β Adrenoreceptor subtype cross regulation in the human heart

J A Hall, A Ferro, J E C Dickerson, M J Brown

Abstract

Objectives—To find out in a prospective study whether β_1 blocker treatment causes selective β_2 adrenoreceptor sensitisation, and to find whether such sensitisation is confined to the heart.

Design—A placebo controlled cross over study of two weeks of selective β_1 blocker treatment with 10 mg of bisoprolol daily.

Subjects—Six healthy volunteers.

Outcome measures—Three days after stopping the 10 mg of bisoprolol or placebo, subjects underwent treadmill exercise (to measure cardiac β_1 receptor responsiveness) and were given salbutamol injections (to measure cardiac β_2 receptor responsiveness). Secondary end points were the responses of serum potassium, glucose, and insulin to β_2 stimulation.

Results—There was no difference in exercise induced increases in heart rate, but after treatment with bisoprolol the dose of salbutamol required to increase heart rate by 40 beats/min was 1.9 μ g/kg compared with 2.9 μ g/kg after placebo ($p < 0.005$). The fall in diastolic blood pressure was not significantly different on the two occasions. Hypokalaemia induced by salbutamol, but not hyperglycaemia or hyperinsulinaemia, was enhanced after bisoprolol.

Conclusion—This study shows that treatment with a β_1 blocker in vivo leads to sensitisation of cardiac β_2 adrenoreceptors but not cardiac β_1 adrenoreceptors or vascular β_2 receptors. This previously unrecognised form of receptor cross sensitisation in the heart may noticeably diminish the efficacy of selective β_1 blockade in preventing arrhythmias in patients with ischaemic heart disease. These findings reopen the question of which type of β blocker is more appropriate for such patients.

(Br Heart J 1993;69:332-337)

The β blockers are among the most widely used drugs in clinical practice. Both β_1 selective and non-selective blockers seem to be equally effective as antihypertensive and antianginal agents, but this has masked our ignorance about which type of β blocker is to be preferred for achieving the long-term objective in both groups of patients, namely a

reduction in the incidence of myocardial infarction and its complications. The possibility that so called cardioselective β blockers offer less cardioprotection than non-selective β blockers has existed since the human heart was found to differ from other species in not, after all, being itself β_1 selective.¹ About 30% of the β receptors are of the β_2 subtype² and selective β_2 receptor stimulation causes tachycardia.³

Chronic β blockade may paradoxically increase the sensitivity of patients to sympathetic stimulation, although in the past this has been considered important only during the immediate withdrawal period.⁴ Recent in vitro studies, however, on strips of atrial myocardium from patients still receiving β_1 blockers have shown a previously unrecognised cross regulatory effect of chronic β_1 blockade on other receptors coupled to adenylyl cyclase, including a selective 10 fold increase in sensitivity to β_2 stimulation by adrenaline, with no change in sensitivity to β_1 stimulation.⁵⁻⁷ Therefore, such patients may be at enhanced risk of tachycardia induced by adrenaline, and have indeed been found to be four times more sensitive to β_2 receptor stimulation by intracoronary salbutamol than patients who are not β blocked.⁸ These previous studies were performed on patients, or on tissue from patients, whose drug treatment had been chosen by referring physicians long before the time of study. Therefore to establish that the β_2 hypersensitivity seen in these studies is being induced by β blocker treatment, rather than being a consequence of patient selection criteria, we undertook the present prospective investigation. This was a cross over study of β_1 blocker treatment in normal volunteers to find whether selective β_2 receptor sensitisation can be induced by β_1 blockade. To find whether any sensitisation occurs in the heart only, we gave salbutamol and measured the dose related changes in diastolic blood pressure and the metabolic responses to salbutamol as indicators of extracardiac β_2 receptor stimulation.

Patients and methods

SUBJECTS

Six healthy men aged 24-35 took part in the study. The subjects were non-smokers with no contraindications to β blockade on history, examination, or electrocardiogram.

PROCEDURE

Before starting drug treatment the subjects

Clinical Pharmacology Unit,
University of Cambridge,
Cambridge
J A Hall
A Ferro
J E C Dickerson
M J Brown

Correspondence to:
Dr J A Hall, South
Cleveland Hospital, Marton
Road, Middlesbrough
TS4 3BW.

Accepted for publication
29 September 1992.

exercised on a treadmill to familiarise themselves with the equipment and protocol. A level of exercise was found for each subject that produced a stable heart rate of about 150 beats/min. The subjects then took a 14 day course of treatment with bisoprolol (10 mg) or matched placebo once daily. The order of treatment was double blinded and randomised according to a latin square design. Bisoprolol was used because its β_1 selectivity (about 75-fold) is higher than that of atenolol or metoprolol.⁹

Three days after stopping each course of treatment the subjects underwent treadmill exercise followed by an intravenous salbutamol dose response study. A similar light breakfast was permitted before the two visits, excluding all caffeine containing drinks. Two intravenous cannulae were inserted in forearm veins. The subjects rested for 30 minutes and the resting heart rate was noted. They then walked on the treadmill at the previously determined level of exercise for two minutes and the heart rate was measured. Blood samples were taken to measure plasma potassium before exercise, at peak exercise, and at five minutes after exercise.

After exercise the subjects rested for 15 minutes and were then given salbutamol by intravenous injections. The bolus injections were given over two minutes, and after a further three minutes the next dose was given. Injections started at 0.5 μ g/kg and were increased by doubling increments up to a final dose of 4 μ g/kg. Heart rate and blood pressure were recorded at one minute and three minutes after the end of each injection. Baseline measurements were taken in duplicate. During the dose response curve heart rate and blood pressure were determined by single measurements. Peak responses to each injection were seen at the one minute recording and these readings were used for further analysis. Blood samples were taken for measurement of potassium, glucose, and insulin concentrations before the start of the salbutamol injections and at five minute intervals for 40 minutes.

METHODS OF ASSESSMENT

Heart rate was calculated from the RR intervals averaged over 15 seconds from a continuously monitored electrocardiogram. Blood pressure was measured with an automated sphygmomanometer (Datascope, USA). Potassium was measured with an ion sensitive electrode, glucose by the glucose oxidase method, and insulin by a double antibody radioimmunoassay.¹⁰

The study was approved by the district

medical ethics committee and was in accord with the Helsinki Convention (Tokyo and Venice ammendments). Subjects gave written informed consent.

STATISTICS

Changes in heart rate induced by exercise and plasma potassium concentration after bisoprolol treatment were compared with those after placebo by a paired Student's *t* test. Changes in systolic blood pressure induced by salbutamol after bisoprolol treatment were compared with those after placebo by repeated measures analysis of variance. The dose of salbutamol needed to decrease diastolic blood pressure by 10 mm Hg (vasodilator dose 10 (VD10)) was found for each dose response curve from a fitted linear equation. VD10s (log doses) were compared after bisoprolol treatment and after placebo by a paired Student's *t* test. The dose of salbutamol to increase heart rate by 40 beats/min (chronotropic dose 40 (CD40)) was found for each individual dose response curve from a fitted quadratic equation, and CD40s (log doses) were compared by a paired Student's *t* test.¹¹ For changes in the metabolic variables, serum potassium, insulin, and glucose concentrations, responses after bisoprolol treatment were compared with those after placebo by repeated measures analysis of variance. A *p* value of < 0.05 was considered significant. All results are expressed as mean (SEM).

Results

There was no significant difference in the basal heart rate or blood pressure three days after treatment with bisoprolol or placebo.

The increases in heart rate in response to exercise (peak exercise rate—resting rate) after treatment with bisoprolol (86.5 (3.0) beats/min) were not significantly different from those after placebo (87.3 (4.0) beats/min) (table 1). The study had a 90% power to detect a > 15% difference in exercise tachycardia at the 5% level.

By contrast, the increases in heart rate in response to salbutamol injection were significantly greater after bisoprolol treatment than placebo. The maximum increases (peak rate after 4 μ g/kg—preinjection heart rate) were 66.3 (6.1) beats/min after bisoprolol and 51.3 (5.9) beats/min after placebo, with CD40s of 1.9 μ g/kg and 2.9 μ g/kg, (*p* < 0.002; fig 1 and table 2). Salbutamol caused a fall in diastolic and no change in systolic blood pressure (fig 1): the dose of salbutamol required to decrease diastolic blood pressure by 10 mm Hg (VD10) was similar on the two occa-

Table 1 Cardiovascular and metabolic responses to two minutes sub-maximal exercise

	Placebo			Bisoprolol		
	Before	Peak	After	Before	Peak	After
Heart rate (beats/min)	61.5 (2.6)	148.8 (4.3)	—	64.0 (2.9)	150.5 (2.5)	—
Plasma potassium (mmol/l)	4.17 (0.08)	4.64 (0.11)	4.20 (0.10)	4.25 (0.06)	4.68 (0.05)	4.33 (0.07)

Values are mean (SEM); differences were non-significant.

Figure 1 Cardiovascular responses to salbutamol infusion. (A) Heart rate (HR) was measured in response to incremental doses of salbutamol injected three days after bisoprolol or placebo. Bars = SEM. The sensitivity to salbutamol, measured as the dose required to raise HR by 40 beats/min, was significantly greater after bisoprolol than after placebo ($p < 0.005$). (B) Systolic and diastolic blood pressures (BP) were measured one minute after the end of each injection of salbutamol. Bars = (SEM). Differences were non-significant.

sions—namely, 1.5 $\mu\text{g/kg}$ after treatment with bisoprolol and 1.4 $\mu\text{g/kg}$ after placebo (table 2). The study had a 90% power to detect a $> 25\%$ difference in change in diastolic blood pressure at the 5% level.

Plasma potassium concentrations rose with exercise and fell with rest. The changes were unaltered by previous bisoprolol treatment (table 1). Plasma potassium concentrations fell in response to salbutamol injection and the maximum fall was greater after bisoprolol treatment (1.06 (0.09) mM) than after placebo (0.83 (0.11) mM, $p = 0.04$; fig 2).

Basal plasma glucose concentration was slightly higher after bisoprolol treatment (5.25 (0.11) mM) than after placebo (4.85

Table 2 Chronotropic and vasodilatory potency of salbutamol

Subject	CD40		VD10	
	After Bisoprolol	After Placebo	After Bisoprolol	After Placebo
1	1.99	4.11	1.76	1.58
2	1.62	2.22	1.23	1.38
3	1.82	3.58	1.16	0.79
4	2.34	3.17	1.71	1.51
5	1.74	2.20	2.02	1.62
6	1.86	2.32	1.34	1.95
Mean (SEM)	1.89 (0.10)	2.93 (0.33)	1.54 (0.14)	1.43 (0.15)

CD40 the dose of salbutamol ($\mu\text{g/kg}$) to increase heart rate by 40 beats/min calculated from a fitted quadratic equation for each individual log dose response curve; VD10 the dose of salbutamol ($\mu\text{g/kg}$) to decrease diastolic blood pressure by 10 mm Hg calculated from a fitted linear equation for each individual log dose response curve. The log CD40s were significantly lower after placebo than after bisoprolol ($p < 0.005$). The difference between VD10s was not significant.

Figure 2 Metabolic responses to salbutamol infusion. (A) Plasma potassium (K^+), (B) plasma glucose, and (C) plasma insulin were measured every five minutes after the start of five minute incremental doses of salbutamol. Subjects were studied three days after stopping treatment with bisoprolol or placebo. Bars = (SEM). The fall in plasma K^+ was greater after bisoprolol treatment ($p < 0.04$), but the increases in glucose and insulin were non-significant.

(0.16) mM, $p = 0.04$). The rise in plasma glucose in response to salbutamol, however, was similar after either treatment (fig 2). Basal plasma insulin concentration was unaltered by bisoprolol treatment and rose equally in response to salbutamol injection (fig 2).

Discussion

The principal finding was that in each of these normal subjects, two weeks of treatment with a β_1 selective blocker led to an increased tachycardia in response to a β_2 agonist, with a significant increase in the chronotropic potency of salbutamol. There was, however, no increase in the β_1 mediated tachycardia on exercise and no enhancement of the peripheral vascular β_2 receptor mediated fall in diastolic blood pressure in response to salbutamol. Does the study therefore confirm, *in vivo*, that β_1 blockade causes selective cross sensitisation of β_2 receptor responses in the human heart?

Our previous studies with intracoronary salbutamol gave doses without systemic effects to show that the tachycardia was solely due to direct stimulation of cardiac β_2 receptors (rather than vagal withdrawal after peripheral vasodilation).³⁸ By giving intravenous salbutamol in the present study we found no effect of previous β_1 blockade on the fall in diastolic blood pressure, again suggesting that the enhanced tachycardia is mediated directly through increased cardiac β_2 receptor sensitivity rather than indirectly through peripheral vascular β_2 receptors causing vasodilation. This conclusion is also consistent with recent organ bath experiments on mammary artery and saphenous vein strips, which show no difference in β_2 mediated vasodilation between β blocked and untreated patients.¹²

In the absence of an appropriate β_1 agonist for intravenous use we used exercise to produce tachycardia mediated by β_1 receptors. Several previous studies have concluded that tachycardia induced by exercise is due to a combination of vagal withdrawal and β_1 receptor stimulation with no evidence of a component due to β_2 receptor stimulation.¹³⁻¹⁶ Tachycardia induced by exercise was unaltered after bisoprolol treatment. Therefore our finding of increased tachycardia induced by salbutamol and no difference in tachycardia induced by exercise after treatment with a β_1 blocker is consistent with our organ bath findings in atrial strips. No change was found in responsiveness of β_1 receptors in atrial strips from β_1 blocked patients despite a 10-fold increase in the responsiveness to stimulation of β_2 receptors.⁵ Also, our results are consistent with a previous study of withdrawal from atenolol in which increased sensitivity to isoprenaline ($\beta_1 + \beta_2$) was accompanied by no increase in exercise tachycardia (β_1).¹⁷ Our *in vivo* and *in vitro* findings were surprising as previous radioligand binding studies had shown that treatment of atrial strips with a β_1 blocker leads to an increase in the density of β_1 receptors and not β_2 receptors; these density changes (upregulation) do not therefore

seem to have functional consequences.¹⁸ The finding of less sensitisation of cardiac β_2 receptors in our present study could be due to the shorter duration of β blocker treatment (two weeks *v* several months) and also due to the need to study the subjects after three days of withdrawal from bisoprolol to compare the exercise induced (β_1 mediated) tachycardia on the two occasions.

From our *in vitro* studies it was apparent that the process of sensitisation was a new phenomenon of receptor cross reaction unrelated to simple upregulation of the number of receptors. Taken with our present findings it seems that the cross sensitisation is a cellular event peculiar to the heart. It is possible that the prerequisite for cross sensitisation is a mixed population of β_1 and β_2 receptor subtypes, and a high basal stimulation of β_1 receptors.

Stimulation of β_2 receptors, unlike β_1 receptors, has additional important effects on metabolism. As a secondary objective of the study therefore, we included measurements of metabolic variables under β_2 receptor control. This was partly to find whether there might be clinically important metabolic effects of β_2 receptor sensitisation and partly to pursue further the mechanistic question of whether β_2 receptor sensitisation can occur only in cell types where both β receptor subtypes are present. The metabolic responses to stimulation of β_2 receptors take longer than the haemodynamic changes to reach equilibrium and we therefore compared their change over time in response to the total dose of salbutamol given. Stimulation of β_2 receptors that occurs when the concentration of the endogenous β_2 receptor agonist adrenaline is high, has been shown repeatedly to cause hypokalaemia. The failure of selective β_1 receptor blockers to reverse this has been one of the theoretical arguments in favour of non-selective β blockade.^{19,20} From the clinical standpoint, therefore, this concern may be enhanced by our finding that β_1 blockade actually potentiates hypokalaemia mediated by β_2 receptors. Hypokalaemia in response to β_2 receptor stimulation is predominantly due to skeletal muscle uptake of potassium through stimulation of sodium-potassium ATPase.²¹ As skeletal muscle is not known to contain β_1 receptors we had not anticipated this to be potentiated after β_1 blockade.²² This finding therefore seems to contradict our hypothesis that only a mixed population of β receptors would allow cross sensitisation. This contradiction could, however, be reconciled if there was a component of the hypokalaemia due to stimulation of β_2 receptors in cells, other than skeletal muscle, which contain both β_1 and β_2 receptors—for example, red blood cells.²³ Involvement of β_1 receptor bearing cells in the hypokalaemic response to β agonists has been suggested by the finding that β_1 selective agonists can lower serum potassium²⁴ and that β_1 selective antagonists can antagonise the hypokalaemic response to adrenaline and isoprenaline,^{20,24} but these findings may only reflect the poor

selectivity of the agents used. An alternative explanation of our increased hypokalaemia in response to salbutamol after treatment with bisoprolol may be that hypokalaemia is greater because the greater increase in cardiac output augments the potassium load delivered to the predominant site of potassium uptake—namely, skeletal muscle.

By contrast there was no increase after β_1 blockade of salbutamol induced release of glucose or insulin consistent with a lack of known β_1 receptors on liver or pancreatic cells.²⁵ We found, however, that basal plasma glucose (before salbutamol infusion) was increased after bisoprolol treatment, with no difference in basal plasma insulin. The implied insulin resistance has been previously noted with β blockade.²⁶ We would not attach too much importance to our own findings until they are repeated with measurements before and after a standard glucose load, but they may shed indirect light on the mechanism of cross sensitisation.

Previous experiments have pointed away from changes in the β receptor itself being responsible for sensitisation and have indicated that the coupling of the receptor to its adenylyl cyclase through G proteins, is a more likely site for regulation of sensitivity. In the mitral valve prolapse syndrome β receptor sensitisation is found due to a change in the stimulatory G protein (Gs).^{27,28} On the other hand, altered β receptor sensitivity could be due to changes in the inhibitory G protein (Gi). Conditions in which there is a chronic increase in β receptor stimulation, such as cardiac failure, have been associated with increased expression of Gi.^{29,30} Consequently one of our hypotheses is that β blockade leads to the reverse of chronic β receptor stimulation—namely, a reduced concentration of Gi. If this hypothesis proves to be correct then the hint that β blockade induces insulin resistance is of mechanistic as well as clinical interest as some of the actions of insulin are Gi dependent and reduced expression of this protein has been found in some experimental models of insulin resistance.³¹

The possible clinical implications are perhaps of greater relevance to the present study. To find sensitisation of β_2 receptors might provide the basis for explaining the clinical syndrome of β blocker withdrawal.⁴ Also a major clinical concern is whether sensitisation of, and failure to block, cardiac β_2 receptors in patients with ischaemic heart disease might paradoxically increase the risk of arrhythmias. There have been no prospective comparisons of β_1 selective and non-selective antagonists in such patients, but we have commented previously on the generally better performance of non-selective antagonists in the secondary prevention trials of β blockade after myocardial infarction and the perhaps surprising failure of the β_1 selective atenolol to prevent arrhythmia when given acutely to such patients.^{32,33} These speculations on the clinical implications will now need to be tested in groups of patients with ischaemic heart disease or hypertension.

We thank Miss L DiSilvio for the metabolic assays and Lederle for the supply of bisoprolol and placebo tablets. A F is a Medical Research Council Training Fellow, and further funding was from the East Anglian Regional Health Authority.

- 1 Lands AM, Arnold A, McAuliff JP, *et al.* Differentiation of receptor subtypes by sympathetic amines. *Nature* 1967;214:597–8.
- 2 Stiles GL, Taylor S, Lefkowitz RJ. Human cardiac beta-adrenergic receptors: subtype heterogeneity delineated by direct radioligand binding. *Life Sci* 1983;33:467–73.
- 3 Hall JA, Petch MC, Brown MJ. Intracoronary injections of salbutamol demonstrate the presence of functional β_2 adrenoreceptors in the human heart. *Circ Res* 1989;65:546–53.
- 4 Prichard BNC, Tomlinson B, Walden RJ, Bhattacharjee P. The β -adrenergic blockade withdrawal phenomenon. *J Cardiovasc Pharmacol* 1983;5(suppl 1):S56–62.
- 5 Hall JA, Kaumann AJ, Brown MJ. Selective β_1 adrenoreceptor blockade enhances positive inotropic responses to endogenous catecholamines mediated through β_2 adrenoreceptors in human atrial myocardium. *Circ Res* 1990;66:1610–23.
- 6 Kaumann AJ, Sanders L, Brown AM, Murray KJ, Brown MJ. A 5-HT receptor in the human atrium. *Br J Pharmacol* 1990;100:879–85.
- 7 Motomura S, Deighton NM, Zerkowski HR, *et al.* Chronic β_1 adrenoreceptor antagonist treatment sensitizes β_2 adrenoreceptors but desensitizes M-2 muscarinic receptors in the human right atrium. *Br J Pharmacol* 1990;101:362–9.
- 8 Hall JA, Petch MC, Brown MJ. In vivo evidence of cardiac β_2 adrenoreceptor sensitisation due to atenolol treatment. *Circ Res* 1991;69:959–64.
- 9 Wellstein A, Palm D, Belz GG, *et al.* Reduction in exercise tachycardia in man after propranolol, atenolol, and bisoprolol in comparison to β -adrenoreceptor occupancy. *Eur Heart J* 1987;8(suppl M):3–8.
- 10 Morgan CR, Lazarow A. Immunoassay of insulin with a two antibody system: plasma concentration in normal, subdiabetic and diabetic rats. *Diabetes* 1963;12:115–26.
- 11 Sumner DJ, Elliot HL, Reid JL. Analysis of the pressor dose response. *Clin Pharmacol Ther* 1982;52:450–8.
- 12 Ferro A, Kaumann AJ, Brown MJ. β -adrenoreceptor subtypes and function in human internal mammary artery and saphenous vein. *Br J Pharmacol* 1992;105:229P.
- 13 Harry JD, Young J, Stribling D. Effects of ICI 118551 (a β_2 adrenoreceptor blocker) on metabolic changes induced by isoprenaline and on tachycardia induced by exercise. *Br J Clin Pharmacol* 1982;14:584P.
- 14 Tattersfield AE, Cragg DJ. Effect of ICI 118551 on bronchial β -adrenoreceptor function and exercise heart rate in normal man. *Br J Clin Pharmacol* 1983;16:587–90.
- 15 Wellstein A, Belz GG, Palm D. β -adrenoreceptor subtype binding activity in plasma and β -blockade by propranolol and β_1 selective bisoprolol in humans. Evaluation with Schild plots. *J Pharmacol Exp Ther* 1988;246:328–37.
- 16 Pringle TH, Riddell JG, Shanks RG. Characterisation of the β -adrenoreceptors which mediate the isoprenaline induced changes in finger tremor and cardiovascular function in man. *Eur J Clin Pharmacol* 1988;35:507–14.
- 17 Walden RJ, Bhatterjee P, Tomlinson B. The effect of ISA on β -adrenoreceptor responsiveness after β -adrenoreceptor blockade withdrawal. *Br J Clin Pharmacol* 1978;5:207.
- 18 Michel MC, Pingsmann A, Beckeringh JJ, *et al.* Selective regulation of β_1 and β_2 adrenoreceptors in the human heart by chronic β -adrenoreceptor antagonist treatment. *Br J Pharmacol* 1988;94:685–92.
- 19 Brown MJ, Brown DC, Murphy MB. Hypokalaemia from beta-2 receptor stimulation by circulating epinephrine. *N Eng J Med* 1983;309:1414–19.
- 20 Struthers AD, Whiteside R, Reid JL, Rodgers JC. Effects of cardioselective and non-cardioselective beta-blockade on hypokalaemia and cardiovascular responses to adrenomedullary hormones in man. *Clin Sci* 1983;65:143–7.
- 21 Clausen T, Flatman JA. Beta-2 adrenoreceptors mediate the stimulating effect of adrenaline on active electrogenic Na/K transport in rat soleus muscle. *Br J Pharmacol* 1980;68:749–55.
- 22 Elfellah MS, Dalling R, Kantola RM, Reid JL. β -adrenoreceptors and human skeletal muscle characterisation of receptor subtype and effect of age. *Br J Clin Pharmacol* 1989;27:31–8.
- 23 Bree F, Gault I, d'Athis P, Tillement J-P. Beta adrenoreceptors of human red blood cells, determination of their subtypes. *Biochem Pharmacol* 1984;33:4045.
- 24 Vincent HH, Boomsma F, Man in't Veld AJ, *et al.* Effects of selective and non-selective β -agonists on plasma potassium and norepinephrine. *J Cardiovasc Pharmacol* 1984;6:107.
- 25 John GW, Doxey J-C, Walter DS, Reid JL. The role of α and β -adrenoreceptor subtypes in mediating the effects of catecholamines on fasting glucose and insulin in the rat. *Br J Pharmacol* 1990;100:699–704.
- 26 Pollare T, Lithell H, Selinus I, Berne C. Sensitivity to insulin during treatment with atenolol and metoprolol: a randomised double blind study of effects on carbony-

- drate and lipoprotein metabolism in hypertensive patients. *BMJ* 1989;298:1152-7.
- 27 Autonomic function in mitral valve prolapse [editorial]. *Lancet* 1987;2:773-4.
- 28 Davies AO, Su CJ, Balasubramanyam A, Codina J, Birnbaumer L. Abnormal guanine nucleotide regulatory protein in MVP dysautonomia: evidence from reconstitution of Gs. *J Clin Endocrinol Metab* 1991;72:867-75.
- 29 Reithmann C, Gierschik P, Sidiropoulos D, Werdan K, Jakobs KH. Mechanism of noradrenaline induced heterologous desensitisation of adenylate cyclase stimulation in rat heart muscle cells: increase in the level of inhibitory G-protein α subunits. *Eur J Pharmacol* 1989; 172:211-21.
- 30 Neumann J, Schmitz W, Scholz H, *et al.* Increase in myocardial G-proteins in heart failure *Lancet* 1988;2: 936-7.
- 31 Green A. Adenosine receptor downregulation and insulin resistance follows prolonged incubation of adipocytes with an A1 adenosine receptor agonist. *J Biol Chem* 1987;262:15702-7.
- 32 First international study of infarct survival collaborative group. Randomised trial of intravenous atenolol among 16,027 cases of suspected acute myocardial infarction: ISIS-1. *Lancet* 1986;1:57-66.
- 33 Norris RM, Brown MA, Clarke ED, *et al.* Prevention of ventricular fibrillation during acute myocardial infarction by intravenous propranolol. *Lancet* 1984;2:883-6.