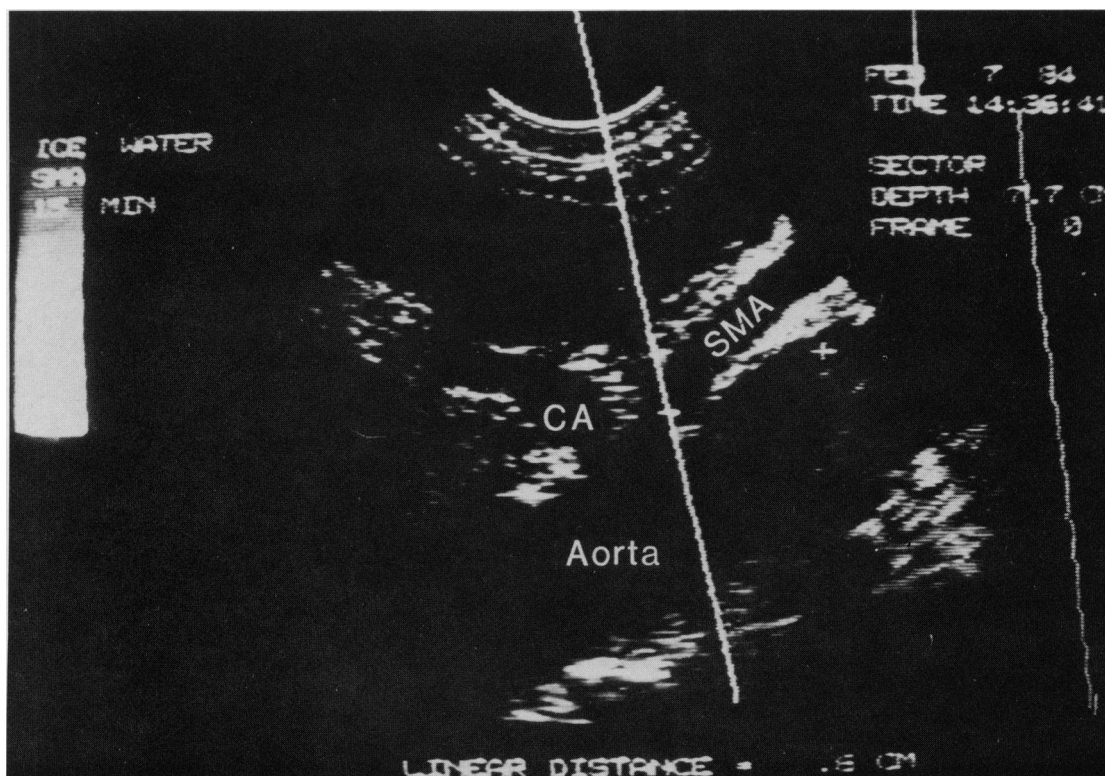


Fig. 1 Real time two dimensional image showing the aorta, superior mesenteric artery (SMA) and coeliac axis (CA) in longitudinal section. White line indicates the direction of Doppler beam and white spot indicates the position of sample volume within the superior mesenteric artery. Angle of isonation is between the line of Doppler beam and longitudinal axis of SMA.

taneous average Doppler shift frequency. Both angle and diameter of blood vessel were measured from the two-dimensional display and an estimate of volume flow was made by multiplying the cross sectional area by the time average instantaneous mean velocity over the cardiac cycle.

A total of 70 subjects of both sexes (34 men and 36 women), aged 20 to 88 years (mean: 37 years), body weight ranging from 45 to 85 kg (mean: 65.5 kg) were studied. Forty six were healthy volunteer medical staff, and the rest ($n=24$) were outpatients in whom cardiovascular and gastrointestinal disease were excluded and a 'normal' SMABF was presumed. All gave informed consent. After an overnight fast and a resting period of 30 minutes in a supine position Doppler ultrasound scanning of the upper abdomen was carried out.

Within subject variability was tested in 21 normal subjects (11 men and 10 women) aged 21 to 52 years (mean: 28 years) over a period of one hour (short

term), and in 18 normal subjects (nine men and nine women) aged 21 to 52 years (mean: 25.2 years) on different days (long term). All subjects were examined in the fasting and resting state. In each subject in the first group five measurements of the SMABF were carried out over 60 minutes, while subjects in the second group had three measurements each on three different days with an interval of two weeks between these measurements. A coefficient of variability (obtained by dividing the standard deviation by the mean) was calculated for each subject in the short term (five measurements) and in the long term (three measurements) tests. In both tests the variability was then expressed as the mean of coefficients of variability.

Statistical analysis of the data was performed using the mean, median, mode, range, frequency distribution, standard deviation (SD), standard error of the mean (SEM) and correlation coefficient.

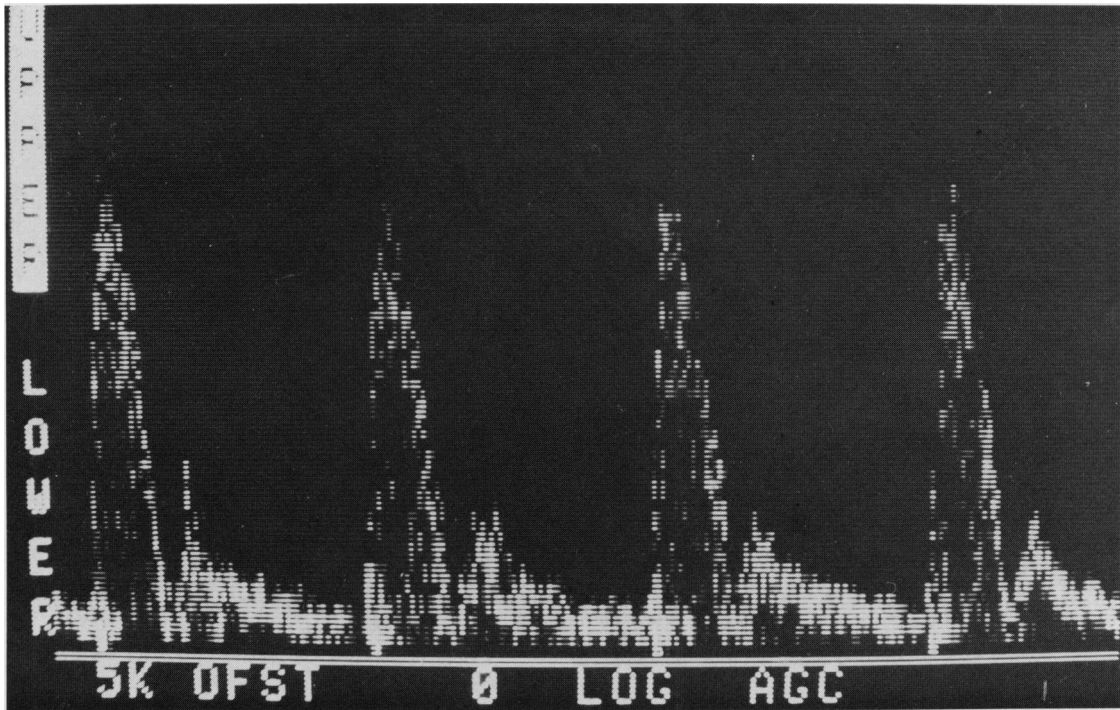


Fig. 2 Doppler shift signals recorded from a normal superior mesenteric artery. Frequency is plotted vertically and time horizontally. Each signal corresponds to one cardiac cycle.

Results

The mean value (\pm SEM) of the SMABF was 517 ± 19 ml/min ($n=70$) (range 250 ml/min to 890 ml/min). The median value was 502 ml/min. Figure 3 shows the frequency distribution of the SMABF of all subjects. There was neither significant difference in flow between the sexes (men 521 ml/min ± 27 ($n=34$), and women 513 ± 28 ml/min ($n=36$), nor correlation between SMABF and age ($r=0.042$) (Fig. 4). The mean of coefficients of variability were 6.8% in the 'short term' test, and 8.2% in the 'long term' test.

Discussion

Blood flow measurement using a Doppler ultrasound technique still has limitations and difficulties. These are related to (i) location of the vessel, (ii) its angulation in relation to the Doppler beam, (iii) measurement of the lumen area, and (iv) measurement of the average velocity within the vessel.¹⁵

Satisfactory solution of the first three difficulties

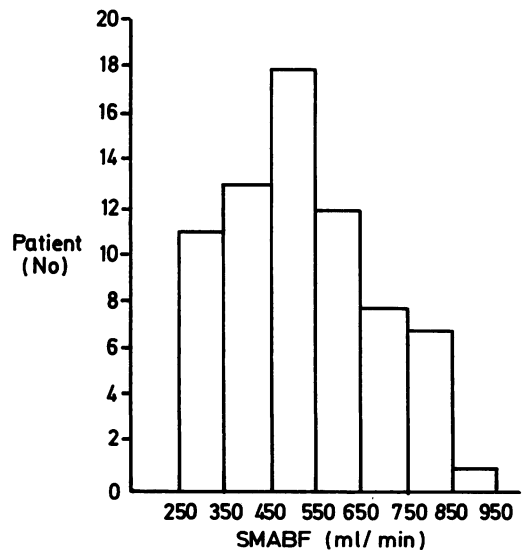


Fig. 3 SMABF in 70 normal subjects in fasting and resting state.

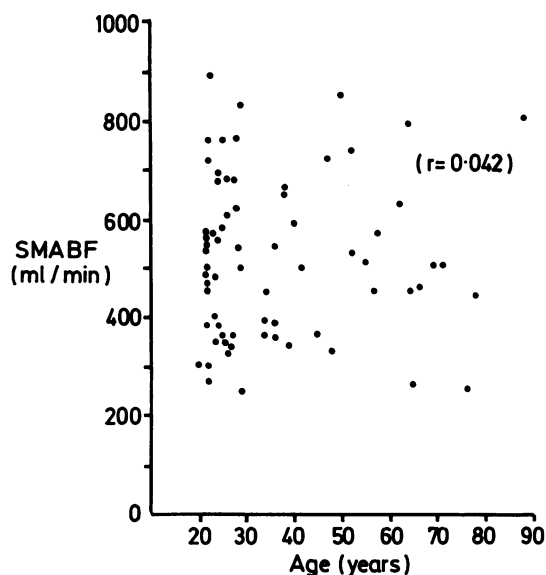


Fig. 4 Relationship between SMABF (ml/min) and age.

was achieved by using the available real time imaging. Visualisation of the superior mesenteric artery allowed precise location and placement of the Doppler sample volume within it.

Errors due to orientation are minimised by having a narrow angle between the blood vessel and the Doppler beam.¹⁶ This was possible in most cases by insonating and sampling the first part of the superior mesenteric artery near its origin. Because of anatomical variations and/or interference by intestinal gas, however, this was not always possible. Sampling a distal point of the artery would have required a more obtuse angle than was desirable. In order to overcome this when the problem was intestinal gas the investigation was repeated on different occasions. Anatomical difficulties were overcome by adjusting the probe to help obtain a suitable angle.

The real time imaging used in this study has a high resolution which allowed satisfactory measurements of the diameter of the blood vessel. These measurements varied from 5–9 mm with an average (\pm standard deviation) of 6.7 ± 0.77 mm. As *in vitro* studies have shown that the inner diameter of tube measurements from β -scan images were slightly lower than the correct ones,¹⁵ it appears that our diameter measurements are slightly underestimated. As these are squared when the cross sectional area of the vessel is calculated an underestimation of the blood flow volume has presumably occurred. In calculating the average velocity we assumed a uniform insonation of the vessel, but as the beam is optimised

for imaging and as the length of the sample volume does not completely match the cross-sectional area of the blood vessel, an incomplete insonation would occur and overestimation of blood flow would result. In a vessel of up to 7 mm in diameter this error was estimated to be below 20% and would be offset by errors in Doppler demodulation because of interfering 'noise' on signals which lead to underestimation of the velocity.¹⁵

Having discussed the main limitations and difficulties facing the accuracy of this method, we believe that the resulting SMABF is slightly underestimated mainly because of error in diameter measurements.

Our results agree largely with those¹⁷ in which a spillover angiographic reflux technique was used, and in which the human SMABF varied from 300 ml/min to 600 ml/min (average 456 ml/min), and with those¹⁸ in which an inert gas washout technique was used and the total blood flow in the small intestine in man was estimated to be 500 to 600 ml/min. In view of the fact that the superior mesenteric artery also supplies parts of the colon this comparison suggests a slight underestimation in SMABF using our method.

A dye dilution technique¹ of injecting indocyanine green into the superior mesenteric artery and sampling the blood flow from the superior mesenteric vein (catheterised through the re-opened umbilical vein) resulted in the SMABF being around 700 ml/min which is higher than our result (517 ml/min). The reason is apparently the difference in the methods. Doppler ultrasound is non-invasive, instantaneous and determines the flow at the origin of the artery. This means instantaneous recording of the arterial inflow under physiological conditions; on the other hand the dye dilution technique measures the venous outflow which is higher than the arterial inflow, and its invasiveness could affect the result. Furthermore this method was found to overestimate flow by 18% when compared with more direct methods in the laboratory.¹⁹

Using a video dilution technique preliminary estimations of the human SMABF varied from 11% to 20% of the cardiac output.³ A direct comparison with our results is not possible because cardiac output was not measured in our subjects.

Direct comparison with other methods has not been conducted in this study for ethical reasons. A good correlation between Doppler ultrasound methods and others has, however, been reported in other organs both in man and animals.

Simultaneous estimations of human cerebral blood flow measured by a ¹³³Xenon intra-arterial method, and common carotid blood flow measured by a non-invasive Doppler ultrasound technique

were well correlated ($r=0.73$).²⁰ In an *in vivo* study²¹ the canine abdominal aorta blood flow measured by a locally implanted pulsed Doppler ultrasonic flowmeter was found to exceed by 2% the bleed-out measurements. In another *in vivo* study the abdominal aorta blood flow in the pig measured by a transcutaneous Doppler ultrasound technique was well correlated with the simultaneous electromagnetic measurements ($r=0.91$).²² Our results show that SMABF does not differ between sexes in accordance with other studies,¹ or correlate with age ($r=0.042$). The variability tests conducted in this study have shown that the method was reproducible in that the means of coefficients of variability were less than 10% over both short and long terms. The range of our results (250 ml/min–890 ml/min) is slightly wider than that of the dye dilution technique (± 230 ml/min),¹ but similar to that of other methods. Canine SMABF measured by an electromagnetic method varied from 216 ml/min to 624 ml/min and a similar range was obtained by a spillover angiographic reflux technique.²³ Human intestinal blood flow measured by an inert gas washout technique varied from 29 to 70 ml/min/100 g of tissue, and the range was even wider in other species using various methods of measuring intestinal blood flow.²⁴

This intra and inter species variability shown by different methods seems to be due to physiological factors. In our method measuring 'resting' SMABF would require small bowel 'rest' which is not necessarily achieved in the fasting condition. Neither is the fasting state conducive to complete mental relaxation.

Anatomical variations could be further reasons to explain the variability. The blood supply to the small and large bowel is extremely variable. In 17% of subjects the superior mesenteric artery gives rise to a replaced or accessory right hepatic artery which supplies the right and middle lobe of the liver.²⁵ Such variations are extremely difficult to verify by ultrasonic means. Varying diameter of the superior mesenteric artery between subjects could be a further contributing factor. Using this method we detected changes in SMABF after the ingestion of a mixed meal.²⁶ Furthermore we have also shown that the chemical nature of the meal was a significant factor determining the postprandial SMABF increase.²⁷ This indicates that the method would be sensitive enough to detect changes in SMABF after either physiological or pharmacological stimuli, or under pathological conditions.

In conclusion, this study showed that transcutaneous ultrasound – despite its difficulties and limitations – is a reliable method for measuring SMABF and has a promising future in studying

the gastrointestinal blood flow both in health and disease.

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