

Use and interpretation of ambulatory blood pressure monitoring: recommendations of the British Hypertension Society

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Over the past 20 years or so, the accuracy of using the conventional Riva-Rocci sphygmomanometer and Korotkoff's sounds to measure blood pressure has been questioned, and efforts have been made to improve measurements with automated devices.^{1 2} In the same period, the phenomenon of white coat hypertension has been recognised—whereby some patients who apparently have raised blood pressure actually have normal blood pressure when the measurement is repeated away from the medical environment; this has focused attention on methods of measurement that provide profiles of blood pressure rather than rely on isolated measurements made under circumstances that may influence blood pressure.³ These methods have included repeated measurements of blood pressure using the traditional technique, self measurement of blood pressure in the home or workplace, and ambulatory blood pressure measurement using automated devices.² Ambulatory monitoring is advantageous because it gives multiple measurements throughout the day and night

This paper considers only the ambulatory measurement of blood pressure in adults. Its purpose is not to make a case for or against ambulatory measurement; others have already done so.^{4 5} Although the results of a number of ongoing, longitudinal studies are forthcoming, there is now firm evidence that ambulatory blood pressure measurement is a more sensitive predictor of cardiovascular outcome than conventional measurement.⁶ We have not considered the complex issues of health economics that the increasing use of ambulatory measurement raises.⁷ We realise that this technique is being used more often and that doctors who find ambulatory measurement useful in the day to day management of patients with high blood pressure need recommendations from those who have experience. However, regardless of the technique used to diagnose hypertension it is only one factor in determining a patient's risk profile and must be assessed in relation to concomitant disease, such as diabetes mellitus, and in relation to the degree of target organ involvement as recommended in the British Hypertension Society's guidelines on the management of hypertension.^{8 9}

Summary points

One of the most important indications for ambulatory monitoring is to exclude white coat hypertension

The technique is also valuable in diagnosing and treating elderly patients and is used increasingly in pregnancy

Practices should consider carefully which monitor to buy, taking into account whether it has been independently validated, and should also consider how the data are analysed and presented

Methods

Recommendations on the use of ambulatory measurement have tended to be ambivalent, although firmer proposals are now being made.^{10 11} Such ambivalence has not assisted doctors wishing to use the technique; however, making recommendations on the basis of incomplete evidence may lead to charges of advocating a technique that is not supported by the evidence. Recognising this, we have based our recommendations on evidence when it is available, and in cases in which it is not we have given advice on the basis of our collective experience of using ambulatory measurement over many years. What seems reasonable today may have to be modified as additional evidence becomes available: such is the essence of scientific reasoning. Where possible we have graded the strength of the evidence on which we have based our recommendations according to the scheme discussed by Shekelle et al.¹²

Setting up an ambulatory blood pressure measurement service

Which monitor?

A large variety of devices for ambulatory measurement are available, and the number will increase as the technique becomes more widespread.¹¹ A number of factors influence the choice of monitor (box); the most important factor is whether the device has been

Table 1 Results of independent evaluation of 23 ambulatory blood pressure measuring devices.¹⁵ Devices were evaluated using the protocols of the British Hypertension Society¹² and the US Association for the Advancement of Medical Instrumentation¹³

Device (manufacturer)	Protocol used		Validated
	Association for the Advancement of Medical Instrumentation*	British Hypertension Society (Systolic/diastolic pressure)†	
Accutacker II (Suntech)	Passed	A/C	At rest
CH-DRUCK (Disetronic)	Passed	A/A	At rest‡
Daypress 500 (Neural Instruments)	Passed	A/B	At rest
DIASYS 200 (Novacor)	Passed	C/C	At rest
DIASYS Integra (Novacor)	Passed	B/A, B/B	At rest‡
ES-H531(Terumo)	Passed	A/A, B/B	At rest‡
Meditech ABPM-04 (Meditech)	Passed	B/B	At rest‡
Nissei DS-240 (IDT France)	Passed	B/A	At rest
OSCILL-IT (FIGI)	Passed	C/B	At rest
Profilomat (Disetronic)	Passed	B/A	At rest‡
	Passed	B/C	In pregnancy
Profilomat II (Disetronic)	SBP Fail/DBP Pass	C/B	At rest‡
QuietTrak (Tycos Instruments)	Passed	A/A, B/B	At rest
	Failed	B/B	In pregnancy
Save 33, model 2 (Save 33:2)	Passed	B/B	At rest
Schiller BR-102 (Schiller)	Passed	B/B	At rest‡
SpaceLabs 90202 (SpaceLabs)	Passed	B/B	At rest
SpaceLabs 90207 (SpaceLabs)	Passed	B/B	At rest‡
	Passed	A/C, B/B, B/C, C/C	In pregnancy
	SBP Pass/DBP Fail	C/D	In children
	Passed	A/C	In elderly patients with postural effect
SpaceLabs 90217 (SpaceLabs)	Passed	A/A	At rest‡
TM-2420, model 5 (A and G Engineering)	Passed	C/C	At rest
TM-2420, model 6 (A and D Engineering)	Passed	B/B	At rest
TM-2420, model 7 (A and D Engineering)	Passed	B/B	At rest
TM-2421 (A and D Engineering)	Passed	B/A	At rest
Takeda 2421 (A and D Engineering)	N/A	C/C, A/B	In children with postural effect
Takeda 2430 (A and D Engineering)	Passed	A/A	At rest‡

NA=not available; SBP=systolic blood pressure; DBP=diastolic blood pressure.

*Criteria for fulfilling protocol are that the mean difference between the standard sphygmomanometer and the device being validated should be within ≤ 5 mm Hg (SD ≤ 8 mm Hg).

†Grades denote agreement with mercury standard: A=best agreement (recommended for clinical use); B=good agreement (recommended); C=poor agreement (not recommended); D=worst agreement (not recommended). Devices must achieve rating of at least B/B to be recommended. For some devices more than one validation study was conducted and the grades for each validation are shown.

‡Validated for high, medium, and low pressure ranges. §Validated during exercise and for standing and lying positions.

validated independently according to either the protocol of the British Hypertension Society¹³ or that of the US Association for the Advancement of Medical Instrumentation,¹⁴ or both. Table 1 shows the results of independent evaluations of devices using these protocols. (A list of the manufacturers of ambulatory systems can be found on the *BMJ's* website.)

What type of service is most appropriate?

Doctors may establish their own service to provide ambulatory measurement, refer patients to a hospital service with open access to ambulatory measurement, or refer patients to a blood pressure clinic for full evaluation, which would include ambulatory measurement. Often an open access referral service is used and difficult cases are referred for fuller evaluation to a blood pressure clinic.

Training

The technique of ambulatory blood pressure measurement is specialised and should be approached with care. An understanding of the principles of traditional blood pressure measurement, cuff fitting, monitor functioning, and interpretation of the data from ambulatory measurement is recommended.¹⁶ In practice, a nurse who is interested and has experience in caring for patients with hypertension can use the devices after a comparatively brief training. However, the analysis and

interpretation of the ambulatory profiles require experience, and this is best learnt from the doctor in charge of the service offering ambulatory measurement.

Using an ambulatory monitor

About 15 to 30 minutes need to be allotted to fitting the monitor and preparing the patient if good results are to be obtained (box). Recommendations for cuff dimensions are shown in table 2.^{9 17} Whichever cuff is

Factors to consider when choosing a monitor

- Has the device been validated by the British Hypertension Society or the US Association for the Advancement of Medical Instrumentation?
- How much does it cost?
- How expensive is the software?
- Does the software offer the information that you need?
- Are the operating instructions adequate?
- How much will maintenance cost?
- How expensive are consumables, such as batteries?
- Does the practice have adequate computer facilities to support the data analysis?
- Is support available from technical or nursing staff within the practice?
- Are training facilities available from the manufacturer or supplier?
- Is the warranty adequate?
- Does the manufacturer or supplier have servicing facilities that are easily accessible?

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Table 2 Recommended size of cuffs for measuring blood pressure¹²

	Dimension
Child or lean adult	12 cm×18 cm
Adult	12 cm×26 cm
Adult with large arm	12 cm×40 cm

Fitting the monitor

This will take about 15 to 30 minutes
 Have the patient relax in a quiet room
 Enter the patient's details, such as name and identification number, into the monitor
 Measure blood pressure in both arms
 If the difference in systolic blood pressure is < 10 mm Hg use the non-dominant arm for monitoring
 If the difference in systolic blood pressure is ≥ 10 mm Hg use the monitor on the arm with higher pressure
 Select the appropriate cuff
 Select the frequency of measurement (usually every 30 minutes)
 Inactivate the display to prevent the patient becoming distracted by the measurements
 Give the patient written instructions
 Show the patient how to remove and inactivate the monitor after 24 hours

chosen, the centre of the inflatable bladder should be placed over the brachial artery. The key to successful ambulatory measurement is educating the patient about the process of monitoring (box).

In clinical practice, measurements are usually made at half hourly intervals so as not to interfere with activity during the day and with sleep at night, but measurements can be made more frequently if necessary. There are a number of ways of analysing the blood pressure values recorded during the 24 hour cycle.¹⁸ One simple

How to prepare the patient so that monitoring is successful**Explain**

- the procedure
- the frequency of inflation and deflation
- how to manually deflate the cuff
- that in the event of failed measurements the monitor will repeat the measurement

Instruct patients

- to keep their arm steady during measurement
- to keep their arm at heart level during measurement
- to engage in normal activities between measurements
- to keep the monitor attached at night
- to place the monitor under a pillow or on the bed at night

Provide

- a telephone number for patients to call in case of problems or anxiety
- a diary card for the patient to record:
 - the time they go to bed
 - the time they get up
 - the time they take their drug treatment
 - any symptoms

and popular method is to divide the 24 hours into day (beginning with the first entry on the diary card) and night (beginning with the last entry). Another is to use a fixed time method in which the retiring (2101 to 0059) and rising (0601 to 0859) periods, during which blood pressure is variable, are eliminated; in this method the daytime period is set at 0900 to 2100 and the night-time from 0100 to 0600. In this way variations that may exist between the young and the old and in different cultures are to some extent eliminated from the analysis.¹⁸

Analysing the data

Many statistical techniques exist for describing different aspects of ambulatory records, and no one method is ideal.^{19, 20} The important points to consider when analysing data are summarised in the box. The detection of artefactual readings and the handling of outlying values (which may not always be erroneous) have been debated,²¹ and we believe that if there have been a sufficient number of measurements editing the values is not necessary.

Analysing and presenting the data**Number of measurements necessary**

Day: > 14 systolic and diastolic blood pressure measurements
 Night: > 7 systolic and diastolic blood pressure measurements

Causes of poor data

Poor technique
 Arrhythmias
 Small pulse volume
 Inability of automated device to measure blood pressure

Editing data

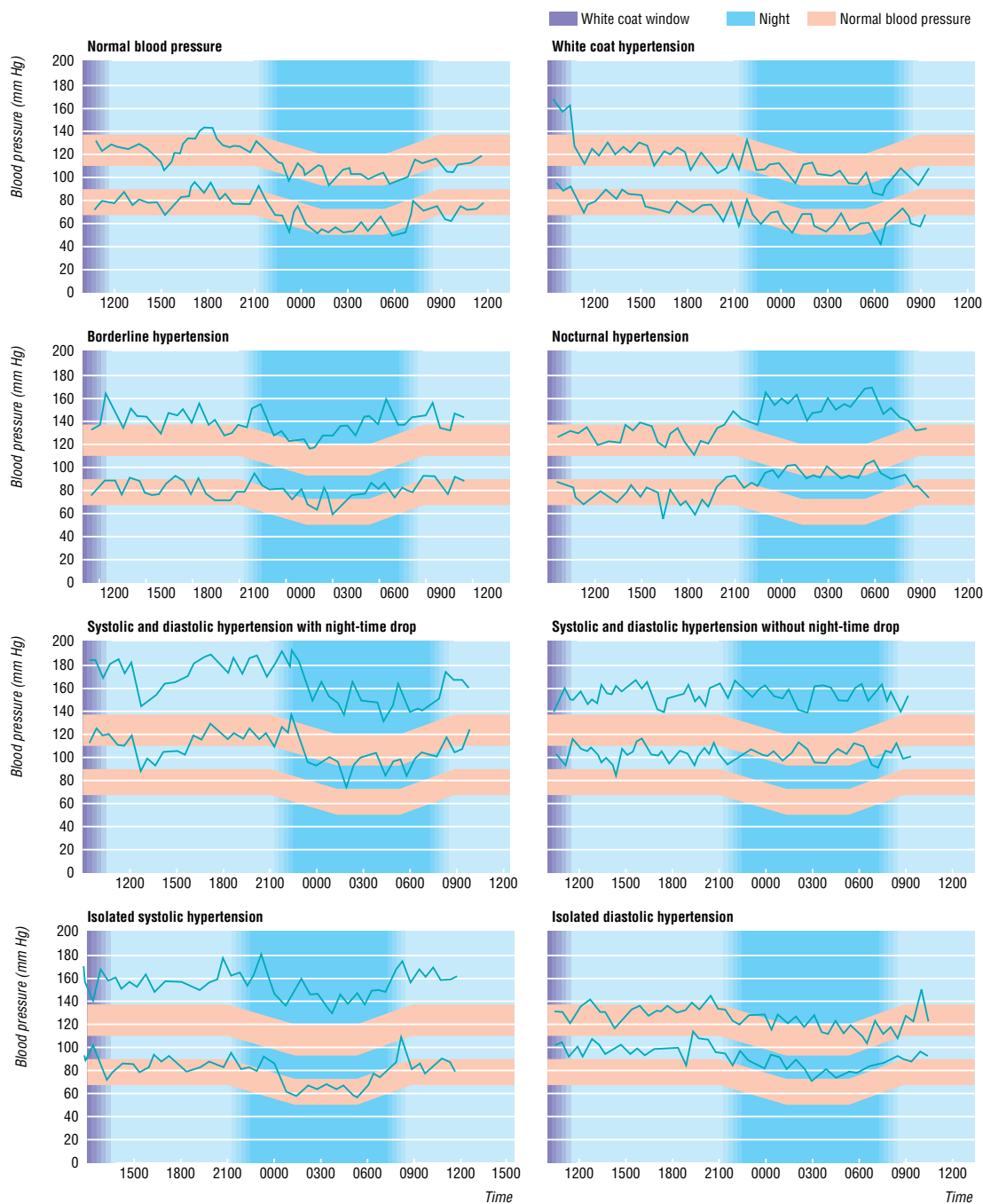
Restrict editing to physiologically impossible pressures, such as if the diastolic pressure equals the systolic pressure

Displaying the data

Statistics should include:

- Mean daytime systolic and diastolic pressures and heart rate
 - Mean night-time systolic and diastolic pressures and heart rate
 - Mean 24 hour systolic and diastolic pressures and heart rate
- Plot the data (figure)

Devices for ambulatory measurement are usually sold with software packages that present the data in a variety of ways. It would facilitate practice if the graphic presentation of the data was standardised, as is the case for electrocardiograms. The presentation of data should be independent of the type of monitor used. A standardised approach could provide a graphical display of the data from the ambulatory measurement (on screen or on a printout) with a graph showing blood pressure on the vertical axis and time on the horizontal axis (figure); normal values could also be shown.^{20, 22} One program (DABL Cardiovascular 2000, ECF Medical, Dublin, Republic of Ireland) already provides a printed report derived from the data obtained by the monitoring.²⁰



Examples of ambulatory blood pressure patterns plotted by the DABL program. The white coat window is the first hour of recording

Deciding what constitutes normal blood pressure and what constitutes abnormal in ambulatory

Table 3 Recommended standards for normal and abnormal pressures during ambulatory measurement. These pressures are only a guide, and lower pressures may be abnormal in patients whose total risk factor profile is high and in whom there is concomitant disease^{8,9}

	Normal	Abnormal
Day	≤135/85	>140/90
Night	≤120/70	>125/75
24 hour	≤130/80	>135/85

measurement is controversial, and the approaches to defining normal values have been discussed,^{23,24} but the values shown in table 3 are commonly used (strength of evidence C).²³ We appreciate that these values may be regarded as conservative by some, but lower values cannot be recommended unless evidence from ongoing longitudinal studies indicates otherwise.

Clinical indications for ambulatory blood pressure measurement

Ambulatory measurement provides a large number of measurements over time—usually 24 hours—which can

White coat hypertension**Definition**

Blood pressure $\geq 140/90$ mm Hg when measured in office

Normal daytime ambulatory pressure
 $< 135/85$ mm Hg

Prevalence of white coat hypertension

15-30% of general population
 Common in elderly people and pregnant women

Risks

Less than from sustained hypertension
 Probably small risk when compared with people with normal blood pressure
 Possibly a precursor to hypertension

Clinical implications

No clinical characteristics assist in diagnosis
 Must be considered in people newly diagnosed with hypertension
 Should be considered before drug treatment is prescribed (could lead to fewer drugs being prescribed)
 Must be placed in context of the overall risk profile
 Should reassure patients, employers, and insurers that risk from white coat hypertension is low or absent
 Patients need follow up and monitoring again

be plotted to give a profile of blood pressure. Although in practice the average daytime (or night-time) blood pressure is used to govern decisions, the clinical use of ambulatory measurement has allowed a number of phenomena in hypertension to be identified that would otherwise not have been (strength of evidence B-C).²²⁻²⁵ Ambulatory measurement is of benefit

- In excluding white coat hypertension (evidence strength C)
- In helping with the diagnosis of patients with borderline hypertension (evidence strength D)
- In deciding on treatment for elderly patients (evidence strength A-C)
- In identifying nocturnal hypertension (evidence strength C)
- In assessing patients whose hypertension has been resistant (evidence strength D)
- As a guide to determining the efficacy of drug treatment over 24 hours (evidence strength B)
- In diagnosing and treating hypertension in pregnancy (evidence strength C-D), and
- In diagnosing hypotension (evidence strength B-C).

White coat hypertension

From the first use of home and ambulatory monitoring, it became apparent that measuring a patient's blood pressure in a clinic or office could raise their blood pressure above their mean ambulatory pressure as a result of the white coat phenomenon.³⁻²⁵⁻²⁹ The features of white coat hypertension are summarised in the box. In patients with normal blood pressure daytime ambulatory pressure may be a little higher than blood pressure measured conventionally, but in those with hypertension daytime blood pressure is usually substantially, but unpredictably, lower than blood pressure measured conventionally.

Borderline hypertension

Patients whose blood pressure is considered to be borderline may also benefit from ambulatory moni-

toring, especially young patients in whom lifelong drug treatment may otherwise be prescribed inappropriately and who may be penalised in terms of insurance or employment if the diagnosis of hypertension is misapplied.

Considering treatment in elderly patients

The results of the ambulatory study of the systolic hypertension in Europe trial show that conventional measurement of systolic pressure in elderly people may produce results that are on average 20 mm Hg higher than daytime ambulatory pressure,³⁰ leading to an overestimation of the occurrence of isolated systolic hypertension among elderly patients and probably excessive treatment. Moreover, results from this study also show that ambulatory systolic pressure is a better predictor of cardiovascular risk than pressure measured conventionally.³¹ A variety of ambulatory patterns are found among elderly people, including a number of hypotensive states associated with baroreceptor or autonomic failure. These blood pressure patterns include white coat hypertension, isolated systolic hypertension, postural hypotension, postprandial hypotension, daytime hypotension and nocturnal hypertension, drug induced hypotension, and autonomic failure. Since elderly people can be particularly susceptible to the adverse effects of drug treatment given to lower blood pressure, identifying hypotension is particularly important, although its management may be challenging.³²

Nocturnal hypertension

Ambulatory measurement is the only non-invasive technique that permits blood pressure to be monitored during sleep. The relevance of nocturnal hypertension is still controversial, but there is increasing evidence that nocturnal blood pressure may provide important information; for example, blood pressure at night is independently associated with end organ damage above the risk associated with daytime values.³³⁻³⁴ It has also been shown that the absence of a night-time drop in blood pressure is associated with target organ involvement, and it may be a useful (although non-specific) clue to the presence of secondary hypertension. (Patients whose blood pressure drops at night are sometimes known as "dippers," and those whose blood pressure does not drop are sometimes known as "non-dippers."³³)

Hypertension resistant to treatment

Patients are classed as having resistant hypertension when their blood pressure remains consistently above 150/90 mm Hg with conventional measurement despite being treated with three or more drugs. In these patients ambulatory monitoring may indicate that the apparent lack of response is caused by the white coat phenomenon; alternatively, the absence of a night-time drop in blood pressure may suggest secondary hypertension.

Pregnancy

The main use of ambulatory measurement in pregnancy is to identify white coat hypertension; it may occur in nearly 30% of pregnant women.³⁵ Recognising it is important so that pregnant women are not admitted to hospital or given antihypertensive drugs unne-

essarily. Normal values for ambulatory blood pressure among pregnant women are available, and the changes in pressure which occur during the different trimesters of pregnancy and in the postpartum period have been defined.³⁶ The evidence that ambulatory measurement may predict pre-eclampsia is not conclusive.³⁷ However, ambulatory blood pressure correlates better with proteinuria than does conventional sphygmomanometry,³⁸ and it is a better predictor of complications of hypertension.³⁹ In addition, women diagnosed with hypertension by ambulatory monitoring have infants with lower birth weights and this association is not found when blood pressure is measured conventionally.⁴⁰ Moreover, women with white coat hypertension tend to be more likely to have a caesarean section than women with normal blood pressure, suggesting that if ambulatory measurement was used rather than conventional measurement, some caesarean deliveries might be avoided.³⁵

Ambulatory hypotension

Ambulatory measurement may be useful in identifying hypotensive episodes in young patients in whom hypotension is suspected of causing symptoms.³² Ambulatory measurement may also identify drops in blood pressure induced by the drugs used to treat hypertension, which may have untoward effects in patients with compromised arterial circulation, such as those with coronary and cerebrovascular disease.⁴¹

As a guide to drug treatment

The role of ambulatory measurement in guiding drug treatment is the subject of much research, and its role in this regard has not been fully established. However, recent reviews of the clinical value of ambulatory measurement have highlighted the potential usefulness of 24 hour recordings of blood pressure in guiding drug treatment.⁴²⁻⁴³ Furthermore, a recent well controlled study showed that when ambulatory measurement rather than measurement in a clinic was used as the basis for prescribing treatment, significantly less antihypertensive drug treatment was prescribed.⁴ Ambulatory measurement gives the prescribing doctor an assessment of the patient's response to treatment that conventional measurement cannot provide: the efficacy of treatment without the white coat effect can be ascertained, an excessive effect of drugs and the occurrence of symptoms can be determined, and the duration of the effect of drugs over 24 hours can be shown.

Who should be monitored again?

Ambulatory blood pressure measurement inconveniences patients, and it should be used with discretion. The decision of when to repeat ambulatory measurement is largely one of clinical judgment, which may be influenced by factors such as an excessive variability of blood pressure, an inappropriate response to treatment, an adverse risk factor profile, and the need for careful control of blood pressure, such as in patients with hypertension who have diabetes mellitus or renal disease. As a general rule it is usually not necessary to repeat ambulatory measurement more frequently than once a year. Conventional measurement may be relied on for follow up in patients who do not have evidence of a white coat effect when monitored with ambulatory

measurement. The patients for whom monitoring again may be helpful are

- Patients with white coat hypertension
- Patients being treated for hypertension who also have evidence of white coat hypertension
- Elderly patients with hypotension
- Patients with night-time hypertension, and
- Patients who have had their drug treatment changed.

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- 1 O'Brien E, Mee F, Atkins N, O'Malley K, Tan S. Training and assessment of observers for blood pressure measurement in hypertension research. *J Hum Hypertens* 1991;5:7-10.
- 2 O'Brien E. "Classic sphygmomanometry: a fin de siècle reappraisal." In: Bulpitt C, ed. *Handbook of hypertension*. Amsterdam: Elsevier, (in press).
- 3 Pickering TG, James GD, Boddie C, Harshfield GA, Blank S, Laragh JH. How common is white coat hypertension? *JAMA* 1988;259:225-8.
- 4 Staessen JA, Byttebier G, Buntinx F, Celis H, O'Brien E, Fagard R, et al. Antihypertensive treatment based on conventional or ambulatory blood pressure measurement. A randomised controlled trial. *JAMA* 1997;278:1065-72.
- 5 Inden Y, Tsuda M, Hayashi H, Takezwa H, Iino S, Kondo T, et al. Relationship between Joint National Committee-VI classification of hypertension and ambulatory blood pressure in patients with hypertension diagnosed by casual blood pressure. *Clin Cardiol* 1998;21:801-6.
- 6 Verdecchia P. Prognostic value of ambulatory blood pressure: current evidence and clinical implications. *Hypertension* 2000;35:844-51.
- 7 Moser M. The cost of treating hypertension: can we keep it under control without compromising the level of care? *Am J Hypertens* 1998;11:120-75.
- 8 Ramsay LE, Williams B, Johnston GD, MacGregor GA, Poston L, Potter JF, et al. Guidelines for management of hypertension: report of the third working party of the British Hypertension Society. *J Hum Hypertens* 1999;13:569-92.
- 9 Ramsay LE, Williams B, Johnston GD, MacGregor GA, Poston L, Potter JF, et al. British Hypertension Society guidelines for hypertension management 1999: summary. *BMJ* 1999;319:630-5.
- 10 Pickering T for the American Society of Hypertension ad hoc panel. Recommendations for the use of home (self) and ambulatory blood pressure monitoring. *Am J Hypertens* 1996;9:1-11.
- 11 Myers MG, Haynes RB, Rabkin SW. Canadian hypertension society guidelines for ambulatory blood pressure monitoring. *Am J Hypertens* 1999;12:1149-57.
- 12 Shekelle PG, Woolf SH, Eccles M, Grimshaw J. Clinical guidelines: developing guidelines. *BMJ* 1999;318:593-6.
- 13 O'Brien E, Petrie J, Littler WA, de Swiet M, Padfield PL, Altman D, et al. The British Hypertension Society protocol for the evaluation of blood pressure measuring devices. *J Hypertens* 1993;11(suppl 2):43-63S.
- 14 Association for the Advancement of Medical Instrumentation. *American national standard for electronic or automated sphygmomanometers: ANSI/AAMI SP10-1987*. Arlington, VA: Association for the Advancement of Medical Instrumentation, 1993:40.
- 15 O'Brien E. Automated blood pressure measurement: state of the market in 1998 and the need for an international validation protocol for blood pressure measuring devices. *Blood Press Monitoring* 1998;3:205-11.
- 16 McLeod MJ, O'Brien ET, Petrie JC, Littler WA, de Swiet M, Padfield PL, et al. *Blood pressure measurement* [CD Rom]. London: British Hypertension Society, BMJ Books, 1998.
- 17 O'Brien ET. A century of confusion: which bladder for accurate blood pressure measurement? *J Hum Hypertens* 1996;10:565-72.
- 18 Fagard R, Staessen J, Thijs L. Optimal definition of daytime and night-time blood pressure. *Blood Press Monitoring* 1997;2:315-21.

- 19 Pickering T, Pieper C. Methods of analysis of ambulatory blood pressure data. In: Pickering TG. *Ambulatory monitoring and blood pressure variability*. London: Science Press, 1991;16:1-16.15.
- 20 Atkins N, O'Brien E, DABL 97—A computer program for the assessment of blood pressure, risk factors and cardiovascular target organ involvement in hypertension. *J Hypertens* 1998;16(suppl 2):198S.
- 21 Staessen J, Fagard R, Lijnen P, Thijs L, van Hoof R, Amery A. Ambulatory blood pressure monitoring in clinical trials *J Hypertens* 1991;9(suppl):13-9S.
- 22 Owens P, Lyons S, O'Brien E. Ambulatory blood pressure in the hypertensive population: patterns and prevalence of hypertensive sub-forms. *J Hypertens* 1998;16:1735-43.
- 23 O'Brien ET, Staessen J. Normotension and hypertension as defined by 24-hour ambulatory blood pressure monitoring. *Blood Press* 1995;4:266-82.
- 24 O'Brien E, Owens P, Staessen J, Imai Y, Kawasaki T, Kuwajima I. What are the normal levels for ambulatory blood pressure measurement? *Blood Press Monitoring* 1998;3:131-2.
- 25 Owens P, Atkins N, O'Brien E. The diagnosis of white coat hypertension by ambulatory blood pressure measurement. *Hypertension* 1999;34:267-72.
- 26 Ayman D, Goldshine AD. Blood pressure determinations by patients with essential hypertension: the difference between clinic and home readings before treatment. *Am J Med Sci* 1940;200:465-74.
- 27 Pickering TG, James GD. Ambulatory blood pressure and prognosis. *J Hypertens* 1994;12 (suppl 8):S29-S33.
- 28 Glen SK, Elliott HL, Curzio JL, Lees KR, Reid JL. White coat hypertension as a cause of cardiovascular dysfunction. *Lancet* 1996;348:654-7.
- 29 Owens P, Lyons S, Rodriguez S, O'Brien E. Is elevation of clinic blood pressure in patients with white coat hypertension who have normal ambulatory blood pressure associated with target organ damage? *J Hum Hypertens* 1998;12:743-8.
- 30 Staessen J, Thijs L, Fagard R, O'Brien E, Clement D, de Leeuw P, et al. Predicting cardiovascular risk using conventional vs ambulatory blood pressure in older patients with systolic hypertension. *JAMA* 1999;282:539-46.
- 31 Staessen JA, Fagard R, Thijs L, Celis H, Arabidze GG, Birkenhager WH, et al. Randomised double-blind comparison of placebo and active treatment for older patients with isolated systolic hypertension. *Lancet*.1997;350:757-64.
- 32 Owens P, O'Brien ET. Hypotension: a forgotten illness? *Blood Press Monitoring* 1996;2:3-14.
- 33 O'Brien E, Sheridan J, O'Malley K. Dippers and non-dippers [letter]. *Lancet* 1988;ii:397.
- 34 Verdecchia P, Schillaci G, Guerrieri M, Gatteschi C, Benemio G, Boldrini F, et al. Circadian blood pressure changes and left ventricular hypertrophy in essential hypertension. *Circulation* 1990;81:528-36.
- 35 Bellomo G, Narducci PL, Rondoni F, Pastorelli G, Stagnoni G, Angeli G, et al. Prognostic value of 24-hour blood pressure in pregnancy. *JAMA* 1999;282:1447-52.
- 36 Halligan A, O'Brien E, O'Malley K, Mee F, Atkins N, Conroy R, et al. Twenty-four hour ambulatory blood pressure measurement in a primigravid population. *J Hypertens* 1993;11:869-73.
- 37 Higgins JR, Walshe JJ, Halligan A, O'Brien E, Conroy R, Darling MR. Can 24 hour ambulatory blood pressure measurement predict the development of hypertension in primigravidae? *Br J Obstet Gynaecol* 1997;104:356-62.
- 38 Halligan AWF, Shennan A, Lambert PC, Taylor DJ, de Swiet M. Automated blood pressure measurement as a predictor of proteinuric pre-eclampsia. *Br J Obstet Gynaecol* 1997;104:559-62.
- 39 Penny JA, Halligan AWF, Shennan AH, Lambert PC, Jones DR, de Swiet M, et al. Automated, ambulatory, or conventional blood pressure measurement in pregnancy: which is the better predictor of severe hypertension? *Am J Obstet Gynecol* 1998;178:521-6.
- 40 Churchill D, Perry JJ, Beevers DG. Ambulatory blood pressure in pregnancy and fetal growth. *Lancet* 1997;349:7-10.
- 41 Owens P, O'Brien ET. Hypotension in patients with coronary disease—can profound hypotensive events cause myocardial ischaemic events? *Heart* 1999;82:477-81.
- 42 Mallion J-M, Bague J-P, Siché J-P, Tremel F, De Gaudemaris R. Clinical value of ambulatory blood pressure monitoring. *J Hypertens* 1999;17:585-95.
- 43 White W. Guidelines on the clinical utility of ambulatory blood pressure. *Blood Press Monitoring* 1998;3:181-4.

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What is the optimal age for starting lipid lowering treatment? A mathematical model

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Coronary heart disease is the major cause of morbidity and mortality in industrialised countries. The Framingham cohort study has identified the quantitative impact of different risk factors and their interactions,¹⁻³ and large intervention studies have confirmed that drug treatment to reduce risk factors decreases progression to heart attack and stroke.⁴⁻⁵ However, with this increased understanding have come additional problems. The treatments to reduce cholesterol concentrations or blood pressure are often expensive, and the population that might benefit is vast. Indeed if every individual who might benefit was treated with a statin or fibrate, a large portion of the total drugs budget would be consumed.⁶ Thus some form of rationing is inevitable, and various recommendations have emerged in an attempt to contain cost while targeting treatment at those who stand to gain the most. Current UK policy recommends treatment should be offered to anyone with an absolute annual risk of 3% or more.⁷ Others, however, favour a 1.5%-2% absolute threshold before beginning treatment,⁸⁻⁹ and some have argued that estimates of relative risk should form the basis for treatment guidelines.¹⁰ Since age is the major determinant of absolute risk, treatment thresholds based on absolute risk will tend to postpone treatment to older age, whereas guidelines based on relative risk will tend to lead to treatment of younger people.

Whichever type of risk assessment is used, guidelines have tended to focus on who to treat, whereas in practice when to start treatment is another equally important and related issue. Faced with a 35 year old man with a total cholesterol concentration of

Summary points

Lipid lowering drugs are expensive and the population that might benefit from treatment is potentially vast

Current guidelines recommend targeting treatment to those who will gain the most; gain being cardiovascular events avoided over a fixed period of 5 or 10 years

Modeling of lifetime risk of cardiovascular disease suggests that many individuals will have accumulated most of their risk before they become eligible for treatment

It is possible to predict an age at which starting treatment provides maximum benefit for each year for which treatment is given by using lifetime risk calculations and presenting benefits as event free life years gained

This approach may help with young individuals at risk whose absolute risk of cardiovascular events is low but whose relative risk of cardiovascular events is high

6.0 mmol/l, a high density lipoprotein cholesterol concentration of 1.1 mmol/l, and a blood pressure of 145/95 mm Hg, should a clinician delay treatment