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Propranolol Fails to Lower the Increased Blood Pressure Caused by Cold Air Exposure

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PROPRANOLOL, a nonselective beta-adrenergic blocking agent, fails to lower blood pressure when individuals suffer from pheochromocytoma (6), overdose on cocaine (15), or perform isometric exercise (13). We hypothesize that increases in circulating norepinephrine (NE) and unopposed alpha-adrenergic receptor stimulation are the common link for this failure. If the elevation of plasma NE with exposure to cold reflects higher concentrations at tissue receptors contributing to the cold pressor response, then this NE excess may override propranolol's usual ability to lower blood pressure through beta adrenergic blockade. Propranolol, widely used to prevent recurrent migraine headaches and myocardial infarction (6), is commonly prescribed as an anti-hypertensive agent (22). Environmental cold exposure may contribute to seasonal elevations in myocardial infarction (21), cerebral vascular accident (11), and hypertension (19). The pressor response to a brief cold water immersion of the hand (4) or foot (8) is inconsistently attenuated with propranolol. The effectiveness of acute beta blockade in blunting the pressor response to cold air in motionless, normotensive men is uncertain (9).

The purpose of this study was to determine the contribution of the beta adrenergic receptor to the pressor response from cold air in normal subjects. We compared acutely administered bradycardia inducing doses of propranolol with placebo to make this assessment.

METHODS

Twelve healthy men gave informed consent to the protocol approved by our Institutional Review Board. The men were of similar age (mean ± S.E.), 27.9 ± 1.9 years, weight, 72.4 ± 2.0 kg, and percent body fat, 13.8 ± 0.3%. Each subject was tested in a climate chamber with alternating exposures at 25°C (25.6 ± 0.2) and 4°C (4.2 ± 0.2) for a total of two exposures at each temperature. There was a minimum of 72 h between exposures. Air flow in the chamber was 2.5 m/s at 20–40% humidity (Airguide Humidity Detector Model 605, Chicago, IL).

Placebo and propranolol were dispensed in double blind fashion as capsules filled with either white wheat flour for placebo or with a propranolol tablet (Wyeth-Ayerst Laboratories, Philadelphia, PA). The initial propranolol dose was 80 mg sustained release, and the second dose was 80 mg standard release. Both placebo and propranolol were self administered, with the first dose taken 10 h prior to entry into the chamber. After can-
nulation of the antecubital vein, each subject ingested the second dose of placebo or propranolol with 500 ml of water while seated in the staging room (25°C) for 30 min before entering the chamber. Subjects were randomly divided into two groups, each with a fixed sequence of alternating temperature and either placebo or propranolol administration. Half the subjects received placebo first, then propranolol, and the other half received the drug treatment in the reverse order. Temperature exposure was alternated for each administration into repeated split plot in time groups for temperature treatments, individual. Estimates for Tft at time 0 min, and Tfin significantly for both treatments (p < 0.0001). With cold exposure, Tfn was lower with propranolol pretreatment (9.5 ± 0.8°C) compared with placebo pretreatment (11.1 ± 0.7°C) (p < 0.008). With both temperature treatments, Tn fell slightly over time without any significant effect of propranolol administration. Compared with 25°C, LDF in cold air fell after 1 min and was lower for this exposure (F(1,22) = 13.65, p < 0.002) (Table 1). No significant differences in LDF between propranolol and placebo pretreatments at either 25° or 4°C was detected.

Blood Pressure and Heart Rate

MAP measured upon arrival at the laboratory (−30 min) was lower with propranolol pretreatment compared to placebo before either the 4°C (85.9 ± 1.3, 89.8 ± 2.1 mm Hg) and 25°C (83.2 ± 1.8, 88.4 ± 2.6 mm Hg) treatments. After 30 min at 25°C, propranolol lowered MAP to 75.7 ± 2.4 mm Hg compared with placebo, 81.9

| Table 1. Comparison of Fingertip Skin Blood Flow with Exposure to 25°C or 4°C Air and Pretreatment with Placebo or Propranolol. |
|---------------------------------|-----------------|---------------|-----------------|-----------------|---------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Time (min.)                     | −30             | 0              | 1               | 5               | 10             | 15             | 20              | 25              | 30              | 60              |
| Placebo 25°C                    | 228.3           | 114.1          | 145.0           | 152.5           | 160.0          | 144.1          | 194.1           | 140.8           | 115.8           | 125.0           |
| Placebo 4°C                     | 54.1            | 31.3           | 55.6            | 52.8            | 53.5           | 42.2           | 67.5            | 44.6            | 34.5            | 48.4            |
| Propranolol 25°C                | 278.3           | 116.6          | 44.1            | 28.3            | 27.5           | 35.8           | 40.8            | 46.6            | 54.1            | 90.0            |
| Propranolol 4°C                 | 75.2            | 38.0           | 9.5             | 5.7             | 6.4            | 8.0            | 6.9             | 6.7             | 7.9             | 23.9            |

The first line is the ANOVA mean of 12 men with the SE of the mean in the second line; Doppler flow is measured in millivolts; temperature treatment p < 0.002.
± 2.2 mm Hg (p < 0.03). In contrast, MAP was similar after 30 min at 4°C in both treatment groups (propranolol, 94.2 ± 1.9; placebo, 94.9 ± 1.8 mm Hg). When we compared the difference between 25 and 4°C, the MAP tended to increase more for propranolol treatment than with placebo treatment (F[1,11] = 4.07, p = 0.068) (Fig. 1). However, after 1 min in the climate chamber, the increase at 4°C compared to 25°C became significantly greater with propranolol pretreatment than with placebo (F[1,11] = 5.11, p < 0.05). After 30 min of cold exposure, the percentage increase over the corresponding value at 25°C was 25.0 ± 2.5% with propranolol and 16.6 ± 3.2% with placebo pretreatment. This marked difference was caused primarily by lower MAP at 25°C with propranolol pretreatment compared with that of placebo at primarily 25°C. Blood pressure is presented in Table II and shows near equal elevations in systolic and diastolic pressure with cold exposure. Basal HR (30 min) was lower in subjects pretreated with propranolol when compared with subjects pretreated with placebo at both 25°C (59 ± 2, 68 ± 5 min⁻¹) and 4°C (59 ± 2, 66 ± 3 min⁻¹) (F[1,11] = 7.75, p < 0.02). The HR after 30 min in both 25°C (p < 0.00001) and 4°C (p < 0.00001) environments was slower for propranolol (52 ± 2, 55 ± 3 min⁻¹) compared with placebo (63 ± 2, 64 ± 2 min⁻¹). There was no significant effect of temperature upon HR.

Plasma Norepinephrine and Epinephrine

Plasma venous NE was unchanged after 30 min at 25°C and after pretreatment with propranolol or placebo. Plasma NE increased after 30 min at 4°C from 2.23 ± 0.25 to 6.09 ± 0.60 (propranolol) and from 2.50 ± 0.28 to 5.96 ± 0.41 (placebo) nmol/L (Fig. 2). Epinephrine (EPI) values were unchanged during 25°C exposure (Fig. 3). However, pretreatment with propranolol prior to cold exposure significantly elevated EPI compared with placebo pretreatment (Fig. 3). Whole blood hematocrit increased after 30 min of cold exposure (F[1,11] = 26.18, p < 0.0004) from 41.40 ± 0.81 to 43.56 ± 0.87% for placebo pretreatment and from 41.91 ± 0.59 to 44.08 ± 0.94% for propranolol pretreatment. Propranolol had no effect upon this increase (p > 0.99).

DISCUSSION

We and others report that when human subjects are exposed briefly to cold air, a characteristic series of thermoregulatory and cardiovascular events are noted (14,16). These events include a fall in the oxygenation of brachial venous hemoglobin (17), an increase of the viscosity of blood (10), a near doubling of the oxygen uptake (1), an increase in mean arterial pressure (20), and a two-fold increase in plasma norepinephrine (7,14,16). We demonstrate in this study that cold air challenge has an acute pressor action that overcomes the normal blood pressure lowering influence of propranolol. We suggest that the pressor response of cold is mediated primarily by a mechanism other than the beta adrenergic component of the sympathetic nervous system.

Cold exposure enhances cutaneous vasoconstriction, shunts blood to the central circulation, and elevates systolic and diastolic blood pressure without an equivalent increase in cardiac output (5,16). In our study, the rapid fall in fingertip skin blood flow (Table I) with cold exposure parallels the rise in MAP (Fig. 1). This finding agrees with a cold-induced shift in blood volume from the cutaneous to the central circulation (16). Heart rates are similar for each treatment group independent of temperature, and both systolic and diastolic pressure rise equally in response to cold (Table II). Therefore, MAP, in contrast to a rate x pressure calculation, is a convenient and accurate way to compare cold responses with those found at room temperature (18). Comparisons of MAP at 4°C and 25°C show that MAP increases 25% for propranolol and only 16% for placebo. This 25% increase in MAP, while the propranolol-treated subjects are bradycardic, suggests that the beta receptor contributes only minimally to generating the cold pressor response in these normal men.

Dosing intervals similar to those used in our study have been shown to provide serum levels of propranolol associated with nonselective beta blockade (2,3,20). Slowing of the resting heart rate, as in our subjects, indicates physiologic myocardial beta-1 blockade; we thus presume beta-2 blockade (22). Because this acute dosing study involves nonsteady-state blood levels of the drug, all physiologic measurements are best compared with their paired drug and temperature counterparts to minimize the interaction of time. At 25°C, propranolol, compared with placebo, significantly lowers blood pressure and HR within 60 min after acute dosing and suggests that serum levels are adequate to achieve beta blockade. At 4°C, propranolol retains its effect of bradycardia. This similar chronotropic effect between temperatures suggests circulating and physiologic levels of propranolol at 4°C are comparable to those found at 25°C. However, at 4°C, propranolol no longer lowers blood pressure, implying an overriding intervention by cold not mediated by HR.

Peripheral venous plasma NE consistently increases with cold exposures (7,14,17). The nearly three-fold elevation in NE at 30 min of cold exposure that we describe is maintained after 30 min of rewarming. Cold-induced alpha-adrenergic receptor activation by NE, unopposed with propranolol blockade of the beta receptor, could produce the changes in MAP we observe.
### TABLE II. COMPARISON OF SYSTOLIC AND DIASTOLIC BLOOD PRESSURE (mm Hg) WITH EXPOSURE TO 25°C or 4°C AIR AND PRETREATMENT WITH PLACEBO OR PROPRANOLOL.

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</table>

The first line is the ANOVA mean of 12 men with the SE of the mean in the second line; pressures are measured in mm Hg.

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**Fig. 3.** Comparison of plasma epinephrine levels (pmol/L) with exposure to 25°C or 4°C air after pretreatment with placebo or propranolol (— 25°C, placebo; — 4°C, placebo; — 25°C, propranolol; — 4°C, propranolol). The dashed line indicates exposure period in the environmental chamber.

**Fig. 2.** Comparison of plasma norepinephrine levels (nmol/L) with exposure to 25°C or 4°C air after pretreatment with placebo (Graph A) or propranolol (Graph B). The dashed line indicates exposure period in the environmental chamber.

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This finding is supported by reports that propranolol does not lower the MAP elevation associated with pheochromocytoma (6), cocaine overdose (15), and isometric exercise (13), conditions also associated with increased alpha-adrenergic stimulation. The acute use of propranolol in maintaining 24-h normotension may have reduced effectiveness in cold climates.

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