Computerized reporting improves the clinical use of ambulatory blood pressure measurement

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Background **Ambulatory blood pressure measurement (ABPM) is being used increasingly in clinical practice. One previous study has shown that there can be considerable variance between expert observers in the interpretation of ABPM data. The purpose of this study was to show whether computer-generated reports with the dabl®ABPM system would provide more consistency in the interpretation of data than reports from expert observers.**

Methods **Twenty-six international experts in hypertension were invited to participate and 17 agreed to do so. Twelve ABPMs generated by the Spacelabs device that were considered representative of the patterns likely to be seen in practice were sent to each participant for reporting. The corresponding dabl reports with an automatic interpretation were generated according to the European Society of Hypertension guideline for comparison with the observer reports. Each of the observer-interpreted Spacelabs reports for the 12 ABPM patterns were coded, analysed and compared with the automatically interpreted dabl®ABPM reports. Both sets of data were analysed for interobserver variability, observer v dabl®ABPM consistency and the time taken for observer reportage. The main analysis determined issues of definite disagreement, namely the presence or absence of nocturnal dipping. Further analysis determined the presence or absence of white-coat phenomena and the severity of hypertension.**

Results **Incorrect diagnoses were made in 13 instances. White-coat hypertension and white-coat effect, although obvious in many instances, were not identified in five ABPMs; the severity of hypertension was not reported in four ABPMs; the severity of nocturnal hypertension was not diagnosed in one ABPM by nine experts and isolated diastolic hypertension was not identified by six experts in two ABPMs.**

Conclusion **This study provides evidence to show that observer variance in reporting ABPMs is common even among experts and that computer-generated interpretative reports of ABPM data improve the diagnostic decisions based on the data generated by 24-h blood pressure recording. *Blood Press Monit* 15:115–123 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Keywords: agreement, ambulatory blood pressure monitoring, concordance, expert interpretation, report agreement

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Introduction

There is abundant evidence that ambulatory blood pressure (ABPM) better predicts clinical outcomes than clinic or office readings and the use of ABPM is commonplace in many countries [1,2]. The use of ABPM is recommended by several national and international guidelines for the management of hypertension [3–11]. Although the guidelines generally acknowledge that ABPM is superior to conventional measurement, and that the technique is indicated in certain circumstances, they inevitably fall back on the conservative recommendation of using repeated conventional blood pressure (BP) measurement in practice and cutoff levels for diagnosis and treatment are based on clinic BP measurement. In the absence of such official guidance, it is unclear how ABPM is used in practice or, indeed, whether there is any uniformity in its use, either between or within centres.

This was first assessed by McGowan *et al.* [12] by comparing the interpretation of ABPM records between experts. The Edinburgh Direct Access Ambulatory monitoring service has a database comprising of 13 000 readings requested by doctors in primary care. A random selection of 252 recordings was made and the doctor responsible for the initial report repeated the exercise blind. The same advice was given in 94.4% (236) of recordings. The forms were then presented to eight other individuals (four consultants, two junior doctors and two nurses familiar with ABPM) who were asked to complete a questionnaire to assess decision-making. On the basis of these results, it was concluded that absolute concordance of decision-making was only 5% and concordance with the modal advice for each report varied from approximately 20% to close to 100%. The nurses regularly exposed to ABPM were the most consistent in their decision-making. The results showed that clinicians, faced with identical ABPM data, did not agree on a decision whether to recommend antihypertensive medication or not. What was more surprising was the wide range of BP levels used by experts as thresholds for initiating therapy. It was

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Table 1 Summary results of questionnaire analysis

Questionnaire responses			17
How often do you use ABPM to confirm a diagnosis of hypertension?	Always		3
	In most cases		8
	Sometimes		6
Do you use ABPM to confirm a diagnosis in low risk patients?	Yes		14[a]
	No		3
Do you use ABPM to confirm diagnosis in patients with target organ damage?	Yes		11[a]
	No		6
Do you use ABPM to confirm diagnosis in other circumstances?	To ascertain treatment efficacy		7
	In suspected masked hypertension		5
	In suspected white coat hypertension		4
	To check home blood pressure		4
	To determine BP variability		3
	To diagnose resistant hypertension		2
	In elderly patients with hypertension		2
	In newly diagnosed hypertensive patients		2
	In patients with previous CV event		2
	In patients without target organ damage		1
	In patients with suspected hypotension		1
	For annual check-up		1
	In symptomatic patients		1
	In pregnant women with hypertension		1
	In patients under 40 years of age with hypertension		1
Do you have a threshold level for normality?	Daytime SBP/DBP	140/85	1
		135/85 (ESH)[b]	10
		130/85 (IDACO)[b]	3
		130/80	2
		None	1
	Night -time SBP/DBP	125/75	1
		120/75	1
		120/70 (ESH)[b]	10
		115/75	1
		115/65	1
		110/70 (IDACO)[b]	1
		None	2
	24-h SBP/DBP	130/80 (ESH)[b]	10
		125/80 or 125/79 (ESH)[b]	3
		125/75 (IDACO)[b]	1
		120/75	1
		None	2
How long did the 12 ABPM interpretations take you in minutes?[c]		Median	32 min 30 s
		Mean	41 min 11 s
		SD	29 min 37 s
		Maximum	120 min
		Minimum	10 min

ABPM, ambulatory blood pressure measurement; CV, cardiovascular; DBP, diastolic blood pressure; ESH, European Society of Hypertension; IDACO, International Database on Ambulatory blood pressure monitoring in relation to Cardiovascular Outcomes.
[a]Includes one 'yes' by inference to 'always' response in the leading question.
[b]ESH thresholds Day time 130–135/85 Night-time 120/70 24-h 125–130/80. IDACO thresholds Day time 130/85 Night -time 110/70 24-h 125/75.
[c]There were 16 responses. One responder gave 3 min and one 1–2 min. Counting these as 'per ABPM', they were multiplied by 12 to give 36 and (using 1.5 for 1–2) 18 min respectively.

concluded that, if experts could not agree, then the only alternative would be to use computerized assessment so as to standardize ABPM interpretation.

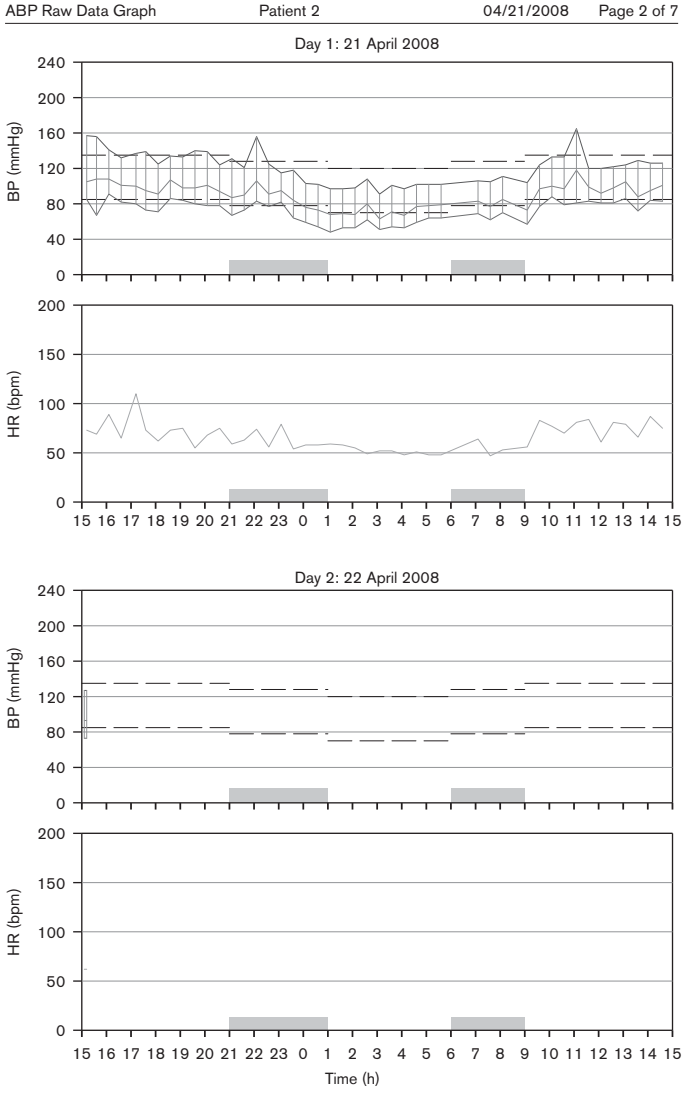
The only ABPM software program providing an interpretative analysis according to the measurement guideline of the European Society of Hypertension (ESH) is the dabl®ABPM system (dabl Limited, Ireland. *www.dabl.ie*), [2,5] and the objective of the study was to assess the accuracy of diagnostic reporting between clinicians and this computerized methodology. In the original Edinburgh study, the data presented to the observers allowed for the comparison of treatment decisions but, as the dabl®ABPM system does not (as yet) make treatment suggestions, the comparison between the dabl®ABPM system and the observers was limited to interpretative (diagnostic) decisions.

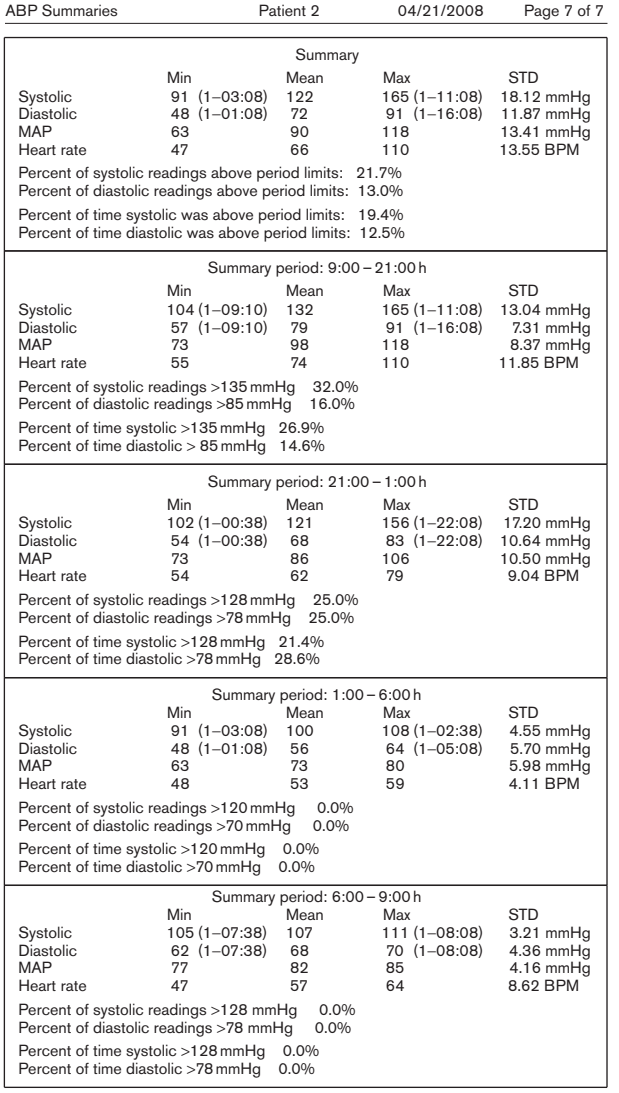
Methods

Observer selection

All 26 members of the dabl®Educational Advisory Board, who are experts in hypertension management, were invited to act as observers.

Fig. 1





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Summary

	Min	Mean	Max	STD
Systolic	91 (1–03:08)	122	165 (1–11:08)	18.12 mmHg
Diastolic	48 (1–01:08)	72	91 (1–16:08)	11.87 mmHg
MAP	63	90	118	13.41 mmHg
Heart rate	47	66	110	13.55 BPM

Percent of systolic readings above period limits: 21.7%
Percent of diastolic readings above period limits: 13.0%
Percent of time systolic was above period limits: 19.4%
Percent of time diastolic was above period limits: 12.5%

Summary period: 9:00 – 21:00 h

	Min	Mean	Max	STD
Systolic	104 (1–09:10)	132	165 (1–11:08)	13.04 mmHg
Diastolic	57 (1–09:10)	79	91 (1–16:08)	7.31 mmHg
MAP	73	98	118	8.37 mmHg
Heart rate	55	74	110	11.85 BPM

Percent of systolic readings >135 mmHg 32.0%
Percent of diastolic readings >85 mmHg 16.0%
Percent of time systolic >135 mmHg 26.9%
Percent of time diastolic > 85 mmHg 14.6%

Summary period: 21:00 – 1:00 h

	Min	Mean	Max	STD
Systolic	102 (1–00:38)	121	156 (1–22:08)	17.20 mmHg
Diastolic	54 (1–00:38)	68	83 (1–22:08)	10.64 mmHg
MAP	73	86	106	10.50 mmHg
Heart rate	54	62	79	9.04 BPM

Percent of systolic readings >128 mmHg 25.0%
Percent of diastolic readings >78 mmHg 25.0%
Percent of time systolic >128 mmHg 21.4%
Percent of time diastolic >78 mmHg 28.6%

Summary period: 1:00 – 6:00 h

	Min	Mean	Max	STD
Systolic	91 (1–03:08)	100	108 (1–02:38)	4.55 mmHg
Diastolic	48 (1–01:08)	56	64 (1–05:08)	5.70 mmHg
MAP	63	73	80	5.98 mmHg
Heart rate	48	53	59	4.11 BPM

Percent of systolic readings >120 mmHg 0.0%
Percent of diastolic readings >70 mmHg 0.0%
Percent of time systolic >120 mmHg 0.0%
Percent of time diastolic >70 mmHg 0.0%

Summary period: 6:00 – 9:00 h

	Min	Mean	Max	STD
Systolic	105 (1–07:38)	107	111 (1–08:08)	3.21 mmHg
Diastolic	62 (1–07:38)	68	70 (1–08:08)	4.36 mmHg
MAP	77	82	85	4.16 mmHg
Heart rate	47	57	64	8.62 BPM

Percent of systolic readings >128 mmHg 0.0%
Percent of diastolic readings >78 mmHg 0.0%
Percent of time systolic >128 mmHg 0.0%
Percent of time diastolic >78 mmHg 0.0%

Two example pages from a seven-page Spacelabs report showing plots and statistics. HR, heart rate; MAP, mean arterial pressure.

Observer questionnaire

Each member was sent a questionnaire to ascertain the criteria applied for ABPM analysis and the thresholds of abnormality used by each observer (Table 1).

Ambulatory blood pressure measurement reports

Twelve ABPMs were selected so as to be representative of common ABPM patterns: normal ABPM record with dipping pattern; white-coat hypertension in first hour – normal day and night-time BP (Fig. 1); white-coat effect first hour – moderate day and night-time hypertension; hypertension (moderate-to-severe); non-dipping pattern (normal day, similar BP at night); nondipping pattern (normal day, more elevated at night); nondipping pattern (moderate hypertension); isolated systolic hypertension; isolated diastolic hypertension; autonomic failure: daytime hypotension with nocturnal hypertension. Each observer was asked to complete a questionnaire and to evaluate the ABPMs that were anonymized and presented as Spacelabs reports (Fig. 1).

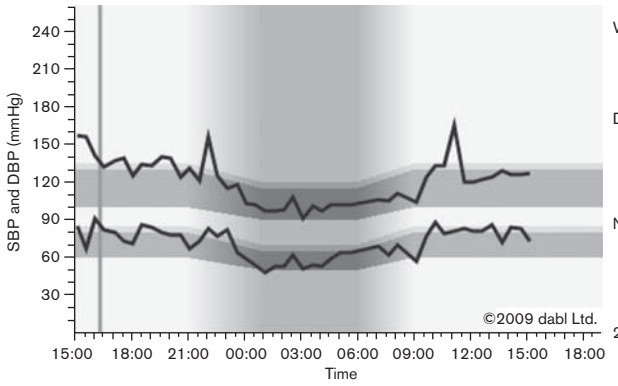
dabl ambulatory blood pressure measurement system

Blind to the observers, the corresponding dabl reports were generated (Fig. 2) and the automatic interpretations, generated according to the ESH guideline on blood pressure measurement [5], were extracted. Mean ABPMs from both systems were compared for anomalies.

Comparison of observer v dabl ambulatory blood pressure measurement data

Both sets of data were analysed for interobserver variability, observer v dabl®ABPM consistency and the time taken for observer reportage.

Fig. 2



White-coat window	SBP	DBP	HR
Readings	3	3	3
First hour max	157	91	89
Load	51	15	0
Daytime (09:00–21:00 h)			
Readings	22	22	22
Mean	130	79	73
SD	11	7	12
Load	12	2	2
Night-time (01:00–06:00 h)			
Readings	10	10	10
Mean	100	56	52
SD	5	6	4
Load	0	0	0
24 h			
Readings	43	43	43
Mean	120	71	65
SD	17	12	13
Load	10	2	1
Dip%	23	29	29

dabl assessment:
The ABPM suggests white-coat hypertension (157/91 mmHg) with otherwise normal daytime systolic blood pressure (130 mmHg), optimal daytime diastolic blood pressure (79 mmHg) and optimal night-time blood pressure (100/56 mmHg).

Extract from the corresponding one-page dabl report showing plot, statistics and interpretation. DBP, diastolic blood pressure; HR, heart rate; SBP, systolic blood pressure.

The analysis consisted of identifying whether or not hypertension was present and, if so, the type of hypertension, for example, isolated systolic hypertension.

The dipping status was also analysed. An ABPM dipping status was marked as 'dipper' if this was stated in the report or if the presence of a dip was necessarily inferred from the report; for example, if a lower level night-time pressure than daytime pressure was stated. An ABPM dipping status was marked as 'nondipper' if either nondipper or reverse dipper was stated in the report or, if the absence of a dip could be inferred from the report; for example, if a higher level of night-time pressure than daytime pressure was stated. ABPM dipping status was marked as 'not stated' if no direct statement was provided and if it was not possible to infer the status from the report, for example, 'high daytime and night-time pressure'.

The phenomena of white-coat hypertension, white-coat effect and more severe hypertension when stated by the experts were also assessed.

Results

Observers

Seventeen of 26 invited experts completed the questionnaire (Appendix). The remaining nine did not respond to the invitation.

Ambulatory blood pressure measurement reports

The results of the questionnaire on the use of ABPM are shown in Table 1. There was some variation in the thresholds. Those that matched the ESH or the International Database on Ambulatory blood pressure monitoring in relation to Cardiovascular Outcomes (IDACO) guidelines are indicated in this table [4,5].

The daytime and night-time mean BPs as reported by the Spacelabs and dabl systems are shown in Table 2; small differences are observed in some cases but the differences do not affect classification as defined by either the ESH or the IDACO guidelines [4,5] (Table 2). The comparative analyses between the automatically interpreted dabl®ABPM reports and the observer interpreted Spacelabs reports are summarised in Tables 3 and 4.

Common patterns were not diagnosed by the experts in a number of instances: isolated diastolic hypertension (three experts in ABPM 3); isolated systolic hypertension (three experts in ABPM 11) (Table 3). On occasions incorrect diagnoses were made, for example, in ABPM 2 (Fig. 2), five experts diagnosed isolated systolic hypertension although the blood pressure levels were normal; in ABPM 5, seven experts identified abnormalities despite normal daytime and night-time blood pressures.

Six of the ABPMs had a nocturnal dip in systolic BP of less than 10%. In the three ABPMs (1, 6 and 8) who had optimal daytime pressure and a higher night-time pressure, this was identified clearly in 50 of the 51 (3×17) reports. However, once the drop became positive, there were conflicting diagnoses. In ABPM 4, which had optimal daytime mean pressure but an upper normal night-time mean pressure with just five pressures above normal over the whole ABPM, eight experts indicated a normal nondipper pattern as suggested by the mean pressures; two indicated a normal dipper pattern, one nocturnal hypertension and one diagnosed autonomic failure. Where hypertensive patients were also nondippers, the tendency was not to indicate it (nine experts in the case of ABPM 10 and eight in the case of ABPM 12) or, where the dip was close to 10%, to indicate a dip (three experts in the case of ABPM 12).

Table 2 Mean blood pressures, as determined by the Spacelabs and dabl systems

	Daytime (09:00–21:00 h) mean BP (mmHg)		Night-time (01:00–06:00 h) mean BP (mmHg)	
ABPM	Spacelabs	dabl	Spacelabs	dabl
1	122/70	122/69	133/79	132/79
2	132/79	130/79	100/56	100/56
3	129/96	128/96	111/79	110/77
4	120/71	123/72	115/63	116/62
5	130/84	130/84	115/67	117/68
6	117/73	116/72	133/76	134/77
7	172/115	172/116	144/90	144/90
8	115/68	112/66	131/79	131/79
9	167/104	166/102	142/86	143/86
10	164/100	168/102	157/101	157/101
11	168/80	170/82	148/67	147/65
12	161/106	161/104	147/91	147/91

The dabl system uses time weighted mean values and automatically separates measurements in the first hour for white-coat window results. The daytime and night-time periods were set to the same values on both systems. The Spacelabs system does not automatically provide white-coat window results and whether or not time weighting is used is not known to the authors.
ABPM, ambulatory blood pressure measurement; BP, blood pressure.

In the largest dippers [24% (ABPM 2, Fig. 2) and 16% (ABPM 7)] no experts indicated a nondipping pattern but only eight and seven experts respectively indicated the dipping pattern. Despite dips of 15 and 11.5%, respectively, for ABPMs 9 and 5, dipping and nondipping patterns were each indicated by four experts in both instances.

Though white coat hypertension is often associated with a high clinic BP and a normal ABPM, it has also been described for ABPM patterns without an accompanying clinic BP [13]. ABPM 2 exhibited this phenomenon but it was identified by only five experts (Table 4). Similarly, a white coat effect was present in four ABPMs but it was not identified by all experts (by 12 experts in ABPM 2 (Fig. 2); by nine experts in ABPM 5; by 14 experts in ABPM 8 and ABPM 9; by 15 experts in ABPM 12). An indication of the severity of hypertension was not made in a number of ABPMs: (seven experts in ABPM 7; 11 experts in ABPM 9; 14 experts in ABPM 11; nine experts in ABPM 12).

Discussion

ABPM is increasingly being incorporated into routine clinical practice because it provides more information in guiding the management of patients with hypertension. The advantages for ABPM are many. First and foremost, the technique simply gives more measurements than conventional measurement, and the real blood pressure is reflected more accurately by repeated measurements; ABPM provides a profile of blood pressure away from the medical environment, thereby allowing identification of individuals with a white coat response, or masked hypertension, who are in need of careful management; ABPM shows blood pressure behaviour over a 24-h period, which contrasts with the snapshot of blood pressure under artificial circumstances using a technique which is prone to inaccuracies, so that the efficacy of antihypertensive medication over a 24-h period becomes apparent rather than relying on one or a few conventional measurements confined to a short period of the diurnal cycle; ABPM can identify patients with abnormal patterns of nocturnal blood pressure – dippers and nondippers, extreme and reverse dippers, morning surge and the technique can show a number of patterns of blood pressure behaviour, which may be relevant to clinical management – isolated systolic and isolated diastolic hypertension, postprandial hypotension, autonomic failure, etc. Finally and importantly, evidence is now available from longitudinal studies that ABPM is a much stronger predictor of cardiovascular morbidity and mortality than conventional measurement – in other words, ABPM identifies patients with hypertension (and individuals whose blood pressure is normal) who are at risk of future cardiovascular events. Moreover, the evidence is growing that nocturnal blood pressure measured by ABPM may be the most sensitive predictor of cardiovascular outcome, from which it follows that the measurement of night-time blood pressure should be an important part of clinical practice [14].

The ESH recommendations for conventional, ambulatory and home blood pressure measurement, which were written 'to serve as a reference source for other guidelines relating to hypertension and cardiovascular disease', identify the patterns that may be obtained with ABPM and the levels of BP used in the definitions of severity of BP with ABPM are stated [5]. However, as with all techniques that influence clinical practice, it is prudent to examine the consistency and accuracy of the information deriving from new methodologies on diagnostic decisions. This issue was first examined by comparing the interpretation of ABPM records between experts [12]. There was considerable variation between clinicians in the interpretation of identical ABPM data, suggesting that it might be necessary to investigate the potential of computerized systems to standardize analyses of ABPM data. In this study, experts in hypertension management and the use of ABPM methodology were asked to report on 12 common ABPM patterns and their responses were

Table 3 Analysis of ambulatory blood pressure measurement reports

ABPM	dabl generated report BP levels as recommended by ESH guidelines	Analysis of diagnosis and dipping status Results as indicated by guidelines are highlighted

1 The ABPM suggests optimal daytime blood pressure (122/69 mmHg) and mild night-time systolic and diastolic hypertension (132/79 mmHg)

	Dipping status −9.0/−12.9%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
Night HBP		16		16
Normal			1	1
Total		16	1	17

2 The ABPM suggests white-coat hypertension (157/91 mmHg) with otherwise normal daytime systolic blood pressure (130 mmHg), optimal daytime diastolic blood pressure (79 mmHg) and optimal night-time blood pressure (100/56 mmHg)

	Dipping status 24.2/29.1%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
Normal	4		8	12
ISH	4		1	5
Total	8		9	17

3 The ABPM suggests mild 24-h isolated diastolic hypertension (128/96 mmHg daytime, 110/77 mmHg night-time)

	Dipping status 14.0/17.7%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
24 h IDH	3		10	13
Day IDH, Night HBP		1		1
Normal	2		1	3
Total	5	1	11	17

4 The ABPM suggests optimal daytime blood pressure (123/72 mmHg), normal night-time systolic blood pressure (116 mmHg) and optimal night-time diastolic blood pressure (62 mmHg)

	Dipping status 4.2/11.3%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
Normal	2	8		15
Night HBP		1	5	1
Autonomic Failure		1		1
Total	2	10	5	17

5 The ABPM suggests white-coat hypertension (157/92 mmHg) with otherwise normal 24-h blood pressure (130/84 mmHg daytime, 117/68 mmHg night-time)

	Dipping status 11.5/20.2%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
Normal	3		7	10
Night HBP		3		3
Day HBP	1			1
IDH		1	2	3
Total	4	4	9	17

Table 3 (*continued*)

ABPM	dabl generated report BP levels as recommended by ESH guidelines	Analysis of diagnosis and dipping status Results as indicated by guidelines are highlighted

6 — The ABPM suggests optimal daytime blood pressure (116/72 mmHg) and mild night-time systolic and diastolic hypertension (134/77 mmHg)

	Dipping status −13.7/−4.1%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
Night HBP		16		16
Day low, Night HBP		1		1
Total		17		17

7 — The ABPM suggests severe daytime systolic and diastolic hypertension (172/116 mmHg) and moderate night-time systolic and diastolic hypertension (144/90 mmHg)

	Dipping status 16.3/21.7%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
HBP	7		10	17

8 — The ABPM suggests optimal daytime blood pressure (112/66 mmHg) and mild night-time systolic and diastolic hypertension (131/79 mmHg) with a white-coat effect (143/79 mmHg)

	Dipping status −13.9/−16.2%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
Night HBP		16		16
Night ISH		1		1
Total		17		17

9 — The ABPM suggests moderate 24-hour systolic and diastolic hypertension (166/102 mmHg daytime, 143/87 mmHg night-time) with a white-coat effect (183/115 mmHg)

	Dipping status 15.0/17.3%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
HBP	4	4	9	17

10 — The ABPM suggests moderate daytime systolic and diastolic hypertension (168/102 mmHg) and severe night-time systolic and diastolic hypertension (157/101 mmHg)

	Dipping status 4.3/−1.0%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
HBP		8	9	17

11 — The ABPM suggests moderate 24-h isolated systolic hypertension (170/82 mmHg daytime, 147/65 mmHg night-time)

	Dipping status −11.9/−16.3%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
ISH	3	2	9	14
HBP		1	2	3
Total	3	3	11	17

12 — The ABPM suggests moderate 24-h systolic and diastolic hypertension (161/104 mmHg daytime, 147/91 mmHg night-time) with a white-coat effect (187/134 mmHg)

	Dipping status 8.7/14.2%			
BP Diagnosis	Dipper	Nondipper	Not stated	Total
HBP	3	6	8	17

ABPM, ambulatory blood pressure measurement; BP, blood pressure; ESH, European Society of Hypertension; HBP, hypertension; IDH, isolated diastolic hypertension; ISH, isolated systolic hypertension.

then compared with a computerized software system that generates an interpretative report (dabl®ABPM, dabl Limited, Ireland. *www.dabl.ie*).

There was considerable variation in the interpretation of ABPM data between experts (Table 3). The only ABPMs in which there was almost total concordance were ABPM 1 and ABPM 6. Common patterns, such as isolated diastolic hypertension and isolated systolic hypertension, were not diagnosed and on occasions incorrect diagnoses were made; for example, in one ABPM, showing white coat hypertension (Fig. 2), five experts diagnosed isolated

Table 4 White-coat-hypertension/effect and blood pressure severity

ABPM	Condition	Stated	Not stated
2	White-coat HBP	5	12
5	White-coat HBP	8	9
7	HBP severity	10	7
8	White-coat effect	3	14
9	White-coat effect	3	14
	HBP severity	6	11
10	HBP severity	8	9
	Nondipper, greater night-time severity	8	9
11	HBP severity	3	14
12	White-coat effect	2	15
	HBP severity	8	9

ABPM, ambulatory blood pressure measurement; HBP, hypertension.

systolic hypertension although, apart from three spikes, the blood pressure levels were largely normal. In one ABPM, with normal daytime and night-time blood pressures, seven experts identified abnormalities. These were broadly grouped into three general diagnoses but there were several subvariations. This was one of three ABPMs where only three experts agreed as to the general pattern and dipping according to the literature.

There was consistency in identifying nondipping only when there was an actual rise in nocturnal pressure. Similarly, dipping had to be very pronounced and obvious before there was consistency and, even then, the phenomenon was identified in only half of the ABPMs. Between these pronounced patterns, there was a lot of disagreement. In some instances, experts remarked that the mean pressures and the plots did not appear to tally and they may have differed in the diagnosis – some with the mean pressures, some with the plot.

White-coat hypertension and white-coat effect, although obvious in many instances, were not identified in the majority of cases (Table 4). An indication of the severity of hypertension was not made in a number of ABPMs and the added severity of nocturnal hypertension in a nondipper was not diagnosed by nine experts in one ABPM.

This study demonstrates that the introduction of the human observer into ABPM brings an unacceptable degree of variance to interpretation of the data generated by the technique, and that this can be removed by using computer-generated interpretative reports. Indeed the situation is not altogether dissimilar to the inaccuracy the human observer brings to the technique of conventional blood pressure measurement. Computer-generated reports should be seen, however, as a means of standardising the analysis of data and not as a substitute for the physician who is free to modify the interpretation within the overall context of the many other factors that comprise the cardiovascular profile of a given patient.

Software interpretation is based on a mathematical analysis of the readings, and determinants, derived from published guidelines. Consistency is guaranteed. Experts may even differ more than physicians who are not as familiar with all the nuances of ABPM patterns. The latter group are more likely to look at the mean values and little else. Different experts may have conducted research into different aspects of ABPM patterns and this may have influenced their interpretation. This does not mean that they are necessarily wrong, but rather that the variation of interpretation demonstrates the evolution and the complexity in the understanding of ambulatory blood pressure measurement. Nonetheless, this tendency shows, all the more, the importance of having a consistent basic interpretation that reflects current accepted recommendations. Indeed, this may also highlight to experts where there may be shortcomings in the recommendations and where the interpretative software of computerized systems needs to be updated in pace with evidence-based research.

In conclusion, this study provides evidence to show that computer-generated interpretative reports of ABPM data improve the diagnostic decisions based on the data generated by 24-h blood pressure recording.

Acknowledgements

Conflicts of interest: E.O.B. and N.A. have contributed financially to the development of the dabl®ABPM software program for ambulatory blood pressure measurement and are members of the board of dabl Limited, Dublin, Ireland (*www.dabl.ie*).

References

1 Pickering TG, Shimbo D, Haas D. Ambulatory blood-pressure monitoring. *N Engl J Med* 2006; **354**:2368–2374.
2 O'Brien E. Ambulatory blood pressure measurement. The case for implementation in primary care. *Hypertension* 2008; **51**:1435–1441.
3 Mancia G, De Backer G, Dominiczak A, Cifkova R, Fagard R, Germano G, *et al.* The Task Force for the Management of Arterial Hypertension of the European Society of Hypertension (ESH) and of the European Society of Cardiology (ESC). 2007 Guidelines for the Management of Arterial Hypertension. *Journal of Hypertension* 2007; **25**:1105–1187.
4 Kikuya M, Hansen TW, Thijs L, Björklund-Bodegård K, Kuznetsova T, Ohkubo T, *et al.*; on behalf of the International Database on Ambulatory blood pressure monitoring in relation to Cardiovascular Outcomes (IDACO) Investigators. Diagnostic thresholds for ambulatory blood pressure monitoring based on 10-year cardiovascular risk. *Circulation* 2007; **115**:2145–2152.
5 O'Brien E, Asmar R, Beilin L, Imai Y, Mallion J-M, Mancia G, *et al.*; on behalf of the European Society of Hypertension Working Group on Blood Pressure Monitoring. European Society of Hypertension recommendations for conventional, ambulatory and home blood pressure measurement. *J Hypertens* 2003; **21**:821–848.
6 Pickering T. Recommendations for the use of home (self) and ambulatory blood pressure monitoring. American Society of Hypertension Ad Hoc Panel. *Am J Hypertens* 1996; **9**:1–11.
7 Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN, *et al.* Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals from the subcommittee of professional and public education of the american heart association council on high blood pressure research. *Hypertension* 2005; **45**:142–161.
8 Williams B, Poulter NR, Brown MJ, Davis M, McInnes GT, Potter JF, *et al.* Guidelines for management of hypertension: report of the fourth working party of the British Hypertension Society, 2004-BHS IV. *J Hum Hypertens* 2004; **18**:139–185.

9 1999 World Health Organization-International Society of Hypertension guidelines for the management of hypertension. *J Hypertens* 1999; **17**:151–183.
10 McGrath BP. Ambulatory blood pressure monitoring. *Med J Aus* 2002; **176**:588–592.
11 Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL Jr, *et al.*; and the National High BP Education Program Coordinating Committee. Seventh Report of The Joint National Committee on prevention, detection, evaluation, and treatment of high BP. *Hypertension* 2003; **42**:1206–1252.
12 McGowan N, Gough K, Maxwell S, Padfield PL. How do we use ambulatory measurement of blood pressure in the management of hypertension? *Blood Press Monit* 2007; **12**:385–386.
13 Owens P, Atkins N, O'Brien E. Diagnosis of white coat hypertension by ambulatory blood pressure monitoring. *Hypertension* 1999; **34**:267–272.
14 Dolan E, Stanton A, Thijs L, Hinedi K, Atkins N, McClory S, *et al.* Superiority of ambulatory over clinic blood pressure measurement in predicting mortality: The Dublin Outcome Study. *Hypertension* 2005; **46**:156–161.

Appendix

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