Ambulatory blood pressure monitoring

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Abstract

Ambulatory blood pressure monitoring (ABPM) in adults is proving to be useful. The aim of this study was to determine if ABPM is accurate in the lower blood pressure range encountered in children and, equally important, whether it is acceptable to children. Thirty one children, between the ages of 6 and 18 years, were assessed using an ambulatory blood pressure monitor that uses an auscultatory method. Blood pressure was measured in the contralateral arm with a mercury sphygmomanometer and an oscillometric device at the beginning and end of the study for comparison. Over a blood pressure range of 90–130 mm Hg systolic and 40–80 mm Hg diastolic, a close agreement was found with the sphygmomanometer; the limits of agreement (± 2 SD) were 11·6 mm Hg for systolic blood pressure and 13·6 mm Hg for diastolic blood pressure. The bias was less than 1·0 mm Hg. The ambulatory device was worn by all patients for at least 16 hours with an average of 52 recordings per patient. The majority found the device comfortable to wear and were not woken from sleep.

(*Arch Dis Child* 1993; **69**: 681–684)

The regular measurement of blood pressure is just as important in childhood as in adult life. However, there are a number of problems that are particularly important in childhood. Firstly, blood pressure varies with age and although population norms have been published,[1-3] there is considerable variation and consequently no internationally agreed standards.[4] Secondly, the size of the cuff must be carefully matched to the size of the arm. It is recommended that the bladder width should be 40 to 50% of mid-arm circumference,[5] although in clinical practice such precision is rarely achieved. Finally, the fourth and fifth Korotkoff sounds are frequently found to occur simultaneously and the fifth phase may not occur at all, adding further imprecision to the measurement of diastolic blood pressure in children.

Hypertension in children can be defined as the state in which the average systolic and/or average diastolic blood pressure is greater than the 95th centile for age and sex with measurements obtained on at least three occasions.[6] The prevalence of hypertension in children is of the order of 1 to 3%. Of these children one tenth will have severe hypertension and in the majority the increased blood pressure will be secondary to renal disease or coarctation of the aorta.[7]

Currently the detection of hypertension is based on periodic blood pressure measurements or the blood pressure response to exercise testing. Continuous recording of interarterial blood pressure has shown little relationship to sporadic measurements and arterial recordings are obviously not appropriate or available for routine clinical use in children. Recent technological advances have produced non-invasive ambulatory blood pressure recorders capable of multiple sampling of blood pressure via sphygmomanometer cuff with the storage of data for later analysis. These devices have been validated in adults and there is now a considerable body of literature reporting their use.[8 9]

The aims of our study were to determine whether ambulatory blood pressure monitoring (ABPM) is accurate in the lower blood pressure range encountered in childhood and, equally important, whether it was acceptable to children.

Patients and methods

PATIENTS

Our study population consisted of 31 children aged 6 to 18 years with a median age of 11 years. There were 15 females. Twenty six were inpatients and the remainder outpatients. None of these children was obese (greater than or equal to 120% ideal body weight based on height age). All but five were normotensive (blood pressure less than 90th centile). One child was on antihypertensive medication. Four patients had successfully undergone cardiac transplantation. The majority were electively admitted for cardiac catheterisation or surgery.

EQUIPMENT

We assessed the A&D ambulatory blood pressure monitor TM 2420/TM 2020, which is a portable non-invasive recorder ($4 \times 6 \cdot 5 \times 14$ cm in size, 390 g in weight) powered by a rechargeable battery. There are two cuff sizes, child (bladder width 9·0 cm and length 16·0 cm) or adult (bladder width 12·0 cm and length 22·0 cm) The cuff is pressurised by a miniature, low noise rotary micropump. To eliminate noises resulting from body motion, two microphones are used to distinguish Korotkoff sounds. The first and fifth Korotkoff sounds are taken as systolic and diastolic pressures respectively. Systolic blood pressure, diastolic blood pressure, and heart rate are measured automatically at intervals of 1–60 minutes throughout 24 hours. These data can be stored as many as 600 times in the recorder's semiconductor memory. After measurement, mean (SD) values and trend

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Figure 1   A 5 year old girl wearing the recorder. This is a lightweight device and can easily be concealed under clothing if desired.

Comparisons of ABPM with measurement by standard mercury sphygmomanometer and an oscillometric device (Dinamap); limits of agreement are mean ± 2SD

	Sphygomanometer		Dinamap	
	Systolic	Diastolic	Systolic	Diastolic
Difference in blood pressure (mm Hg)				
Mean	0·56	0·80	−6·10	1·00
SD	5·8	6·8	7·2	8·5
% Readings differing by (mm Hg)				
<5	56	54	46	44
<10	87	85	73	73
<15	100	95	88	90

graphs of systolic blood pressure, diastolic blood pressure, and heart rate are printed out by means of a miniature analyser measuring 5×7·5×15 cm. Error readings are indicated by one of 12 codes. The machines measure in a range for systolic pressure of 60 to 280 mm Hg with a diastolic pressure of 40 to 160 mm Hg. Readings are edited if they fall outside this range or if the pulse pressure is less than 10 or greater than 150 mm Hg. This is the quietist (noise 40 dB) and the lightest product of its kind on the market currently. Figure 1 illustrates a 5 year old girl wearing the recorder and the analyser coupled to the recorder reading to program or retrieve data.

PROTOCOL
This project was approved by the joint ethics committee of the Newcastle Health Authority. After informed consent was obtained the patient was fitted with the recorder and the cuff attached to the non-dominant arm. Selection of cuff size was based on measurement of the mid-arm circumference and corresponded to the manufacturer's recommendation. At the beginning and/or end of the 24 hour period comparison measurements were made in the contralateral arm using the same cuff size and measured by both oscillometric method (Dinamap) and a standard mercury sphygmomanometer. Each instrument was used in random order. Three measurements were taken with each device over a period of five minutes and averaged for statistical comparison. Automatic recordings were made every 30 minutes during the day time and every 60 minutes at night. The child

was instructed to remain still with the arm extended during the recording. The time each child fell asleep and awoke was recorded by a nurse or parent to the nearest 15 minutes. Finally, each child was asked what they thought of the device and whether it awoke them from sleep.

Results
ACCURACY
Comparisons between the methods was made using the technique of Bland and Altman.[10] These data are summarised in the table. Requirements for validation of the accuracy of ABPM have been proposed.[11] It is suggested that the mean difference of the paired measurements by the monitor and reference technique should be within ± 5 mm Hg with a standard deviation of the difference between techniques to be ≤8 mm Hg. It can be seen that using these criteria there is a satisfactory agreement between ABPM and measurement by the standard mercury sphygmomanometer but not with the Dinamap recorder.

ERRORS
Error readings occurred in 16% of all recordings (range 0–46%). Six whole day recordings were rejected because they had more than 25% errors. The patient who had an unusually high number of error recordings (20/57) possibly had a recorder malfunction. The machine continued to register a wide pulse pressure without interruption for a period of four hours. The commonest reason for an error reading was failure of the microphone to detect the Korotkoff sounds (42%) followed by a wide pulse pressure (21%).

ACCEPTABILITY
Thirty six children were initially approached to wear the device (fig 2); in two it failed to record. A further three disliked the machine after an initial trial. We therefore had 31 patients who completed a whole day record of at least 16 hours with a mean duration of 22·5 hours. One child, the youngest in the study, asked to have the machine taken off. In all other situations where recordings terminated short of 24 hours this was due to ward routine, for example, a child going to theatre or being discharged. The average number of blood pressure recordings made by the monitor was 52 per patient. Six children were woken briefly
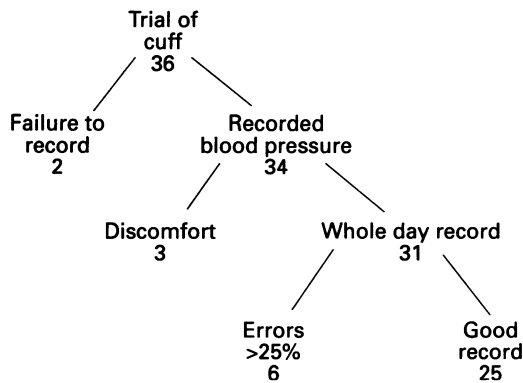
Figure 2   Summary of the data on reliability and acceptability for whole day recordings (greater than 16 hours) with ABPM.

from sleep but only two because of discomfort. Twenty five children said they would wear the device again.

WHOLE DAY RECORD

Figure 3 shows a typical profile of a whole day ambulatory blood pressure record. The patient was an 11 year old boy who had successfully undergone cardiac transplantation three years previously. He was normotensive with a blood pressure of 110/65 mm Hg in clinic. He was an outpatient during this study. Note the variability of his systolic blood pressure rising above 200 mm Hg at 1800 hours when he was at a disco and at 0900 hours when he went to school.

Discussion

The A&D ambulatory blood pressure monitor has previously been validated in adults by Tochikubo *et al.*[12] Sixty two normal adults between the age of 25 and 60 years were assessed. Simultaneous measurements with a mercury sphygmomanometer and the monitor were compared. Over a blood pressure range of 75–200 mm Hg systolic blood pressure and 50–125 mm Hg diastolic blood pressure very close agreement was found, the limits of

agreement being ±9·4 mm Hg for systolic blood pressure and ±10·0 mm Hg for diastolic blood pressure, the bias being 1·2 and 2·7 mm Hg respectively.

There are few studies of ambulatory blood pressure monitoring in children. Daniels *et al* assessed the Del Mar Avionics Ambulatory Pressurometer III on a group of 84 hypertensive children aged 6 to 23 years (mean age 14·8 years).[13] This device also ausultates the Korotkoff signs but with a single microphone. They compared readings at the beginning and end of the 24 hour period with sphygmomanometer readings taken simultaneously via a connecting jack. After the initial readings they calibrated the device to read within 5 mm of the sphygmomanometer reading. Despite this, the median difference at the beginning of the assessment was 5·3 mm Hg for systolic blood pressure (range 1·0–21·4 mm Hg) and 4·7 mm Hg for diastolic blood pressure (range 1·2–11·5 mm Hg). Recordings were made every 7·5 minutes and each child had on average 178 measurements. Interestingly, this machine weighed over 2 kg and no mention of patient acceptability was made.

Portman *et al* report their use of an oscillometric ABPM device (Space Labs 90202) in a group of 99 normal 10 year olds.[14] Diaries enabled retrospective assessment of activity level and emotional state. This device had a similar accuracy to ours but they found systolic blood pressure measured by their device was 5 mm Hg higher than comparison measurements with a mercury manometer. It is now clear that oscillometric ABPM devices record a wider pulse pressure than auscultatory monitors,[15] and their validation may have improved by comparison with a standard oscillometric blood pressure recorder such as Dinamap. Their device was also lightweight and quiet but 27% reported sleep disturbance and their error rate was high at 27%. This type of ABPM appears to be limited by vibratory interference in active children.[16]

Loirat *et al* used a Nippon Colin monitor 630 that simultaneously obtains blood pressure values by the auscultatory and oscillometric methods.[15] This reduced their error rate to a very acceptable 2·7% for both methods combined. This group went on to assess 28 children, aged 8–17 years, with borderline hypertension. For reasons we discuss later, interpretation of data from this type or application is fraught with difficulty as it is not clear what is an abnormal or 'hypertensive' ABPM profile.

Our study does show a reasonable agreement between a state of the art ambulatory blood pressure monitor and two generally accepted non-invasive techniques. It complies with the criteria of O'Brien *et al*[11] and compares favourably with two other devices used in children.[14 15] 'White coat' hypertension exists in children just as it does in adults.[17 18] It is therefore likely that this new technology will prove useful in the assessment and management of hypertension in children and adolescence. However, a number of important
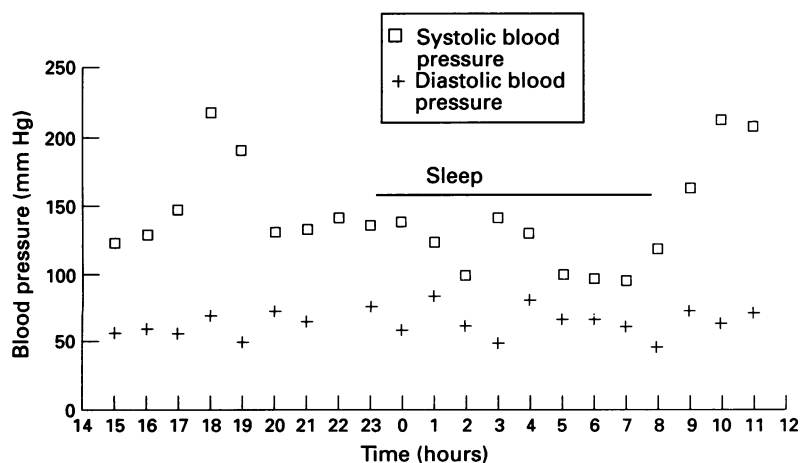

Figure 3   Whole day record of an 11 year old boy. His mean blood pressure in outpatient clinic was 110/65 mm Hg. Note the variability in systolic blood pressure during a normal day. Between 1730 and 1900 he was at a disco but did not dance. He awoke briefly at 0300; note the early morning rise in blood pressure before awakening. He was driven to school in the morning and started class at 0900.

questions need to be answered before ABPM is recommended for routine clinical use in childhood. (1) Is there now an established need for this new methodology? Are the current techniques of blood pressure measurement inadequate? (2) Is the equipment reliable and practical enough to give useful data? (3) Is it safe for and acceptable to children? (4) Is there an adequate definition of a normal or an abnormal result? Do we have the basis for diagnostic interpretation of results for an individual patient? (5) Is it cost effective? Do the benefits of the technique outweigh the expense? We have attempted to address the first three questions in our present study.

An enormous amount of data is generated by this technique and it is not clear how this should be handled and interpreted. A mean 24 hour systolic and diastolic blood pressure is commonly quoted in adult studies but it seems to be an over simplification that conceals important information about variability. An alternative might be to record mean sleeping and awake blood pressures or present a summated profile with hourly or two hourly average blood pressure plotted against time (fig 3).

In conclusion ABPM in children gives results that are reliable and most children over the age of 6 years find this investigation acceptable. Further research is needed to establish how to make the most effective use of this new technology.

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