

Home blood pressure monitoring improves the diagnosis of hypertension in hemodialysis patients

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Using interdialytic ambulatory blood pressure (BP) recordings as the reference standard, we compared the performance of routine, standardized and home BP monitoring in 104 predominantly black patients on chronic hemodialysis for at least 3 months. Dialysis unit BP recordings were averaged over 2 weeks and home BP over 1 week. Awake ambulatory BP of ≥ 135 mmHg systolic or ≥ 85 mmHg diastolic was taken as evidence of hypertension. Average awake ambulatory BP was $128.1 \pm 21.6/73.5 \pm 13.5$ mmHg, home BP $141.3 \pm 21.9/78.7 \pm 11.9$ mmHg, standardized pre-dialysis BP $141.7 \pm 22.6/74.2 \pm 13.5$ mmHg and post-dialysis $119.9 \pm 20.5/69.1 \pm 13.1$ mmHg, routine pre-dialysis $145.4 \pm 21.8/79.0 \pm 13.1$ mmHg and post-dialysis $131.5 \pm 19.2/72.5 \pm 11.4$ mmHg. Sixty-three percent of the patients had well-controlled BP by ambulatory BP monitoring and isolated diastolic hypertension was rare (3%). The standard deviation of the differences between ambulatory and routine pre-dialysis BP was 17.6 mmHg, routine post-dialysis was 16.1 mmHg, standardized pre-dialysis was 16.4 mmHg, standardized post-dialysis was 14.1 mmHg, and home BP was 14.2 mmHg. The area under receiver operating characteristic curves was similar for home and standardized BP but lower for routine BP. Home systolic BP of ≥ 150 mmHg averaged over 1 week had the best combination of sensitivity (80%) and specificity (84.1%) in diagnosing systolic hypertension – present in 94% of the hypertensive dialysis patients. Home BP monitoring is similar to standardized recording of BP in hemodialysis patients. A systolic BP threshold of 150 mmHg at home averaged over 1 week serves as a useful predictor of hypertension diagnosed by ambulatory BP monitoring.

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Identification and treatment of hypertension is an ongoing challenge that nephrologists face when managing patients on hemodialysis. Blood pressure (BP) control is believed to be important in reducing morbidity and mortality in this high-risk population,¹ although there is no consensus on target BP.² Difficulties in making an accurate diagnosis of hypertension in hemodialysis patient arise in part due to large swings in BP with the hemodialysis procedure. We have previously shown that 2-week routine BP recordings in the dialysis unit when averaged can give a qualitative estimate of presence or absence of hypertension.³ However, thresholds for these qualitative estimates were such that high sensitivity and specificity were not shared by any individual BP recording. Thus, substantial uncertainty exists on making an accurate diagnosis of hypertension in hemodialysis patients.⁴

Subsequent investigations have shown that routine assessment of BP measurement does not agree well with readings obtained by standardized methods.⁵ Pilot data also demonstrated that home BP recordings may be promising in making a more accurate diagnosis of hypertension in hemodialysis patients.⁶ These studies did not explore whether standardized or home BP recordings can improve the prediction of hypertension as assessed by ambulatory BP monitoring. However, it became clear that the accuracy of recordings of standardized BP as well as home BP needed further evaluation in making a diagnosis of hypertension in hemodialysis patients. Accordingly, we designed this prospective cross-sectional study to assess the relationship between BP recordings obtained in the dialysis unit by routine and standardized methods; home BP recordings obtained by the patients; and the reference standard of 44-h interdialytic ambulatory BP recordings.

RESULTS

Between September 2003 and February 2005, we recruited 150 patients from four dialysis units staffed by the nephrology faculty of Indiana University, Indianapolis. The sample was drawn from 355 patients of which 48% were women, 36% were diabetic, and 72% were black patients.

Twenty-five patients had inadequate or refused ambulatory BP recordings. In five patients, the cuff-size used for

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home BP recordings was inappropriately small for the arm circumference; these patients were excluded from the analysis. Six patients had no monitor-recorded BP readings and 10 recorded <6 readings. After excluding these patients, 104 patients were available for overall BP analysis.

The clinical characteristics of the remaining 104 patients are shown in Table 1. The population was predominantly black with limited education and low income. Average Kt/V, serum albumin and hemoglobin reflect a generally healthy population. Interdialytic weight gain was 2.7 ± 1.5 kg. All patients were on three times weekly dialysis and were prescribed a dialysis time of 238 ± 25 min, blood flow rate of 405 ± 32 ml/min and dialysate flow rate of 754 ± 88 ml/min.

The characteristics of the sample, except ethnicity, were similar to the population from which it was drawn. We further analyzed, why fewer white patients were recruited. Ethnicity of 126 patients who were screened but who did not participate were analyzed. Forty-one black (76%), 12 (22%) white patients, and one (2%) Asian met the recruitment criteria but refused participation. Fifty-five (76%) black, 15 white patients (21%), and two (3%) Asians did not meet one of the inclusion or exclusion criteria. Because 27/126 (21%) white patients did not meet eligibility or refused participa-

tion, our sample comprised of more black participants than the overall composition from which the sample was derived from.

Majority of the patients received antihypertensive drugs, with an average of 2.2 drugs in those who took antihypertensives (Table 2). Beta blockers were the most commonly utilized antihypertensive agent. Average time that ambulatory BP recorder was worn was 45 ± 7.5 h, whereas the successful recordings were made over 36.3 ± 9 h. An average of 97 ± 19 recordings per patient were obtained, of which 36 ± 10 were recordings on day 1 during the awake state and 30 ± 10 were awake recordings on day 2. The average number of home BP recordings was 16 ± 4 . Awake ambulatory BPs were similar to 44-h interdialytic ambulatory BPs reflecting the absence of nocturnal decline in most patients. As expected, pre-dialysis BPs were higher than post-dialysis BPs.

Figure 1 shows that 66/104 patients (63%) had well-controlled BP by awake ambulatory BP recordings. Fifty of these 66 patients were on antihypertensive drugs (treated, controlled hypertension) and 16/66 (24%) were not on any medications (normotensive). Of 48/104 (37%) who were hypertensive, only three patients (3%) had isolated diastolic hypertension, whereas 35 (34%) had systolic hypertension. Of those with systolic hypertension 17 (16%) had isolated systolic hypertension, and 18 (17%) had combined systolic and diastolic hypertension. As diastolic hypertension is nearly always accompanied by systolic hypertension in hemodialysis patients, only systolic BP recordings were analyzed further.

Table 1 | Clinical characteristics of the study population

Clinical characteristic	n=104
Age (years)	55.9 ± 12.6
Men	73 (70%)
Race	
White	7 (7%)
Black	95 (91%)
Other	2 (2%)
Years of education	11.9 ± 2.1
12 year education or more	87 (84%)
Income <\$25 000 per year	93 (89%)
Pre-dialysis weight (kg)	81.3 ± 18.1
Post-dialysis weight (kg)	78.6 ± 17.6
BMI (kg/m ²)	26.8 ± 5.9
Years of end-stage renal disease	5 ± 5.2
Current alcohol use	25 (24%)
Smoking	
Current	42 (40%)
Former	30 (29%)
Never	32 (31%)
Diabetes mellitus	46 (44.2%)
Etiology of end-stage renal disease	
Diabetes mellitus	33 (32%)
Hypertension	58 (56%)
Glomerulonephritis	6 (6%)
Obstruction	1 (1%)
Other	6 (6%)
Kt/V	1.6 ± 0.44
Albumin (g/dl)	3.8 ± 0.4
Hemoglobin (g/dl)	12.5 ± 1.5

± Indicates standard deviation. Values in parentheses represent percent of patients.

Table 2 | Antihypertensive drug use and BP measurements

Number receiving antihypertensive drugs	86 (83%)
Number of antihypertensives in users	2.2 ± 1.0
Nature of antihypertensive agent	
Dihydropyridine calcium channel blockers	38 (37%)
Non-dihydropyridine calcium-channel blockers	4 (4%)
Beta-blockers	66 (63%)
Alpha-blockers	6 (6%)
Centrally acting agents	57 (55%)
Vasodilators	17 (16%)
ACE Inhibitors	44 (42%)
Angiotension receptor blockers	15 (14%)
44-hour ambulatory BP (mmHg)	$127.9 \pm 21.5/72.7 \pm 13.0$
Awake ambulatory BP (mmHg)	$128.1 \pm 21.6/73.5 \pm 13.5$
Home BP (mmHg)	$141.3 \pm 21.9/78.7 \pm 11.9$
Standardized BP (mmHg)	
Pre-dialysis	$141.7 \pm 22.6/74.2 \pm 13.5$
Post-dialysis	$119.9 \pm 20.5/69.1 \pm 13.1$
Routine BP (mmHg)	
Pre-dialysis	$145.4 \pm 21.8/79.0 \pm 13.1$
Post-dialysis	$131.5 \pm 19.2/72.5 \pm 11.4$

BP, blood pressure.

± Indicates standard deviation. Values in parentheses represent percent of patients. Standardized and routine BP are average of 2-week recordings, whereas home BP are average of 1-week recording. Medications reported are those actually taken by the patients.

The receiver operating characteristic (ROC) curves for various systolic BPs are shown in Figure 2. The area under the curve (AUC) for 2-week averaged dialysis unit BP was higher for post-dialysis standardized measurement compared to post-dialysis routine BP. Standardized post-dialysis BP had a higher AUC compared to routine post-dialysis BP ($P=0.045$). Routine pre-dialysis and post-dialysis AUCs were similar ($P=0.395$). Also, standardized pre-dialysis and post-dialysis AUCs were similar ($P=0.162$). AUC for home BP recordings was as good as 2-week averaged standardized BP measurements ($P=0.241$ for comparison with pre-standardized and $P=0.729$ for comparison with post-standardized)

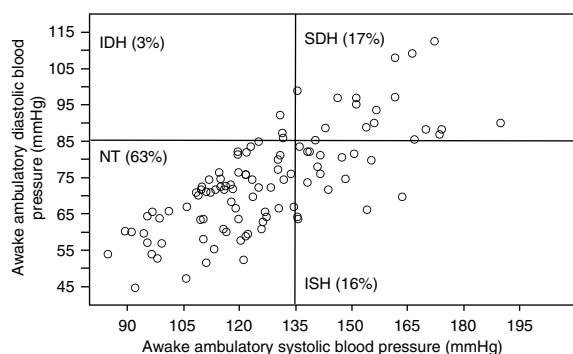


Figure 1 | Distribution of systolic and diastolic BPs shows that IDH is uncommon. Sixty-three percent of the population had well-controlled awake ambulatory BPs (NT), 17% had systolic and diastolic hypertension (SDH) and 16% isolated systolic hypertension (ISH). The cloud is jittered 5% for clarity of presentation.

and superior to pre-dialysis routine BP ($P=0.029$ for comparison). The optimal cutoff thresholds for home BP were 148.9 mmHg that gave 82.9% sensitivity and 84.1% specificity with the highest Youden index of 0.669 (Table 3).

Clinically relevant sensitivities and specificities that assist in making a diagnosis of hemodialysis hypertension are shown in Table 4. Routine pre-dialysis systolic BP of ≥ 146 mmHg has a sensitivity of 82.9% but a specificity of only 65.2%. By contrast, post-dialysis systolic BP of ≥ 130.8 mmHg had a sensitivity of 80.4% and specificity of 72.5%. Standardized pre-dialysis BP of ≥ 147.1 mmHg had a sensitivity of 80.0% and specificity of 78.3%. Standardized post-dialysis systolic BP of ≥ 121.9 mmHg had a sensitivity of 80.0% and specificity of 79.7%. The best combination of sensitivity and specificity was seen with systolic home

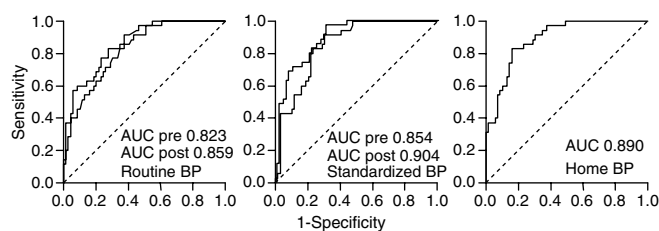


Figure 2 | ROC curves of routine and standardized hemodialysis unit BP obtained before and after dialysis and home BPs. The dotted curve represents the pre-dialysis BPs. The diagonal dotted line indicates a hypothetical test with no predictive value. The AUC for home BP was as good as standardized measurement of BPs.

Table 3 | BP thresholds for diagnosing hemodialysis hypertension

	Two-week averaged routine BP		Two-week averaged standardized BP		One-week averaged home BP
	Pre-HD	Post-HD	Pre-HD	Post-HD	
Area under ROC curve (95% CI)	0.823 (0.744–0.902)	0.859 (0.789–0.929)	0.854 (0.783–0.924)	0.904 (0.849–0.960)	0.890 (0.829–0.950)
Youden index (diagnostic efficiency)	0.509	0.553	0.610	0.667	0.669
BP threshold	145.3	130.0	143.3	114.9	148.9
Sensitivity	86.7	82.8	91.4	97.1	82.9
Specificity	65.2	72.5	69.6	69.6	84.1

BP, blood pressure; CI, confidence interval; HD, hemodialysis.

Table 4 | BP thresholds for diagnosing hemodialysis hypertension

	Two-week averaged routine BP		Two-week averaged standardized BP		One-week averaged home BP
	Pre-HD	Post-HD	Pre-HD	Post-HD	
Sensitivity					
=95%	136.8 (95.7, 49.3)	123.6 (97.1, 53.6)	135.6 (94.3, 58.0)	114.9 (97.1, 69.6)	134.7 (97.1, 62.3)
=90%	140.6 (91.4, 56.5)	125.4 (91.4, 62.3)	143.3 (91.4, 69.6)	116.4 (91.4, 71.0)	140.7 (91.4, 69.6)
=80%	146 (82.9, 65.2)	130.8 (80.4, 72.5)	147.1 (80.0, 78.3)	121.9 (80.0, 79.7)	150 (80.0, 84.1)
Specificity					
=95%	165.8 (40.0, 95.7)	151.5 (42.9, 95.7)	164.4 (42.9, 95.7)	139.8 (51.4, 95.7)	161.6 (37.1, 95.7)
=90%	162.4 (45.7, 91.3)	145.5 (60.0, 91.3)	162.8 (42.9, 91.3)	130.7 (68.6, 91.3)	156.3 (57.1, 91.3)
=80%	154.4 (60.0, 81.2)	138.3 (65.7, 81.2)	151.9 (60.0, 81.2)	123.9 (74.3, 81.2)	147.4 (82.9, 81.2)

Sensitivity and specificity associated with the systolic BP are shown in parentheses. The sensitivity and specificities selected are those that may be clinically relevant. BP, blood pressure; HD, hemodialysis.

BP of ≥ 150 mmHg (rounded off to nearest 10) that was associated with a sensitivity of 80% and specificity of 84.1%.

AUC of the ROC curves analyzed for 125 patients who had adequate ambulatory recordings and dialysis unit BP recordings and 114 patients who had at least one home BP recorded confirmed the above results (data not shown). These additional analyses showed that routine BP recordings had the lowest AUC. Post-dialysis recordings had a better AUC compared to pre-dialysis recordings. Home BP recordings averaged over 1 week had a performance that was similar to standardized BP measurements.

Table 5 shows the average difference and the standard deviation of the difference between BP measurements. Pre-dialysis routine systolic BP has the greatest overestimation, 16.2 mmHg, of awake ambulatory systolic BP. By contrast, post-dialysis routine systolic BP overestimated ambulatory BP by only 2.4 mmHg. The standard deviation of the difference was greatest for pre-dialysis routine BP and least for home BP. The Bland-Altman plots illustrate these relationships in Figure 3 for dialysis unit BPs and Figure 4 for home BP recordings.

Quantitative analyses of test performance using the methods proposed by Minini *et al.*⁷ revealed differences between methods of measurements. The homogeneity index of corrected errors were in the following order: Routine pre-HD (16.3 mmHg), standardized pre-HD (15.6 mmHg), routine post-HD (13.9 mmHg), home BP (13.6 mmHg) and standardized post-BP (13.0 mmHg). There was highly significant differences between the methods of measurements ($P < 0.0001$). Comparisons between all possible pairs showed statistical differences between standardized post-HD BP vs routine pre-HD BP ($P = 0.021$), and marginal differences between standardized pre-HD BP vs standardized post-HD BP ($P = 0.057$) and home BP vs routine pre-HD BP ($P = 0.065$).

DISCUSSION

The threshold BP for making a diagnosis of hypertension should be both sensitive and specific. An ideal threshold would be 100% sensitive and specific. This is rarely achieved. Accordingly, a threshold that is both 80% sensitive and 80% specific is considered acceptable since it has a high accuracy in making a diagnosis of hypertension. Our study shows that routine BP measurements, even when averaged over 2 weeks, have marginal performance in the diagnosis of hemodialysis hypertension. This combination of an acceptable sensitivity

and specificity was seen only for home BP recording or post-dialysis standardized BP. One week averaged systolic home BP of ≥ 150 mmHg or post-dialysis standardized BP of ≥ 122 mmHg has both high sensitivity and specificity to predict hypertension assessed by ambulatory BP monitoring. While home BP monitoring may perform well in an educated population should come as little surprise.⁸ That the performance of home BP recordings was at least as good as

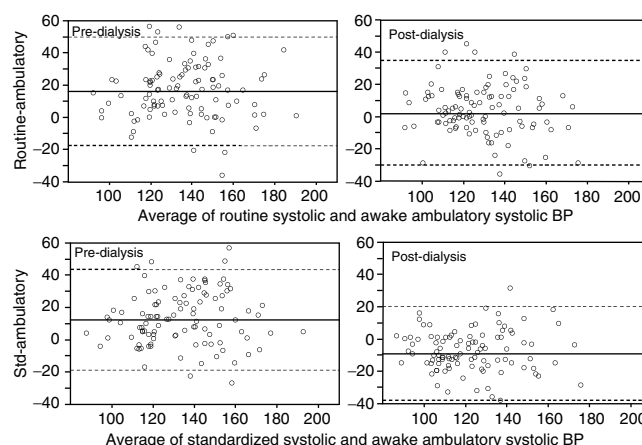


Figure 3 | Bland-Altman plots for hemodialysis unit – routine and standardized – systolic BPs compared to awake ambulatory systolic BPs. The horizontal solid line is the average difference between the two tests and the dotted line is ± 2 s.d. of the difference reflecting the limits of agreement. The cloud is jittered 5% for clarity of presentation.

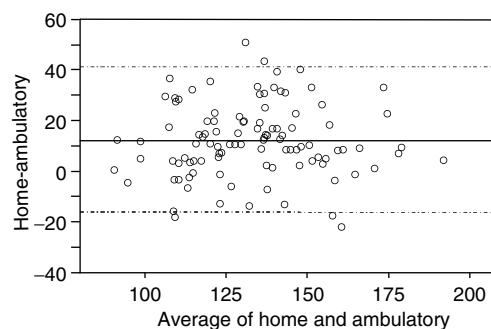


Figure 4 | Bland-Altman plots for home systolic BPs compared to awake ambulatory systolic BPs. The horizontal solid line is the average difference between the two tests and the dotted line is ± 2 s.d. of the difference reflecting the limits of agreement. The cloud is jittered 5% for clarity of presentation.

Table 5 | Agreement between routine, standardized and home systolic BP and awake ambulatory systolic BP

	Two-week averaged routine BP (n=125)		Two-week averaged standardized BP (n=125)		One-week averaged home BP (n=114)
	Pre-HD	Post-HD	Pre-HD	Post-HD	
Non-ambulatory BP minus awake ambulatory BP (95% CI)	16.2 (13.2 to 19.2)	2.4 (−0.4 to 5.2)	12.4 (9.7–15.2)	−9.1 (−11.6 to 6.6)	12.2 (9.6 to 14.8)
SDD between non-ambulatory BP and awake ambulatory BP	16.9	16.1	15.6	14.4	14.2

BP=blood pressure, CI=confidence interval, HD=hemodialysis, SDD=standard deviation of the difference.

resource-intensive, nurse-recorded, standardized recordings averaged over 2 weeks demonstrates that home BP measurement technique is robust and can be readily taught and utilized even by hemodialysis patients with less education.

Systolic hypertension either with or without diastolic hypertension was more prevalent compared to isolated diastolic hypertension confirms our earlier result.³ As isolated diastolic hypertension is relatively uncommon, the focus of treatment should be on systolic BP control.⁹ The prevalence of well-controlled systolic BP or normotension of 63% was much higher than 24% we reported earlier. In our previous study, we selected those patients in whom we wanted to judge the adequacy of BP control or to make a diagnosis of hypertension. Whereas the better control rate of hypertension may be due to greater recognition of this problem, it is more likely that the results of the present study were due to lack of selection bias that may have existed in our previous report. Because adequate control in epidemiological surveys is estimated at only 30%,¹⁰ it is possible that hemodialysis patients, like those with chronic kidney disease not on dialysis,¹¹ may have a large white-coat effect. We speculate that the lower prevalence of true hypertension found with ambulatory BP measurements may contribute to the failure of epidemiological studies using routine BP monitoring techniques to uncover hypertension as a risk factor for cardiovascular disease.^{12,13} Post-dialysis BP recordings had slightly better predictive performance based on AUC and narrower limits of agreement on the Bland–Altman plot. In cohort studies, high post-dialysis – not pre-dialysis – systolic BP correlates with poor survival.^{12,13} For any given systolic BP, post-dialysis hypertension is more specific in diagnosing hypertension and therefore reflects a greater cardiovascular BP load compared to pre-dialysis hypertension.

The average standardized systolic post-dialysis BP was about 10 mmHg lower compared to routine post-dialysis BP. We found that using routine post-dialysis systolic BP of ≥ 130.8 mmHg or standardized post-dialysis systolic BP of ≥ 121.9 mmHg at least 80% sensitivity can be achieved in diagnosing hypertension in hemodialysis patients. The lower threshold for standardized measurement may reflect the time elapsed from the end of the dialysis session to the time of measurements. Whereas the routine post-dialysis BP was measured in the dialysis chair, those obtained via the standard method required walking away from the dialysis chair, seated rest for at least 5 min and measurement of BP. BP is known to fall post-dialysis and this may simply reflect the time-dependent fall in systolic BP.^{6,14} Rahman *et al.*⁵ have also reported that in 55% of the patients, the post-dialysis systolic BP was at least 10 mmHg higher than the standard reading. Routine systolic post-dialysis recordings overestimated post-dialysis standardized recordings by 13.6 mmHg. These results are also consistent with Mitra *et al.*¹⁵ who have reported that 20 min post-dialysis BP may be the best predictor of hypertension in hemodialysis patients.

Which technique of measurement of BP – home, dialysis unit, or interdialytic ambulatory – is more reliable in

predicting target organ damage is currently unknown. An ideal reference standard would be one where hard outcomes such as cardiovascular deaths and events are related to a certain level of the risk factor and modulation of the level of risk-factor leads to differences in outcomes. Interdialytic ambulatory systolic BP has been linked to cardiovascular mortality in a sample size that was limited to 57 treated hypertensive patients on hemodialysis.¹⁶ Averaged dialysis unit BP measurements have failed to show such a relationship.² Furthermore, ambulatory BP monitoring is more reproducible and accurate compared to dialysis unit BP measurements.¹⁷ Thus, ambulatory BP monitoring is accurate, reproducible and correlates with cardiovascular death. Although no study has demonstrated that modulation of BP in hemodialysis patients can influence outcomes, it appears reasonable to use ambulatory BP as the ‘gold standard’.

Some limitations of our study must be addressed. The majority of the patients in our study were black. Although ethnicity should not influence the measurement of BP, whether these data are applicable to non-black subjects is uncertain. Standardized measurements of BP are resource-intensive and may not be practical outside the research setting. Although standardized measurement of BP had a better performance than routine recordings, home BP monitoring appears to be a better alternative than standardized measurements in clinical practice. Whether at least 1-week average home BP monitoring is required for a firm diagnosis is also unclear from the present analysis and will be the subject of future analyses. It is possible that 1-week home BP monitoring may be cumbersome for many patients, reducing its feasibility in the clinical setting. Thus, shorter periods of home BP monitoring may need to be tested for adequacy in predicting ambulatory BP while retaining the sensitivity and specificity seen in this study.

We conclude that 1 week averaged home systolic BP of ≥ 150 mmHg has the best combination of sensitivity and specificity to diagnose hypertension in hemodialysis patients. Home BP monitoring is as good as standardized measurements of BP taken before and after dialysis and outperforms the routine measurements of BP as currently performed in the dialysis units even when averaged over 2-weeks. By reducing the magnitude of the white coat effect, home BP monitoring may better clarify the relationship between systolic hypertension and cardiovascular outcomes in hemodialysis patients and improve the ability of clinicians in making a more accurate diagnosis of hypertension. Standardized recording of BP provides similar information as home BP in predicting ambulatory BP.

MATERIALS AND METHODS

Subjects

Patients 18 years or older who had been on chronic hemodialysis for more than 3 months, and were free of vascular, infectious or bleeding complications within 1 month were enrolled in the study. Those who missed two hemodialysis treatments or more over 1

month, abused drugs, had chronic atrial fibrillation or body mass index of 40 kg/m² or more were excluded. Patients who had a change in dry weight or antihypertensive drugs within 2 weeks were also excluded. Presence or absence of hypertension was not a selection criterion. All patients underwent a standard three times a week dialysis at one of the four dialysis units in Indianapolis affiliated with Indiana University.

Anthropometric and demographic characteristics and antihypertensive medications actually taken by the patient were recorded. The study was approved by the Institutional Review Board of Indiana University and Research and Development Committee of the Roudebush VA Medical Center, Indianapolis and all subjects gave written informed consent.

Ambulatory BP monitoring

Ambulatory BP monitoring was performed after the mid-week hemodialysis session for 44 h. Ambulatory BPs were recorded every 20 min during the day (0600–1100) and every 30 min during the night (2200–0600) using a Spacelab 90207 ABP monitor (SpaceLabs Medical Inc., Redmond, WA, USA) in the non-access arm, as performed previously.¹⁸ Recordings began immediately after hemodialysis and terminated immediately before the subsequent dialysis. Accuracy of ambulatory BP recordings was confirmed against auscultated BP at baseline. Data were analyzed using ABP Report Management System software, version 1.03.05 (SpaceLabs Medical Inc, Redmond, WA, USA). Ambulatory BP and heart rates were averaged over the entire course of recording, as well as separately during the day and during night.

Dialysis patients have abnormal sleep cycles and the division of day and night by the clock is artificial. Therefore, awake and asleep readings were calculated for each patient by self-reported sleep and awake times by means of a diary. A weighted average of the awake readings on each of the 2 days of ambulatory BP monitoring was taken to represent average awake ambulatory BP. For the purposes of this study, awake ambulatory BP of 135/85 mmHg or more was considered hypertensive.¹⁹ Those patients who had <14 recordings on awake ambulatory BP were excluded from analysis ($n=25$).

Dialysis unit BPs

Dialysis unit BP recordings as measured by the dialysis unit staff before and after dialysis were collected prospectively at the time of the patient visit. These BP recordings were obtained using the sphygmomanometer equipped with hemodialysis machines without a specified technique and were averaged over 2 weeks. Thus, each patient had six pre-dialysis and six post-dialysis BP recordings to provide routine dialysis unit BP.

BP was also recorded using a standard technique following at least a 5-min rest and using a validated oscillometric device (HEM 907, Omron Healthcare, Vernon Hills, IL, USA) by research nurses trained in this technique. Three readings at each visit were averaged to provide one recording. Pre-dialysis and post-dialysis recordings were averaged separately over 2 weeks to provide a standardized dialysis unit BP.

Home BP monitoring

Home BP monitoring was performed over 1 week using a validated self-inflating automatic oscillometric device (HEM 705 CP, Omron Healthcare). The protocol specified home BP monitoring in the first week. Patients were instructed in the use of this monitor and asked not to share this monitor with others. Patients were asked to record their BP three times daily – on waking up, between noon and 1900

and at bedtime – and log this on a chart provided for this purpose. As this monitor is equipped with a memory and printer, we only used those recordings that were recorded in the memory of the monitor. Those providing <6 recordings were excluded (see Results).

Data analysis

To analyze the sensitivity and specificity of hemodialysis unit BPs, we generated ROC curves, including AUC and their 95% confidence intervals.²⁰ The interdialytic BP load is most reproducibly estimated using multiple measurements using the ambulatory BP monitor and was taken as the reference standard.¹⁷ The ROC curve depicts the relation between true-positive results (number with hypertension on awake ambulatory BP) and false-positive results (number with well-controlled BP on awake ambulatory BP) for each BP. The greater the area under ROC curve, the better the diagnosis by the respective BP. The best cutoff BP was calculated based on the Youden index.²¹ The Youden index, a measure of overall diagnostic effectiveness, is the maximum vertical distance or difference between the ROC curve and the diagonal or chance line; it occurs at the cut-point that optimizes the BP's differentiating ability when equal weight is given to sensitivity and specificity. Youden index was calculated as sensitivity + specificity – 1. The higher the index, the better the prediction at the cutoff point. Bland–Altman plots were created for the analysis of agreement.²² In this analysis, average difference between awake ambulatory BP and dialysis unit BP or awake ambulatory BP and home BP was calculated along with the 95% confidence interval and the standard deviation of the difference. Accuracy of various techniques to measure BP was analyzed quantitatively using the methods proposed by Minini *et al.*⁷ The homogeneity index of corrected errors for systolic BP served as the classification index of accuracy of the measurement techniques compared to the gold standard to awake ambulatory BP. The homogeneity index is the standard deviation of the leverage corrected raw residuals of the test BP regressed against the gold standard (for details of the analysis see Minini *et al.*⁷). All analyses were conducted using SPSS Software version 13.0 (SPSS Inc., Chicago, IL, USA). Area under the ROC curves was compared using Stata 8.0 (Stata Corp, College Station, TX, USA). The *P*-values reported are two-sided and taken to be significant at <0.05.

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