Schedules for Self-monitoring Blood Pressure: A Systematic Review

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BACKGROUND
Self-monitoring of blood pressure better predicts prognosis than clinic measurement, is popular with patients, and endorsed in hypertension guidelines. However, there is uncertainty over the optimal self-monitoring schedule. We therefore aimed to determine the optimum schedule to predict future cardiovascular events and determine "true" underlying blood pressure.

METHODS
Six electronic databases were searched from November 2009 (updating a National Institute for Health and Care Excellence [NICE] systematic review) to April 2017. Studies that compared aspects of self-monitoring schedules to either prognosis or reliability/reproducibility in hypertensive adults were included. Data on study and population characteristics, self-monitoring regime, and outcomes were extracted by 2 reviewers independently.

RESULTS
From 5,164 unique articles identified, 25 met the inclusion criteria. Twelve studies were included from the original NICE review, making a total of 37 studies. Increasing the number of days of measurement improved prognostic power: 72%–91% of the theoretical maximum predictive value (asymptotic maximum hazard ratio) was reached by 3 days and 86%–96% by 7 days. Increasing beyond 3 days of measurement did not result in better correlation with ambulatory monitoring. There was no convincing evidence that the timing or number of readings per day had an effect, or that ignoring the first day's measurement was necessary.

CONCLUSIONS
Home blood pressure should be measured for 3 days, increased to 7 only when mean blood pressure is close to a diagnostic or treatment threshold. Other aspects of a monitoring schedule can be flexible to facilitate patient uptake of and adherence with self-monitoring.

Keywords: blood pressure; blood pressure monitoring; hypertension; regression dilution; schedule; self-monitoring; systematic review.

doi:10.1093/ajh/hpy185

Hypertension is a key risk factor for cardiovascular disease, the most important cause of morbidity and mortality worldwide.[1] The detection and subsequent management of hypertension requires appropriate monitoring, and self-monitoring of blood pressure (SMBP) is increasingly used for this purpose with endorsement by guidelines worldwide.[2–4] Compared to office blood pressure measurement, home readings better predict end organ damage, provide a more accurate diagnosis of hypertension, and improve patient involvement in their own care.[5–7]

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Initially submitted October 11, 2018; date of first revision November 22, 2018; accepted for publication December 18, 2018; online publication January 22, 2019.

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Despite the growing popularity of SMBP, there is little agreement as to the optimal self-monitoring schedule. The Japanese Society of Hypertension guidelines recommend 2 readings on each occasion, using the mean of the 2 over 5–7 days.[8] The European Society of Hypertension, along with the American Heart Association and the American Society of Hypertension and National Institute for Health and Care Excellence (NICE), recommend that blood pressure (BP) should be measured on at least 3–4 days and preferably on 7 consecutive days in the morning and evening, with 2 measurements per occasion taken 1–2 minutes apart. The readings taken on the first day should be discarded and then the average of the remaining readings used.[2,3,9] There are no separate schedules recommended for ongoing management of patients with hypertension once the initial diagnosis has been made.

This study aimed to assess the evidence for these various guideline recommendations using the systematic search undertaken for the NICE (2011) Hypertension Guidelines[2] as a starting point, and updating and reappraising the literature.

METHODS

Data sources and searches

Electronic databases (Cochrane Central Register of Controlled Trials [The Cochrane Library, Wiley] (issue 3, March 2017), Medline [OvidSP] (1946–present, in process), Embase [OvidSP] (1974–present), CINAHL [EBSCOhost] (1980–present), Science Citation Index [Web of Knowledge] (1945–present), and Conference Proceedings Citation Index–Science [Web of Knowledge] (1945–present)) were searched up to April 2017, for articles published from November 2009 onward based on a search strategy developed for the NICE Hypertension Guidelines.[2] The original NICE search was of Medline, Embase, CINAHL, and the Cochrane Library from inception to November 2010 and the update search dates were chosen with some overlap to ensure relevant studies would not be missed. The search strategy for Medline can be found in Supplementary Appendix 1, which was then adapted for the other databases.

Study selection

Two reviewers independently reviewed the titles and abstracts of potentially relevant articles for inclusion. Full papers of potentially eligible articles resulting from the search plus all included articles from the NICE review were then assessed.

All study design types were eligible for inclusion. Studies must have assessed SMBP defined as BP measurement by a patient or carer, without the involvement of a health professional. It was anticipated that included studies would compare one or more of the following protocol components: number, timing, frequency, and duration of measurements and whether any readings should be discarded, but included all studies that compared any aspects of self-monitoring schedules. Studies that assessed regimes in terms of BP variability, machine validation studies, those containing inadequate description of the self-monitoring protocol, or where self-monitoring was not conducted using an upper arm device were excluded.

Participants of interest were adults (18 years and older) with treated or untreated hypertension, who may or may not have had a comorbid disease. Reliability/reproducibility studies were included where at least some of the participants had hypertension or were being assessed to confirm suspicion of hypertension (e.g., where a previous clinic reading had indicated hypertension), and similarly prognostic studies (which were all conducted in the general population) where at least some participants either had hypertension or were treated with antihypertensive medication.

Articles written in a language other than English were translated to assess eligibility.

Data extraction and quality assessment

Data from each article were extracted independently by at least 2 reviewers using piloted forms (Supplementary Appendix 2). Information collected included study (e.g., country, hypothesis) and sample (e.g., sample size, age, comorbidities) characteristics, self-monitoring regime details (e.g., frequency, duration, whether devices used were validated), and outcome measures (see later). Any discrepancies were resolved by consensus.

A priori outcomes of interest varied with the type of study

(1) Prognostic studies: mortality, stroke, myocardial infarction, angina, and heart failure or composites thereof.
(2) Reliability/reproducibility studies: reproducibility of SMBP or correlations with ambulatory blood pressure measurement (ABPM) or office blood pressure measurement.

Methodological quality was assessed using an adaptation of 3 validated checklists: Effective Public Health Practice Project, Downs and Black, and Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2).[10–12] Additional questions about the validation status of the BP monitoring equipment used in each study were incorporated, for which we consulted the dabl Educational Trust and British and Irish Hypertension Society websites[13,14] rather than rely on author-reported validation status (Supplementary Appendix 3 provides details of the methodological quality checklist applied).

Data synthesis and analysis

Imprecision in a measurement makes associations, such as hazard ratios (HRs) or correlations, harder to observe. Averaging over several measurements can reduce imprecision. Hence, a single imprecise measurement will show a weaker apparent association with an outcome, but increasing the number of measurements increases the apparent association.

To enable a consistent measure of comparison, the adjusted HR per 5 mm Hg increase in systolic BP was calculated for prognostic studies across the number of days of readings they considered. Study-specific curves for HR against number of days (n) were estimated by assuming that the reciprocal of estimated log HR was linear in $1/n$, and for estimated correlation coefficient against n by assuming

that the reciprocal of correlation squared was linear in $1/n$. These relationships were derived from standard results for linear regression dilution, which have been shown to apply approximately for HRs, under independence assumptions, when censoring is present and the sample size is large[15] (Supplementary Appendix 4 provides a further explanation of the method of analysis used, including the approach to regression dilution). For each study, the "maximum log hazard ratio" was defined as the asymptotic maximum of the fitted curve on the log HR scale (i.e., the best log HR that could theoretically be achieved given an infinite number of days for measurement) and the fitted log HR at day 3 and day 7 is reported as a percentage of this maximum.

For reliability/reproducibility studies, the correlations reported between systolic and diastolic SMBP and ABPM as the reference standard were summarized. The remaining studies, in particular reliability studies that reported correlations with measures other than ABPM, were considered too dissimilar to group.

RESULTS

A total of 5,164 unique citations were identified of which 297 were assessed in detail along with 13 articles from the NICE search (Figure 1). Thirty-seven studies proved eligible for inclusion in the analysis comprising 25 from the update and 12 from the original NICE search (the remaining

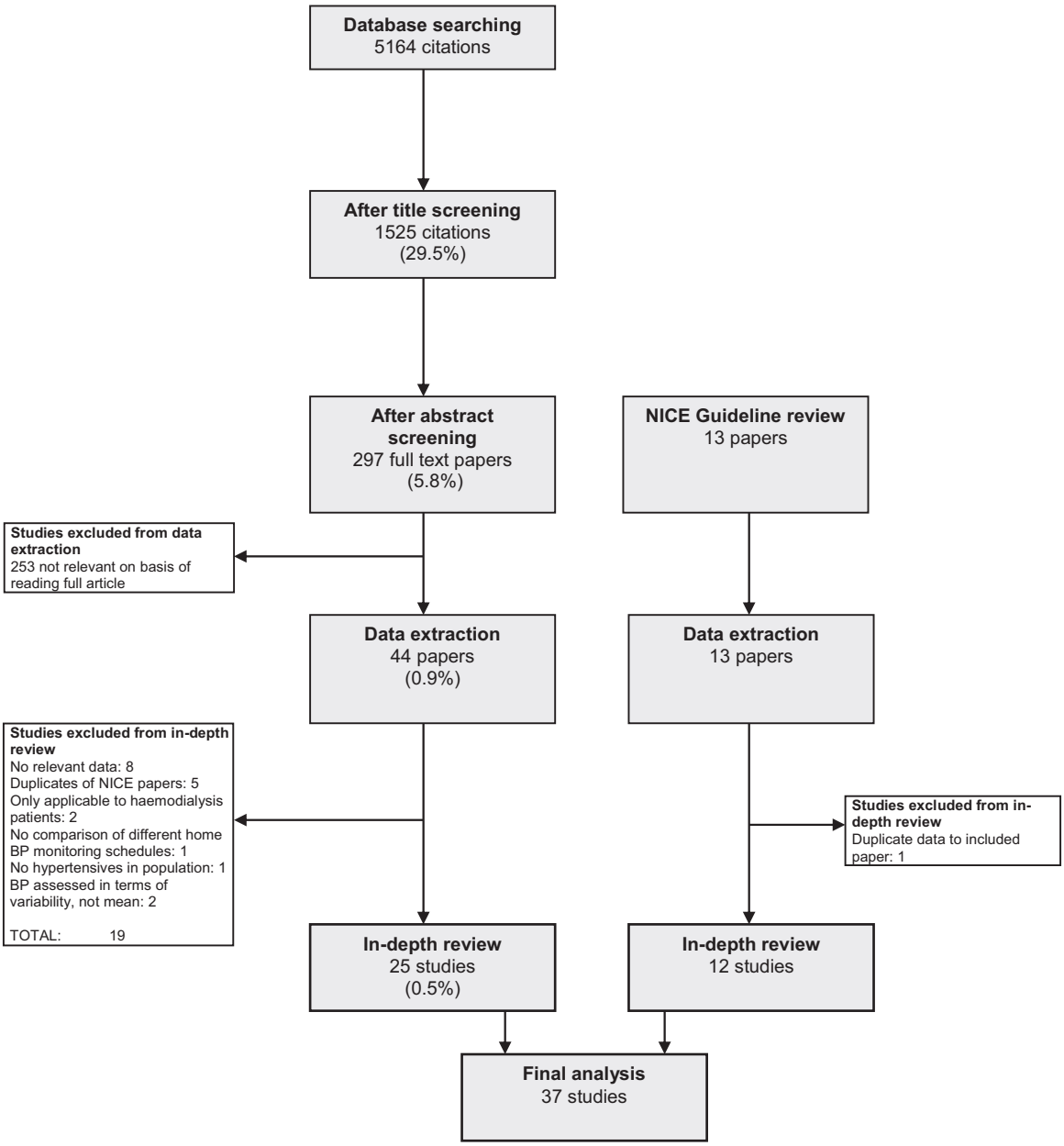

Figure 1. Filtering of papers from searching to synthesis.
Abbreviations: BP, blood pressure; NICE, National Institute for Health and Care Excellence.

article from the NICE review provided only duplicate data). Participants in the included studies (Supplementary Table 1) were drawn from 18 different countries and varied markedly in terms of mean age (range 40–70 years), gender (percentage male 26%–100%), sample size (43–21,591), and the proportion with hypertension and/or on antihypertensive medication (0%–100%).

Of the 37 articles, 10 were prognostic and 27 were reliability/reproducibility studies. The wide range of aspects of monitoring schedule assessed in the included studies is shown in Supplementary Table 2. Owing to the heterogeneity of the self-monitoring protocols, and the variability in the clinical outcomes and analyses in the eligible studies, meta-analysis was not possible.

Methodological issues

All studies had some degree of methodological flaw (or lack of clarity in what was reported), with 16 (43%) studies not clearly using validated devices throughout (Supplementary Table 1). Although selection criteria of participants were generally clear, only 16 (43%) studies used selection methods likely to avoid bias (Supplementary Table 2). Attrition reporting provided reasons for dropouts but typically not the characteristics thereof. Validation (from monitor memory or telemonitoring) of self-monitored readings was only clear and adequate in 10 studies. Reporting of results was generally adequate.

Prognostic studies

The 10 prognostic studies analyzed cohort data from Japan (Ohasama and home blood pressure measurement with Olmesartan Naive patients to Establish Standard Target blood pressure study [HONEST]), Finland (FINN Home), and Greece (Didima), or meta-analyzed data from Ohasama, FINN Home, and an additional Japanese cohort, Tsurugaya, which had not been published separately in a format we could extract relevant data from.[16,17] There was overlap of populations within each cohort but differences in type of regime considered and/or the outcomes assessed. All participants in the prognostic studies were sampled from a general population. Three studies (Supplementary Table 1) had prediction of stroke/transient ischemic attack as the main outcome, whereas 4 used cardiovascular-related events, one considered both types of outcome separately, and 2 used composite cardiovascular end points including stroke.

Figure 2 shows the adjusted log HR per 5 mm Hg increase in systolic BP for each of the 5 studies (1 provided only unadjusted HRs with confidence intervals) that considered how outcome varied by length of monitoring in days (see also Table 1). HRs increased with additional days of readings across the studies with a flattening of the curves after 1 week for the 2 studies with longer follow-up and similar shaped curves for the shorter studies. However, confidence intervals overlapped between the most and least predictive measurement regimes (in terms of days of monitoring).

In Figure 2 the dotted line represents the maximum log HR for the 5 prognostic studies: 86%–96% of the maximum predictive value (asymptotic maximum HR, based on an estimate given infinite number of days measurement) was achieved by 7 days, and 72%–91% by 3 days.

Few data on the impact of time of day were available, but suggested that there was a maximum difference in HR of 0.09 per 5 mm Hg increase in systolic BP with overlapping confidence intervals between morning and/or evening measurements. There was also no convincing difference in prognostic ability when using the first and/or the second measurement on each occasion (Table 2).

Considering the total number of readings added little to the results for number of days, reflecting the limited data on readings per day (Supplementary Table 3). Only 1 prognostic study considered the effect of omitting first-day readings from the analysis, which made no difference to the HR (Table 3).

Analysis of reliability/reproducibility studies

Participants in the 27 reliability/reproducibility studies were largely either treated or untreated patients with hypertension, though populations ranged from heart transplant recipients and renal outpatients to company volunteers and attendees at a health education program (Supplementary Table 1). Three studies shared populations with the Japanese and Finnish prognostic studies.

Of the 20 studies considering reliability/reproducibility, 15 reported correlations with ABPM as the reference standard, 8 using mean daytime ABPM, 5 using 24-hour ABPM, and 2 using both daytime and 24-hour ABPM. These 15 studies were included in the remainder of the analyses.

The correlation between cumulative mean home systolic BP and diastolic blood pressure from 1 to 7 days of monitoring with ABPM as the comparator measurement is shown in Figure 3 (analysis restricted to those studies ($n = 5$) with correlations for at least 3 different counts of days; the dotted line represents the maximum correlation coefficient) and Table 4. Here the curves were very flat and there was no convincing increase in correlation after the fourth day of monitoring. Better than 90% of the maximum correlation with ABPM was achieved by 3 days. In many correlation studies, numbers of participants were small and confidence intervals were wide, but this pattern was observed even in larger studies ($n = 464$).

Data could only be extracted from 3 studies to assess the relationship between correlation with ABPM and the number of readings on each occasion, time of day of 2 readings (Figure 4 and Table 5), and total number of measurements (Table 6). As for the prognostic studies, varying the number of readings on each occasion and time of day of readings appeared to have little impact, while examining the effect of number of measurements overall again largely replicated the results for number of days. Similarly, discarding the readings from the first day of home monitoring made little difference to correlation with ABPM, whether readings more than 3 days or 1 week were being considered (Table 3).

Three studies considered particular aspects of monitoring schedules uniquely—the time interval between readings, a schedule including before-morning micturition and afternoon readings vs. 1 involving post-morning micturition

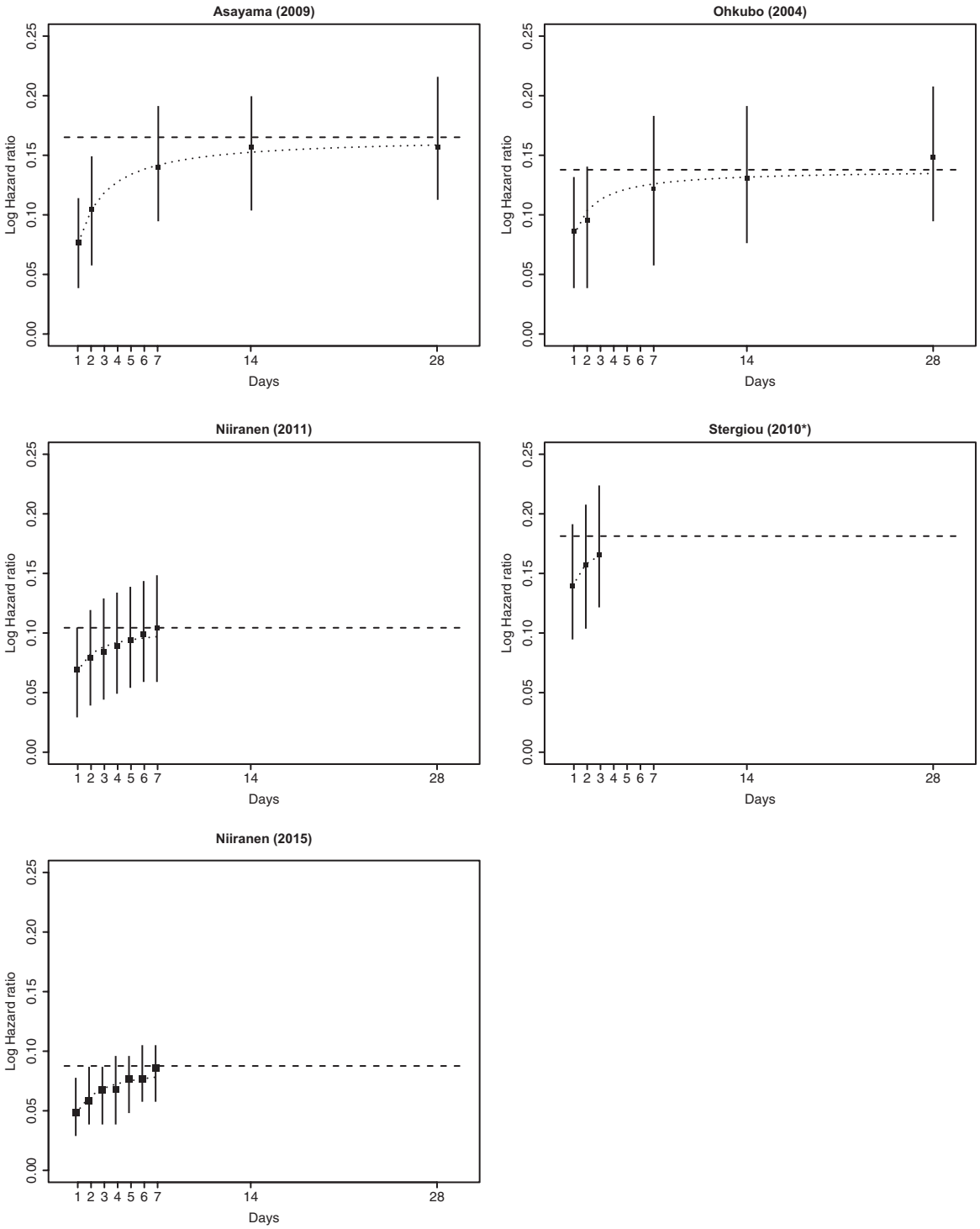

Figure 2. Log hazard ratios per 5 mm Hg for prognostic outcomes by cumulative numbers of days of self-monitoring. *Values from Stergiou (2010) are unadjusted hazard ratios (HRs).

and evening readings, and resting for 5 minutes before readings vs. not resting. However, the complexity of the schedule comparison in 1 study and the small sample size of the other studies prevented drawing any firm conclusions.

No study provided evidence on the timings of readings in relation to medications, how frequently monitoring should be repeated, or on whether fewer readings may be required for routine ongoing management.

Table 1. Adjusted hazard ratios (HRs) per 5 mm Hg increase in systolic blood pressure (SBP) in prognostic studies across number of days of readings

Study (first author; publication date)	Years of follow-up	*N* (events)	Readings per day	Outcome	Adjusted HR per 5 mm Hg increase in systolic BP (95% CI)								
					1 day	2 days	3 days	4 days	5 days	6 days	7 days	14 days	4 weeks
Asayama (2009)[a] Ohasama	11.9 (median)	2,234 (226)	1 daily (1 in the evening)	Stroke and TIA	1.08 (1.04–1.12)	1.11 (1.06–1.16)					1.15 (1.10–1.21)	1.17 (1.11–1.22)	1.17 (1.12–1.24)
Niiranen (2015)[b] Multiple studies	8.3 (median)	4,802 (568)	1 daily (1 in the morning)	CVD events	1.05 (1.03–1.08)	1.06 (1.04–1.09)	1.07 (1.04–1.09)	1.07 (1.04–1.10)	1.08 (1.05–1.10)	1.08 (1.06–1.11)	1.09 (1.06–1.11)		
Niiranen (2013)[b] Multiple studies	Not stated	5,030 (588)	1 daily (1 in the morning)	CVD events							1.09 (1.06–1.11)		
	Not stated	2,762 (360)	1 daily (1 in the morning)	CVD events								1.11 (1.07–1.15)	
	Not stated	4,225 (509)	2 daily (1 in the morning and evening)	CVD events							1.11 (1.08–1.14)		
Niiranen (2011) FINN Home	6.8 (median)	2,081 (162)	4 daily (2 in the morning and evening)	CVD events	1.07 (1.03–1.11)	1.08 (1.04–1.13)	1.09 (1.05–1.14)	1.09 (1.05–1.14)	1.10 (1.06–1.15)	1.10 (1.06–1.15)	1.11 (1.06–1.16)		
Ohkubo (2004)[a] Ohasama	10.6 (mean)	1,491 (136)	1 daily (1 in the morning)	Stroke and TIA	1.09 (1.04–1.14)	1.10 (1.04–1.15)					1.13 (1.06–1.20)	1.14 (1.08–1.21)	1.16 (1.10–1.23)
Stergiou (2010)[c] Didima	8.2 (mean)	662 (67)	4 daily (2 in the morning and evening)	CVD events	1.15		1.18 (1.13–1.25)						

Abbreviations: BP, blood pressure; CI, confidence interval; CVD, cardiovascular disease; TIA, transient ischemic attack.

The references in the tables are cited in Supplementary Table 1.

[a]All 3 studies from the same population, over slightly different time periods with slightly different focus—morning only, evening only, and morning and evening.

[b]These 2 studies both use 3 datasets (including Ohasama and FINN Home). The 2013 study is an abstract before the main paper in 2015, but includes some different analyses.

[c]Study reported unadjusted HRs without CIs (just $P < 0.05$).Values in italics are unadjusted HRs. CIs taken from secondary paper[18]. Adjusted HRs also available from secondary paper but for all measurements (i.e., 3 days) only.

Table 2. Adjusted hazard ratios (HRs) per 5 mm Hg increase in systolic blood pressure (SBP) in prognostic studies across number of readings on each occasion and time of day

Study. (first author; publication date)	Years of follow-up	*N* (events)	Readings schedule	Outcome	Adjusted HR per 5 mm Hg increase in systolic BP (95% CI)						
					Number of readings on each occasion			Time of day			
					All first measurements	All second measurements	All measurements	All morning measurements	All evening measurements	All measurements	Other
Asayama (2006) Ohasama	10.6 (median)	1,766 (156)	2 daily (1 AM and 1 PM) for 4 weeks	Stroke and TIA				1.14 (1.09–1.21)	1.16 (1.10–1.22)	1.17 (1.10–1.23)	
Hoshide (2016) Ohasama	4.0 (mean)	4,278 (74)	6 daily (3 AM and 3 PM) for 14 days	Stroke				1.17 (1.09–1.25)	1.12 (1.04–1.22)	1.18 (1.09–1.28)	
		4,278 (77)		CVD events				0.96 (0.89–1.05)	1.05 (0.96–1.14)	1.00 (0.92–1.10)	
Niiranen (2013)[a] Multiple studies	Not stated	5,030 (588)	1 daily (1 AM) for 7 days	CVD events				1.09 (1.06–1.11)			
	Not stated	4,225 (509)	2 daily (1 AM and 1 PM) for 7 days	CVD events						1.11 (1.08–1.14)	
Niiranen (2011) FINN Home	6.8 (median)	2,081 (162)	4 daily (2 AM and 2 PM) for 7 days	CVD events	1.10 (1.06–1.15)	1.11 (1.07–1.16)	1.11 (1.06–1.16)	1.10 (1.06–1.15)	1.10 (1.06–1.15)	1.11 (1.06–1.16)	
Saito (2016) HONEST	2.0 (mean)	21,591 (280)	4 daily (2 AM and 2 PM) for 2 days over 7 periods	CVD events	1.21 (1.15–1.27)	1.20 (1.14–1.27)	1.21 (1.15–1.27)				
Stergiou (2010)[b] Didima	8.2 (mean)	662 (67)	4 daily (2 AM and 2 PM) for 3 days	CVD events	1.18	1.19	1.18 (1.13–1.25)	1.18	1.17	1.18 (1.13–1.25)	

Abbreviations: BP, blood pressure; CI, confidence interval; CVD, cardiovascular disease; HONEST, home blood pressure measurement with Olmesartan Naive patients to Establish Standard Target blood pressure; TIA, transient ischemic attack.

Kario (2016) reports HRs for blood pressure categories for time of day, rather than per 1/5/10 mm Hg, and so cannot be included in the above table.

[a]This study uses 3 datasets (including Ohasama and FINN Home). The paper is an abstract before the full paper in 2015, but data in this table were only published in this form.

[b]Study reported unadjusted HRs without CIs (just $P < 0.05$).Values in italics are unadjusted HRs. CIs taken from secondary paper: Stergiou GS, Baibas NM, Kalogeropoulos PG. Cardiovascular risk prediction based on home blood pressure measurement: the Didima study. *J Hypertens* 2007; 25: 1590–1596. Adjusted HRs also available from secondary paper but for all measurements only.

Table 3. Effect of discarding the first day of measurement across all types of study (systolic blood pressure)

Study (first author; publication date)	Comparator	*N*	Using all measurements	Omitting measurements from the first day
3 days of home measurement			Correlation with ABPM (95% confidence interval)	
Johansson (2010)	24-hour ABPM	464	0.88 (0.86–0.90)	0.89 (0.87–0.91)
Stergiou (1998)	Daytime ABPM	189	0.68 (0.60–0.75)	0.67 (0.58– 0.74)
Verberk (2006)	Daytime ABPM	216	0.60 (0.51–0.68)	0.60 (0.51–0.68)
	24-hour ABPM	216	0.66 (0.58–0.73)	0.69 (0.61–0.75)
4 days of home measurement			Correlation with ABPM (95% confidence interval)	
Di Monaco (2016)	Daytime ABPM	310	0.59 (0.51–0.65)	0.57 (0.49–0.64)
	24-hour ABPM	310	0.59 (0.51–0.66)	0.57 (0.49–0.64)
Stergiou (1998)	Daytime ABPM	189	0.70 (0.62–0.77)	0.69 (0.61–0.76)
Verberk (2006)	Daytime ABPM	216	0.62 (0.53–0.70)	0.62 (0.53–0.70)
	24-hour ABPM	216	0.68 (0.60–0.75)	0.69 (0.61–0.75)
1 week of home measurement[a]			Correlation with ABPM (95% confidence interval)	
Johansson (2010)	24-hour ABPM	464	0.89 (0.87–0.91)	0.87 (0.85– 0.89)
Nunan (2015)	Daytime ABPM	203	0.67 (0.59–0.74)	0.68 (0.60–0.75)
Stergiou (1998)	Daytime ABPM	189	0.71 (0.63–0.77)	0.71 (0.63–0.77)
Verberk (2006)	Daytime ABPM	216	0.65 (0.57–0.72)	0.65 (0.57–0.72)
	24-hour ABPM	216	0.70 (0.62–0.76)	0.71 (0.64–0.77)
1 week of home measurement[a]			Hazard ratio for future CVD (95% confidence interval)	
Niiranen (2011)	Future CVD	162[b]	1.11 (1.06–1.16)	1.11 (1.06–1.16)

Abbreviations: ABPM, ambulatory blood pressure measurement; CVD, cardiovascular disease.
[a] 1 week refers to 7 days of home measurement, except for Stergiou (1998) where home monitoring was only conducted for 6 days.
[b]162 CVD events.

DISCUSSION

Summary of main findings

The literature has been comprehensively reviewed, finding 37 studies relating self-monitoring regimes to prognosis and/or correlation to reference standard, with the aim of making evidence-based recommendations for future practice. For prognostic studies, only a small increase in precision was gained from undertaking more than 3 days of readings and the results from correlation studies were similar. Such differences are likely only to impact on clinical decision making around diagnostic or treatment thresholds. There was no convincing difference in terms of how many readings were taken per day, whether morning and/or evening measures are used, or whether the first day was removed.

Strengths and limitations of the study

This review used a comprehensive search strategy in multiple databases and all languages, incorporating hand searching, and is unlikely to have missed relevant articles. A thorough assessment of methodological quality was undertaken including assessment of the validation status of the monitors used.[13,14] By estimating study-specific curves for either HR or correlation coefficient against regime, the available data were synthesized in a robust form, despite any heterogeneity. By including a broad range of potential elements of monitoring schedules, this provides the most complete evidence to date on which to base recommendations.

The key weakness of this review is the paucity of studies of prognosis. Despite several different publications, only 4 sources of participants make up the full data set. While covering populations from Japan, Finland, and Greece, these data are lacking large relevant populations, in particular of South Asian and African/African Caribbean origin. Though used in a combined population, 1 cohort (Tsurugaya)[16,17] was included, which has not been published separately in a format we could extract the relevant data from, and hence was only included as part of the Niiranen et al. meta-analysis.

Furthermore, the findings of small differences in both prognostic ability and correlation between different regimes must be tempered by the heterogeneity of design and methodological flaws identified in some studies. This reflected a lack of uniformity of method used between studies, and precluded comparison of more diverse regimes of measurement across multiple studies. Similarly, several studies used unvalidated equipment (Supplementary Table 1).

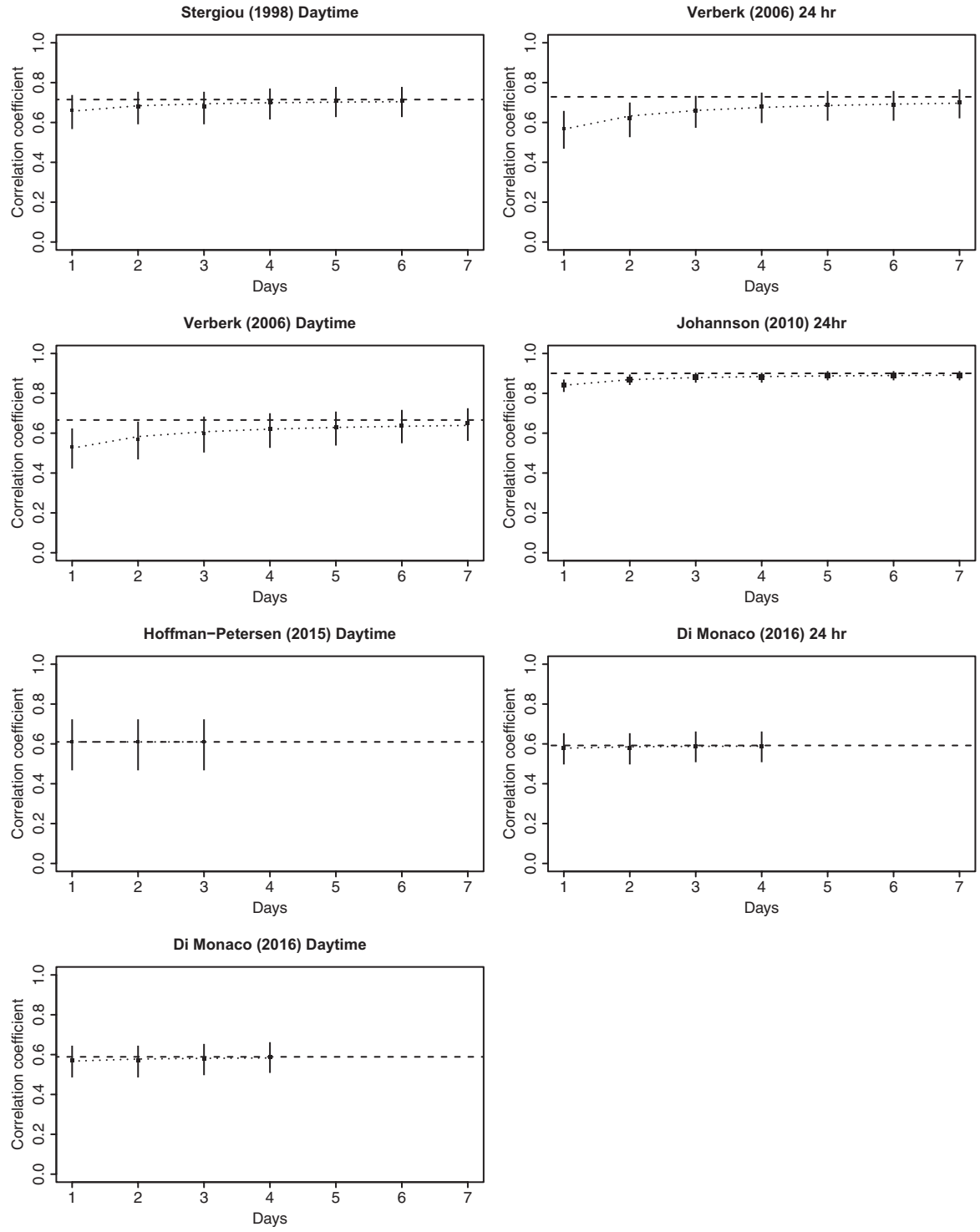

Figure 3. Correlation coefficient between ambulatory blood pressure measurement (ABPM) and self-monitoring of blood pressure (SMBP) by cumulative number of days of self-monitoring.

Comparisons with existing literature

One previous systematic review over a decade ago including 4 reliability/reproducibility studies[19] considered multiple aspects of monitoring schedules but did not include any prognostic studies. In comparison, the current analysis includes 10 prognostic studies and 27 reliability/reproducibility studies. More recently, Niiranen et al.[20] combined 3 cohorts (2 Japanese and 1 Finnish) with consideration of prognosis in terms of number of days per week, but did not assess correlation data or other aspects of a monitoring regime, as the current work has.

Table 4. Correlation with ambulatory blood pressure measurement (ABPM) for reliability/reproducibility studies across number of days of readings and time between readings

Study (first author; publication date)	Measurement schedule	Comparator	*N*	Correlation coefficient between home systolic/diastolic BP and the comparator measurement								
				Time between readings		Number of days (from first day onwards unless otherwise stated)						
				10 seconds	1 minute	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Almeida (2014)	3 days Before-morning micturition and in afternoon: 15 (3 day 1, 6 on days 2 and 3)	24-hour wakefulness ABPM	158					0.769/0.826				
	3 days post-morning micturition and evening: 15 (3 day 1, 6 on days 2 and 3)	Before SMBP						0.722/0.742				
Almeida (2013)	3 days and 33 readings (9 on day 1, 12 on each of day 2 and day 3)	24-hour ABPM	158					0.76/0.80				
	5 days and 27 readings (3 on day 1, 6 on days 2–5)	Day before SMBP								0.61/0.69		
Ambrosi (2014)	7 days (2 readings in the morning and 2 readings in the evening on each day)	24-hour ABPM Within 15 days end of SMBP	58					0.75/0.62			0.71/0.65 (Days 2–7)	
Boivin (2014)	3 readings without rest, i.e., immediately after positioning cuff (AM and PM for 3 days, total 18 readings)	Daytime ABPM	52					0.69/0.66				
	3 readings 5 minutes after first series (AM and PM for 3 days, total 18 readings)	Within 3 days before SMBP						0.70/0.66				
Di Monaco (2016)	4 days (2 readings in the morning and 2 readings in the evening on each day)	Daytime ABPM Day before SMBP	310			0.57/0.72	0.57/0.72	0.58/0.72	0.59/0.72			
		24-hour ABPM Day before SMBP				0.58/0.71	0.58/0.71	0.59/0.71	0.59/0.72			
Eguchi (2009)	4 days per week for 8 weeks (3 readings in the morning and 3 in the evening on each day)	Daytime ABPM ABPM on second visit during SMBP schedule	56	0.712/0.693	0.725/0.673							
Hoffman-Petersen (2015)	4 days. 3 AM (6–8 AM), 3 before dinner (5–7 PM), 3 before bedtime (9–11 PM)	Daytime ABPM Just after completion after SMBP	102			0.61/0.56	0.61/0.55 (days 2–3)	0.69/0.61 (days 2–4)				
Johannson (2010)	7 days (2 readings in the morning and 2 readings in the evening on each day)	24-hour ABPM	464			0.84/0.82	0.87/0.84	0.88/0.85	0.88/0.86	0.89/0.86	0.89/0.87	0.89/0.87
		Timing in relationship to SMBP unclear					0.89/ 0.87 (days 2–3)				0.87/ 0.85 (days 2–7)	

Table 4. *Continued*

Study (first author; publication date)	Measurement schedule	Comparator	*N*	Correlation coefficient between home systolic/diastolic BP and the comparator measurement								
				Time between readings		Number of days (from first day onwards unless otherwise stated)						
				10 seconds	1 minute	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Kim (2015)[a]	7 days (3 readings in the morning and 3 readings in the evening on each day)	24-hour ABPM	266					0.80		0.79		0.79
McGowan (2010)	7 days (2 readings in the morning and 2 readings in the evening on each day)	Daytime ABPM	87								0.72/0.89 (days 2–7)	
		ABPM and SMBP within total 8-day period (i e., ABPM 1 day before or after SMBP)— some ABPM first and some SMBP first										
Muxfeldt (2015)	5 days (3 AM between 6 and 10 AM) and 3 PM between 6 and 10 PM)	Daytime ABPM	240						0.68/0.73 (days 2–5)			
		SMBP initiated day after ABPM										
Nunan (2015)	7 days (2 readings in the morning and 2 in the evening)	Daytime ABPM	203						0.658/0.707 (days 2–5)	0.649/0.703	0.68/0.71 (days 2–6)	0.671/0.708
		After completing SMBP										
Stergiou (1998)	3 work days per week for 2 weeks (2 readings in the morning and 2 readings in the evening on each day)	Daytime ABPM	189			0.66/0.70	0.68/0.73	0.68/0.75	0.70/0.77	0.71/0.78	0.71/0.79	
		Some ABPM first and some SMBP first, one after the other					0.67/0.76 (days 2–3)	0.69/0.77 (days 2–4)	0.71/0.79 (days 2–5)	0.71/0.79 (days 2–6)		
Verberk (2006)	7 days (3 readings in the morning and 3 readings in the evening, with the first of each triplicate discarded)	Daytime ABPM	216			0.53/0.59	0.57/0.61	0.60/0.63	0.62/0.63	0.63/0.66	0.64/0.66	0.65/0.66
		Timing vs. SMBP unclear					0.60/0.61 (days 2–3)	0.62/0.62 (days 2–4) 0.66/0.66 (days 3–5) 0.66/0.67 (days 4–6) 0.64/0.66 (days 5–7)	0.64/0.66 (days 2–5) 0.66/0.67 (days 3–6) 0.66/0.67 (days 4–7)	0.65/0.66 (days 2–6) 0.66/0.67 (days 3–7)	0.65/0.66 (days 2–7)	
		24-hour ABPM	216			0.57/0.61	0.62/0.63	0.66/0.66	0.68/0.66	0.69/0.69	0.69/0.69	0.70/0.69
		Timing vs. SMBP unclear					0.66/0.64 (days 2–3)	0.69/0.66 (days 2–4) 0.71/0.69 (days 3–5) 0.70/0.69 (days 4–6) 0.69/0.68 (days 5–7)	0.69/0.69 (days 2–5) 0.71/0.69 (days 3–6) 0.71/0.70 (days 4–7)	0.69/0.69 (days 2–6) 0.71/0.69 (days 3–7)	0.70/0.69 (days 2–7)	

Abbreviations: BP, blood pressure; SMBP, self-monitoring of blood pressure.

[a]Conference abstract only. Study provides intraclass correlation coefficient data, not Pearson correlation coefficient data, so is not strictly comparable to other studies.

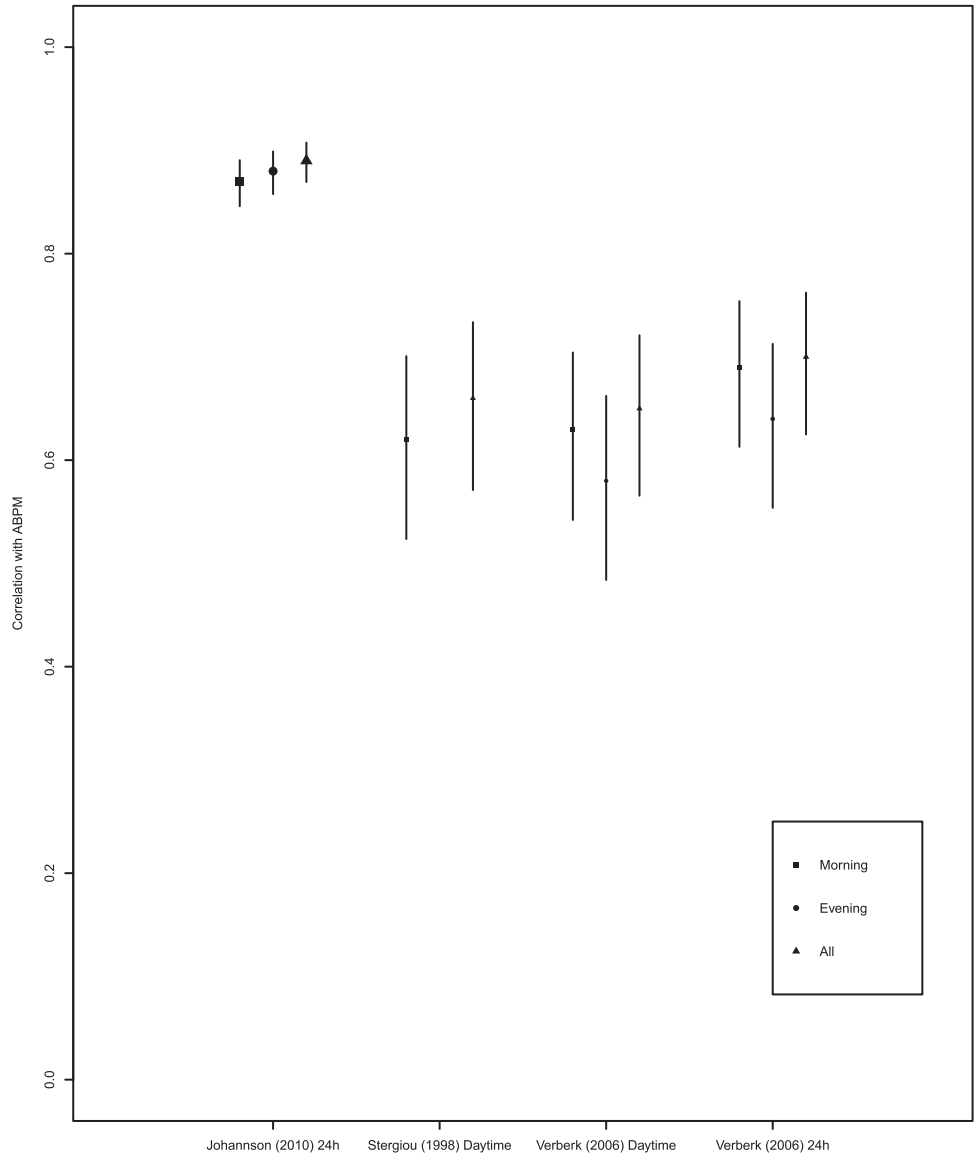

Figure 4. Correlation coefficient between ambulatory blood pressure measurement (ABPM) and self-monitoring of blood pressure (SMBP) by time of day of self-monitoring. The comparison in Stergiou (1998) is between first morning vs. first day; all other comparisons are between all morning, all evening or all readings.

Despite the heterogeneity and variable methodological quality of the evidence reviewed, many authors of the individual included studies drew strong and clear conclusions from their results. This was in spite of many HRs fully overlapping between apparently optimum and less optimum regimes. Subsequent guidelines from NICE, Europe, and the United States followed these conclusions in terms of recommendations on the number of days, the number of readings to take on each occasion, a preference for measuring in both the morning and evening, which values to discard, and total number of measurements.[2–4] However, we found that for most aspects of monitoring schedules, evidence was either missing or at best ambivalent, suggesting excessive influence of the interpretation of individual studies by the study authors rather than the observed results.

Linked qualitative work by our group suggests that patients value flexibility in regime, and given the lack of evidence underpinning fixed regimes, incorporating such flexibility in future guideline iterations seems sensible.[21] This might increase uptake and compliance,[22] thus facilitating further implementation of self-monitoring.

Implications for clinical practice

The relatively modest benefit from more than 3 days of readings or of any particular quantity or timing of readings within these 3 days suggests that more protracted schedules are only likely to be worthwhile around diagnostic or treatment thresholds. Given the widespread use of telemonitoring, automated patient feedback could be used to

Table 5. Correlation with ambulatory blood pressure measurement (ABPM) for reliability/reproducibility studies across number of readings on each occasion and time of day

Study (first author; publication date)	Measurement schedule	Comparator	*N*	Correlation coefficient between home systolic/diastolic BP and the comparator measurement					
				Number of readings on each occasion			Time of day		
				All first measurements	All second measurements	All measurements	All morning measurements	All evening measurements	All measurements
Johannson (2010)	7 days (2 readings in the morning and 2 readings in the evening on each day)	24-hour ABPM Timing in relationship to SMBP unclear	464	0.89/0.87	0.89/0.87	0.89/0.87	0.87/0.85	0.88/0.87	0.89/0.87
Stergiou (1998)[a]	3 work days per week for 2 weeks (2 readings in the morning and 2 readings in the evening on each day)	Daytime ABPM Some ABPM first and some SMBP first, one after the other	189	0.59/0.64		0.62/0.67	0.62/0.67		0.66/0.70
Verberk (2006)	7 days (3 readings in the morning and 3 readings in the evening, with the first of each triplicate discarded)	Daytime ABPM Timing vs. SMBP unclear	216				0.63/0.65	0.58/0.60	0.65/0.66
		24-hour ABPM Timing vs. SMBP unclear	216				0.69/0.69	0.64/0.62	0.70/0.69

Abbreviation: SMBP, self-monitoring of blood pressure.
[a]Study reports first blood pressure (BP), first double (same as first morning), and day 1, rather than all measurements.

Table 6. Correlation with ambulatory blood pressure measurement (ABPM) for reliability/reproducibility studies across number of measurements

Study. (first author; publication date)	Measurement schedule	Comparator	*N*	Correlation coefficient between home systolic/ diastolic BP and the comparator measurement														
				1	2	3	4	5	6	7	8	9	10	11	12	16	20	24	28
Johannson (2010)	7 days (2 readings in the morning and 2 readings in the evening on each day)	24-hour ABPM Timing in relationship to SMBP unclear	464				0.84/0.82				0.87/0.84				0.88/0.85	0.88/0.86	0.89/0.86	0.89/0.87	0.89/0.87
Stergiou (1998)	3 work days per week for 2 weeks (2 readings in the morning and 2 readings in the evening on each day)	Daytime ABPM Some ABPM first and some SMBP first, one after the other	189	0.59/0.64	0.62/0.67		0.66/0.70				0.68/0.73				0.68/0.75	0.70/0.77	0.71/0.78	0.71/0.79	
Verberk (2006)	7 days (3 readings in the morning and 3 readings in the evening, with the `first of each triplicate discarded)	Daytime ABPM Timing vs. SMBP unclear	216		0.53/0.62		0.53/0.59				0.57/0.61				0.60/0.63	0.62/0.63	0.63/0.66	0.64/0.66	0.65/0.66
		24-hour ABPM Timing vs. SMBP unclear	216		0.57/0.65		0.57/0.61				0.62/0.63				0.66/0.66	0.68/0.66	0.69/0.69	0.69/0.69	0.70/0.69

Abbreviation: SMBP, self-monitoring of blood pressure.

inform individuals where more than 3 days of measurements are appropriate.

These data hold for both diagnosis and ongoing management. There are theoretical reasons (peaks and troughs of medication for example) that support recommendations for morning and evening readings.[23] In terms of diagnosis, the prognostic studies did not suggest any particular difference in time of measurement and neither were differences in correlation seen dependent on time of day of monitoring, perhaps suggesting that such considerations are not paramount.

On the basis of the evidence we have synthesized, a pragmatic revision of current guidelines for self-monitoring would be that measurement of BP should be undertaken for 3 days, whether for diagnostic purposes or when monitoring the effect of treatment change, unless mean blood pressure after 3 days is close to a treatment or diagnostic threshold when longer schedules—perhaps a further 3 days of monitoring—bring small increases in prognostic power. Precise timings of measurements within these days and the precise days of measurement are less important and might be varied to suit individual circumstances. There remains a need for more and higher quality research, particularly prognostic studies in diverse populations, involving comparison of different regimes of measurement across multiple studies.

DATA AVAILABILITY

Dataset available from the corresponding author at j.a.hodgkinson@bham.ac.uk. The dataset includes only anonymized material already in the public domain.

SUPPLEMENTARY DATA

Supplementary data are available at *American Journal of Hypertension* online.

ACKNOWLEDGEMENTS

We thank Siobhan Milner, Nashat Qamar, and Sally Fillingham for their support in screening studies. This article presents independent research commissioned by the National Institute for Health Research (NIHR) under its Programme Grants for Applied Research funding scheme (RP-PG-1209–10051). R.J.M. was funded by an NIHR Professorship (NIHR-RP-R2-12–015). R.J.M. and F.D.R.H. receive support from the NIHR Collaborations for Leadership in Applied Health Research and Care (CLAHRC) Oxford. The guideline development work undertaken by R.O.M., R.J.M, and B.W. received funding from the National Institute for Health and Care Excellence. The views expressed in this publication are those of the authors and not necessarily those of the NHS, the NIHR, the Department of Health, or the National Institute for Health and Care Excellence.

DISCLOSURE

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare no support from any organization for the submitted work, no financial relationships with any organizations that might have an interest in the submitted work in the previous 3 years, and no other relationships or activities that could appear to have influenced the submitted work.

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