Elevated blood pressure (BP) is a risk factor for the development of cardiovascular disease and may be exacerbated by regular consumption of coffee. Some cross-sectional1 and randomized, controlled studies2,3 suggest an association between coffee drinking and increased BP, possibly due to caffeine.4,5

After abstinence from coffee6 or caffeine7 for at least 12 hours, acute ingestion of caffeine increases BP and decreases heart rate (HR). With continued coffee or caffeine intake, tolerance develops, usually within 2 to 3 days, even in former caffeine nonusers.8 Although no significant association between long-term caffeine or coffee intake and BP was found in some controlled trials in young and middle-aged9,10 normotensive11 and untreated hypertensive individuals,12 other studies have reported short- and long-term pressor effects.13–15 In a study that used ambulatory BP monitoring (ABPM), young mildly hypertensive men who were regular coffee drinkers had 2 to 3 mm Hg higher daytime systolic ambulatory BP (ABP) than nondrinkers.16 However, there have been few studies in older men and women,17 whose cardiovascular system is more likely to have an impaired ability to buffer pressor stimuli. One controlled study showed that chronic caffeine ingestion by elderly subjects had no significant effect on clinic or 24-hour BP levels, irrespective of BP status.17

The present study aimed to assess, in a controlled 2-week intervention, the effects of regular coffee drinking on ABP in normotensive or hypertensive, nonsmoking older men and women, with careful control of dietary caffeine intake.

Methods

One hundred seventy-one independent-living nonsmoking men and women older than 50 years (range, 53 to 95 years) were recruited from local retirement homes by advertisements to take part in a 2-week-long controlled trial of the effects of coffee drinking on postprandial BP.18 Forty-eight of these subjects (10 men and 38 women) also agreed to undergo ABPM. Ethical approval was given by the University of Western Australian Committee for Human Rights.

After initial measurements of BP at baseline (supine: 7 readings every 2 minutes; standing: 3 readings every 2 minutes) using a Dinamap 1846 SX automatic oscillometric BP recorder (Critikon Inc), subjects with systolic BP (SBP) > 180 mm Hg or diastolic BP (DBP) > 110 mm Hg were excluded from the study, as were current smokers and individuals with diabetes mellitus, arrhythmia, cardiac failure, or renal disease. One normotensive and 1 untreated hypertensive subject were on nitrates and lipid-lowering medication, respectively. Five subjects treated for hypertension were receiving a single medication (ACE inhibitor, β-blocker, calcium channel blocker, or other antihypertensives). In some subjects, calcium channel blockers were used in combination with ACE inhibitors (n = 2), cardiac inotropics (n = 1), or lipid-lowering (n = 1) drugs. Other drug combinations were cardiac inotropics and diuretics (n = 1).

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and an ACE inhibitor, and a calcium channel blocker and a diuretic (n=1). During the study, subjects remained on the treatment prescribed by their physicians.

All subjects were asked to abstain from caffeine-containing foods and beverages for 2 weeks. After this period, subjects were randomly assigned to continue the caffeine-free diet (abstainers) or to drink 5 cups of instant coffee per day in addition to the caffeine-free diet. As decaffeinated coffee has been reported to increase DBP, abstainers were asked to refrain from purchasing decaffeinated beverages and were provided with an optional standard caffeine-free (not decaffeinated) beverage during the study (“Red Bush” tea, Vital Health Foods). Coffee drinkers consumed 5 cups of instant coffee per day (Nescafe blend 43, Nestle Australia Ltd) provided in prepackaged sachets each containing 60 mg caffeine per cup. Individuals were asked to consume coffee with each meal, at mid-morning, and at mid-afternoon.

Subjects were seen on the last 2 days of the second week of preintervention and intervention. All subjects were having no caffeine at the time of the preintervention ABPM and were continuing the appropriate intervention (abstinence or coffee drinking) during the second ABPM. ABPM over a 24-hour period began after breakfast, at preintervention, and at postintervention, using the Accutracker II (Suntech) ABP monitor. An ABPM cuff of appropriate size was placed on the nondominant arm, and the instrument was programmed to record BP and HR every 20 minutes during waking hours (6 AM to 10 PM) and every hour during the night (10 PM to 6 AM). Each subject was carefully informed about the operation of the Accutracker II and asked to complete a diary recording the time, location, and activities during their BP measurements. They were asked to maintain their normal level of physical activity during the ABPM sessions. Readings with test codes and pulse pressure (SBP−DBP) <20 mm Hg were discarded. Daytime BP was classified as 7:01 AM to 10 PM and nighttime BP as 10 PM to 7 AM.

Subjects were asked to stop drinking alcohol 24 hours before BP measurements. Alcohol intake was recorded at preintervention and postintervention visits in a 7-day retrospective alcohol diary detailing the amount and type of drinks consumed in the week preceding the visit. The average amount of alcohol consumed per week was calculated and expressed as milliliters of alcohol. Compliance was assessed by measuring caffeine concentrations in serum at preintervention and postintervention and by counting the number of unused coffee sachets returned at the end of intervention. Height was measured with a stadiometer at screening. Weight was recorded at screening and postintervention using platform scales, with subjects in light clothing and without shoes.

Statistical Analysis

All statistical analysis was performed with the Statistical Analysis System (SAS version 6.12) and Statistical Package for Social Sciences (SPSS for Windows version 8.0). The results are expressed as mean (SEM), and a value of P<0.05 was considered significant. General linear models with adjustment for weight change were used for further analyses of the 24-hour ABPM profiles and included interaction terms between treatment group and BP status (normotensive subjects, SBP<140 and DBP<90 mm Hg; hypertensive subjects, SBP>140 or DBP>90 mm Hg and/or treatment for hypertension). Additional models examined treatment with antihypertensive drugs and interaction terms.

Results

Among hypertensive subjects, 14 were randomized to drink coffee and 13 to abstain. Nine normotensive subjects abstained from coffee and 12 were randomized to drink coffee. Because data analysis after intervention consistently showed interactions between coffee drinking and hypertension status with respect to BP, all beverage effects were examined separately for normotensive and hypertensive subjects. At baseline, there were no significant differences in age, weight, alcohol intake, BP, or HR between abstainers and coffee drinkers within the normotensive and hypertensive groups (Tables 1 and 2).

Change in weight did not differ significantly between abstainers and coffee drinkers in the normotensive and hypertensive groups, but in individuals, change in weight ranged from a loss of 3 kg to a gain of 2 kg. For this reason, subsequent analyses were adjusted for change in weight. Mean change was −0.6 (0.4) kg in normotensive abstainers, −0.1 (0.2) kg in normotensive coffee drinkers, −0.4 (0.3) kg in hypertensive abstainers, and −0.2 (0.3) kg in hypertensive coffee drinkers.

The difference between postintervention and preintervention SBP and DBP over 24 hours is shown in Figure 1. Table 2 shows mean SBP, DBP, and HR preintervention and postintervention for normotensive and hypertensive abstainers and coffee drinkers. In the hypertensive group, change in mean 24-hour SBP was greater by 4.8 (1.3) mm Hg (P=0.031) and change in mean 24-hour DBP was higher by 3.0 (1.0) mm Hg (P=0.010) in coffee drinkers than in abstainers (Table 2). Change in daytime DBP was also significantly greater in coffee drinkers than in abstainers in the hypertensive group, with a difference of 4.7 (1.2) mm Hg (P=0.001). Daytime SBP differed by 3.6 (1.6) mm Hg between abstainers and coffee drinkers in the hypertensive group, but this difference was not significant (P=0.158). Change in nighttime DBP or SBP did not differ significantly between abstainers and coffee drinkers in the hypertensive group, with mean differences of 0.8 (1.3) mm Hg for DBP and 1.6 (1.1) mm Hg for SBP. As seen in Figure 2, there was a consistent pattern of fall in BP in the abstainers and increase in BP in the coffee drinkers among the hypertensive subjects. There were no significant differences between abstainers and coffee drinkers in the normotensive group for 24-hour, daytime, or nighttime SBP or DBP. There were no significant changes in HR related to coffee drinking in the normotensive or hypertensive groups. Figure 1 shows the differences between preintervention and postintervention BP unadjusted

### Table 1. Characteristics of Subjects According to Intervention Group

| Characteristic | Normotensive | | | Hypertensive | | |
|----------------|--------------|----------------|----------------|----------------|----------------|
| | Abstaining (n=9) | | | | | |
| | Coffee (n=12) | | | | | |
| | | | | | | |
| | Abstaining (n=13) | | | | | |
| | Coffee (n=14) | | | | | |
| Age, y | 72.6 (1.5) | 71.5 (1.2) | | | 77.4 (2.1) | 76.5 (1.2) |
| Male | 3 | 3 | | | 2 | 2 |
| Weight, kg | 68.3 (2.3) | 69.3 (2.6) | | | 65.9 (2.4) | 68.2 (2.3) |
| Preintervention | 67.8 (2.4) | 69.2 (2.6) | | | 65.6 (2.1) | 67.9 (2.2) |
| Postintervention | 24.4 (0.6) | 27.0 (1.4) | | | 25.2 (1.2) | 25.1 (1.2) |
| Postintervention | 24.2 (0.6) | 26.9 (1.4) | | | 25.1 (1.4) | 25.0 (1.3) |
| BMI, kg/m² | 30.7 (11.1) | 30.9 (13.0) | | | 30.5 (9.9) | 30.8 (9.1) |
| Preintervention | 30.3 (10.7) | 31.0 (14.2) | | | 30.3 (10.3) | 30.8 (12.1) |

Values are mean (SEM). BMI indicates body mass index.

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for change in weight, whereas weight-adjusted changes are shown in Figure 2.

Because of the increase in BP in the normotensive group, whether abstainers or coffee drinkers, the possible contribution of borderline hypertension was examined. Normotensive subjects were classified according to the criteria of Sung et al. 19 as having SBP, 130 mm Hg. This classification excluded 4 individuals: 2 abstainers and 2 coffee drinkers. With the exclusion of these subjects, an increase in BP was still seen in both groups of normotensive subjects, but the increase was not as great, with a rise in 24-hour SBP of 1.5 mm Hg (2.1) in the coffee drinkers and 1.9 (2.4) mm Hg in the abstainers.

For DBP, with inclusion only of individuals with SBP<130 mm Hg, the respective increases were 0.5 mm Hg (2.2) and 0 mm Hg (2.3).

All models were examined with the inclusion of a variable coding for treatment with antihypertensive agents. This variable was not significant in any of the models using 24-hour, daytime, or nighttime SBP or DBP, and there were no significant interactions between coffee drinking and treatment with antihypertensive drugs in any of these models.

Serum caffeine, as an indicator of compliance, was measured in a randomly selected subgroup of 14 subjects. All samples were obtained after subjects had fasted overnight. No serum caffeine was detected in abstainers. In coffee drinkers, the mean serum caffeine concentration postintervention was 1.4 ± 0.7 mg/mL and was not positively correlated with systolic or diastolic ABP.

### Discussion

In the present study, the effects of regular coffee intake on BP over 2 weeks in older nonsmoking men and women differed according to whether subjects were normotensive or hypertensive, as defined by raised BP or treatment with antihypertensive agents. In hypertensive subjects, ambulatory SBP and DBP over a 24-hour period showed significant differences related to coffee drinking, with a pattern of a decrease in BP in abstainers and increase in BP in coffee drinkers. Daytime DBP showed a greater difference in relation to coffee drinking than did nighttime DBP.

Previous studies have also shown significant pressor effects of coffee 14,16,17 and caffeine 15 on ABP, but 2 of these studies were in normotensive subjects who were younger than those we studied. In middle-aged males switching from regular to decaffeinated coffee or ceasing regular caffeinated coffee intake for 2 months, there was a significantly lower mean systolic and diastolic ABP compared to those who drank decaffeinated coffee. 14 In normotensive individuals aged 18 to 52 years, caffeine administration equivalent to 3 to 4 cups of coffee was not significant in any of the models using 24-hour, daytime, or nighttime SBP or DBP, and there were no significant interactions between coffee drinking and treatment with antihypertensive drugs in any of these models.
coffee per day over 6 days resulted in an increase of both systolic and diastolic ABP (6.0/5.2 mm Hg). 15

We found a substantial increase in 24-hour ambulatory SBP and DBP in hypertensive subjects drinking coffee relative to hypertensive subjects who abstained from coffee. However, a crossover study in 23 treated hypertensive patients (mean age, 56 years) drinking 3 to 4 cups of instant coffee per day 10 failed to demonstrate a pressor effect. In a study of 52 untreated hypertensive patients (26 to 67 years) consuming a normal diet, a caffeine-free diet alone, and a caffeine-free diet with either decaffeinated or caffeinated instant coffee, no differences in mean 24-hour ABP levels were found. 12 One explanation for the conflicting results may be the age difference in subjects, as those in the present study were older (mean age, 72 years) than those reported in either of the previous 2 studies 10,12 and therefore more likely to have had an impaired capacity for baroreflex adaptation to pressor agents.

In the present study, we found a significant effect of coffee drinking relative to abstinence in hypertensive individuals, with a decrease in BP during abstinence and an increase during coffee drinking. This differential effect in hypertensive individuals, detected with a controlled study design, may partly explain inconsistent results reported in previous studies.

Some intervention studies have shown negative results with respect to ABP levels and frequent caffeine administration in normotensive caffeine-naive 11 and elderly 17 subjects receiving 300 to 400 mg caffeine per day (equivalent to 3 to 5 cups of coffee per day). The inconsistencies in the reported effects of coffee or caffeine intake are largely attributed to methodological defects and failure to control for confounding variables, including baseline BP, smoking, gender, dietary and alcohol intake, stress, obesity, and inaccurate determination of daily coffee or caffeine intake. 20,21 The combination of regular coffee or caffeine consumption and psychological (eg, type A behavior pattern) and environmental (eg, job strain) factors may substantially influence ABP, 22 as was recently reported.

Since coffee contains many other substances besides caffeine, the effects of coffee drinking cannot necessarily be equated with caffeine intake. The use of decaffeinated coffee as a control was considered inappropriate, because significant increases in DBP have been associated with decaffeinated coffee intake. 6 We therefore provided an optional caffeine-free tea ("Red Bush" tea), that is, a preparation that had not undergone decaffeination, for the abstainers to avoid the consumption of a variety of caffeine-free or decaffeinated beverages chosen by the participants. The possibility that certain components in the tea, such as flavanoids, may be potential confounders in contributing to a fall in BP among hypertensive abstainers is unlikely, as randomized controlled trials in our department have shown no effect of flavanoid supplements on ABP. 23 Furthermore, in the 20% of subjects who did not drink any substitute tea during the intervention, BP response did not differ from that in caffeine-free tea drinkers. It would also be necessary to postulate differential effects of the caffeine-free tea depending on hypertension status, as BP rose in normotensive abstainers.

In the present study, compliance was good, in that no serum caffeine was detected in abstainers and caffeine was
detected in all coffee drinkers. Although serum caffeine levels in the coffee drinkers were lower than those reported previously, this may be related to the time of blood sampling for caffeine determination, as we measured caffeine levels in the morning after 12 hours of abstinence whereas other researchers measured caffeine levels in the afternoon.

In conclusion, our results would suggest that in older, nonsmoking men and women with hypertension, a moderate intake of instant coffee (5 cups per day) has substantial pressor effects, relative to abstinence from coffee, assessed using 24-hour ABP. Some restriction of regular coffee intake may be a simple and effective strategy in the prevention and management of elevated BP with aging.

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