

Stereoselective Disposition and Pharmacologic Activity of Propafenone Enantiomers

Heyo K. Kroemer, PhD, Christian Funck-Brentano, MD,
David J. Silberstein, PhD, Alastair J.J. Wood, MD, Michel Eichelbaum, MD,
Raymond L. Woosley, PhD, MD, and Dan M. Roden, MD

Propafenone is an antiarrhythmic drug that produces a variable degree of β -blockade in humans and is administered as a racemate. To examine the relative contribution of the individual enantiomers to pharmacologic effects seen during treatment with propafenone, we assessed the steady-state plasma concentrations of (+)-*S*-propafenone and (–)-*R*-propafenone in seven patients who were on long-term oral therapy, and we evaluated the electrophysiologic and β -blocking properties of both enantiomers in vitro. The metabolism of propafenone is known to be polymorphic and to cosegregate with that of debrisoquine-4-hydroxylation. Among five patients with the extensive metabolizer phenotype (EM), the ratio of the area under the plasma concentration–time curve of (+)-*S*-propafenone to (–)-*R*-propafenone was 1.73 ± 0.15 (mean \pm SD). In the other two patients, who had the poor metabolizer phenotype (PM), the concentrations of both enantiomers were elevated but the *S/R* ratios were similar to those seen in patients with EM. In canine cardiac Purkinje fibers, both enantiomers produced similar frequency-dependent depression of maximum upstroke of phase 0. In contrast, the affinity of the human lymphocyte β_2 -adrenoceptor was approximately 100-fold greater for (+)-*S*-propafenone (K_i , 7.2 ± 2.9 nM) than for the (–)-*R*-enantiomer (K_i , 571 ± 141 nM). We conclude that during long-term oral therapy, propafenone undergoes stereoselective disposition in patients with either EM or PM. β -Blockade during propafenone therapy is likely related to accumulation of (+)-*S*-propafenone. The lower β -blocking activity of the (–)-*R*-enantiomer without significant difference in sodium channel blockade suggests that administration of this enantiomer rather than the racemic mixture may be of advantage in patients intolerant of β -blockade. (*Circulation* 1989;79:1068–1076)

Propafenone is a recently developed antiarrhythmic agent that has proven to be effective in a variety of arrhythmias, including frequent ventricular ectopic depolarizations,¹ sustained ventricular tachyarrhythmias,² and arrhythmias related to accessory atrioventricular pathways.³ The drug produces sodium channel- and β -blocking actions as well as weak calcium channel antagonism.⁴

Propafenone undergoes extensive and saturable hepatic metabolism in humans.⁵ In addition, considerable variability in the dose-plasma concentration

relation has been reported. One explanation for this variability is the genetically determined impairment in approximately 7% of the Caucasian population to metabolize propafenone.¹ This polymorphism cosegregates with the ability to 4-hydroxylate the antihypertensive debrisoquine and correlates with the functional presence or absence of the hepatic cytochrome P-450_{db1}.⁶ Patients with the extensive metabolizer phenotype (EM) or the poor metabolizer phenotype (PM) can be distinguished,¹ and the metabolic pathway affected by polymorphic oxidation is the formation of the active metabolite 5-hydroxy propafenone.^{7,8}

Propafenone is administered as a racemic mixture of (+)-*S*- and (–)-*R*-enantiomers. Pharmacokinetic differences between the enantiomers of other racemic drugs, such as metoprolol and *N*-propylajmaline, which are substrates for P-450_{db1}, have been found in EM but not in PM subjects, indicating the potential for stereoselective metabolism of substrates for this cytochrome P-450.^{9,10} The in vitro electrophys-

From the Departments of Medicine and Pharmacology, Vanderbilt University, Nashville, Tennessee, and the Dr. Margarete-Fischer-Bosch Institut für Klinische Pharmakologie (M.E.), Stuttgart, FRG.

Supported in part by a grant from the US Public Health Service (GM-31304). H.K.K. was supported by a Fellowship of the Scientific Committee of NATO received through the Deutsche Akademische Austauschdienst. C.F.B. was a recipient of a Merck, Sharp & Dohme International Fellowship in Clinical Pharmacology.

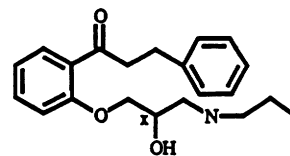
Address for correspondence: D.M. Roden, MD, Department of Pharmacology, Vanderbilt University, Nashville, TN 37232.

iologic actions of antiarrhythmic drugs can also be dependent on stereochemical conformations. For example, *S*-disopyramide and quinidine increase action potential duration, while *R*-disopyramide and quinine shorten it.^{11,12} Also, *S*-disopyramide is a more potent anticholinergic agent than the *R*-enantiomer.¹³ In contrast, *l*-sotalol and *d*-sotalol are equipotent as action potential-prolonging agents.¹⁴ Interestingly, despite their effects on action potential duration, quinidine and quinine as well as the enantiomers of disopyramide exert similar depressant effects on the maximum upstroke velocity of phase O (\dot{V}_{\max}), an index of sodium current. Presumably, such differences reflect important stereospecific conformations that impact on drug interactions with transmembrane ion channel proteins.

Similarly, many agents exhibit stereoselectivity in the β -blocking actions of their enantiomers. For example, Barrett and Cullum¹⁵ showed that β -blockade by propranolol is related to the *S*-isomer. Propafenone (Figure 1) has some structural features in common with propranolol and has been reported to produce variable β -blocking actions. The relative potency was estimated to be about $\frac{1}{20}$ th to $\frac{1}{40}$ th of that obtained with propranolol,¹⁶⁻¹⁸ and propafenone can produce β -blockade in patients. Hill et al¹⁹ demonstrated an increased airway reactivity in patients with mild asthma after administration of propafenone. Recently, Lee et al²⁰ found dose-related decreases in maximum heart rate and isoproterenol sensitivity during steady-state administration of propafenone in normal subjects, with the effect being greater in the PM subset. Interestingly, combination therapy with sodium channel blockers plus β -blockers can result in increased clinical antiarrhythmic efficacy.²¹ Thus, block of both sodium channels and β -receptors by propafenone may be a desirable combination of attributes. On the other hand, β -blockade appears to cause at least some of the side effects seen during propafenone therapy. To investigate differences in the pharmacokinetic, pharmacodynamic, or combined properties of propafenone for both enantiomers, three different experimental approaches have been used in the present study.

First, the disposition of propafenone enantiomers during long-term oral administration was investigated in patients with either EM or PM phenotypes. Second, the ability of propafenone enantiomers to depress \dot{V}_{\max} and to modify action potential characteristics was assessed in isolated canine Purkinje fibers. And third, the affinity of propafenone enantiomers for the β_2 -adrenergic receptor was determined in human lymphocytes.

Analysis of these experiments should determine whether one of the enantiomers is predominant in plasma and whether sodium channel blockade and β -blockade due to propafenone are related to one particular enantiomer. A prediction can then be made whether administration of a single enantiomer



Propafenone

FIGURE 1. Chemical structure of propafenone. *x*, Position of the chiral center.

rather than the racemic mixture might lead to fewer side effects without reducing clinical efficacy.

Methods

Disposition Kinetics of Propafenone Enantiomers

Patients. Data were obtained in seven patients (three men and four women) who were receiving long-term oral propafenone therapy (150 mg/8 hr) for treatment of symptomatic and frequent isolated ventricular ectopic depolarizations.

The phenotype of five patients for debrisoquine 4-hydroxylation had been previously determined according to the method of Wedlund et al.²² Three patients had the EM phenotype and two had the PM phenotype based on an antimode of 12.6 for the amount of debrisoquine versus 4-hydroxy debrisoquine excreted in urine within 8 hours after the oral administration of 10 mg debrisoquine. Two other patients were classified as EM subjects based on the clearance of propafenone and plasma concentrations of metabolites.¹ Blood samples were collected during an 8-hour interval at 0, 1, 2, 3, 4, 6, and 8 hours after the 8:00 AM dose. No food intake was allowed 2 hours before and after the administration of propafenone.

Patients participated as part of a protocol approved by the Committee for the Protection of Human Subjects at Vanderbilt University, and written informed consent was obtained from each patient.

High-Performance Liquid Chromatography Determination of Propafenone Enantiomers

The concentrations of (+)-*S*-propafenone and (–)-*R*-propafenone were determined by a high-performance liquid chromatography assay. One milliliter of plasma was spiked with 500 ng internal standard (2'-(2-hydroxy-3-ethylamino-propoxy)-3-phenyl-propiophenone hydrochloride, Knoll Pharmaceuticals, Whippany, New Jersey), alkalized with 0.1 M Tris buffer (pH 12.0), and shaken with 6 ml diethylether for 10 minutes. After centrifugation, the organic layer was transferred to a conical tube, and 200 μ l 0.5N phosphoric acid was added. The tube was shaken for 10 minutes and centrifuged, and the organic layer was removed. The acid phase was alkalized again with 2N NaOH, and 5 ml dichloromethane was added. The mixture was shaken for 10 minutes and centrifuged. The organic layer was transferred to a conical tube and again

evaporated under vacuum at 40° C. Subsequently, 40 μ l of a solution of 2,3,4,5-tetra-*O*-acetyl- β -D-glucopyranosyl-isothiocyanate (GITC; Polyscience Inc) solution in toluene (1 mg/ml) and 60 μ l toluene were added. The mixture was allowed to react for 30 minutes and then evaporated at 40° C under vacuum. The residue was dissolved in 30 μ l acetonitrile and injected to a high-performance liquid chromatography system. The mobile phase consisted of 60% acetonitrile, 40% water, and 0.01% glacial acetic acid, and the peaks were monitored by ultraviolet detection at a wavelength of 208 nm after separation on a reverse-phase column (Altex Ultrasphere ODS, 4.6 \times 250 mm, 5 μ m). The retention times were 8.1 and 8.9 minutes for the diastereomers of the internal standard, 10.0 minutes for the GITC derivative of (+)-*S*-propafenone, and 11.5 minutes for derivatized (–)-*R*-propafenone. Calibration curves were established in plasma for each individual enantiomer and were linear in a range of 0 to 1,000 ng/ml ($r=0.99$) for the (+)-*S*-propafenone and the (–)-*R*-enantiomer ($r=0.99$). The purity of the enantiomers exceeded 98%. Recovery averaged 40%, presumably reflecting the multistep extraction. The detection limit was 100 ng/ml.

The area under the concentration versus time curve during one dosing interval (AUC) _{τ} was calculated by the trapezoidal rule.²³ The apparent oral clearance was determined by dose/AUC _{τ} , where the dose is 67.85 mg of the base of the individual enantiomer.

Electrophysiologic Studies

Studies were conducted in isolated canine Purkinje fibers using methods described recently by Thompson et al,⁷ which consisted of removal of the hearts of mongrel dogs through a thoracotomy after deep anesthesia with pentobarbital (30 mg/kg i.v.). The hearts were rinsed with cold Tyrode's solution (NaCl 137 mM, NaHCO₃ 12 mM, dextrose 5.5 mM, MgCl₂ 0.5 mM, NaH₂PO₄ 1.8 mM, KCl 4 mM, and CaCl₂ 2.7 mM). The Tyrode's had been gassed with 95% O₂-5% CO₂. Free running false tendons were dissected, stored in oxygenated Tyrode's solution at room temperature for 30 minutes to allow recovery from dissection, and then placed in a Lucite tissue bath and perfused with warm oxygenated Tyrode's solution (15 ml/min). The preparations were stimulated using two Teflon-coated silver wires placed above one end of the preparation (current pulses <2 msec delivered at 1.5–2 times threshold). Machine-pulled glass capillary microelectrodes (tip resistance, 10–20 M Ω) filled with 3 M KCl were used to impale single Purkinje cells, and transmembrane potential was measured with respect to an extracellular ground in the tissue bath. Both the ground and the microelectrode were connected through 3 M KCl silver-silver chloride junctions to a high input impedance amplifier with variable input capacitance. The action potential was displayed with a Tektronix 5113 dual time base multichannel

oscilloscope. The action potential signal was also processed by a differentiator having a linear output between 100 and 1,000 V/sec, and the differentiated phase 0 upstroke was displayed on a second channel of the oscilloscope with a different time base. This oscilloscopic display of \dot{V}_{\max} was calibrated with a 200 V/sec signal from a sawtooth signal generator. Before each impalement, the action potential signal was zeroed and calibrated with a 100 mV signal on the oscilloscope.

Before each study, the preparation was stimulated at a basic cycle length of 1,000 msec for 30 minutes to ensure stability of the impalement. The preparation was then stimulated over a wide range of frequencies (300–8,000 msec), and a Polaroid photograph was taken of the oscilloscope screen once action potentials had stabilized at each frequency. After baseline data were obtained, the preparation was superfused for 30 minutes with Tyrode's solution containing 1 μ M of either (+)-*S*-propafenone or (–)-*R*-propafenone and the entire baseline protocol was repeated. Action potential characteristics, including action potential amplitude, takeoff potential, overshoot, and action potential duration at 50% and 90% repolarization (APD₅₀ and APD₉₀, respectively), were measured from each photograph with a digitizing board (Bit Pad One, Summagraphics Corp, Fairfield, Connecticut) connected to a microcomputer. \dot{V}_{\max} was measured directly with the differentiated 200 V/sec signal and a permanent measurement scale on the oscilloscope, both of which were present on each photograph.

Affinity of β_2 -Adrenoceptors for Propafenone Enantiomers

Blood was drawn from five healthy, drug-free, nonsmoking male volunteers (age, 22–29 years) using ethylenediamine tetraacetic acid (EDTA) as the anticoagulant. Mononuclear leukocyte (MNL) membranes were prepared according to a modification of a previously described method.²⁴ Competition binding studies were performed with [¹²⁵I]-iodopindolol (2,200 Ci/mmol; New England Nuclear, Boston, Massachusetts) as the radioligand (20 pmol) in presence of either (\pm)-propafenone, (+)-*S*-propafenone, or (–)-*R*-propafenone (10^{–4} to 10^{–10} M). MNL membranes were incubated at 37° C for 60 minutes in a final volume of 250 μ l containing 12 mM Tris-HCl (pH 7.6 at 37° C), 60 mM NaCl, 9 mM MgCl₂, 1.8 mM EDTA, 3.6 mM sucrose, 4 ng/ml BSA, and 0.5 mM ascorbic acid. The binding reaction was stopped by the addition of 10 ml wash buffer containing 10 mM Tris-HCl (pH 7.6 at 37° C), 90 mM NaCl, 15 mM MgCl₂, and 3 mM EDTA. Samples were filtered through Whatman GF/C filters, and filters were then washed with an additional 10 ml wash buffer and dried by vacuum filtration at a pressure of 15–20 psi. Radioactivity retained on the filters was determined in a gamma counter (Beckmann Gamma 5500). Duplicate values were obtained at each concentration of displacing drug. Nonspe-

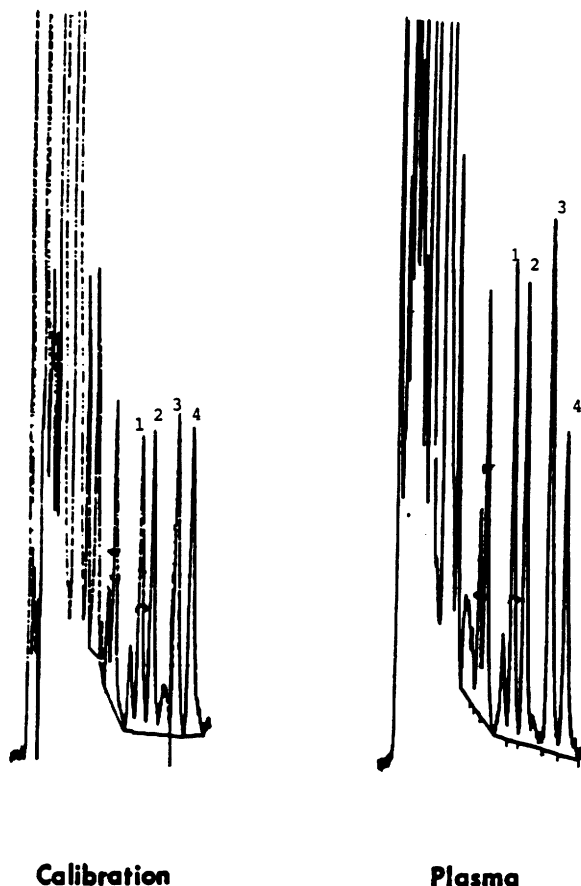


FIGURE 2. High-performance liquid chromatograms of propafenone in plasma after derivatization with 2,3,4,5-tetra-O-acetyl- β -D-glucopyranosylisothiocyanate. Peaks 1 and 2 represent the diastereomers formed with the internal standard; peaks 3 and 4 represent the (+)-S-propafenone and (-)-R-propafenone, respectively. Left: Blank plasma spiked with 500 ng racemic propafenone and 500 ng internal standard. Right: Plasma obtained from a patient (extensive metabolizer phenotype) on long-term oral therapy (150 mg/8 hr).

cific binding was assessed in the presence of 0.1 mM isoproterenol and was between 5% and 10% of total binding. Displacement curves were analyzed with a four-parameter logistic equation²⁵ that provided estimates for IC_{50} (the concentration of the competitor that displaced 50% of the specific binding) and the slope factor (pseudo-Hill coefficient). A constant factor (K_i) describing the affinity of the β -adrenoceptor for each of the competing ligands was determined by analysis of the binding data with the computer program LIGAND.²⁶

Statistic Calculation

All values are given as mean \pm 1 SD. The statistic analysis of predrug and drug data derived from Purkinje fibers was performed using paired Student's t test after confirming normal distribution of the data. Other comparisons were performed by Student's t test for unpaired data after confirming

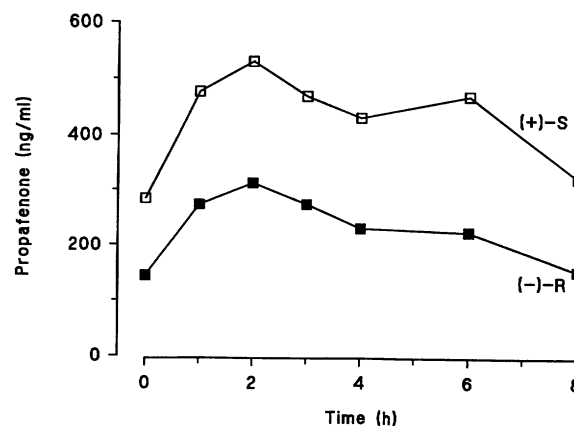


FIGURE 3. Plot of plasma concentration versus time of (+)-S-propafenone (\square) and (-)-R-propafenone (\blacksquare) for one patient with EM during long-term oral therapy with propafenone (150 mg/8 hr).

normal distribution of the data. Correlation between metabolic ratio and clearance was evaluated by Spearman's rank correlation test.

Results

Stereoselective Disposition of Propafenone Enantiomers

Typical chromatograms using the HPLC system described above are shown in Figure 2. A baseline separation between the enantiomers was achieved.

Figure 3 shows the time versus plasma concentration profile for one patient with EM. During the 8 hours of interdose sampling, plasma concentrations of (+)-S-propafenone were greater than those of (-)-R-propafenone. The results of the pharmacokinetic calculations are summarized in Table 1. The AUC_7 for (+)-S-propafenone was 1.73 ± 0.15 (range, 1.56–1.92) times greater than that of the (-)-R-propafenone ($p < 0.002$) in the EM group, indicating that the latter compound is cleared 1.7 times faster than (+)-S-propafenone. Clearance of both enantiomers was reduced in the two patients with PM (Table 1) but remained stereoselective. The clearance of both enantiomers correlated well with the metabolic ratio of debrisoquine/4-hydroxy debrisoquine in the five patients in whom an accurate metabolic ratio was obtained (Figure 4).

Electrophysiologic Studies

(+)-S-Propafenone and (-)-R-propafenone ($n=6$ each) both depressed \dot{V}_{max} in a frequency-dependent manner (Figure 5). The effect was significantly different from baseline at the shorter basic cycle lengths—300, 500, and 1,000 msec. A comparison between the enantiomers showed a trend toward a greater effect of (+)-S-propafenone (\dot{V}_{max} , $80.2 \pm 8.8\%$ of baseline) compared with (-)-R-propafenone ($88.4 \pm 4.5\%$ of baseline) at fast rates (basic cycle length, 300 msec), but the difference was not statistically significant ($p < 0.069$).

TABLE 1. Area Under the Time Versus Concentration Curve During an 8-hour Dosage Interval (AUC_8) and Apparent Oral Clearance (Cl) of (+)-S-Propafenone and (-)-R-Propafenone During Long-term Oral Therapy With Racemic Propafenone HCl (150 mg q8h) in Five Extensive Metabolizers (EM) and Two Poor Metabolizers (PM₁ and PM₂)

	EM (n=5)		PM ₁		PM ₂	
	(+)-S	(-)-R	(+)-S	(-)-R	(+)-S	(-)-R
AUC_8 (ng/ml/hr)	2,905±1,010	1,698±670	6,895	4,646	21,220	10,000
S/R ratio of AUC_8	1.73±0.15		1.48		2.12	
Cl (ml/min)	424±126	735±226	164	243	53	113

Figure 6 illustrates the changes in action potential duration at 50% repolarization (APD_{50}). (-)-R-Propafenone significantly reduced APD_{50} at basic cycle lengths of 300, 500, and 8,000 msec, while (+)-S-propafenone had no effect. Comparison of the two groups showed significant differences at 300 msec ($95.4\pm8.2\%$ of baseline for (+)-S-propafenone versus $84.4\pm7.9\%$ of baseline for (-)-R-propafenone; $p<0.04$), at 500 msec ($96.9\pm6.9\%$ of baseline for (+)-S-propafenone versus $83.2\pm6.5\%$ of baseline for (-)-R-propafenone; $p<0.005$), and at 8,000 msec ($100.4\pm7.1\%$ of baseline for (+)-S-propafenone versus $87.1\pm9.6\%$ of baseline for (-)-R-propafenone; $p<0.021$). Typical tracings, which illustrate the changes in APD_{50} by propafenone enantiomers, are shown in Figure 7.

Propafenone enantiomers did not alter action potential duration at 90% repolarization, action potential amplitude, overshoot, and the takeoff potential.

Affinity of β_2 -Adrenoceptors for Propafenone Enantiomers

Each compound displaced 125 I-iodopindolol from β_2 -adrenoceptors on MNL membranes. The displacement curve of (+)-S-propafenone was shifted to the left compared with the (-)-R-enantiomer (Figure 8). The values of K_i and IC_{50} indicated that the affinity of (+)-S-propafenone for the β_2 -adrenoceptor was about 100 times greater than that for (-)-R-propafenone (Table 2). Differences between the enantiomers for both IC_{50} and K_i were highly significant ($p<0.005$).

Discussion

Pharmacokinetic and pharmacodynamic profiles of drug enantiomers have gained increasing attention in the clinical evaluation of new compounds.²⁷ Several consequences of stereoselective drug metabolism that might have important implications for the therapeutic effect of a drug have been described by Eichelbaum.²⁸ First, stereoselective first-pass metabolism can cause different concentration-response relations depending on the route of administration (e.g., verapamil²⁹). Second, stereoselective drug interactions may have important therapeutic implications if the enantiomers have substantially differing potencies (e.g., warfarin³⁰). Third, stereoselective drug oxidation may be phenotype dependent. This has been investigated in detail for metoprolol⁹ and N-propylalajmaline.¹⁰ Both drugs

undergo polymorphic oxidation of the debrisoquine type. Differences in the pharmacokinetics of the enantiomers were shown in patients with EM, while patients with PM were characterized by a loss of stereoselectivity. In the present study, we have shown that (-)-R-propafenone is cleared faster than (+)-S-propafenone in patients with EM, leading to a higher concentration of the (+)-S-enantiomer in plasma. In contrast to metoprolol and N-propylalajmaline, the two patients with PM included in our study exhibited a similar degree of enantioselective disposition as those with EM. The major oxidative metabolic pathways of propafenone during long-term oral therapy in humans are 5-hydroxylation and N-dealkylation.³¹ In PMs of propafenone, 5-hydroxylation is impaired and the apparent oral clearance of propafenone is dramatically reduced.^{1,32} Thus, routes of metabolism other than 5-hydroxylation contribute to the stereoselective disposition of propafenone during long-term oral therapy. This conclusion is further supported by the fact that we did not observe significant changes in stereoselective steady-state disposition of propafenone after coadministration of quinidine (H. Kroemer, unpublished results), an inhibitor of propafenone 5-hydroxylation.³²

However, stereoselective drug disposition is of little consequence if the enantiomers produce similar pharmacologic actions. Consequently, the other

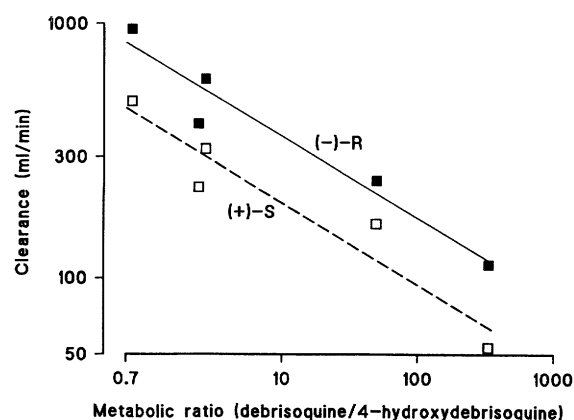


FIGURE 4. Plot of correlation between metabolic ratio (excretion of debrisoquine versus 4-hydroxy debrisoquine in urine after oral administration of 10 mg) and clearance of (+)-S-propafenone ($r=-0.90$, $p<0.05$; □) and (-)-R-propafenone ($r=-0.90$, $p<0.05$; ■).

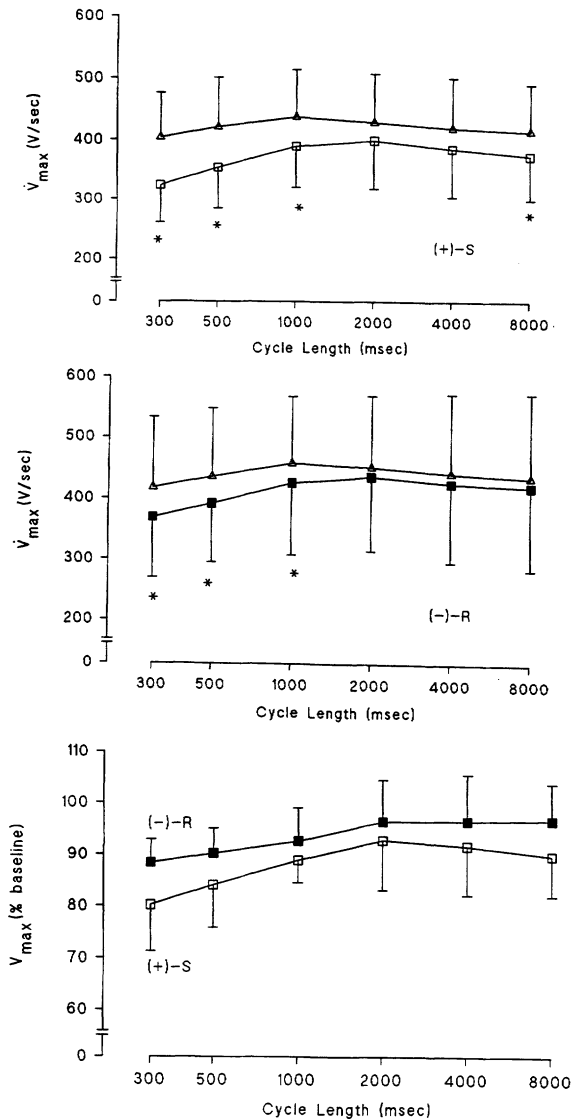


FIGURE 5. Plots of reduction of maximum phase 0 upstroke slope (\dot{V}_{max}) in canine Purkinje fibers by (+)-S-propafenone (\square) and (-)-R-propafenone (\blacksquare). Upper panel: Reduction of \dot{V}_{max} by (+)-S-propafenone (\square) compared with baseline (Δ ; * $p < 0.05$; paired t test). Middle panel: Reduction of \dot{V}_{max} by (-)-R-propafenone (\blacksquare) compared with baseline (Δ ; * $p < 0.05$; paired t test). Lower panel: Reduction of \dot{V}_{max} by (+)-S-propafenone (\square) and (-)-R-propafenone (\blacksquare) in percentage of baseline.

aim of our study was to determine whether electrophysiologic or β -blocking effects of propafenone are stereoselective. Several groups have previously reported that racemic propafenone depresses \dot{V}_{max} .^{7,33,34} Our experiments show that this depressed sodium conductance is due to both enantiomers and is, like the effect produced by virtually all Class I antiarrhythmic drugs, frequency dependent (Figure 5). Thus, the depression of the fast inward sodium channel is not sensitive for steric differences of propafenone enantiomers, suggesting that the puta-

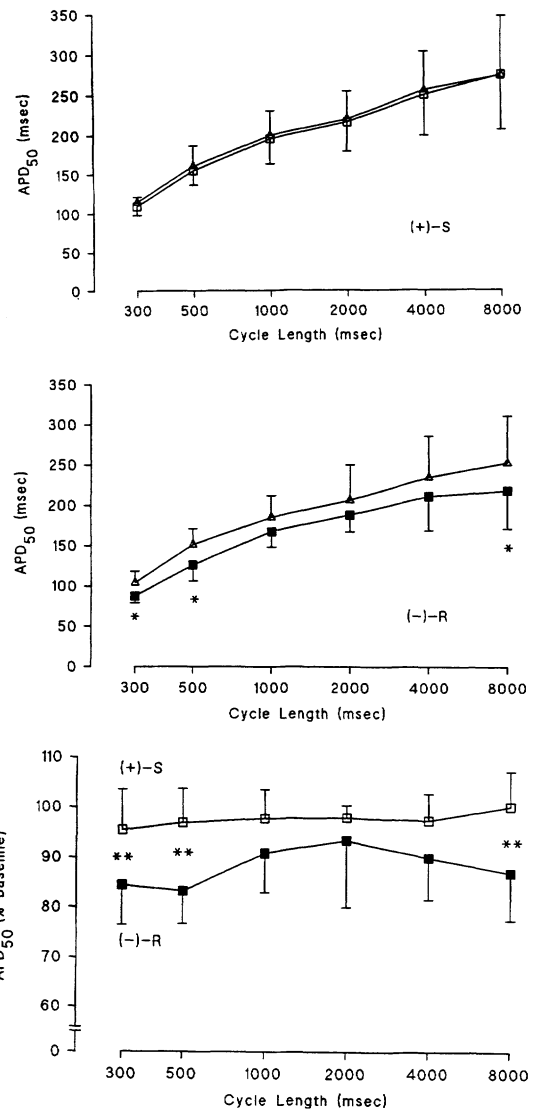


FIGURE 6. Plots of reduction of action potential duration at 50% repolarization (APD_{50}) by (+)-S-propafenone (\square) and (-)-R-propafenone (\blacksquare). Upper panel: Reduction of APD_{50} by (+)-S-propafenone (\square) compared with baseline (Δ). Middle panel: Reduction of APD_{50} by (-)-R-propafenone (\blacksquare) compared with baseline (Δ ; * $p < 0.05$; paired t test). Lower panel: Reduction of APD_{50} by (+)-S-propafenone (\square) and (-)-R-propafenone (\blacksquare) in percentage of baseline (** $p < 0.05$; nonpaired t test).

tive binding site³⁵ of propafenone to the channel is distant from the chiral center of the drug.

In agreement with previous reports,^{4,7} we found that APD_{90} was not altered by propafenone concentrations of 1 μ M. The APD_{90} prolongation reported by Dukes and Vaughan Williams⁴ occurred at propafenone concentrations of 3.96 μ M, whereas no change was observed at 1 μ M. In contrast, the action potential duration at 50% repolarization (APD_{50}) was reduced only by (-)-R-propafenone (Figures 6 and 7). Changes in APD_{50} indicate alterations in the phases 2 and 3 of the action potential,

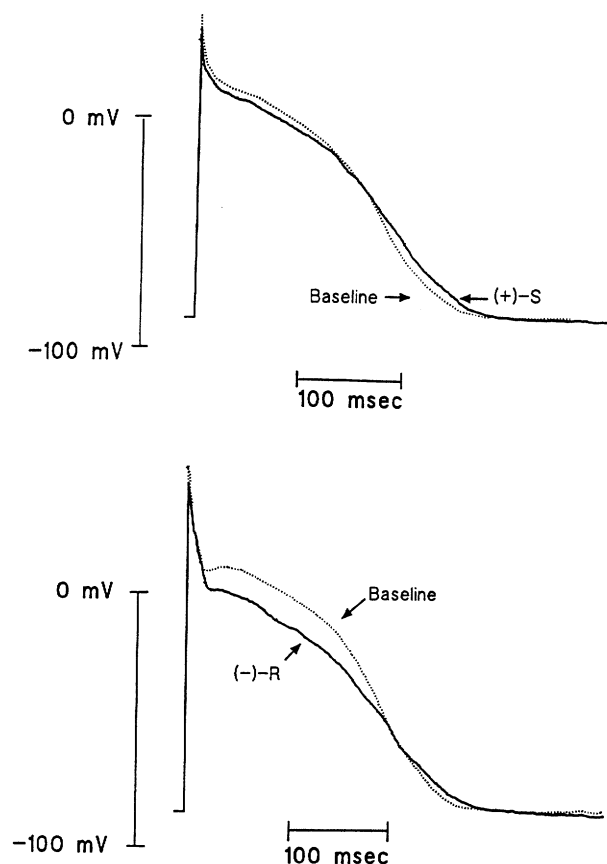


FIGURE 7. Tracings of action potentials (basic cycle length, 500 msec) before (.....) and after superfusion with $1 \mu\text{M}$ (+)-S-propafenone (upper panel) or (-)-R-propafenone (lower panel).

and changes in multiple ion currents may be responsible. One possible explanation is blockade of the plateau or "window" sodium current previously described by Attwell et al³⁶ with action potential shortening in analogy to that produced by tetrodotoxin.³⁷ The contribution of the APD₅₀ reduction to the clinical effects of the drug remains to be evaluated.

Finally, we demonstrated that (+)-S-propafenone is a much more potent β -blocker than (-)-R-propafenone when measured as binding to β_2 -adrenoceptors on human lymphocytes. Changes in lymphocyte β_2 -adrenoceptors have been shown to correlate with changes in cardiac sensitivity to the β -adrenergic agonist isoproterenol.³⁸ Moreover, data obtained using rat lung membranes and human left ventricular membranes¹⁸ have indicated that propafenone-induced β -blockade is nonselective. Thus, binding data obtained in the present study also provide an indication of propafenone interaction with β_1 -adrenoceptors. In our study, we observed a large disparity in the ability of the compounds to displace the radioligand iodopindolol from the β_2 -adrenoceptor on human lymphocytes. The IC₅₀ found for racemic propafenone (31.6 ± 18.7 nM) was in the same range as reported by McLeod

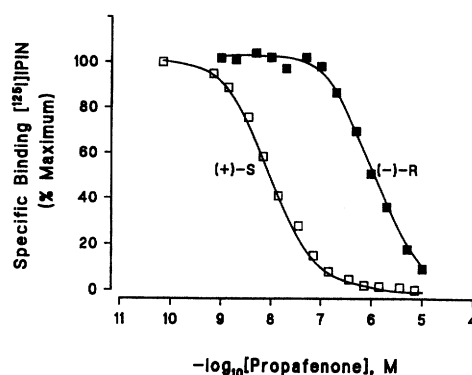


FIGURE 8. Plot of displacement of ^{125}I -iodopindolol from β_2 -adrenoceptors on human lymphocytes by (+)-S-propafenone and (-)-R-propafenone. Each point represents the mean of duplicate values from five experiments.

et al.¹⁸ Because (+)-S-propafenone was found to be about 100 times more potent than (-)-R-propafenone, we conclude that (+)-S-propafenone is responsible for the β -blocking properties of propafenone. This is in contrast to propranolol where the (-)-enantiomer is the more potent β -blocker.¹⁵ However, determination of the configuration has shown that the (+)-enantiomer of propafenone has the S-configuration,³⁹ whereas the (+)-enantiomer of propranolol has the R-configuration. Therefore, for both agents, the S-configured enantiomer appears responsible for β -blockade.

Integration of the three parts of our study allows us to make some inferences on the role of propafenone enantiomers in man. Regardless of phenotype, (+)-S-propafenone is predominant in plasma. As a consequence of their impaired metabolism, subjects with PM have a decreased clearance and substantially higher plasma levels than those with EM for (-)-R-propafenone and (+)-S-propafenone. Thus, the PM subset is more likely to develop β -blocking effects because the latter compound is responsible for β -blocking effects of propafenone. In agreement are recent findings of Lee et al,²⁰ who described a greater degree of β -blockade in those with PM. A simple reduction of the propafenone dose in those with PM may lead to reduced therapeutic effect because those with PM lack the ability to form 5-hydroxy propafenone, which contributes to the sodium channel-blocking effect.^{7,32} Therefore, higher plasma levels of the parent compound are required in those with PM than in those with EM to achieve similar suppression of arrhythmias.

TABLE 2. Competition of (\pm)-Propafenone, (+)-S-Propafenone, and (-)-R-Propafenone With ^{125}I -Iodopindolol for β_2 -Adrenoceptors on Human Lymphocytes ($n=5$)

	IC ₅₀ (nM)	K _i (nM)
(\pm)-Propafenone	31.6 ± 18.7	11.7 ± 4.4
(+)-S-Propafenone	18.7 ± 10.3	7.2 ± 2.9
(-)-R-Propafenone	$1,538 \pm 422$	571 ± 141

Because (+)-S-propafenone and (–)-R-propafenone have comparable sodium channel-blocking activities, the (–)-R-propafenone may suppress arrhythmias without blocking β -adrenoceptors and may be of advantage for therapy in those at risk for β -mediated side effects. Conversely, therapy with the (+)-S-enantiomer may produce greater arrhythmia suppression in those patients in whom a combined sodium channel and β -blocking effect is desirable.

Acknowledgments

The authors are grateful to Professor G. Blaschke, Münster, FRG, and Dr. C.O. Meese, Stuttgart, FRG, for providing the propafenone enantiomers.

References

- Siddoway LA, Thompson KA, McAllister CB, Wang T, Wilkinson GR, Roden DM, Woosley RL: Polymorphism of propafenone metabolism and disposition in man: Clinical and pharmacokinetic consequences. *Circulation* 1987; 75:785–791
- Heger JJ, Hubbard J, Zipes DP, Miles WM, Prystowsky EN: Propafenone treatment of recurrent ventricular tachycardia: Comparison of continuous electrocardiographic recording and electrophysiologic study in predicting drug efficacy. *Am J Cardiol* 1984;54:40D–44D
- Breithardt TG, Borggrefe M, Wiebringhaus E, Seipel L: Effect of propafenone in the Wolff-Parkinson-White syndrome: Electrophysiologic findings and long-term follow up. *Am J Cardiol* 1984;54:29D–39D
- Dukes I, Vaughan Williams EM: The multiple modes of action of propafenone. *Eur Heart J* 1984;5:115–125
- Connolly S, Kates RE, Lebsack CS, Harrison DC, Winkle RA: Clinical pharmacology of propafenone. *Circulation* 1983; 68:589–596
- Gonzalez FJ, Skoda RC, Kimura S, Umeno M, Zanger UM, Nebert DW, Gelboin HV, Hardwick JP, Meyer UA: Characterization of the common genetic defect in humans deficient in debrisoquine metabolism. *Nature* 1988;331:442–446
- Thompson KA, Iansmith DHS, Siddoway LA, Woosley RL, Roden DM: Potent electrophysiologic effects of the major metabolites of propafenone in canine Purkinje fibers. *J Pharmacol Exp Ther* 1988;244:950–955
- Kroemer HK, Mikus G, Kronbach T, Meyer UA, Eichelbaum M: The *in vitro* metabolism of propafenone in human liver microsomes. *Clin Pharmacol Ther* 1988;43:134
- Lennard MS, Tucker GT, Silas JH, Freestone S, Ramsey LE, Woods HF: Differential stereoselective metabolism of metoprolol in extensive and poor debrisoquine metabolizers. *Clin Pharmacol Ther* 1983;34:732–737
- Zekorn C, Achtert G, Hausleiter HJ, Moon CH, Eichelbaum M: Pharmacokinetics of N-propylajmaline in relation to polymorphic sparteine oxidation. *Klin Wochenschr* 1985; 63:1180–1186
- Mirro MJ, Watanabe AM, Bailey JC: Electrophysiological effects of the optical isomers of disopyramide and quinidine in the dog. *Circ Res* 1981;48:867–874
- Kidwell GA, Schaal SF, Muir WW: Stereospecific effects of disopyramide enantiomers following pretreatment of canine cardiac Purkinje fibers with verapamil and nisoldipine. *J Cardiovasc Pharmacol* 1987;9:276–284
- Giacomini KM, Cox BM, Blaschke TF: Comparative anticholinergic potencies of R and S disopyramide in longitudinal muscle strips from guinea pig ileum. *Life Sci* 1980; 27:1191–1197
- Kato R, Ikeda N, Yabek SM, Kannan R, Singh BN: Electrophysiologic effects of levo and dextrorotatory isomers of sotalol in isolated cardiac muscle and their *in vivo* pharmacokinetics. *J Am Coll Cardiol* 1986;7:116–125
- Barrett AM, Cullum VA: The biological properties of the optical isomers of propranolol and their effects on cardiac arrhythmias. *Br J Pharmacol* 1968;34:43–55
- Cherix EC, Krijne R, Brugada P, Heymeriks J, Wellens HJJ: Lack of clinically significant β -blocking effect of propafenone. *Eur Heart J* 1987;8:53–56
- Mueller Peltzer H, Greger G, Neugebauer G, Hollmann M: Beta-blocking and electrophysiological effects of propafenone in volunteers. *Eur J Clin Pharmacol* 1983; 25:831–833
- McLeod AA, Stiles GL, Shand DG: Demonstration of beta-adrenoceptor blockade by propafenone hydrochloride: Clinical pharmacologic, radioligand binding and adenylate cyclase activation studies. *J Pharmacol Exp Ther* 1984; 228:461–466
- Hill MR, Gotz VP, Harman E, McLeod E, Hendeles L: Evaluation of the asthmogenicity of propafenone, a new antiarrhythmic drug: Comparison of spirometry with methacholine challenge. *Chest* 1986;90:698–702
- Lee JT, Funck-Brentano C, Lineberry MD, Chaffin PL, Roden DM, Woosley RL: Beta receptor antagonism by propafenone in man: Influence of polymorphic metabolism. *Clin Res* 1988;36:294A
- Hirsowitz G, Podrid PJ, Lampert S, Stein J, Lown B: The role of beta-blocking agents as adjunct therapy to membrane stabilizing drugs in malignant ventricular arrhythmia. *Am Heart J* 1986;111:852–860
- Wedlund PJ, Aslanian WS, McAllister CB, Wilkinson GR, Branch RA: Mephenytoin hydroxylation deficiency in caucasians: Frequency of a new oxidative drug metabolism polymorphism. *Clin Pharmacol Ther* 1984;36:773–780
- Gibaldi M, Perier D (eds): *Pharmacokinetics*, ed 2. New York, Marcel Dekker, 1982, pp 445–449
- Feldmann RD, Limbird LE, Nadeau J, Robertson D, Wood AJJ: Alterations in leucocyte beta affinity with aging. *N Engl J Med* 1984;310:815–819
- De Lean A, Munson PJ, Rodbard D: Simultaneous analysis of families of sigmoidal curves: Application of bioassay, radioligand assay and physiological dose-response curves. *Am J Physiol* 1978;235:E97–E101
- Munson PJ, Rodbard D: LIGAND: A versatile computerized approach for characterization of ligand binding systems. *Anal Biochem* 1980;107:220–239
- Williams K, Lee E: Importance of drug enantiomers in clinical pharmacology. *Drugs* 1985;30:333–354
- Eichelbaum M: Pharmacokinetic and pharmacodynamic consequences of stereoselective drug metabolism in man. *Biochem Pharmacol* 1988;37:93–96
- Vogelgesang B, Echizen H, Schmidt E, Eichelbaum M: Stereoselective first pass metabolism of highly cleared drugs: Studies of the bioavailability of L- and D-verapamil examined with a stable isotope technique. *Br J Clin Pharmacol* 1984;18:733–740
- O'Reilly RA, Trager WF, Motley CH, Howald W: Stereoselective interaction of phenylbutazone with (12C/13C) warfarin pseudoracemates in man. *J Clin Invest* 1980;65:746–753
- Kates RE, Yee YG, Winkle RA: Metabolite cumulation during chronic propafenone dosing in arrhythmia. *Clin Pharmacol Ther* 1985;37:610–614
- Funck-Brentano C, Kroemer HK, Pavlou H, Wright GM, Woosley RL, Roden DM: Inhibition of propafenone metabolism by low doses of quinidine in man. *Clin Res* 1988; 36:363A
- Zeiler RH, Gough WB, El-Sherif N: Electrophysiologic effects of propafenone on canine ischemic cardiac cells. *Am J Cardiol* 1984;54:424–429
- Kohlhardt M, Seifert C: Inhibition of \dot{V}_{\max} of the action potential by propafenone and its voltage, time and pH dependence in mammalian ventricular myocardium. *Naunyn Schmiedeberg's Arch Pharmacol* 1980;315:55–62
- Hondeghem LM, Katzung BG: Time and voltage dependent interactions of antiarrhythmic drugs with cardiac sodium channels. *Biochim Biophys Acta* 1977;472:373–398

36. Attwell D, Cohen I, Eisner D, Ohba M, Ojeda C: The steady state TTX-sensitive ("window") sodium current in cardiac Purkinje fibers. *Pflugers Arch* 1979;379:137-142
37. Coraboeuf E, Deroubaix E, Coulombe A: Effect of tetrodotoxin on action potentials of the conducting system in the dog heart. *Am J Physiol* 1979;236:H561-H567
38. Fraser J, Nadeau J, Robertson D, Wood AJJ: Regulation of human leucocyte β -receptors by endogenous catecholamines: Relationship of leucocyte β -receptor density to the cardiac sensitivity to isoproterenol. *J Clin Invest* 1984; 67:1777-1784
39. Blaschke G, Walther B: Racemattrennung von Propafenon und Diprafenon, Konfiguration der Propafenon-Enantiomeren. *Liebigs Annalen der Chemie* 1987;561-563

KEY WORDS • propafenone • sodium channel blockade • enantiomers • β -blockade