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CARLOS HUMBERTO PALACIO EASTMAN, vecino de Bogotá, portador de la tarjeta profesional No. 62154, obrando como apoderado sustituto de la sociedad **NEUROSEARCH A/S** según el poder sustituto adjunto, de acuerdo con el artículo 46 de la Decisión 486 de la Comisión de la Comunidad Andina, me permito anexar copia de las siguientes publicaciones, para dar cumplimiento al requerimiento notificado por fijación en lista el 14 de agosto de 2009.

- Berge et al. J. Pharm. Sci. 1977; 66 (1); 1-19.
- Kathryn I. Keverline-Frantz et al: Synthesis and ligand binding of tropane ring analogues of paroxetine. J. Med. Chem. Vol 41. No 2, 1998, páginas 247-257.

De la señora Jefe atentamente,


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REVIEW ARTICLE

Pharmaceutical Salts

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Keyphrases □ Pharmaceutical salts—general pharmacy, physicochemical properties, bioavailability, pharmaceutical properties, toxicology, review □ Salts, pharmaceutical—general pharmacy, physicochemical properties, bioavailability, pharmaceutical properties, toxicology, review □ Physicochemical properties—dissolution, solubility, stability, and organoleptic properties of pharmaceutical salts, review □ Bioavailability—formulation effects, absorption alteration and pharmacokinetics of pharmaceutical salts, review □ Toxicology—pharmaceutical salts, review

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The chemical, biological, physical, and economic characteristics of medicinal agents can be manipulated and, hence, often optimized by conversion to a salt form. Choosing the appropriate salt, however, can be a very difficult task, since each salt imparts unique properties to the parent compound.

Salt-forming agents are often chosen empirically. Of the many salts synthesized, the preferred form is selected by pharmaceutical chemists primarily on a practical basis: cost of raw materials, ease of crystallization, and percent yield. Other basic considerations include stability, hygroscopicity, and flowability of the resulting bulk drug. Unfortunately, there is no reliable way of predicting the influence of a particular salt species on the behavior of the parent compound. Furthermore, even after many salts of the same basic agent have been prepared, no efficient screening techniques exist to facilitate selection of the salt most likely to exhibit the desired pharmacokinetic, solubility, and formulation profiles.

Some decision-making models have, however, been developed to help predict salt performance. For example, Walkling and Appino (1) described two techniques, "decision analysis" and "potential problem analysis," and applied them to the selection of the most suitable derivative of an organic acid for development as a tablet. The derivatives considered were the free acid and the potassium, sodium, and calcium salts. Both techniques are based on the chemical, physical, and biological properties of these specific derivatives and offer a promising avenue for developing optimal salt forms.

Information on salts is widely dispersed throughout the pharmaceutical literature, much of which addresses the use of salt formation to prolong the release of the active component, thereby eliminating various undesirable drug properties (2-6). This review surveys literature of the last 25 years, emphasizing comparisons between the properties of different salt forms of the same compound. Included also is a discussion of potentially useful salt forms. Our purpose is twofold: to present an overview of the many different salts from which new drug candidates can be chosen and

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Table I—FDA-Approved Commercially Marketed Salts

Anion	Percent ^a	Anion	Percent ^a
Acetate	1.26	Iodide	2.02
Benzenesulfonate	0.25	Methionate ^f	0.88
Benzoate	0.51	Lactate	0.78
Bicarbonate	0.13	Lactobionate	0.13
Bitartrate	0.63	Malate	0.13
Bromide	4.68	Maleate	3.03
Calcium edetate	0.25	Mandelate	0.38
Camylate ^h	0.25	Mesylate	2.02
Carbamate	0.38	Methylbenzamide	0.78
Chloride	4.17	Methylnitrate	0.38
Citrate	3.03	Methylsulfate	0.88
Dihydrochloride	0.51	Mucate	0.13
Edetate	0.25	Napsylate	0.25
Edisylate ^e	0.38	Nitrate	0.04
Katolate ^d	0.13	Pamoate (Embonate)	1.01
Esylate ^e	0.13	Pantothenate	0.25
Fumarate	0.25	Phosphate/diphosphate	3.16
Glucaptate ^f	0.18	Polylacturonate	0.13
Glucuronate	0.51	Salicylate	0.88
Glutamate	0.25	Stearate	0.25
Glycylglycylsarcosinate ^g	0.13	Subacetate	0.38
Hexylresorcinate ^h	0.13	Succinate	0.38
Hydrabamine ^h	0.25	Sulfate	7.46
Hydrobromide	1.50	Tannate	0.88
Hydrochloride	42.98	Tartrate	3.54
Hydroxynaphthate	0.25	Teclate ⁱ	0.13
		Triethiodide	0.13
Cation	Percent ^a	Cation	Percent ^a
Organic:		Metallic:	
Benzathine ^e	0.68	Aluminum	0.66
Chlorprocaine	0.33	Calcium	10.49
Choline	0.33	Lithium	1.84
Diethanolamine	0.98	Magnesium	1.31
Ethylenediamine	0.66	Potassium	10.62
Meglumine ⁱ	2.29	Sodium	61.97
Procaine	0.66	Zinc	2.95

^a Percent is based on total number of anionic or cationic salts in use through 1974. ^b Camphorsulfonate. ^c 1,2-Ethanedithiolate. ^d Lauryl sulfate. ^e Ethanesulfonate. ^f Glucoheptonate. ^g p-Glycylamidophenylarsinate. ^h N,N'-Di(dehydroabietyl)ethylenediamine. ⁱ 2-Hydroxyethanesulfonate. ^j 8-Chlorotheophyllinate. ^k N,N'-Dibenzylethylenediamine. ^l N-Methylglucamine.

to assemble data that will provide, for the student and practitioner alike, a rational basis for selecting a suitable salt form.

POTENTIALLY USEFUL SALTS

Salt formation is an acid-base reaction involving either a proton-transfer or neutralization reaction and is therefore controlled by factors influencing such reactions. Theoretically, every compound that exhibits acid or base characteristics can participate in salt formation. Particularly important is the relative strength of the acid or base—the acidity and basicity constants of the chemical species involved. These factors determine whether or not formation occurs and are a measure of the stability of the resulting salt.

The number of salt forms available to a chemist is large; surveys of patent literature show numerous new salts being synthesized annually. Various salts of the same compound often behave quite differently because of the physical, chemical, and thermodynamic properties they impart to the parent compound. For example, a salt's hydrophobicity and high crystal lattice energy can affect dissolution rate and, hence, bioavailability. Ideally, it would be desirable if one could predict how a pharmaceutical agent's properties would be affected by salt formation.

Tables I and II list all salts that were commercially marketed through 1974. The list was compiled from all agents listed in "Martindale The Extra Pharmacopoeia,"

26th ed. (7). Table I categorizes all salt forms approved by the Food and Drug Administration (FDA), while Table II lists those not approved by the FDA but in use in other countries. (Only salts of organic compounds are considered because most drugs are organic substances.) The relative frequency with which each salt type has been used is calculated as a percentage, based on the total number of anionic or cationic salts in use through 1974. Because of simple availability and physiological reasons, the monoprotic hydrochlorides have been by far the most frequent choice of the available anionic salt-forming radicals, outnumbering the sulfates nearly six to one. For similar reasons, sodium has been the most predominant cation.

Knowledge that one salt form imparts greater water solubility, is less toxic, or slows dissolution rate would greatly benefit chemists and formulators. In some cases, such generalizations can be made. Miller and Heller (8) discussed some properties associated with specific classes of salt forms. They stated that, in general, salt combinations with monocarboxylic acids are insoluble in water and lend themselves to repository preparations, while those of dicarboxylic acids confer water solubility if one carboxylic group is left free. Pantoic acid, an aromatic dicarboxylic acid, is an exception since it is used as a means of obtaining prolonged action by forming slightly soluble salts with certain basic drugs. Seias et al. (9) reviewed the use of this salt form in preparing sustained-release preparations. More recently, latentiation of dihydrostreptomycin (10)

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Table II—Non-FDA-Approved Commercially Marketed Salts

Anion	Percent ^a
Adipate	0.13
Alginate	0.13
Aminosalicylate	0.25
Anhydromethylenecitrate	0.13
Arecoline	0.13
Aspartate	0.25
Bisulfate	0.25
Butylbromide	0.13
Camphorate	0.13
Digluconate	0.13
Dihydrobromide	0.13
Disuccinate	0.13
Glycerophosphate	0.88
Hemisulfate	0.13
Hydrofluoride	0.13
Hydroiodide	0.25
Methylenebis(salicylate)	0.13
Napadisylate ^b	0.13
Oxalate	0.25
Pectinate	0.13
Persulfate	0.13
Phenylethylbarbiturate	0.13
Picrate	0.13
Propionate	0.13
Thiocyanate	0.13
Tosylate	0.13
Undecanoate	0.13
Cation	Percent ^a
Organic:	
Benethamine ^c	0.33
Clemizole ^d	0.33
Diethylamine	0.33
Piperazine	0.98
Tromethamine ^e	0.33
Metallic:	
Barium	0.33
Bismuth	0.98

^a Percent is based on total number of anionic and cationic salts in use through 1974. ^b 1,5-Naphthalenedisulfonate. ^c N-Benzylphenethylamine. ^d 1-*p*-Chlorobenzyl-2-pyrrolidin-1'-ylmethylbenzimidazole. ^e Tris(hydroxymethyl)aminomethane.

using pamoic acid resulted in the formation of a delayed-action preparation. Numerous studies using pamoate salts are dispersed throughout the literature (11-15).

Alginic acid also has been used to prepare long-acting pharmaceuticals. Streptomycin alginate was prepared (16) and shown to be effective in sustained-release preparations. A striking example of a long-acting alginate salt is that of pilocarpine. When dispersed in sterile water and dried to a solid gel, this compound was found useful in the preparation of long-acting ophthalmic dosage forms (17). While liquid preparations of the alginate and hydrochloride salts possess similar miotic activity, studies showed that solid pilocarpine alginate flakes constricted pupil size more effectively and increased the duration of miosis significantly when compared with the liquid preparations. Solid dose pilocarpine may be more uniformly available, because it diffuses more slowly through the gel matrix which holds the drug in reserve. In contrast, drops of the commonly employed solution dosage form release the dose immediately to the conjunctival fluid.

Málek *et al.* (18) devised a unique way of prolonging action through salt formation; they showed that the distribution of several antibiotics could be markedly altered by merely preparing macromolecular salts. Since macromolecules and colloidal particles have an affinity for the lymphatic system, streptomycin, neomycin, viomycin, and

streptothrycin were combined with high molecular weight compounds such as polyacrylic acids, sulfonic or phosphorylated polysaccharides, and polyuronic derivatives. Parenteral administration of these compounds produced low blood levels of the antibiotic for long periods, while lymph levels were high. (In comparison, streptomycin sulfate gave high blood levels but low lymph levels.) This alteration in distribution caused the streptomycin to prolong its passage through the body, since lymphatic circulation is quite slow.

The appropriate choice of a salt form has been found to reduce toxicity. It can be rationalized that any compound associated with the normal metabolism of food and drink must be essentially nontoxic. The approach of choosing organic radicals that are readily excreted or metabolized opened up a new class of substances from which to select a salt form. For example, certain salts of the strong base choline have proven to be considerably less toxic than their parent compound. The preparation and properties of choline salts of a series of theophylline derivatives were reported (19), and it was shown that choline theophyllinate possessed a greater LD₅₀ than theophylline or its other salts (20). It was postulated that this agent would be less irritating to the GI tract than aminophylline, because "its basic constituent, choline, is an almost completely nontoxic substance of actual importance to the physiologic economy." This evidence led to the preparation of choline salicylate (21) as an attempt to reduce the GI disturbances associated with salicylate administration. Clinical studies indicated that choline salicylate elicited a lower incidence of GI distress, was tolerated in higher doses, and was of greater benefit to the patient than was acetylsalicylic acid (aspirin).

Amino acids and acid vitamins also have been used as salt-forming agents. Based on the evidence that coadministration of amino acids with aminoglycoside antibiotics reduced their toxicity, a series of amino acid salts of dihydrostreptomycin was prepared (22). In all but one case, the acute toxicities of these salts were lower than the toxicity of the sulfate. The ascorbate and pantothenate also were synthesized and shown to be less toxic than the sulfate. Of the salts prepared, the ascorbate had the highest LD₅₀.

The vitamins most commonly used for forming salts exhibiting reduced toxicity are ascorbic and pantothenic acids. Keller *et al.* (23) were the first to use pantothenic acid as a means of "detoxifying" the basic streptomycins antibiotics. Parenteral administration of the pantothenates of streptomycin and dihydrostreptomycin had a significantly reduced incidence of acute neurotoxicity in cats as compared with the sulfates. Subsequent studies (24-28) supported this finding and showed that the pantothenates of neomycin and viomycin also are less toxic. The ascorbate of oleandomycin was synthesized and its pharmacological properties were reported (29). Upon intramuscular injection in rats, it produced less irritation than the phosphate.

p-Acetamidobenzoic acid, an innocuous metabolite of folic acid present in normal blood and urine, has been used in preparing salts. In particular, it yields stable salts with amines that otherwise tend to form hygroscopic products with conventional acid components (30).

Often the salt form is chosen by determining a salt

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component that will pharmacologically antagonize an unfavorable property or properties exhibited by the basic agent. Salts of *N*-cyclohexylsulfamic acid are an example of the practical application of this approach. *N*-Cyclohexylsulfamic acid salts, better known as cyclamates, have a characteristic sweet, pleasing taste. Although presently under investigation by the FDA for potentially carcinogenic properties, salts incorporating this compound can render unpleasant or bitter-tasting drugs acceptable. For example, the cyclamates of dextromethorphan and chlorpheniramine exhibit greatly improved bitterness thresholds compared to commonly occurring salts (31). Furthermore, their stability in aqueous solution was described as good when maintained at a pH not greater than 4.

N-Cyclohexylsulfamic acid salts of thiamine hydrochloride and lincomycin also have been synthesized. Thiamine *N*-cyclohexylsulfamate hydrochloride was reported to have a more pleasant taste than other thiamine salts while having an equal or greater stability (32). Lincomycin cyclamate, shown to possess an enhanced thermal stability over its hydrochloride, was prepared (33) to test the hypothesis that reduced lincomycin absorption in the presence of small quantities of cyclamates was due to a simple metathetic reaction. However, this assumption was found not to be true. An extensive study of the preparation and characterization of cyclamic acid salts of several widely used classes of drugs including antihistamines, antibiotics, antitussives, myospasmolytics, and local anesthetics was reported (34, 35).

Various salts of penicillin and basic amine compounds have been formulated in an effort to produce a long-acting, nonallergenic form of penicillin. Since antihistamines appear to mitigate the symptomatology of penicillin reactions in some patients, coadministration of the two has been advocated. The preparation of the benzhydralamine salt of penicillin was an attempt to produce a repository form of penicillin with antiallergic properties (36). Blood levels achieved with this salt were comparable to those of penicillin G potassium; however, its antiallergic properties were not evaluated. In fact, the investigators noted that antihistamines can actually cause sensitization at times and stated that "despite their occasionally favorable influence on the symptoms of penicillin sensitivity, they contribute directly to the potential of drug sensitivity when co-administered with penicillin."

Silver salts of sulfanilamide, penicillin, and other antibiotics have been prepared and represent cases where the species (ions) are complementary. When aqueous solutions of the salts were applied topically to burned tissue, they yielded the combined benefits of the oligodynamic action of silver and the advantages of the antibacterial agents (37).

The use of 8-substituted xanthines, particularly the 8-substituted theophyllines, as salt-forming agents was first reported in the preparation of a series of antihistamine salts (38-41). Synthesis of these xanthine salts was an attempt to find a drug to counteract the drowsiness caused by the antihistamines with the stimulant properties of the xanthines. When an electronegative group is introduced into the xanthine molecule at the 8-position, the electron-drawing capacity of the substituent results in the creation of an acidic hydrogen at position 7. Thus, these

moderately strong acidic compounds can undergo salt formation with various organic bases.

The 8-halothephyllines were the first group of xanthines studied as potential salt-forming agents. Since the report on the preparation of the 8-chlorotheophylline salt of diphenhydramine (42), synthesis of the 8-halothephyllinates of a number of organic bases has been attempted. The 8-chlorotheophylline salts of quinine, ephedrine, and strychnine were prepared and characterized (43). These salts were less water soluble than the corresponding free alkaloidal bases. In a similar report, the 8-chlorotheophyllinates of three synthetic narcotics, meperidine, levorphanol, and metopon, were prepared (44).

Pharmacological and clinical studies involving the 8-bromotheophylline pyrilamine salt revealed the unusual diuretic properties associated with the 8-halothephylline portion of the compound (45, 46). This finding initiated an investigation into the preparation of a soluble 8-bromotheophylline salt of high diuretic activity. With readily available amines, over 30 salts were synthesized and screened for diuretic activity (47). When tested against theophylline salts of the same amines, the 8-bromotheophyllinates showed greater activity in every case.

With the successful formation of 8-halothephyllines of organic bases, Morozowich and Bope (48) proposed that, if the halogen moiety was replaced with a more electronegative substituent such as a nitro group, a more acidic compound would be formed. Presumably, more stable salts would result and precipitation of the free xanthine derivative in the stomach would be less likely to occur. On this premise, they successfully prepared pharmacologically effective 8-nitrotheophyllinates of several pharmaceutically useful bases.

Duesel *et al.* (19), in their study of choline theophyllinate, prepared the 8-chloro-, 8-bromo-, and 8-nitrotheophylline salts of choline. Oral toxicity studies in mice showed that the LD₅₀ of the 8-nitrotheophyllinate was much greater than that of either 8-halothephylline. In fact, it remained nonlethal at doses as high as 5 g.

Polygalacturonic acid, a derivative of pectin, has been used to prepare quinidine salts exhibiting reduced toxicity (49, 50). The compound possesses special demulcent properties and inhibits mucosal irritation. The rationale for use of this agent is to reduce the ionic shock to the GI mucosa resulting from the flood of irritating ions liberated by rapid dissociation of the conventional inorganic quinidine salts. Studies have shown that it is four times less toxic orally than the sulfate. This difference was attributed to the slower release of quinidine from the polygalacturonate.

Other compounds reported to be potentially useful as pharmaceutical salt forms are listed in Table III.

PHYSICOCHEMICAL STUDIES

Biological activity of a drug molecule is influenced by two factors: its chemical structure and effect at a specific site and its ability to reach—and then be removed from—the site of action. Thus, a knowledge of the physicochemical properties of a compound that influence its absorption, distribution, metabolism, and excretion is essential for a complete understanding of the onset and duration of ac-

Table III—Potentially Useful Salt Forms of Pharmaceutical Agents

Salt-Forming Agent	Compound Modified	Modification	Reference
Acetylaminoacetic acid	Doxycycline	Solubility	51
N-Acetyl-L-asparagine	Erythromycin	Solubility, activity, stability	52
N-Acetylcystine	Doxycycline	Combined effect useful in pneumonia	53
Adamantoic acid	Alkylbiquanides	Prolonged action	54
Adipic acid	Piperazine	Stability, toxicity, organoleptic properties	55
N-Alkylsulfamates	Ampicillin	Absorption (oral)	56
	Lincomycin	Solubility	57
Anthraquinone-1,5-disulfonic acid	Cephalexin	Stability, absorption	58
Arabogalactan sulfate (arabino)	Various alkaloids	Prolonged action	59, 60
Arginine	Cephalosporins	Toxicity	61
Aspartate	α -Sulfobenzylpenicillin	Stability, hygroscopicity, toxicity	62
Betaine	Erythromycin	Solubility	63
Bis(2-carboxychromen-5-yl-oxy)alkanes	Tetracycline	Gastric absorption	64
Carnitine	7-(Aminoalkyl)theophyllines	Activity, prolonged prophylactic effect	65
4-Chloro-m-toluenesulfonic acid	Metformin	Toxicity	66
Decanoate	Propoxyphene	Organoleptic properties	67
Diacetyl sulfate	Heptaminol	Prolonged action	68
Dibenzylethylenediamine	Thiamine	Stability, hygroscopicity	69
Diethylamine	Ampicillin	Prolonged action	70, 71
Diguaiacyl phosphate	Cephalosporins	Reduced pain on injection	72
Dioctyl sulfosuccinate	Tetracycline	Activity	73
Embonic (pantoic) acid	Vincamine	Organoleptic properties	74
	Kanamycin	Toxicity	75
Fructose 1,6-diphosphoric acid	2-Phenyl-3-methylmorpholine	Toxicity	76
	Tetracycline	Solubility	77
Glucose 1-phosphoric acid, glucose 6-phosphoric acid	Erythromycin	Solubility	
1-Glutamine	Tetracycline	Solubility	77
Hydroxymaphthosate	Erythromycin	Solubility, activity, stability	82
2-(4-Imidazolyl)ethylamine	Erythromycin	Toxicity	78
Isobutanolamine	Bephenium	Prolonged action	79
Lauryl sulfate	Prostaglandin	Stability	80
Lysine	Theophylline	Organoleptic properties	81
	Vincamine	Toxicity, stability, hygroscopicity	82
Methanesulfonic acid	α -Sulfobenzylpenicillin		81
N-Methylglucamine	Cephalosporins	Solubility	82
	Pralidoxime (2-PAM)	Toxicity, stability, hygroscopicity	82
N-Methylpiperazine	α -Sulfobenzylpenicillin	Reduced pain on injection	72
Morpholine	Cephalosporins	Reduced pain on injection	83
2-Naphthalenesulfonic acid	Phenylbutazone	Toxicity, faster onset of action	83
Octanoate	Cephalosporins	Reduced pain on injection	72
Probenecid	Propoxyphene	Organoleptic properties	84
Tannic acid	Heptaminol	Prolonged action	68
Theobromine acetic acid	Pivampicillin	Organoleptic properties	85
3,4,5-Trimethoxybenzoate	Various amines	Prolonged action	86, 87
	Propoxyphene	Activity	88
Tromethamine	Tetracycline	Organoleptic properties	89
	Heptaminol	Prolonged action	68
	Aspirin	Absorption (oral)	90
	Dinoprost (prostaglandin F _{2α})	Physical state	91

tion, the relative toxicity, and the possible routes of administration (2).

In a review in 1966, Miller and Holland (92) stated that "different salts of the same drug rarely differ pharmacologically; the differences are usually based on the physical properties." In a subsequent review (93), Wagner expanded upon this statement, asserting that, although the nature of the biological responses elicited by a series of salts of the same parent compound may not differ appreciably, the intensities of response may differ markedly.

The salt form is known to influence a number of physicochemical properties of the parent compound including dissolution rate, solubility, stability, and hygroscopicity. These properties, in turn, affect the availability and formulation characteristics of the drug. Consequently, the pharmaceutical industry has systematically engaged in extensive preformulation studies of the physicochemical properties of each new drug entity to determine the most suitable form for drug formulation. Published information concerning such studies, however, is sparse. Preformulation studies have been outlined, and the influence of the salt form on the volatility and hygroscopicity of an agent under investigation was discussed (94).

In one such study, methylpyridinium-2-aldoxime (pralidoxime) salts were investigated (95). This study set out to prepare a salt with water solubility adequate to allow intramuscular injection of a low volume (2-3 ml) therapeutic dose. The original compound, the methiodide, had the disadvantages of limited aqueous solubility and high potential toxicity, since its high iodine content could result in iodism. On the basis of physiological compatibility, better water solubility, favorable stability, and relatively high percentage of oxime, the chloride salt of pralidoxime was selected for therapeutic administration; it was claimed that "the anion used to form the salt can confer physical properties of importance and significance for the formulation and administration of the compound" (95).

Some physicochemical properties of a series of mineral acid salts of lidocaine also were determined (96). While the hydrochloride and hydrobromide were more hygroscopic, they were more soluble in a number of solvents than the nitrate, perchlorate, phosphate, or sulfate salts.

Dissolution Rate—The dissolution rate of a pharmaceutical agent is of major importance to the formulator. In many cases, particularly with poorly soluble drugs, this characteristic best reflects the bioavailability of the com-

pound. As a rule, a pharmaceutical salt exhibits a higher dissolution rate than the corresponding conjugate acid or base at an equal pH, even though they may have the same equilibrium solubility. The explanation for this result lies in the processes that control dissolution.

Dissolution can be described by a diffusion layer model¹ in terms of an equation developed by Nernst and Brunner (97):

$$\frac{dW}{dt} = \frac{DS}{h} (C_s - C) \quad (\text{Eq. 1})$$

where W is the mass of the solute dissolved at time t , dW/dt is the rate of mass transfer per unit time, D is the solute molecule diffusion coefficient, S is the surface area of the dissolving solid, h is the diffusion layer thickness, C is the concentration of the drug in the bulk solution at time t , and C_s is the saturation solubility of the solute in the diffusion layer.

The driving force for dissolution in Eq. 1 is the difference between the saturation solubility of the drug and the concentration of the drug in the bulk fluid. If the drug is not rapidly absorbed after it dissolves, then C , the concentration in the bulk solution, approaches C_s and the dissolution rate is retarded. When this occurs, absorption is "absorption rate" limited (or "membrane transport" limited). If the absorption rate is rapid (or if the absorption mass transfer coefficient is much larger than DS/h of Eq. 1), however, C becomes negligible compared to C_s and dissolution occurs under "sink" conditions. Absorption is then said to be dissolution rate limited, which is what occurs with most poorly soluble drugs. In either case, an increase in C_s , as in salt formation, increases dissolution.

Salts often speed dissolution by effectively acting as their own buffers to alter the pH of the diffusion layer, thus increasing the solubility of the parent compound, C_s , in that layer over its inherent solubility at the pH of the dissolution medium. Hence, dissolution is controlled by solubility in the diffusion layer which, in turn, is determined by the pH of that layer. The influence of K_{sp} on the solubility term, C_s , and dissolution rate, should an accumulation of ions be allowed to occur, will be treated later.

Nelson (98), in a study of theophylline salts, was the first to show the correlation between diffusion layer pH and dissolution rate. The major impact that this study had on the pharmaceutical sciences was its conclusion that, if other factors remained constant, the dissolution rate of a compound determined the rate of buildup of blood levels with time and the maximum levels obtained. Those salts of the acidic theophylline with high diffusion layer pH's had greater *in vitro* dissolution rates than those exhibiting a lower diffusion layer pH. And, indeed, the rank order of dissolution rates correlated well with clinically determined blood levels. Presumably, the higher pH in the diffusion layer retards hydrolysis of the salt, thereby maintaining the anionic charge of the theophyllinate ion. This report led to many additional studies which illustrate the influence of the salt form on dissolution and the beneficial effects of changing nonionized drugs into salts.

Juncher and Raaschou (99) demonstrated that the rank order of peak blood levels of penicillin V, obtained upon

administration of three different salts and the free acid, was the same as the rank order of their rates of dissolution *in vitro*. While the investigators ascribed these differences to the solubility properties of the salts, their experiments actually compared dissolution rates, not solubilities. The relative order of dissolution rates and mean maximal blood levels was: potassium salt > calcium salt > free acid > benzathine salt.

Nelson (100) determined dissolution rates for several weak acids and their sodium salts in media whose pH's represented GI fluids. In all cases, the sodium salt dissolved more rapidly than the free acid. This finding resolved the misconception that absorption of drugs is related only to solubility in the appropriate medium; rather, solubility affects absorption only to the extent that it affects dissolution rate. Absorption of drugs is a dynamic process, and the ultimate solubility of a drug in fluid at absorption sites is of limited consequence since absorption prevents the attainment of saturated solutions. Therefore, dissolution rate, more than solubility, influences absorption since it is a preceding process.

In two subsequent studies, Nelson and coworkers further illustrated the effects of changing nonionized drugs into salts. A report concerning tolbutamide (101), a weak acid, showed that the initial dissolution rate of tolbutamide sodium was approximately 5000 times more rapid than the free acid in acidic media and 300 times more rapid in neutral media. This difference, measured *in vitro*, reflected the differences observed between the free acid and the salt when administered to human subjects. Oral administration of tolbutamide sodium produced an immediate drop in blood sugar comparable to that produced by intravenous injection of the salt, while the slowly dissolving tolbutamide produced a smooth, sustained fall in blood sugar (102).

Correlation of urinary excretion rates and dissolution rates of tetracycline and some of its acid salts also was demonstrated by Nelson (103). The salts that exhibited greater *in vitro* dissolution rates showed greater urinary excretion rates, indicating more rapid absorption.

Benet (104), in a discussion of the biopharmaceutical basis for drug design, referred to the influence of the salt form on dissolution. He compared the dissolution rates of tetracycline and tolbutamide and their salts, as reported in the studies previously cited, and explained why the rates differ at the pH's exhibited by physiological fluids.

Although salt formation usually increases the dissolution rate of a drug, studies with aluminum acetylsalicylate (105, 106), warfarin sodium (107), and benzphetamine pamoate (108) showed that administration of the salt slowed dissolution of the drug and subsequent absorption compared to the nonionized form. This decrease appeared to result from precipitation of an insoluble particle or film on the surface of the tablet. Such a phenomenon decreases the effective surface area and prevents deaggregation of the particles. Theoretical considerations of the processes controlling dissolution of an acid salt of a base (108) and the sodium salt of a weak acid (109, 110) in reactive media have been discussed.

Tablet processing and various formulation factors can decrease the dissolution rate of a salt in human gastric juice over its nonionized form (111). Granulation and tableting caused the dissolution rate of phenobarbital sodium to

¹ The authors recognize the existence of other models; this one was chosen simply for illustrative purposes.

decrease but had the opposite effect on phenobarbital. Therefore, as a tablet dosage form, the dissolution rate of the sodium salt was slower than that of the free acid. These results were attributed to differences in the disintegrating properties of the tablets; in some instances, rapid dissolution may in fact be a problem for very soluble drugs.

Others have illustrated a phenomenon that decreases the dissolution rate of a salt below that of its nonionized form. Lin *et al.* (112) studied the relationship between salts and biological activity by dissolving three salts and the free base of an experimental antihypertensive in water, 0.1 N HCl, and pH 7.2 phosphate buffer. The dissolution rate of the monohydrochloride salt was lower than that of the free base in 0.1 N HCl and higher than the free base in both water and phosphate buffer. These authors ascribed this variation to the common ion effect and substantiated it experimentally. Although the biological activity of the monohydrochloride was greater than that of the free base, the implications of altered absorption characteristics on the activity of any other hydrochloride salt in GI fluids must be considered. Similar results also were reported for hydrochloride salts of some tetracyclines (113).

Some consideration must be given to the influence of salt formation on oral toxicity, which often reflects the relationship between the *in vivo* dissolution rate and the appearance of drug in the circulation (114, 115). Morozowich *et al.* (114) showed that the relative toxicities of a series of salts of a drug reflect the rate of absorption, providing the salt-forming agents themselves are relatively nontoxic. They stated that "when absorption is rate-limited by dissolution of the salt in the gastrointestinal tract, as will be the case with slowly soluble salts, the toxicity of a slowly dissolving salt will most probably be lower than that of a more rapidly dissolving salt." The implications of salt formation on toxicology will be discussed under *Toxicological Considerations*.

Several reviews dealt with the influence of the dissolution rate on drug availability and, in particular, salt effects (116, 117). Other reports illustrating the influence of salts and salt form on dissolution rate are listed in Table IV.

Solubility—Knowledge of the solubility characteristics of a pharmaceutical agent is essential, because solubility is usually an important factor in the pharmacokinetic profile, the chemical stability, and, ultimately, the formulation of the drug. As discussed previously, it is certainly a primary factor in controlling dissolution rates. The solubility of a compound depends basically upon the physical and chemical properties of the solute; *e.g.*, a lower melting point for a compound within a series reflects a decreased lattice energy, which would suggest a higher solubility. Solubility depends as well upon such elements as temperature, pressure, solvent properties (such as resulting pH), and, to a lesser extent, the state of subdivision of the solute.

An important solvent property which is often overlooked involves the common ion effect; in particular, hydrochloride salts of drugs often exhibit less than desirable solubility in gastric juice because of the abundance of chloride ions. The equilibrium involved is shown in Scheme I.



Salt formation is perhaps one of the first approaches

Table IV—Additional References on Salt Form and Dissolution Rate

Topic	Reference
Dissolution rate of mixtures of weak acids and tribasic sodium phosphate	118
Physiological availability and <i>in vitro</i> dissolution characteristics of some solid dosage formulations of aminosalicylic acid and its salts	119
Biopharmaceutics, rate of dissolution: chronological bibliography	120
Biopharmaceutics: rate of dissolution <i>in vitro</i> and <i>in vivo</i>	121
Dissolution tests and interpretation of anomalies observed in the dissolution process of sulfaquinoxaline based on salt formation	122
Influence of the dissolution rate of lithium tablets on side effects	123
Dissolution kinetics of drugs in human gastric juice	124
Comparison of dissolution and absorption rates of different commercial aspirin tablets	125
<i>In vitro</i> dissolution rates of aminorex dosage forms and their correlation with <i>in vitro</i> availability	126

considered as a means of increasing a compound's water solubility. As with dissolution rates, however, salt formation does not always confer greater solubility. Liberally dispersed throughout the pharmaceutical literature are studies that compare the solubilities of different salt forms of the same compound with those of its free acid or base (Table IV). Selection of the salt form exhibiting the desired solubility properties is critical, since these properties often dictate the formulation characteristics of the drug.

Phase solubility techniques were used to study the formation of complex salts of triamterene (127). The results indicated that the organic acid salts of basic drugs, such as amines, were more soluble in water than the corresponding inorganic (halide) salts. This consideration is important in the synthesis and selection of a salt form that will exhibit enhanced bioavailability and desirable formulation characteristics.

The hydrogen-ion concentration can significantly affect the solubility of a salt. Anderson (128) discussed the influence of pH on the solubility of pharmaceuticals. Mathematical relationships between pH and solubility of therapeutically useful weak acids and bases and their salts were given along with some considerations in the formulation of solutions of these particular agents.

An extensive study on the solubility interrelationships of the hydrochloride and free base of two pharmaceutically useful amines was reported (129). Mathematical equations describing the total solubility at an arbitrary pH in terms of the independent solubilities of the hydrochloride and free base species and the dissociation constant of the salt were derived and fitted to experimental data with good results. This report elucidated the point that, while the solubility of the amine hydrochloride generally sets the maximum obtainable concentration for a given amine, the solubility of the free base and the pKa determine the maximum pH at which formulation as a solution is possible (assuming that the desired concentration exceeds the free base solubility). Shifting the pH-solubility profile to higher pH values for formulation purposes may require increasing the solubility of the free base. This increase might be accomplished by using an appropriate cosolvent. Since the dissociation characteristics of carboxylic acids and other acidic organic species are similar to those of organic hydrochlorides, it is expected that the pH-solubility profiles

of these organic acids, although reversed, can be characterized theoretically using the same treatment.

Several reports showed that the structure of an organic salt-forming radical influences the solubility of the resulting salt. The water solubilities of 16 salts (carboxylates, sulfates, sulfamates, and phosphates) of the weak base erythromycin were dependent on the size of the alkyl group of the acid (130). In a study with *N*-alkylsulfamates of lincomycin (66), a similar phenomenon was observed: solubility of these salts decreased as the size of the alkyl group attached to the acidic function increased.

Senior (131), in a study on the formulation and properties of the antibacterial chlorhexidine, determined the water solubilities of 35 salts and the free base. He found that inorganic salts had remarkably low solubilities while those of the lower aliphatic acids proved to be somewhat more soluble. Hydroxylation of the acid increased solubility, since salt formation with polyhydroxy acids, particularly the sugar acids, conferred extensive water solubility to the molecule.

Several investigators reported the influence of the solubility of a drug on its formulation and subsequent availability from the dosage form. In a discussion of the preparation and formulation of epinephrine salts in an aerosol system using liquefied gas propellants, Sclarra *et al.* (132) pointed out that the solubility characteristics of the agent are important in two respects. First, the solubility of the therapeutically active ingredient in the various propellants is an important consideration if the product is to be used for either local action in the lungs or systemic therapy. Second, the solubility of the drug in extracellular fluids plays an important role in selection of the compound. The bitartrate, malate, maleate, and fumarate salts of epinephrine were prepared and subjected to solubility and stability studies. While all salts had similar partition coefficients, the solubility of the maleate in several propellants and its stability in formulated aerosols made it the drug form of choice.

Ephedrine hydrochloride was more rapidly released than the free base from theobroma oil suppositories containing different surfactants (133). This enhanced rate of release (dialysis) was ascribed primarily to the greater aqueous solubility of the hydrochloride, which solubilized faster from the oil-in-water emulsion, whereas the ephedrine alkaloid base tended to remain behind in the oil phase.

The solubility of the active ingredient in ointment bases can dramatically influence its diffusion properties. A study of salicylic acid and its sodium salt showed that the diffusion of both was very low from hydrophobic bases, whereas the solubility of the drug significantly affected the diffusion from hydrophilic bases. The more soluble sodium salicylate diffused much faster from these latter bases than did salicylic acid (134).

Additional references on the relationship of salt form and solubility are listed in Table V.

Organooleptic Properties—Modern medicine requires that a pharmaceutical formulation be efficacious, safe, stable, and acceptable to the patient. Of primary importance in the development of oral dosage forms is taste acceptability. This factor presents no major problems when the drug is to be administered as a tablet or a capsule and swallowed as a unit but is clearly a prominent factor in

Table V—Additional References on Salt Form and Solubility

Topic	Reference
Influence of solubility on the rate of GI absorption of aspirin	135
Effect of dosage form upon the GI absorption rate of salicylates	136
Physical-chemical properties of polyene macrolide esters and their water-soluble salts	137
Isolation and reaction products of orotic acid and amines and their solubility in water	138
Solubility and stability of erythromycin salts	139
Studies on pharmaceutical preparations of orotic acid: water-soluble properties of orotic acid salts	140
Solubility of antibiotics in 24 solvents	141, 142
Solubility of antibiotics in 26 solvents	143

patient acceptability when it is to be administered as a liquid, chewable tablet, or lozenge.

Since taste is a chemical sense, a substance must be dissolved if it is to elicit a taste sensation—either by taking it as a solution or by its dissolving in the saliva. Therefore, one method used to minimize undesirable organoleptic properties of pharmaceuticals involves the preparation of a poorly soluble salt form of the drug such that the saturation concentration is less than the taste threshold.

Erythromycin estolate (lauryl sulfate) has approximately one-twelfth the solubility of the free base, is tasteless, and is useful in the formulation of oral suspensions (144). A study on erythromycin salts showed that the bitterness level was dependent on two properties: (a) the water solubility of the salt, which is dependent on the size of the alkyl group attached to the acid function; and (b) the strength of the acid used to form the salt, *i.e.*, the stability of the salt (130). The stearyl sulfamate salt possessed the most desirable organoleptic properties.

Many problems concerned with formulation and stability of topical and oral pharmaceuticals containing bacitracin have been overcome by incorporating bacitracin into the formulation as its zinc salt. One distinct advantage over the parent compound is its lack of taste, caused by its relative insolubility. Thus, it is the preferred drug form for preparations where taste is a factor (145). Taste panel evaluations of the comparative bitterness of bacitracin zinc and bacitracin indicate that the taste of the zinc salt is more easily masked and that the presence of a bitterness-masking adjuvant, such as sucrose, increases the bitterness threshold ratio differences between the two compounds even further (146).

Propoxyphene napsylate, nearly water insoluble, is only slightly bitter to the taste as compared to the highly water-soluble hydrochloride (147) and can be readily formulated into a flavored aqueous suspension. The taste of these suspensions can be improved significantly by the addition of a common ion (sodium or calcium napsylate) to depress solubility further.

A newer approach to the improvement of drug palatability has been to form insoluble salts with ion-exchange resins. Several investigators described and tested the practical application of this method (148-150). Spross *et al.* (149) outlined the conditions necessary for improving the palatability of a drug by adsorbing it onto an ion-exchange resin without appreciably modifying its pharmacological effects. They found that: (a) the degree of drug release from the ion-exchange adsorbate depends on the

equivalent quotient between the electrolytes in the surrounding fluid and the ionic drugs, (b) the amount of ions is far less in the saliva than in the gastric juice (the temporary electrolyte contents can be estimated at 0.05 mEq in the saliva and at 10 mEq in the gastric juice), and (c) the exchange rates should allow the equilibria to be attained within a fairly short period. Insoluble drug resins formed between dextran gel² cation exchangers and several basic drugs were in many cases much more pleasant tasting than their parent compounds. Furthermore, release of the drug from the ion-exchange adsorbate was quite rapid and complete under conditions prevailing in the GI tract.

Similar findings were reported using a polymethacrylic acid ion-exchange resin (150). In addition, coating the adsorbate particles with a 4:1 ethylcellulose-hydroxypropyl methylcellulose mixture further reduced bitterness. While *in vitro* release from the uncoated resinate was rapid and complete, release from coated adsorbates varied with the extent of coating.

Another approach to improving the taste properties of pharmaceutical agents is to prepare a pleasant-tasting soluble salt of a poor-tasting parent drug. This approach often can be very difficult, however, since solubilization of the parent compound usually imparts its unpleasant taste to the preparation. Nevertheless, some success has been reported using the artificial sweeteners cyclamate sodium and saccharin.

As described earlier, formation of *N*-cyclohexylsulfamate salts of several drug substances has produced better tasting derivatives with enhanced solubility properties (31, 32). The physicochemical and toxicological properties of benzalkonium saccharinate and a series of saccharinates of other quaternary ammonium compounds were reported (151). While conventional quaternary ammonium compounds have a very bitter taste, their saccharin analogs are sweet.

Potassium salts frequently possess an unpleasant taste and a metallic aftertaste. The palatability of some potassium salts in flavored vehicles was reported (152); while the salts had similar taste thresholds at effective therapeutic levels, all potassium salts exhibited inferior palatability.

Table III includes several samples of other salts that exhibit an improved taste relative to their free acid or base forms.

Stability—The chemical and physical stability of a pharmaceutical must be known, because it can influence the choice of dosage form, the manufacturing and packaging, and the therapeutic efficacy of the final preparation. Systematic determination of the thermal stability, solution stability (at various pH's), and light sensitivity of a drug and its derivatives, both alone and in the presence of common additives, provides essential input toward selecting the most suitable derivative and dosage form.

Depending on the route of degradation, different salt forms impart different stability characteristics to the parent drug by various mechanisms. Most commonly used are sparingly soluble salts which, when used in the formulation of suspensions, reduce the amount of drug in solution and, hence, its degradation. Differences in hygroscopicity of several salts influence the stability of the

drug in the dry state. In some cases, the salt-forming radical itself enhances the stability of the parent agent.

The stability of penicillin G and its salts has been widely studied due to the drug's therapeutic importance and its characteristic instability. Schwartz and Buckwalter (153) described some of the stability characteristics of this antibiotic, stating that, with present techniques, a solution of penicillin cannot be made stable for more than 2 weeks, even at refrigerator temperatures. They also discussed the use of suspensions of sparingly soluble amine salts in aqueous vehicles as a means of "allowing marketing of a 'ready-made' penicillin product." Procaine, benzathine, and hydrabamine salts are marketed, and their acceptable stability as aqueous suspensions is based mainly on their insolubility and the minimization of degradation in solution.

A theoretical treatment of the solubility of these salts was presented in which equations were derived for calculating the solubility as a function of pH and the pH of minimum solubility (154, 155). These equations are based on the mass action law and its relationship to the ionization constants of the amine and the penicillin and the solubility of the salt in water. Since the salt in solution is partially dissociated, further suppression of the solubility may be achieved by the common ion effect. Swintosky *et al.* (156) demonstrated this effect with penicillin G procaine by adding procaine hydrochloride to the preparation and further enhancing its stability. The 8-chlorotheophylline salt (or complex) of penicillin G was reported to be water soluble, yet stable in solution (157). Since 8-chlorotheophylline is acidic, it has been postulated that a buffer effect could account for the stabilization of this "salt."

While penicillin G procaine is more stable in aqueous vehicles, it is less thermally stable than the sodium or potassium salts, decomposing if heated much above 60°. The sodium and potassium salts are known to withstand heating up to 100° for 4 days with little loss in potency (158). This behavior might well be due to differences in melting points—*viz.*, 106° for penicillin G procaine and ~215° dec. for the potassium salt.

Since hydrolysis of penicillin is dependent on moisture content, preparations in which moisture is rigorously excluded are quite stable in the dry state. A study on the effect of moisture on penicillin salts found the calcium salt to be less hygroscopic than the sodium salt and, hence, more stable in moist atmospheres (159). Similarly, penicillin G potassium is also much less hygroscopic than penicillin G sodium and has become the preferred form for marketing in the dry state (160).

Several studies reported the relative stabilities of thiamine salts, particularly the hydrochloride and the mononitrate (161-163). The mononitrate is observed to be less hygroscopic and is accordingly much less water soluble than the hydrochloride. Investigations of various preparations including compressed tablets, multivitamin capsules, and dry-filled vitamin B complex capsules at various temperatures showed that the mononitrate was more stable than the hydrochloride (164, 165). The stabilities of numerous thiamine salts were studied in aqueous solution and in dry powder preparations with various excipients (166, 167). In aqueous solution, the resulting pH was the chief factor controlling hydrolysis and oxidative decomposition of thiamine salts; their stability as powder

² Nephadex.

$$H_2^2$$

multiple dosing (207). This finding is explained by the fact that this salt is acid stable and alkaline dissociable, permitting its passage through the acid of the stomach both in fasting and nonfasting subjects (209). Accordingly, the antibacterial activity remained essentially the same when this form of erythromycin was given, regardless of the state of fasting of the subject (209).

On first inspection, the higher serum levels attained with erythromycin estolate suggest that the salt form is more readily absorbed. Also critical to efficacy, however, is the volume of distribution of the drug, since extensive binding to plasma proteins can render a drug unavailable for activity at the biophase. Therefore, the significance of blood level data greatly depends on the measure of the free or unbound fraction of total antibiotics in the blood, which more directly indicates probable therapeutic benefit.

Wiegand and Chun (210) showed that, despite the higher blood levels attained with erythromycin estolate (after correction for half-life differences), the stearate salt produced seven times more free drug in serum than did the estolate salt. This finding explained the higher total tissue levels observed on administration of the stearate. They attributed the difference to a greater serum protein binding of the intact erythromycin estolate, proving that its higher serum levels did not necessarily reflect more efficient absorption.

Marked differences have been observed following oral administration of various salts of penicillin. Penicillin G potassium has been compared with penicillin G benzathine (benzethacil) (211, 212), penicillin G hydrabamine (213), penicillin V (214), penicillin G procaine (212), and penicillin G ammonium (215). As anticipated, penicillin G potassium produced higher and earlier blood levels than penicillin G benzathine (211, 212). Furthermore, tablets of penicillin G potassium buffered with sodium citrate yielded higher peak levels than unbuffered penicillin G potassium. While the absorption of buffered tablets was apparently not significantly affected by food intake, the unbuffered tablets yielded lower average levels and irregular absorption under similar conditions.

When penicillin G potassium was compared with penicillin G hydrabamine (213), a less soluble salt, blood levels similar to those produced by penicillin G benzathine were observed. When equivalent doses were administered, the penicillemia that occurred with penicillin G hydrabamine was only one-third or one-fourth as great and was of shorter duration than that produced by penicillin G potassium.

Budolfson *et al.* (212) found that peak concentrations of penicillin G potassium were three to four times those obtained with penicillin G procaine and five to six times those of penicillin G benzathine, indicating a more rapid rate of absorption. The therapeutic action was related to the maximum concentration attained, but it also depended on the persistence of penicillemia, which was greater with penicillin G potassium than with the other two compounds. The authors suggested that the lower blood levels attained with the relatively insoluble penicillin G benzathine were caused by its destruction in the GI tract prior to absorption. This suggestion seems unlikely, however, since the drug should not degrade very rapidly as an undissolved suspension.

Because of its superior stability in gastric juice, penicillin

V produces higher blood penicillin levels than corresponding doses of penicillin G. As a result, extensive investigations have been conducted with various salts of penicillin V (99, 214-220). For instance, tablets, capsules, and oral suspensions of penicillin V acid produced significantly higher blood concentrations than comparable penicillin G preparations (214). In the same study, the average serum levels produced by the benzathine salt of penicillin V were significantly higher than comparable doses of penicillin G benzathine for the first 4 hr but lower thereafter, again illustrating the value of using an insoluble salt to prolong blood levels of an acid-unstable compound. In another study (215), penicillin V acid was shown to produce higher and more prolonged plasma concentrations than either penicillin G potassium or ammonium, whose properties were comparable.

Plasma levels were correlated with dissolution rates of various forms of penicillin V (99). As solid dosage forms, the readily soluble potassium and calcium salts produced earlier and higher blood levels in fasting subjects than either the free acid or its benzathine salt. On the other hand, when the potassium and benzathine salts were administered orally as solutions, absorption was the same, implying that the poor solubility of the benzathine salt was responsible for the inferior blood levels obtained from its solid dosage forms. Other studies found that, while the potassium salt is 40% better absorbed than the free acid in fasting subjects, both forms produce therapeutic levels when administered with food (218).

Experiments with fistulated dogs indicated that penicillin V is absorbed primarily from the stomach. Therefore, it is not surprising that the potassium salt should show higher blood levels on oral administration since it is the most soluble salt in gastric pH (216). In accordance with this observation, it was also reported that the benzathine salt exhibited higher serum levels in patients with gastric achlorhydria (pernicious anemia) than in patients with normal gastric function (219). Differences in gastric emptying time may also explain this result.

Several studies compared the absorption of tetracycline and its salts (103, 221, 222). For example, serum concentrations in dogs and humans showed that a phosphate complex salt of tetracycline was absorbed more rapidly and gave higher blood levels during the first 6-8 hr than did tetracycline hydrochloride (221). The total amount of drug absorbed was about twice as great with the former compound.

Another study (222) suggested that tetracycline base produced higher blood levels than tetracycline hydrochloride. However, a subsequent investigation (223) showed that, in the absence of adjuvants or fillers, tetracycline hydrochloride and tetracycline base were absorbed equally well. Results obtained in this same study indicated that tetracycline hydrochloride encapsulated with citric acid produced higher serum concentrations than tetracycline hydrochloride mixed with hexametaphosphate or the phosphate complex salt of tetracycline.

In a study comparing urinary excretion rates and *in vitro* dissolution, the absorption of tetracycline and tetracycline phenolsulfonaphthaleinate was rate limited by their dissolution rates, whereas tetracycline hydrochloride absorption was rate limited by the absorption process itself (103).

Several lincomycin salts were studied for their comparative availability (224). In particular, the blood levels obtained with the relatively water-insoluble hexadecylsulfamate salt were compared to those of the hydrochloride following oral administration. Higher and extended whole blood and serum concentrations were obtained in mice, rats, and dogs with the hexadecylsulfamate. However, subcutaneously administered lincomycin did not produce significantly different fractions absorbed, regardless of which salt was administered. It is not known whether the greater area under the curve with oral administration of lincomycin hexadecylsulfamate is due to greater absorption from the GI tract, slower renal clearance, or greater enterohepatic circulations.

Salts of streptomycin, neomycin, viomycin, and streptothricin have been formed with: (a) polyacrylic acids, (b) sulfonic or phosphorylated polysaccharides, and (c) natural polycarboxyl acids from a series of polyuronic substances and polysaccharide derivatives containing carboxyl groups (18). The report indicated that these salts were absorbed from the injection locus primarily by the lymph system. Blood levels from the salts were generally lower but were maintained for a longer time than the equivalent amount of antibiotic alone, and higher concentrations of longer duration may actually be produced in the lymphatic drainage.

The influence of salt formation on the onset and duration of pharmacological activity also was illustrated with tolbutamide and several of its salts (101). Following oral administration, the sodium salt produced a rapid decrease in blood sugar level followed by a rapid recovery. By contrast, the free acid of tolbutamide caused a slow and prolonged drop in blood sugar level, a preferred effect since the chance of hypoglycemic shock would be lessened. This finding also illustrates the often overriding influence of the actual disease state on the choice of drug form.

Additional references on the implications of salt formation on absorption are listed in Table VIII.

Pharmacokinetics—Because of the various new properties that are usually imposed on a compound by salt formation, the pharmacokinetics of the drug necessarily change as a function of these properties.

For example, a pharmacokinetic evaluation comparing ampicillin sodium and potassium with ampicillin trihydrate was performed after oral administration to beagle dogs (243). The absorption rate constants of the sodium and potassium salts, which were similar, proved significantly greater than the rate constant of ampicillin trihydrate, resulting in earlier, higher peak concentrations with two to three times higher serum concentrations during the 1st hr. Yet, any differences between the fraction absorbed for the three products were not statistically significant. Apparently, although dissolution of the ampicillin trihydrate was the rate-limiting step in its absorption, the overall extent of bioavailability remained unaffected.

An interesting study of the biliary excretion of erythromycin base and erythromycin estolate was reported (244). The biliary excretion of erythromycin base was high, while that of erythromycin estolate was much lower; preferential secretion of erythromycin in the bile could partially account for the lower serum levels exhibited by the base. However, the proportion of the ingested dose secreted in the bile was small, and the total amounts in-

Table VIII—Additional References on Bioavailability and Absorption Alteration

Topic	Reference
Blood levels produced by three theophylline-containing elixirs	225
Naproxen oral absorption characteristics	226
Effect of food on absorption of a new form of erythromycin propionate	227
Effect of the anion on the absorption of tetracycline from the rat stomach	186
Blood levels following oral administration of different preparations of novobiocin	228
Absorption of iopanoic acid and its sodium salt	229
Oral absorption of secobarbital (quinalbarbitone) and its sodium salt	230
Absorption rate of barbiturates in humans	231
Morphine and atropine mucate	232
Excretion of buphenium salts in urine of human volunteers	233
Polymethylene bis(isothluronium) salts: antituberculous activity	234
Prolonged antitussive action of a resin-bound noscapine preparation	235
Pharmacology of sulfapyridine and sulfathiazole	236
Evaluation of plasma concentrations of propoxyphene utilizing a hybrid principal component analysis of variance technique: equimolar doses	237
Antrycide, a new trypanocidal drug	238
Pralidoxime methanesulfonate: plasma levels and pharmacokinetics after oral administration to humans	239
Intestinal absorption of pralidoxime and other oldoximes	240
Blood plasma levels and elimination of salts of pralidoxime (2-PAM) in humans after oral administration	241
Enhancement of GI absorption of a quaternary ammonium compound by trichloroacetate	242

involved were not sufficient to account entirely for the differences in serum concentrations attained. Undoubtedly, the protein binding studies of Wiegand and Chun (210) (discussed under *Absorption Alteration*) more satisfactorily explain the difference in serum concentrations.

Often, salt formation can be used to modify drug absorption and dose tolerance favorably. For example, aminosalicilic acid exhibits a short half-life and, therefore, requires large and frequent doses which may cause gastric irritation. Consequently, different chemical forms such as salts have been prepared (119, 245-247) to reduce the incidence of gastric irritation, increase absorption, and prolong blood levels.

Aminosalicilic acid is an interesting example in other ways; considerable confusion about this drug exists because many fail to recognize its nonlinear pharmacokinetics. Several definitive studies were reported regarding the absorption of the acid and its sodium, potassium, and calcium salts from solution, suspension, and tablet formulations (245, 246). Comparison of the relative bioavailabilities of aminosalicilic acid suspended in water and its salts dissolved in water showed that, while differences in rate of absorption were found to exist, absorption of both the acid and its salts was essentially complete. Absorption of the free acid from tablets reached only 77% of the dose, whereas that of the tableted salts was rapid and complete.

Regardless of formulation, the area under the plasma concentration-time curve of unmetabolized drug from free acid administration was less than that for the salts. This result was attributed to concentration-dependent metabolism during absorption: when the rate of absorption is high, the metabolic processes become saturated and more unmetabolized drug remains in the blood; conversely,

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Table IX—Additional References on Bioavailability and Pharmacokinetics

Topic	Reference
Pharmacodynamics of fosfomycin (phosphonomycin) after intravenous administration to humans	248
Pharmacodynamics of phosphonomycin after oral administration to humans	249
Comparative studies on distribution, excretion, and metabolism of ³ H-hydroxyzine and its ¹⁴ C-methiodide in rats	250
Pharmacokinetics of ampicillin trihydrate, ampicillin sodium, and dicloxacillin sodium following intramuscular injection	251
Physiological disposition of fenopropfen in humans: pharmacokinetic comparison of calcium and sodium salts administered orally	252

when the absorption rate is low, as for the free acid, a higher percentage of drug is metabolized.

Additional references regarding bioavailability and pharmacokinetics are presented in Table IX.

GENERAL PHARMACY

Pharmacological Effect—Chlorpromazine hydrochloride and quaternary chlorpromazine chloride were investigated with respect to their effects on the central nervous system (CNS) (253). The quaternized compound was less potent and more toxic in rodents than the parent tertiary compound.

Naloxone, an effective opiate antagonist, is generally used as the hydrochloride salt; however, the drug has a very short duration of action. The mucate salt was prepared to extend its duration of action, since mucic acid is only slightly soluble in water (254). In a test on the blocking of morphine activity in mice, however, the mucate salt did not differ in duration from the hydrochloride. These investigators assumed the same receptor site for naloxone as for morphine and, since Heron's (232) work suggested that the receptor had a greater affinity for morphine mucate than for the free base, it also should have a greater affinity for naloxone mucate. The results disproved this hypothesis. Furthermore, this theory implies that intact salt reaches the receptor, which is highly unlikely, regardless of whether the drug is administered as a solution or as a suspension.

A series of salts of 9-aminoacridine and its derivatives was prepared and screened for antifungal and antibacterial activity (255-257). By using salts of fatty acids, the antifungal action was found to parallel the length of the carbon chain of the anion, with maximal activity occurring with acridine caproate, undecylate, and undecylenate (where undecylenic acid also exhibits some intrinsic antifungal activity) (255). This result appears reasonable, because these salts would be more lipid soluble and could be expected to pass through the cell wall of the infecting organism more readily, probably as an ion-pair.

The efficacy of bases or salts as topical anesthetics for relieving cutaneous itch, burning, and pain in unbroken skin has also been examined (258). In these experiments, itching and pricking were induced by an alternating current of low amperage and voltage applied to the skin or by exposure of the skin to UV light. Interestingly, aqueous solutions of salts of the local anesthetics did not alleviate itching or burning in any of the subjects, although saturated solutions of their bases in a mixture of water, 40%

Table X—Additional References on General Pharmacy and Pharmacological Effect

Topic	Reference
Differential excretion of bromide and chloride ions and its role in bromide retention	259
Pharmacological study of calcium methionate	260
Synthesis and <i>in vitro</i> fungistatic evaluation of some <i>N</i> -substituted amides and amine salts of sorbic acid	261
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alcohol, and 10% glycerol were claimed to be effective. Such transport phenomena across the stratum corneum are often dependent on the polarity of the drug and vehicle and on the binding of the drug to keratin.

Additional references on pharmacological effects can be found in Table X.

Dialysis—Dialysis through a cellophane membrane of the hydrochloride or sodium salts has been studied with several drugs (270). In many cases, it appeared that the ionic form of the drug was bound to the membrane whereas the nonionized form was not. Ephedrine hydrochloride presented an interesting example, however, since it dialyzed considerably faster than its corresponding base. It was theorized that the chloride ion dialyzed rapidly, enhancing the rate of dialysis of the ephedrine ion. Accordingly, when chloride ion was present on both sides of the membrane, the observed rate of dialysis for the ephedrine ion was comparable to the ephedrine base.

The diffusion of sodium chloride through a lipoprotein interface was very slow, especially if calcium chloride was present on both sides of the interface (271). In the presence of low concentrations of choline chloride or carbamylcholine chloride, the diffusion of sodium chloride is more rapid. Apparently, choline salts are able to increase the permeability of the lipoprotein to salts, which may relate to the physiological action of choline salts.

Miscellaneous—Release rates were determined for aminophylline, ephedrine alkaloid, and ephedrine hydrochloride from theobroma oil suppositories containing nonionic surfactants (133). While surfactants with hydrophilic-lipophilic balance (HLB) values less than 11 only minimally affected release rate, rates increased with surfactants of HLB values greater than 11. Under optimal conditions, aminophylline was faster than ephedrine hydrochloride which, in turn, was superior to the ephedrine base.

Willis and Banker (272) reported on the formation of polymer-drug salts as an approach to the physicochemical design of dosage forms. Poly(methyl vinyl ether)/maleic

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anhydride) salts of methapyrilene were prepared and tested with the free base for *in vitro* dissolution and dialysis. Their dissolution and dialysis rates were not appreciably different from the free drug or its hydrochloride salt. Various poly(methyl vinyl ether/maleic anhydride) hemiester salts of methapyrilene exhibited substantially slower release than the polymer ether salts, hydrochloride salt, or free base forms. Polymer-drug salts thus appear to have promise.

A series of metallic salts of edetic (ethylenediaminetetraacetic) acid were tested *in vitro* to determine their effect on blood coagulation (273). The results showed that only the dipotassium and disodium salts had any effect on coagulation. It was theorized that the lack of anticoagulant activity resulted from an almost complete suppression of ionization of the heavy metal salts.

Interesting research regarding the angina-preventive effect of some chromone-2-carboxylate salts showed a direct correlation between biological activity and pKa of the salt-forming amines (274).

Lin *et al.* (112) investigated the relationship between salt form and biological activity of a given antihypertensive. While the intrinsic dissolution rates of the dihydrochloride and disulfate salts were many fold greater than the monohydrochloride, the hypotensive potencies of the salts did not differ significantly from one another in an anesthetized dog study. Yet, when administered to renal hypertensive dogs, the dihydrochloride and disulfate salts produced greater hypotensive effects than did the monohydrochloride.

TOXICOLOGICAL CONSIDERATIONS

Toxicity of Salt Ion—Any discussion regarding the toxicity of salts of a drug must consider the pharmacological properties of the cation or anion used to form the salt as well as those of the free drug, since any of these may produce toxic effects. The toxicology of several ions that are commonly used to form salts and that are relevant to this review were discussed in depth (275).

Toxicity from ingestion of calcium salts of drugs is rare. If hypercalcemia occurs, however, calcium deposits in the kidney can bring on a reduction of renal function. The principal toxic effects of lithium also involve the kidneys. When small amounts of lithium are taken, no apparent damage occurs; yet large amounts of the metal can lead to irreversible damage. An apparent correlation was observed between lithium dosage and sodium intake (276). When lithium dosage was low or sodium intake was high, rats were able to excrete all lithium given and sustained a reversible polyuria. Conversely, if large amounts of lithium were administered to the rats or if their sodium intake was lowered, they incurred irreversible kidney damage. Ammonium ion, although it serves a major role in maintenance of the acid-base balance of the body, can be toxic in high concentrations and initiate CNS derangements.

Sulfate ions given orally tend to be minimally absorbed and may act as a laxative. The nitrate ion is irritating to the GI tract, causing nausea and gastric distress. Also, intestinal bacteria may convert the nitrate ion to nitrite which oxidizes hemoglobin to methemoglobin. The citrate ion, an intermediary in carbohydrate metabolism, can form a soluble complex with calcium which is poorly dissociable

and rarely causes any toxic reactions. While tartrate ions are usually absorbed minimally from the GI tract, high concentrations reaching the circulation can cause renal damage.

Acetate and lactate ions are normal metabolites and appear to be well tolerated in relatively large amounts. Iodide and bromide ions can produce conditions known as iodism and bromidism, respectively. Bromide intoxication occurs quite frequently, since bromides are used as ingredients in some nonprescription preparations (277-280). Bromide is slowly excreted by the kidney (its half-life is 12 days) and tends to accumulate when taken for prolonged periods or when used by patients with decreased renal function (277).

Toxicity of Salt Form—Provided the salt-forming agents are nontoxic, the relative toxicities of a series of salts of a compound are often observed to reflect directly their absorption rates. For example, the toxicities of dibromide, dichloride, diiodide, and dimethylsulfate salts of quina-pyramine³, a trypanocidal drug, were determined (238). The sparingly soluble halogen salts were much less toxic subcutaneously or intramuscularly than the freely soluble dimethylsulfate, yet all salts showed about equal toxicity upon intravenous administration. The difference in toxicities obviously resulted from rapid absorption of the methylsulfate compared to the slowly absorbed, poorly soluble halogen salts. Similar reasoning has been used to explain the acute oral toxicity of propoxyphene hydrochloride in rodents, which is twice that of equimolar doses of the napsylate salt (281).

Several salts of benzphetamine and etryptamine were prepared as potential sustained-release formulations (114). The water solubility, *in vitro* dissolution rates at pH 1.0 and 7.2, and the median lethal times (LT₅₀) were determined for each salt. Both the LT₅₀ and LD₅₀ (determined on only a few salts) increased as the *in vitro* dissolution rate at pH 7.2 decreased. While dissolution at pH 1.0 did not correlate well with toxicity, the LT₅₀'s were inversely related to the square root of the dissolution rates at pH 7.2.

Toxicity studies comparing iopanoic acid, a cholecystographic contrast medium, with its sodium salt (115) showed that the salt form has 10-fold greater toxicity. The LD₅₀'s of the free acid and the salt were 22 and 2.32 g/kg, respectively. It was postulated that the free acid precipitated from the sodium salt upon its reaction with gastric hydrochloric acid. The fine, amorphous particles of precipitated acid had a greatly increased surface area and, therefore, dissolved more rapidly than even fine crystals of the free acid. The faster and more complete drug absorption then resulted in increased toxicity.

Salts exhibiting greater water solubility than their parent compounds or less soluble salts are not always more toxic. For example, various inorganic and organic ions were used to prepare salts of methyl pyridinium-2-aldoxime that would have greater water solubility and would eliminate undesirable side effects due to the iodide ion (95). Even though the aqueous solubility of the majority of these salts was many times greater than the iodide, their toxicity on a molar basis was not significantly different, with the exception of the dihydrogen phosphate salt which was 15%

³ Antrycide.

Table XI—Additional References on Toxicological Considerations

Topic	Reference
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Further toxicological studies with erythromycin	288
Pharmacology and toxicology of erythromycin estolate	289
Erythromycin propionate (propionylerythromycin): a review of 20,628 case reports for side-effect data	290
New class of antibiotic salts of reduced toxicity	22
GI intolerance to oral iron preparations	291
Comparative toxicology of iron compounds	292
Influence of the dissolution rate of lithium tablets on side effect	123
Toxicity and tissue distribution studies on the hydrochloride, bismuth iodide complex, and a resinate of emetine	293
Acitracin zinc in pharmaceutical preparations	145
New approach to quaternary ammonium compounds	151
Pharmacology of choline theophyllinate	294

more toxic. Further research with oximes revealed that other salts are also toxic (282).

GI bleeding is a common toxic effect of aspirin for a large percentage of the population. Consequently, a search was initiated for an aspirin derivative that would not induce GI blood loss (283). All compounds prepared, however, including the sodium and calcium salts, caused GI hemorrhage with a severity similar to aspirin.

Polyene antibiotics are potent antifungal agents but bear considerable toxicity. Even though the methyl ester hydrochlorides of these compounds are more soluble, they retain almost all of their antifungal activity and, more significantly, show a uniform decrease in toxicity compared to their parent compounds (284).

Additional references on toxicological considerations of salt formation are given in Table XI.

CONCLUSIONS

Salt formation is a means of altering the physical, chemical, and biological characteristics of a drug without modifying its chemical structure. Clearly, the salt form can have a dramatic influence on the overall properties of the parent compound. At present, selecting a salt form that exhibits the desired combination of properties is a difficult semiempirical choice. Pharmaceutical scientists now recognize these facts and are beginning to study the effects of different salt forms on the physicochemical properties, bioavailability, and toxicity of drug substances.

Although now only a few generalizations are available to predict the effect of particular salt forms on the characteristics of a drug, perhaps in time it will be possible to evolve increasingly more powerful generalizations regarding the effect of a salt on the properties of its parent compound. In addition, we predict that polymer-drug salts will have a revolutionary effect on future trends in drug therapy, particularly in the areas of reducing drug toxicity and in controlling the release profile of novel drug delivery systems.

REFERENCES

- (1) D. Walkling and J. Appino, *Drug Cosmet. Ind.*, 112 (3), 39 (1973).
- (2) N. J. Harper, *J. Med. Pharm. Chem.*, 1, 467 (1959).

- (3) N. J. Harper, *Progr. Drug Res.*, 4, 221 (1962).
- (4) K. Munzel, *ibid.*, 10, 255 (1968).
- (5) V. J. Stella, *Aust. J. Pharm. Sci.*, NS2 (2), 57 (1973).
- (6) A. A. Sinkula and S. H. Yalkowsky, *J. Pharm. Sci.*, 64, 181 (1975).
- (7) "Martindale The Extra Pharmacopoeia," 28th ed.; Pharmaceutical Press, London, England, 1973.
- (8) L. C. Miller and W. H. Heller, in "1974-75 Drugs of Choice," W. C. Modell, Ed., Mosby, St. Louis, Mo., p. 26.
- (9) E. Seiss, A. Jondet, and J. Philippe, *Ann. Pharm. Fr.*, 27, 567 (1969); through *Chem. Abstr.*, 72, 126018s (1970).
- (10) H. C. Caldwell, A. B. Rednick, G. C. Scott, G. J. Yakatan, and D. Ziv, *J. Pharm. Sci.*, 59, 1689 (1970).
- (11) G. R. Coatsney, P. G. Contacos, and J. S. Lunn, *Am. J. Trop. Med. Hyg.*, 13, 383 (1964).
- (12) P. E. Thompson, B. J. Olszewski, E. F. Elsager, and D. F. Worth, *ibid.*, 12, 481 (1963).
- (13) W. C. Miller, Jr., D. B. Marcotte, and L. McCurdy, *Curr. Ther. Res., Clin. Exp.*, 15, 700 (1973).
- (14) H. L. Goldberg and L. Nathan, *Psychosomatics*, 13, 131 (1972).
- (15) E. F. Elsager, *Ann. Rep. Med. Chem.*, 1965, 137.
- (16) H. A. M. El Shihini, M. Abdel Nasser, and M. M. Motawi, *Pharmazie*, 26, 630 (1971).
- (17) S. P. Loucas and H. M. Haddad, *J. Pharm. Sci.*, 61, 985 (1972).
- (18) P. Mälek, J. Kolc, M. Herold, and J. Hoffman, in "Antibiotics Annual, 1957-1958," Medical Encyclopedia, New York, N.Y., 1958, p. 546.
- (19) B. F. Duesel, H. Berman, and R. J. Schacter, *J. Am. Pharm. Assoc., Sci. Ed.*, 43, 619 (1954).
- (20) B. F. Duesel and T. I. Fand, *Int. Rev. Med. Gen. Pract. Clin.*, 167, 245 (1954).
- (21) R. H. Broh-Kahn, *ibid.*, 173, 217 (1960).
- (22) F. A. Alves, M. F. C. A. N. Graca, and H. L. Baptista, *Nature*, 181, 182 (1958).
- (23) H. Keller, W. Krüpe, H. Sous, and H. Mückter, *Arzneim.-Forsch.*, 5, 170 (1955).
- (24) *ibid.*, 6, 61 (1956).
- (25) H. Keller, W. Krüpe, H. Sous, and H. Mückter, in "Antibiotics Annual, 1955-1956," Medical Encyclopedia, New York, N.Y., 1956, p. 35.
- (26) A. C. Osterberg, J. J. Olsson, N. N. Yuda, C. E. Rauh, H. G. Parr, and L. W. Will, in "Antibiotics Annual, 1956-1957," Medical Encyclopedia, New York, N.Y., 1957, p. 564.
- (27) R. Ducrot, O. Leau, and C. Cosser, *Antibiot. Chemother.*, 6, 404 (1956).
- (28) R. S. Brigham and J. K. Nielsen, *ibid.*, 8, 122 (1958).
- (29) M. Khristov, *Rhim.-Farmaceut. Zh.*, 11, 19 (1972).
- (30) A. Lasso, C. Pfeiffer, and P. D. Waller, *J. Am. Pharm. Assoc., Sci. Ed.*, 48, 346 (1959).
- (31) J. A. Campbell and J. G. Slater, *J. Pharm. Sci.*, 51, 931 (1962).
- (32) J. A. Campbell, *ibid.*, 51, 270 (1962).
- (33) G. A. Neville and J. C. Ethier, *ibid.*, 60, 497 (1971).
- (34) T. Sciortino, *Boll. Chim. Farm.*, 105, 223 (1966); through *Chem. Abstr.*, 65, 622h (1966).
- (35) *ibid.*, 104, 292 (1965); through *Chem. Abstr.*, 63, 6783g (1965).
- (36) W. P. Beger, S. C. Strickland, and J. M. Gylfe, *Antibiot. Med. Clin. Ther.*, 1, 372 (1955).
- (37) C. L. Fox, Jr., South African pat. 68 03, 461 (Oct. 31, 1968); through *Chem. Abstr.*, 71, 33401a (1969).
- (38) J. W. Cusic, U.S. pat. 2,499,059 (Feb. 29, 1950); through *Chem. Abstr.*, 44, 4026g (1950).
- (39) J. W. Cusic, U.S. pats. 2,534,236-2,534,247 (Dec. 19, 1950); through *Chem. Abstr.*, 46, 527b-1 (1952).
- (40) J. W. Cusic, British pat. 677,798 (Aug. 20, 1952); through *Chem. Abstr.*, 48, 4010a (1954).
- (41) G. D. Searle Co., British pats. 683,845 (Dec. 3, 1952) and 683,236 (Nov. 26, 1952); through *Chem. Abstr.*, 48, 2769b (1954).
- (42) J. W. Cusic, *Science*, 109, 574 (1949).
- (43) M. L. Robinette and F. W. Bope, *J. Am. Pharm. Assoc., Sci. Ed.*, 44, 32 (1955).
- (44) D. J. Lamb and F. W. Bope, *ibid.*, 45, 178 (1956).
- (45) W. Bickers and M. Woods, *Tex. Rep. Biol. Med.*, 9, 406 (1951).

1829

- (46) W. Bickers and M. Woods, *N. Engl. J. Med.*, 245 453 (1951).
- (47) J. M. Holbert, I. W. Grote, and H. Smith, *J. Am. Pharm. Assoc., Sci. Ed.*, 44, 355 (1955).
- (48) W. Morozowich and F. W. Bope, *ibid.*, 47, 173 (1958).
- (49) A. Halpern, N. Shaftel, and G. Schwartz, *Antibiot. Chemother.*, 9, 97 (1959).
- (50) A. Halpern, N. Shaftel, and A. J. Monte Bovi, *Am. J. Pharm.*, 130, 190 (1958).
- (51) P. A. Fernander, German Offen. 2,259,151 (June 7, 1973); through *Chem. Abstr.*, 79, 53102x (1973).
- (52) A. Reiner, German Offen. 2,330,380 (Jan. 31, 1974); through *Chem. Abstr.*, 80, 100203b (1974).
- (53) J. R. Blanco, F. J. U. Fernandez, and L. S. Vinals, German Offen. 2,144,679 (Dec. 21, 1972); through *Chem. Abstr.*, 78, 71781b (1973).
- (54) VEB Berlin-Chemie, German Offen. 2,316,721 (Dec. 20, 1973).
- (55) M. T. Davies, J. Forrest, F. Hartley, and V. Petrow, *J. Pharm. Pharmacol.*, 6, 707 (1954).
- (56) Laboratorios Hoesbon S. A., French Demande 2,138,498 (Feb. 9, 1973); through *Chem. Abstr.*, 79, 83485s (1973).
- (57) B. J. Magerlein, *J. Pharm. Sci.*, 54, 1065 (1965).
- (58) E. H. Massey, German Offen. 2,138,049 (Feb. 3, 1972); through *Chem. Abstr.*, 76, 117507f (1972).
- (59) R. Tixier, German Offen. 1,936,723 (May 14, 1970); through *Chem. Abstr.*, 73, 28895b (1970).
- (60) P. Wirth, German Offen. 2,117,902 (Nov. 4, 1971); through *Chem. Abstr.*, 76, 46462z (1972).
- (61) Takeda Chem. Ind. Ltd., German Offen. 2,332,878 (Jan. 17, 1974); through *Chem. Abstr.*, 80, 96362v (1974).
- (62) Takeda Chem. Ind. Ltd., German Offen. 2,332,840 (Jan. 17, 1974); through *Chem. Abstr.*, 80, 87531x (1974).
- (63) G. Fabrizio, U.S. pat. 3,764,595 (Oct. 9, 1973); through *Chem. Abstr.*, 80, 6945k (1974) or *Chem. Abstr.*, 73, 133984e (1970).
- (64) Koninklijke Nederlandsche Gist en Spiritusfabriek, French pat. 2,128,443 (Oct. 6, 1972).
- (65) R. Aries, French pat. 2,190,410 (Mar. 8, 1974).
- (66) Otsuka Pharmaceutical Co., Ltd., Japanese pat. 71 03,600 (Jan. 28, 1971); through *Chem. Abstr.*, 75, 40421t (1971).
- (67) V. C. Stephens, U.S. pat. 3,728,379 (Apr. 17, 1973).
- (68) Investigations Scientifiques Pharmaceutiques S. A., French Demande 2,097,064 (Apr. 7, 1972); through *Chem. Abstr.*, 77, 168654e (1972).
- (69) C. Jarowski, *Trans. N.Y. Acad. Sci., Ser. II*, 21, 290 (1959).
- (70) Andreu SA, West German pat. 2,237,267 (Feb. 1, 1973).
- (71) E. N. Lazareva, L. A. Kovaleva, V. K. Vasil'ev, and P. S. Braginskaya, *Antibiotiki (Moscow)*, 14, 813 (1969); through *Chem. Abstr.*, 71, 111183z (1969).
- (72) O. B. Ferno, T. O. E. Linderat, and B. Hansen, South African pat. 68 01,104 (July 12, 1969); through *Chem. Abstr.*, 70, 60832c (1969).
- (73) A. Allais and M. Paturet, French M. 5,309 (Sept. 25, 1967); through *Chem. Abstr.*, 71, 64078e (1969).
- (74) Cent. Ind. Pharmaceutique, French pat. 2,193,586 (Mar. 29, 1974).
- (75) G. Guadagnini and F. Fabi, German Offen. 2,040,143 (Feb. 25, 1971); through *Chem. Abstr.*, 74, 126005b (1971).
- (76) Ciba-Geigy A.G., Canadian pat. 916,713 (Dec. 12, 1972).
- (77) R. Ferrari, S. Magnaghi, and G. Ghielmetti, British pat. 1,205,441 (Sept. 16, 1970); through *Chem. Abstr.*, 73, 133979e (1970).
- (78) L. G. Goodwin, L. G. Jayewardene, and O. D. Standen, *Br. Med. J.*, 2, 1672 (1958).
- (79) A. Zaffaroni, U.S. pat. 3,708,492 (Jan. 2, 1973).
- (80) F. K. Hansel, *Ann. Allergy*, 1, 199 (1943).
- (81) Cent. Ind. Pharmaceutique, French pat. 2,193,587 (Mar. 29, 1974).
- (82) N. H. Creasey and A. L. Green, *J. Pharm. Pharmacol.*, 11, 485 (1959).
- (83) J. M. De Muylder, German Offen. 2,310,447 (Sept. 13, 1973); through *Chem. Abstr.*, 80, 6982v (1974).
- (84) V. C. Stephens, U.S. pat. 3,066,261 (1962).
- (85) Merck & Co., Inc., West German pat. 2,256,538 (May 24, 1973).
- (86) C. J. Cavallito and R. Jewell, *J. Am. Pharm. Assoc., Sci. Ed.*, 47, 165 (1958).
- (87) R. L. Kile, *Antibiot. Med. Clin. Ther.*, 3, 578 (1958).
- (88) Whitefin Holding S. A., Belgian pat. 793,548 (Apr. 16, 1973).
- (89) Officina Therapeutica Italiana SRL, French pat. 2,099,449 (Mar. 17, 1972).
- (90) J. Kloss, West-German pat. 2,134,972 (Jan. 25, 1973); through *Chem. Abstr.*, 78, 87334h (1973).
- (91) T. J. Roseman and S. H. Yalkowsky, *J. Pharm. Sci.*, 62, 1680 (1973).
- (92) L. C. Miller and A. H. Holland, *Mod. Med.*, 28, 312 (1960).
- (93) J. G. Wagner, *J. Pharm. Sci.*, 50, 359 (1961).
- (94) T. H. Simons, abstracted from a paper presented at the APHA Academy of Pharmaceutical Sciences, Las Vegas meeting, Apr. 1967.
- (95) A. A. Kondritzer, R. I. Ellin, and L. J. Edberg, *J. Pharm. Sci.*, 50, 109 (1961).
- (96) H. M. Koehler and J. J. Hefferren, *ibid.*, 53, 1176 (1964).
- (97) W. Nernst and E. Brunner, *Z. Phys. Chem.*, 47, 52, 56 (1904).
- (98) E. Nelson, *J. Am. Pharm. Assoc., Sci. Ed.*, 48, 607 (1957).
- (99) H. Juncher and F. Raaschou, *Antibiot. Med. Clin. Ther.*, 4, 497 (1957).
- (100) E. Nelson, *J. Am. Pharm. Assoc., Sci. Ed.*, 47, 297 (1958).
- (101) E. Nelson, E. L. Knoechel, W. E. Hamlin, and J. G. Wagner, *J. Pharm. Sci.*, 51, 509 (1962).
- (102) J. G. Wagner, *ibid.*, 50, 375 (1961).
- (103) E. Nelson, *J. Am. Pharm. Assoc., Sci. Ed.*, 48, 96 (1959).
- (104) L. Benet, in "Drug Design," vol. 4, E. Ariens, Ed., Academic, New York, N.Y., 1973, p. 1.
- (105) G. Levy and B. A. Sahli, *J. Pharm. Sci.*, 51, 58 (1962).
- (106) G. Levy and J. A. Procknal, *ibid.*, 51, 294 (1962).
- (107) R. A. O'Reilly, E. Nelson, and G. Levy, *ibid.*, 55, 435 (1966).
- (108) W. I. Higuchi and W. E. Hamlin, *ibid.*, 52, 575 (1963).
- (109) W. I. Higuchi, N. A. Mir, A. P. Parker, and W. E. Hamlin, *ibid.*, 54, 8 (1965).
- (110) W. I. Higuchi, E. Nelson, and J. G. Wagner, *ibid.*, 53, 333 (1964).
- (111) S. Solvang and P. Finholt, *ibid.*, 59, 49 (1970).
- (112) S.-L. Lin, L. Lachman, C. J. Swartz, and C. F. Huebner, *ibid.*, 61, 1418 (1972).
- (113) S. Miyazaki, M. Nakano, and T. Arita, *Chem. Pharm. Bull.*, 23, 1197 (1975).
- (114) W. Morozowich, T. Chulski, W. E. Hamlin, P. M. Jones, J. L. Northam, A. Purmalis, and J. G. Wagner, *J. Pharm. Sci.*, 51, 993 (1962).
- (115) R. Peterhoff, *Acta Radiol.*, 46, 719 (1956).
- (116) G. Levy, *J. Mond. Pharm.*, 3, 237 (1967).
- (117) S. S. Davis, *Br. Med. J.*, 1, 102 (1972).
- (118) E. Nelson, *J. Am. Pharm. Assoc., Sci. Ed.*, 47, 300 (1958).
- (119) E. J. Middleton, H. S. Chang, and D. Cook, *Can. J. Pharm. Sci.*, 3, 97 (1968).
- (120) J. G. Wagner, *Drug Intell. Clin. Pharm.*, 4, 17 (1970).
- (121) *ibid.*, 4, 232 (1970).
- (122) T. Paal and P. Regos, *Gyogyszereszet*, 17, 59 (1973); through *Chem. Abstr.*, 78, 128377f (1973).
- (123) K. O. Borg, J. Jeppeson, and J. Sjogren, *Acta Pharm. Suec.*, 11, 133 (1974).
- (124) P. Finholt and S. Solvang, *J. Pharm. Sci.*, 57, 1322 (1968).
- (125) G. Levy, *ibid.*, 50, 368 (1961).
- (126) W. A. Cressman, C. A. Janicki, P. C. Johnson, J. T. Dolusio, and G. A. Braun, *ibid.*, 58, 1516 (1969).
- (127) L. W. Dittert, T. Higuchi, and D. R. Reese, *ibid.*, 53, 1325 (1964).
- (128) R. Anderson, *Aust. J. Pharm.*, 42, 919 (1961).
- (129) S. F. Kramer and G. L. Flynn, *J. Pharm. Sci.*, 61, 1696 (1972).
- (130) P. H. Jones, E. K. Rowley, A. L. Weiss, D. L. Bishop, and A. H. C. Chun, *ibid.*, 58, 337 (1969).
- (131) N. Senior, *J. Soc. Cosmet. Chem.*, 24, 259 (1973).
- (132) J. J. Sciarra, J. M. Patel, and A. L. Kapoor, *J. Pharm. Sci.*, 61, 219 (1972).
- (133) J. M. Plaxco, Jr., C. B. Free, Jr., and C. R. Rowland, *ibid.*, 56, 809 (1967).
- (134) J. Kucera and V. Veber, *Cenk. Dermatol.*, 41, 229 (1966); through *Chem. Abstr.*, 63, 18431e (1966).
- (135) J. R. Leonard, *Clin. Pharmacol. Ther.*, 4, 476 (1963).
- (136) G. Levy, R. H. Guntow, and J. M. Rutowski, *Can. Med. Assoc. J.*, 85, 414 (1961).
- (137) C. P. Schaffner and W. Mechliniski, *J. Antibiot. (Tokyo)*, 25, 259 (1972).
- (138) H. Nakatani, *Yakugaku Zasshi*, 83, 6 (1963); through *Chem. Abstr.*, 58, 11170e (1963).
- (139) H.-C. Wang and P.-Y. Wang, *Yao Hsueh Hsueh Pao*, 13, 63

- (1966); through *Chem. Abstr.*, 65, 6307b (1966).
- (140) H. Nakatani, *Yakugaku Zasshi*, 84, 1057 (1964).
- (141) P. J. Weiss, M. L. Andrew, and W. W. Wright, *Antibiot. Chemother.*, 7, 374 (1957).
- (142) P. J. Weiss and M. L. Andrew, *ibid.*, 9, 277 (1959).
- (143) J. Marsh and P. J. Weiss, *J. Assoc. Offic. Anal. Chem.*, 50, 457 (1967).
- (144) V. C. Stephens, J. W. Conine, and H. W. Murphy, *J. Am. Pharm. Assoc., Sci. Ed.*, 48, 620 (1959).
- (145) H. M. Gross, *Drug Cosmet. Ind.*, 75, 612 (1954).
- (146) H. M. Gross, W. A. Johnson, and G. J. Lafferty, *J. Am. Pharm. Assoc., Sci. Ed.*, 45, 447 (1956).
- (147) C. M. Gruber, Jr., V. C. Stephens, and P. M. Terrill, *Toxicol. Appl. Pharmacol.*, 19, 423 (1971).
- (148) N. Brudney, *Can. J. Pharm.*, 92, 246 (1959).
- (149) B. Spross, M. Ryde, and B. Nyström, *Acta Pharm. Suec.*, 2, 1 (1965).
- (150) S. BoRodkin and D. P. Sundberg, *J. Pharm. Sci.*, 60, 1823 (1971).
- (151) W. J. Shibe, Jr., and D. H. Hanson, *Soap Chem. Spec.*, 40, 83 (1964).
- (152) G. E. Schumacher and W. J. Crowell, *Am. J. Hosp. Pharm.*, 21, 226 (1964).
- (153) M. A. Schwartz and F. H. Buckwalter, *J. Pharm. Sci.*, 51, 1119 (1962).
- (154) R. Brunner, *Monatsh. Chem.*, 86, 767 (1955).
- (155) R. Brunner and H. Margreiter, *ibid.*, 88, 958 (1955).
- (156) J. V. Swintosky, E. Rosen, M. J. Robinson, R. E. Chamberlain, and J. R. Guarini, *J. Am. Pharm. Assoc., Sci. Ed.*, 45, 34 (1956).
- (157) W. Störbeck, German pat. 971,830 (Apr. 2, 1959); through *Chem. Abstr.*, 55, 4893d (1961).
- (158) F. H. Buckwalter, *J. Am. Pharm. Assoc., Pract. Ed.*, 15, 694 (1954).
- (159) W. A. Woodward, *Q. J. Pharm. Pharmacol.*, 20, 197 (1947).
- (160) C. A. Johnson, in "Advances in Pharmaceutical Sciences," vol. 2, H. S. Bean, A. H. Beckett, and J. E. Carless, Eds., Academic, New York, N.Y., 1967, p. 227.
- (161) A. Bojarski, D. Blitek, and B. Borkowski, *Diss. Pharm. Pharmacol.*, 19, 297 (1967); through *Chem. Abstr.*, 67, 102734t (1967).
- (162) A. Bojarski, D. Blitek, and B. Borkowski, *Diss. Pharm.*, 17, 345 (1965); through *Chem. Abstr.*, 64, 4874c (1966).
- (163) J. C. Bird and R. S. Shelton, *J. Am. Pharm. Assoc., Sci. Ed.*, 39, 500 (1950).
- (164) T. J. Macek, B. A. Feller, and E. J. Hanus, *ibid.*, 39, 365 (1950).
- (165) A. Taub, I. Katz, and M. Katz, *ibid.*, 38, 119 (1949).
- (166) R. Yamamoto, I. Takahashi, and M. Harada, *J. Pharm. Soc. Jpn.*, 76, 853 (1956).
- (167) R. Yamamoto, I. Takahashi, and K. Inazu, *ibid.*, 77, 82 (1957).
- (168) G. A. Nevill, J. C. Ethier, N. F. H. Bright, and R. H. Lake, *J. Assoc. Offic. Anal. Chem.*, 54, 1200 (1971).
- (169) J. D. Mullins and T. J. Macek, *J. Am. Pharm. Assoc., Sci. Ed.*, 49, 245 (1960).
- (170) R. R. Goodall, J. Goldman, and J. Woods, *Pharm. J.*, 200, 33 (1968).
- (171) J. Dolby, B. Gunnarsson, L. Kronberg, and H. Wikner, *Pharm. Acta Helv.*, 47, 615 (1972).
- (172) V. C. Walton, M. R. Howlett, and G. B. Selzer, *J. Pharm. Sci.*, 59, 1160 (1970).
- (173) J. K. Guillory and T. Higuchi, *ibid.*, 51, 100 (1962).
- (174) N. Narasimhachari and G. R. Rao, *Hind. Antibiot. Bull.*, 4, 163 (1962); through *Chem. Abstr.*, 57, 16758b (1962).
- (175) D. Kodnja and K. Weber, *Sci. Pharm.*, 39, 34 (1971); through *Chem. Abstr.*, 75, 40339x (1971).
- (176) A. M. Nagle, E. I. Rodionovskaya, D. M. Trakhtenberg, and G. I. Kleiner, *Antibiotiki*, 12, 420 (1967); through *Chem. Abstr.*, 67, 76283p (1967).
- (177) H. Nakatani, *Yakuzogaku*, 23, 75 (1963); through *Chem. Abstr.*, 59, 12596h (1963).
- (178) L. Kiss, B. Rozondai, and T. Scholz, *Gyogyszereszet*, 8, 341 (1964); through *Chem. Abstr.*, 62, 406d (1965).
- (179) D. Stefanescu, N. Tachel, and V. Antonescu, *Farmacia (Bucharest)*, 12, 465 (1964); through *Chem. Abstr.*, 62, 1620b (1965).
- (180) M. G. Kostareva, *Antibiotiki (Moscow)*, 16, 312 (1972); through *Chem. Abstr.*, 75, 40334s (1971).
- (181) N. Tauska and S. Takino, *Yakugaku Zasshi*, 82, 329 (1962).
- (182) H. Nogami, K. Kigasawa, N. Ikari, H. Ohtani, and M. Takayama, *ibid.*, 90, 967 (1970).
- (183) I. I. Inozemtseva, D. M. Trakhtenberg, and E. S. Zinatullina, *Antibiotiki*, 19, 448 (1974); through *Chem. Abstr.*, 81, 158634s (1974).
- (184) H. Jalli and A. W. H. Daoud, *J. Fac. Med., Baghdad*, 9, 175 (1967); through *Chem. Abstr.*, 69, 54272h (1968).
- (185) F. Kubo, K. Imasaka, and A. Kaneko, *Kyoritsu Yakka Daigaku Kenkyu Nempo*, 6/7, 5 (1961/2); through *Chem. Abstr.*, 60, 375d (1964).
- (186) G. Fiesse and J. Perrin, *J. Pharm. Sci.*, 58, 599 (1969).
- (187) J. Perrin and J. Vallier, *J. Pharm. Pharmacol.*, 22, 758 (1970).
- (188) G. Zograf and I. Zarenda, *Biochem. Pharmacol.*, 15, 591 (1966).
- (189) D. D. Heard and R. W. Ashworth, *J. Pharm. Pharmacol.*, 20, 505 (1968).
- (190) A. J. Aguiar, J. E. Zelmer, and A. W. Kinkel, *J. Pharm. Sci.*, 56, 1243 (1967).
- (191) T. Higuchi, A. Michaelis, T. Tan, and A. Hurwitz, *Anal. Chem.*, 39, 979 (1967).
- (192) T. Higuchi and K. Kato, *J. Pharm. Sci.*, 55, 1080 (1966).
- (193) A. F. Michaelis and T. Higuchi, *ibid.*, 58, 201 (1969).
- (194) A. H. Fenton and M. Warren, *Pharm. J.*, 188, 5 (1962).
- (195) R. A. O'Reilly, P. M. Aggeler, and L. S. Leong, *Thromb. Diath. Haemorrhag.*, 11, 1 (1964).
- (196) W. Lowenthal, J. F. Borzelleca, and C. D. Corder, Jr., *J. Pharm. Sci.*, 59, 1353 (1970).
- (197) E. H. Dearborn, J. T. Litchfield, Jr., H. J. Eisner, J. J. Corbett, and C. W. Dunnett, *Antibiot. Med. Clin. Ther.*, 4, 627 (1957).
- (198) L. L. Kaplan, *J. Pharm. Sci.*, 54, 457 (1965).
- (199) D. A. Schlichting, *ibid.*, 51, 134 (1962).
- (200) L. E. Josselyn, C. Endicott, and J. C. Sylvester, in "Antibiotics Annual, 1954-1955," Medical Encyclopedia, New York, N.Y., 1955, pp. 279-282.
- (201) F. Neuwald and P. Aekad, *Am. J. Hosp. Pharm.*, 23, 347 (1966).
- (202) J. Gagliani, A. C. DeGraff, and H. S. Kupperman, *Int. Rev. Med. Gen. Pract. Clin.*, 167, 251 (1964).
- (203) A. E. Vivino, *J. Am. Pharm. Assoc., Sci. Ed.*, 43, 234 (1954).
- (204) J. Schlager, J. T. McGinn, and D. J. Hennessy, *Am. J. Med. Sci.*, 233, 296 (1957).
- (205) G. Hiltzenberger and I. Jaschek, *Int. J. Clin. Pharmacol., Ther. Toxicol.*, 9, 114 (1974).
- (206) R. S. Griffith and H. R. Black, *Antibiot. Chemother.*, 12, 396 (1962).
- (207) R. S. Griffith and H. R. Black, *Am. J. Med. Sci.*, 247, 69 (1964).
- (208) S. M. Bell, *Med. J. Aust.*, 2, 1280 (1971).
- (209) R. S. Griffith, *Antibiot. Med. Clin. Ther.*, 7, 320 (1960).
- (210) R. G. Wiegand and A. H. C. Chun, *J. Pharm. Sci.*, 61, 425 (1972).
- (211) S. S. Wright, E. M. Purcell, E. H. Cass, and M. Finland, *J. Lab. Clin. Med.*, 42, 417 (1953).
- (212) S. E. Budolfson, S. E. J. Hansen, and E. Rud, *Acta Pharmacol. Toxicol.*, 11, 49 (1955).
- (213) S. C. Strickland, J. M. Gylfe, and W. P. Boger, *Antibiot. Med. Clin. Ther.*, 1, 368 (1955).
- (214) L. E. Putnam, W. W. Wright, A. DeNunzio, and H. Welch, in "Antibiotics Annual, 1955-1956," Medical Encyclopedia, New York, N.Y., 1956, p. 483.
- (215) W. P. Boger and S. C. Strickland, *Antibiot. Med. Clin. Ther.*, 4, 452 (1957).
- (216) C. C. Lee, R. O. Froman, R. C. Anderson, and K. K. Chen, *Antibiot. Chemother.*, 8, 354 (1958).
- (217) W. J. Karpainen and P. Harkonen, *Scand. J. Clin. Lab. Invest.*, 8, 18 (1956).
- (218) F. B. Peck, Jr., and R. S. Griffith, in "Antibiotics Annual, 1957-1958," Medical Encyclopedia, New York, N.Y., 1958, pp. 1004-1011.
- (219) J. Colquhoun, E. C. Scorer, G. Sandler, and G. M. Wilson, *Br. Med. J.*, 1, 1451 (1957).
- (220) W. W. Wright and H. Welch, *Antibiot. Med. Clin. Ther.*, 5, 189 (1959).
- (221) M. A. Kaplan, H. L. Dickson, K. A. Hubel, and F. H. Buckwalter, *ibid.*, 4, 99 (1957).
- (222) H. Welch, W. W. Wright, and A. Kirshbaum, *ibid.*, 4, 293 (1957).

- (223) W. M. Sweeney, S. M. Hardy, A. C. Downbush, and J. M. Rueggger, *ibid.*, 4, 642 (1957).
 (224) C. Lewis, F. Stern, and J. E. Gfady, *Antimicrob. Ag. Chemother.*, 1964, 13.
 (225) J. T. McGinn, *Curr. Ther. Res. Clin. Exp.*, 7, 110 (1965).
 (226) R. A. Runkel, K. S. Kraft, G. Boast, H. Sevellus, E. Forchielli, R. Hill, R. Magoun, J. B. Szakacs, and E. Segre, *Chem. Pharm. Bull.*, 20, 1457 (1972).
 (227) H. A. Hirsch, C. V. Pryles, and M. Finland, *Am. J. Med. Sci.*, 239, 193 (1960).
 (228) S. Fürész, *Antibiot. Chemother.*, 8, 446 (1958).
 (229) K. H. Holmdahl and H. Lodin, *Acta Radiol.*, 51, 247 (1959).
 (230) K. W. Anderson, *Arch. Int. Pharmacodyn. Ther.*, 147, 171 (1964).
 (231) J. Sjögren, L. Sölvell, and I. Karlsson, *Acta Med. Scand.*, 178, 553 (1965).
 (232) J. S. Heron, *Can. Med. Assoc. J.*, 72, 302 (1955).
 (233) E. W. Rogers, *Br. Med. J.*, 2, 1576 (1958).
 (234) A. C. Glasser and R. M. Doughty, *J. Pharm. Sci.*, 54, 1055 (1965).
 (235) O. Wulff, *ibid.*, 54, 1058 (1965).
 (236) O. W. Barlow and D. R. Climenko, *J. Am. Med. Assoc.*, 116, 282 (1941).
 (237) B. E. Rodda, N. E. Scholz, C. M. Gruber, Jr., and R. L. Wolen, *Toxicol. Appl. Pharmacol.*, 19, 554 (1971).
 (238) F. H. S. Curd and D. G. Davey, *Br. J. Pharmacol.*, 5, 25 (1950).
 (239) F. R. Sidell, F. A. Groff, and A. Kaminski, *J. Pharm. Sci.*, 61, 1136 (1972).
 (240) R. R. Levine and G. M. Steinberg, *Nature*, 209, 269 (1966).
 (241) A. A. Kondrizer, P. Zvirblis, A. Goodman, and S. H. Paplanus, *J. Pharm. Sci.*, 57, 1142 (1968).
 (242) G. M. Irwin, H. B. Kostenbauder, L. W. Dittert, R. Staples, A. Misher, and J. V. Swintosky, *ibid.*, 58, 313 (1969).
 (243) B. E. Cabana, L. E. Willhite, and M. E. Bierwagen, *Antimicrob. Ag. Chemother.*, 1969, 35.
 (244) J. B. Hammond and R. S. Griffith, *Clin. Pharmacol. Ther.*, 2, 308 (1961).
 (245) S. H. Wan, P. J. Pentikainen, and D. L. Azarnoff, *J. Pharm. Sci.*, 63, 708 (1974).
 (246) S. H. Wan, P. J. Pentikainen, and D. L. Azarnoff, *J. Pharmacokin. Biopharm.*, 2, 1 (1974).
 (247) R. V. Cohen, L. Malthan, and C. J. D. Zafaronis, *Dis. Chest*, 30, 418 (1956).
 (248) E. L. Foltz and H. Wallick, *Antimicrob. Ag. Chemother.*, 1969, 316.
 (249) E. L. Foltz, H. Wallick, and C. Rosenblum, *ibid.*, 1969, 322.
 (250) S. F. Pong and C. L. Huang, *J. Pharm. Sci.*, 63, 1527 (1974).
 (251) J. T. Doluisio, J. C. LaPlana, and L. W. Dittert, *ibid.*, 60, 715 (1971).
 (252) A. Rubin, B. E. Rodda, P. Warrick, A. Ridolfo, and C. M. Gruber, *ibid.*, 60, 1797 (1971).
 (253) N. Watzman, A. A. Manian, H. Barry, III, and J. P. Buckley, *ibid.*, 57, 2058 (1968).
 (254) M. Jain, E. Bakutis, and J. C. Krantz, Jr., *Am. J. Pharm.*, 145, 174 (1973).
 (255) S. M. Viscia and D. C. Brodie, *J. Am. Pharm. Assoc., Sci. Ed.*, 43, 52 (1954).
 (256) G. R. Goetichius and C. A. Lawrence, *J. Lab. Clin. Med.*, 29, 134 (1944).
 (257) *ibid.*, 30, 145 (1945).
 (258) H. Dalili and J. Adriani, *Clin. Pharmacol. Ther.*, 12, 913 (1971).
 (259) O. Bodansky and W. Modell, *J. Pharmacol. Exp. Ther.*, 73, 51 (1941).
 (260) G. V. Rossi, T. S. Miya, and L. D. Edwards, *J. Am. Pharm. Assoc., Sci. Ed.*, 45, 47 (1956).
 (261) L. W. Morgan, D. H. Cronk, and R. P. Knott, *J. Pharm. Sci.*, 58, 942 (1969).
 (262) P. E. Thompson, A. Bayles, P. McClay, and J. E. Meisenhelder, *J. Parasitol.*, 51, 817 (1965).
 (263) J. W. Crook, A. I. Goodman, J. L. Colbourn, P. Zvirblis, F. W. Oberst, and J. H. Wills, *J. Pharmacol. Exp. Ther.*, 126, 397 (1962).
 (264) D. R. Davies, A. L. Green, and G. L. Willey, *Br. J. Pharmacol.*, 14, 5 (1959).
 (265) J. F. O'Leary, A. M. Kunkel, and A. H. Jones, *J. Pharmacol. Exp. Ther.*, 132, 50 (1961).
 (266) D. M. Anderson and W. G. Smith, *J. Pharm. Pharmacol.*, 13, 393 (1961).
 (267) R. S. H. Finney and A. L. Tarnoky, *ibid.*, 12, 49 (1960).
 (268) G. H. Copper, D. M. Green, R. L. Rickard, and P. B. Thompson, *ibid.*, 23, 682 (1971).
 (269) Y. Kase, T. Yuzono, T. Yamasaki, T. Yamada, S. Ito, M. Tamiya, and I. Kondo, *Chem. Pharm. Bull.*, 7, 372 (1959).
 (270) A. Agren, *Acta Pharm. Suec.*, 5, 37 (1968).
 (271) L. Saunders, *J. Pharm. Pharmacol.*, 15, 348 (1963).
 (272) C. R. Willis, Jr., and G. S. Banker, *J. Pharm. Sci.*, 57, 1598 (1968).
 (273) R. Brendel, V. Swayne, R. Preston, J. M. Bellef, and G. J. Martin, *J. Am. Pharm. Assoc., Sci. Ed.*, 42, 123 (1953).
 (274) J. Couquale, P. Bastide, J. B. Le Polles, and A. Paturet, *C. R. Soc. Biol.*, 164, 329 (1970); through *Chem. Abstr.*, 74, 21748t (1971).
 (275) "The Pharmacological Basis of Therapeutics," 3rd ed., L. S. Goodman and A. Gilman, Eds., Macmillan, New York, N.Y., 1965, p. 741 and chaps. 37 and 38.
 (276) M. Schou, *Acta Pharmacol. Toxicol.*, 15, 70 (1958).
 (277) G. Torosian, K. F. Finger, and R. B. Stewart, *Am. J. Hosp. Pharm.*, 30, 716 (1973).
 (278) M. W. P. Carney, *Lancet*, 2, 523 (1971).
 (279) J. A. Ewing and W. J. Grant, *South. Med. J.*, 58, 148 (1965).
 (280) R. B. Stewart, *Am. J. Hosp. Pharm.*, 30, 85 (1973).
 (281) J. L. Emerson, W. R. Gibson, and R. C. Anderson, *Toxicol. Appl. Pharmacol.*, 19, 445 (1971).
 (282) R. I. Eilin and J. H. Wills, *J. Pharm. Sci.*, 53, 1143 (1964).
 (283) P. H. N. Wood, E. A. Harvey-Smith, and A. St. J. Dixon, *Br. Med. J.*, 1, 669 (1962).
 (284) D. P. Bonner, W. Mechliniski, and C. P. Schaffner, *J. Antibiot. (Tokyo)*, 25, 261 (1972).
 (285) E. K. Marshall, Jr., A. C. Bratton, and J. T. Litchfield, Jr., *Science*, 88, 597 (1938).
 (286) H. J. Deuel, Jr., R. Alfin-Slater, C. S. Weil, and H. F. Smyth, Jr., *Food Res.*, 19, 1 (1954).
 (287) R. C. Anderson, P. N. Harris, and K. K. Chen, *J. Am. Pharm. Assoc., Sci. Ed.*, 41, 555 (1952).
 (288) *ibid.*, 44, 199 (1955).
 (289) R. C. Anderson, C. C. Lee, H. M. Worth, and P. N. Harris, *ibid.*, 45, 623 (1959).
 (290) H. V. Kuder, *Clin. Pharmacol. Ther.*, 1, 604 (1960).
 (291) D. N. S. Kerr and S. Davidson, *Lancet*, 2, 489 (1958).
 (292) L. C. Weaver, R. W. Gardier, V. B. Robinson, and C. A. Bunde, *Am. J. Med. Sci.*, 241, 296 (1961).
 (293) K. J. Child, B. Davis, M. G. Dodds, and E. G. Tomich, *J. Pharm. Pharmacol.*, 16, 65 (1964).
 (294) R. J. Schachter, E. T. Kimura, G. M. Nowarra, and J. Mestern, *Int. Rec. Med. Gen. Pract. Clin.*, 167, 248 (1954).

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Synthesis and Ligand Binding of Tropane Ring Analogues of Paroxetine

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(3*S*,4*R*)-4-(4-Fluorophenyl)-3-[[3,4-(methylenedioxy)phenoxy]methyl]piperidine [(3*S*,9*R*)-3, paroxetine] is a selective serotonin reuptake inhibitor (SSRI) used as an antidepressant in humans. In previous studies, we reported that certain (1*R*)-3β-(substituted phenyl)nortropane-2β-carboxylic acid methyl esters (2a) exhibited high affinity and reasonable selectivity for the serotonin transporter (5-HTT). The major structural differences between 2a and (3*S*,4*R*)-3 are that 2a possesses a different absolute stereochemistry and has an ethylene bridge not present in 3. In addition, 2a possesses a carbomethoxy substituent adjacent to the aryl ring, whereas (3*S*,4*R*)-3 contains a [3,4-(methylenedioxy)phenoxy]methyl group. In this study, we present the synthesis and biological evaluations of six of the possible eight isomers of 3-(4-fluorophenyl)-2-[[3,4-(methylenedioxy)phenoxy]methyl]nortropane (4). The data for inhibition of [³H]paroxetine binding show that (1*R*)-2β,3α-4c, which has the same stereochemistry as paroxetine, has the highest affinity at the 5-HTT. Strikingly, the most potent compounds for inhibition of [³H]WIN-35,428 binding were not the (1*R*)-2β,3β-isomers but rather (1*R*)-2β,3α-4c and (1*S*)-2β,3α-4f. Conformational analyses show that these isomers exist in a flattened boat conformation with pseudoequatorial substituents. Thus, the binding data show that this conformation is recognized by the DAT-associated binding site and also suggest that this conformation of paroxetine is recognized by the 5-HTT-associated binding site.

Much research has been devoted to gaining an understanding of the pharmacological action of cocaine (1).^{1,2} Considerable evidence suggests that the reinforcing or addicting properties of cocaine are due to its ability to inhibit dopamine uptake in the limbic brain area.³⁻⁷ Similar to dopamine, the reuptake of previously released serotonin plays the major role in regulating the synaptic availability of serotonin and thus serotonergic neurotransmission. Numerous neurochemical and behavioral outcomes are known to result from the treatment of animals with serotonin uptake inhibitors. For example, neuroendocrine, anticonvulsant, and analgesic effects, as well as changes in food intake and alcohol consumption, are observed.⁸ In addition, evidence suggests that inhibition of serotonin reuptake modulates the reinforcing properties of cocaine.⁹⁻¹³ Even though the importance of the serotonin transporter in mediating the neurochemical and behavioral actions of cocaine is now recognized, the molecular mechanism of action and regulation of this transporter are not well understood.

We, and others, have reported that certain (1*R*)-3β-(substituted phenyl)nortropanes possessing 2β-carboxylic acid ester groups (2a)¹⁴ and 2β-ketone groups (2b)¹⁵ exhibit high potency at, and reasonable selectivity for,

the serotonin transporter relative to the dopamine and norepinephrine transporters. These compounds share structural features with the 4-(4-fluorophenyl)-3-[[3,4-(methylenedioxy)phenoxy]methyl]piperidine (3) class of serotonin uptake inhibitors. The serotonin uptake inhibitor paroxetine, which is (3*S*,4*R*)-3, has proven to be an effective antidepressant in humans.⁶ Both classes of compounds, 2 and 3, contain a piperidine ring with an aryl moiety in a similar position. The major structural differences between 2a and (3*S*,4*R*)-3 are that (a) in 2a the substituent β to the amino group is a carbomethoxy group whereas the analogous position in 3 is occupied by a [3,4-(methylenedioxy)phenoxy]methyl group, (b) the substituents in 2a are *cis* to each other while they are in *trans* orientation in (3*S*,4*R*)-3, and (c) in the nortropane 2a the positions α to the amino group are ethylene bridged. To gain a better understanding of the important structural features required by the nortropane class of compounds for good affinity and selectivity at serotonin transporters, we have prepared and evaluated the transporter binding properties of six of the possible eight isomers of 3-(4-fluorophenyl)-2-[[3,4-(methylenedioxy)phenoxy]methyl]nortropane (4).

Synthesis

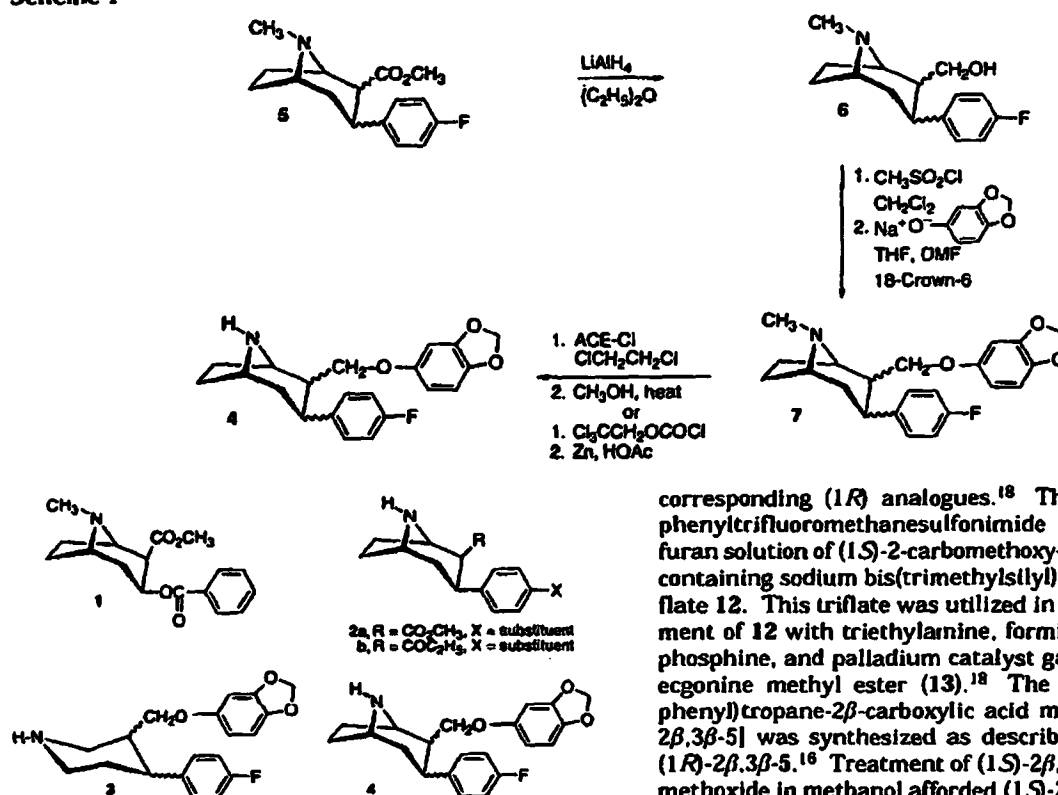
Scheme 1 outlines the general synthesis used to prepare the nortropane analogues 4. Lithium aluminum hydride reduction of the appropriate 3-(4-fluorophenyl)tropane-2-carboxylic acid methyl ester isomer 5 gives the 2-(hydroxymethyl)tropane 6. Treatment of 6 with methanesulfonyl chloride afforded the 2-hydroxymethyl mesylate which, when heated in a tetrahydro-

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Scheme 1



furan:DMF (5:1) mixture containing 18-crown-6 with the sodium salt of sesamol, yields 3-(4-fluorophenyl)-2-[[3,4-(methylenedioxy)phenoxy]methyl]tropane 7. N-Demethylation using 1-chloroethyl chloroformate (ACE-Cl) in ethylene dichloride followed by treatment with methanol, or using trichloroethyl chloroformate followed by treatment with zinc, affords the nortropane analogues 4.

The synthesis used to prepare three of the 3-(4-fluorophenyl)tropane-2-carboxylic acid methyl esters (5) (possessing the (1*R*)-configuration) is shown in Scheme 2. The addition of (*p*-fluorophenyl)magnesium bromide to anhydroecgonine methyl ester (8), which was derived from (–)-cocaine as previously reported, gives (1*R*)-2β,3β-5.¹⁶ Isomerization of (1*R*)-2β,3β-5 with sodium methoxide in methanol affords (1*R*)-2α,3β-5. The addition of (*p*-fluorophenyl)lithium to the α,β-unsaturated 1,2,4-oxadiazole 9 gives the *cis*-addition product 10. Subjection of 10 to reduction with nickel boride in methanol results in conversion of the oxadiazole to a methyl ester and effects complete isomerization at the 2-position to give (1*R*)-2β,3α-5.¹⁷ We had hoped to prepare (1*R*)-2α,3α-5 by appropriate modification of this reductive opening of the oxadiazole ring to the 2β-methyl ester. However, all attempts to effect this conversion resulted in isomerization of the 2α group to the 2β-isomer.

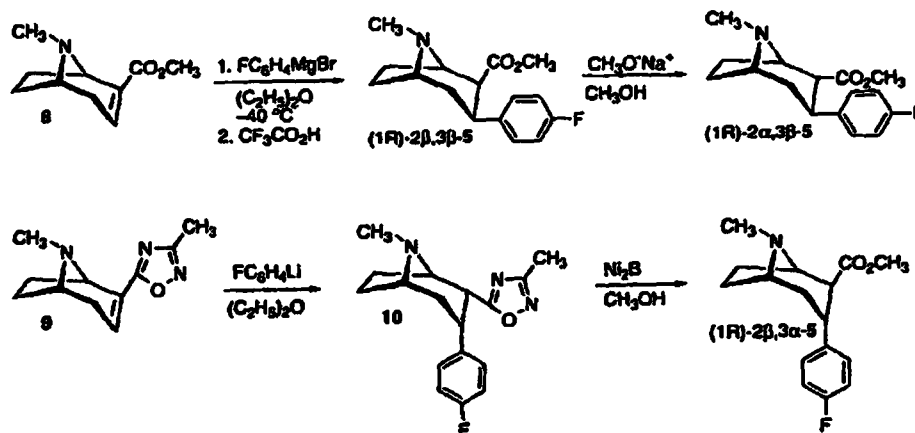
Three of the (1*S*) isomers of 3-(4-fluorophenyl)tropane-2-carboxylic acid methyl esters were prepared by routes given in Scheme 3. The synthesis of 12–14, (1*S*)-2β,3α-5, and (1*S*)-2β,3β-5 is analogous to that presented in a preliminary communication for the synthesis of the

corresponding (1*R*) analogues.¹⁸ The addition of *N*-phenyltrifluoromethanesulfonimide to a tetrahydrofuran solution of (1*S*)-2-carbomethoxy-3-tropinone (11)¹⁹ containing sodium bis(trimethylsilyl)amide yielded triflate 12. This triflate was utilized in two ways. Treatment of 12 with triethylamine, formic acid, triphenylphosphine, and palladium catalyst gave (1*S*)-anhydroecgonine methyl ester (13).¹⁸ The (1*S*)-3β-(4-fluorophenyl)tropane-2β-carboxylic acid methyl ester [(1*S*)-2β,3β-5] was synthesized as described previously for (1*R*)-2β,3β-5.¹⁶ Treatment of (1*S*)-2β,3β-5 with sodium methoxide in methanol afforded (1*S*)-2α,3β-5. Reaction of 12 with (4-fluorophenyl)boronic acid in refluxing diethoxymethane using tris(dibenzylideneacetone)dipalladium(0) as catalyst, followed by chromatographic purification, gave the (4-fluorophenyl)tropene 14.¹⁸ Reduction of 14 with samarium (II) iodide at –78 °C using methanol as the proton source, followed by quenching with trifluoroacetic acid at 0 °C, gave a mixture of (1*S*)-3α-(4-fluorophenyl)-2β-carboxylic acid methyl ester [(1*S*)-2β,3α-5] as the major product and (1*S*)-3β-(4-fluorophenyl)-2β-carboxylic acid methyl ester [(1*S*)-2β,3β-5], which were separated by column chromatography.

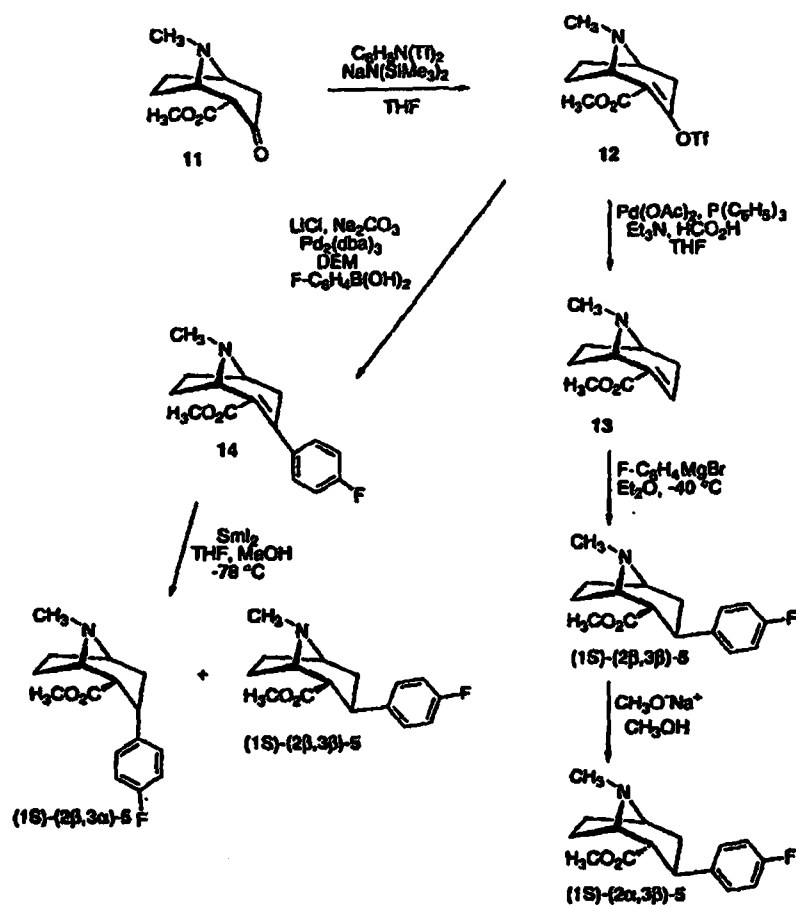
Specific structural and stereochemical assignments were made for the compounds (1*R*)-7 and (1*R*)-4 using 1D ¹H and ¹³C NMR spectra and 2D COSY,^{20,21} NOESY,²² and HMQC²³ spectra. Thus, the presence of a large (10.6 Hz) coupling in the pattern of H3 in the ¹H NMR spectrum of (1*R*)-2β,3β-7a requires H3 to be axial, showing that the aryl substituent at C3 must occupy the equatorial (β) position. Similarly, the magnitude of *J*_{2,3} (5.8 Hz), which is characteristic of axial–equatorial coupling, taken together with the axial nature of H3, mandates that H2 must be equatorial, confirming the β-position of the C2 substituent. The observed NOESY interaction between H3 and H6 further confirms the axial configuration of H3 and requires that (1*R*)-2β,3β-7a be in the chair conformation. Similar arguments confirm the structural assignment of 2β,3β-4a. The observation of two large coupling constants (*J* = 12.0 Hz) for H3, which are both (COSY) associated with H2 and H4β, characterize the structure of 2α,3β-7b. The observed NOESY interactions of H2 with H4β and of H3 with H6 provide further evidence for the 2α,3β-stereochemistry and show that the compound is

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Scheme 2



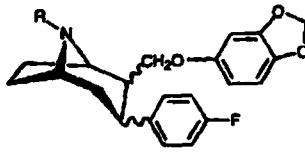
Scheme 3



in the chair conformation. The structure of the *N*-nor analogue 2 α ,3 β -4b is deduced from similar considerations. The compound 2 β ,3 α -7c also exhibits two large couplings and one smaller coupling for H3. The large couplings ($J = 10.8$ and 10.3 Hz) are associated with H2 and H4 α , respectively, while the smaller coupling ($J = 8.3$ Hz) is associated with H4 β . In addition, the NOESY spectrum shows an interaction between H2 and H4 α . These observations cannot be reconciled with a chair conformation for this compound. Since the struc-

tures of the 3 β isomers are definite, this isomer must possess a 3 α substituent, i.e., H3 must be equatorial. However, the two large coupling constants between H3 and its geminal neighbors are inconsistent with dihedral angles of $\sim 60^\circ$, which are associated with equatorial-equatorial or equatorial-axial protons in a chair conformation. Therefore, the preferred conformation for this compound must be boatlike. This observation is supported by molecular modeling where the global energy minimum conformation was found to be a

Table 1. Comparison of Transporter Binding Potencies of the Isomers of 4 and 7



compd	sterenchemistry			IC ₅₀ (nM) ^a				
	R	2	3	5-HT [³ H]Paroxetine	DA [³ H]WIN 35,428	NE [³ H]Nisoxetine	DA/5-HT ratio ^b	NE/5-HT ratio ^b
paroxetine				0.28 ± 0.02	623 ± 25	535 ± 15	2230	1910
(1 <i>R</i>)-7a	CH ₃	β	β	294 ± 18	308 ± 20	5300 ± 450	1.0	18
(1 <i>R</i>)-4a	H	β	β	480 ± 21	835 ± 90	37400 ± 1400	1.7	78
(1 <i>R</i>)-7b	CH ₃	α	β	52.9 ± 3.6	172 ± 8.8	26600 ± 1200	3.3	500
(1 <i>R</i>)-4b	H	α	β	90 ± 3.4	142 ± 13	2500 ± 250	1.6	28
(1 <i>R</i>)-7c	CH ₃	β	α	422 ± 16	3.01 ± 0.2	123 ± 9.5	0.007	0.29
(1 <i>R</i>)-4c	H	β	α	5.62 ± 0.2	3.86 ± 0.2	14.4 ± 1.3	0.7	2.6
(1 <i>S</i>)-7d	CH ₃	β	β	88.1 ± 2.8	1050 ± 45	27600 ± 1100	12	310
(1 <i>S</i>)-4d	H	β	β	424 ± 15	1210 ± 33	17300 ± 1800	2.9	41
(1 <i>S</i>)-7e	CH ₃	α	β	447 ± 47	1500 ± 74	2,916 ± 1950	32	640
(1 <i>S</i>)-4e	H	α	β	55.8 ± 5.73	27.6 ± 2.4	1690 ± 150	0.49	30
(1 <i>S</i>)-7f	CH ₃	β	α	178 ± 13	298 ± 17	12400 ± 720	1.7	70
(1 <i>S</i>)-4f	H	β	α	19 ± 1.8	407 ± 33	1990 ± 176	21	100

^a Data are mean ± standard error of three or four experiments with triplicate values at each concentration. ^b DA/5-HT and NE/5-HT are ratios of IC₅₀ values.

flattened boat. This conformation is preferred over the lowest energy chair conformation by >3 kcal/mol. The similarity of the NMR parameters of the *N*-nor analogue 2β,3α-4 indicates that it exists in a similar conformation.

Ligand Binding Studies

IC₅₀ values at the DA, NE, and 5HT transporters represent inhibition of 0.5 nM [³H]WIN 35,428, 0.5 nM [³H]nisoxetine, and 0.2 nM [³H]paroxetine binding, respectively, and were determined as previously described.²⁴ The IC₅₀ values for paroxetine, the six nortropane analogues 4, and six *N*-methyl analogues 7 are listed in Table 1.

Discussion

Cocaine (1) is an inhibitor of the neuronal transport of norepinephrine (NE), dopamine (DA), and serotonin (5-HT) at roughly similar concentrations, i.e., with *K*_i's between 220 and 310 nM.²⁵ Biochemical binding studies indicate slight DA selectivity.^{26,27} In recent years, structure-activity relationship studies of cocaine analogues for binding at monoamine transporters, particularly at the dopamine transporter, have been explored,^{28–32} and some structural modifications that result in selectivity for the dopamine transporter over the norepinephrine and serotonin transporters have been reported.^{33–35} In the Introduction section, we pointed out that serotonergic activity may affect the reinforcing effects of cocaine. Since the *in vitro* potency of cocaine (1) to inhibit serotonin reuptake is essentially identical with its potency to inhibit dopamine reuptake, some of the pharmacological properties of cocaine might be due to its inhibition of reuptake of serotonin. Even though the importance of the serotonin transporter in mediating the neurochemical and behavioral actions of

cocaine is now recognized, the biochemical mechanism of action and regulation of this transporter is not well understood.

The nortropane derivatives 4 were designed to be similar to known serotonin uptake inhibitors 3. Both classes of compounds contain a piperidine ring with a 4-fluorophenyl group and a [3,4-(methylenedioxy)phenoxy]methyl moiety in similar positions on the ring. The eight possible isomers of 4 are listed in Figure 1. The major structural difference between 3 and 4 is the presence of an ethylene bridge, not present in 3, which leads to reduced conformational heterogeneity. For example, whereas the piperidine ring in the (3*S*,4*R*)-isomer of 3, which is paroxetine, may interconvert between the chair conformations C_{aa} and C_{ee}, and the boat conformation B_{ee} and B_{aa}, the piperidine ring in the analogous isomer of 4 can only interconvert between the chair and boat conformations (see Figure 2) but not between two chair conformations. In the series of analogues 3, the potency of paroxetine, i.e., the *trans*-(+)-3*S*,4*R* isomer, exceeds that of the other isomers by factors of 60–160.³⁶ This isomer may exist in either a diequatorial (C_{ee}) or a diaxial (C_{aa}) chair conformation, as well as in boat conformations B_{aa} and B_{ee}, all of which are interconvertible. The chair conformations C_{aa} and C_{ee} are mimicked by the isomers (1*R*)-2β,3α-4c and (1*S*)-2α,3β-4e, respectively, each of which can adopt a boat conformation, but which are not interconvertible. Therefore, it would be expected that, if conformation C_{ee} were responsible for the high potency of paroxetine, (1*S*)-2α,3β-4e would possess high potency to inhibit [³H]-paroxetine binding. Conversely, if conformation C_{aa} were the potent form of paroxetine, (1*R*)-2β,3α-4c would exhibit high potency. However, since the chair conformation of (1*R*)-2β,3α-4c possesses two axial substituents, the chair may not be the energy minimum conformation for this compound. Thus, we had found that although the chair is the preferred conformation of allococaine, the (2α,3α)-diaxial isomer of cocaine, boat

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Tropane Ring Analogues of Paroxetine

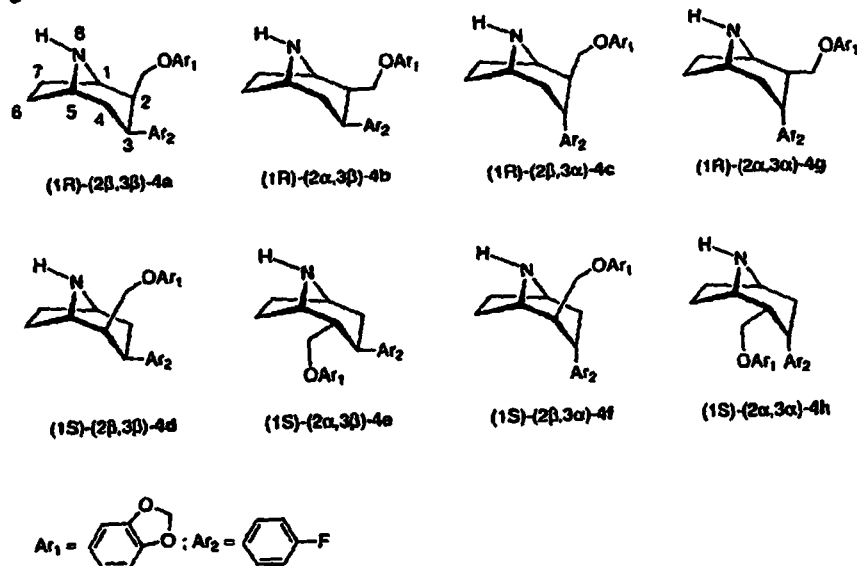


Figure 1. Isomers of 4.

conformations were preferred for diaxial analogues of 3-aryltropane-2-carboxylates.^{17,37}

Binding affinities at the 5-HT transporter, determined by inhibition of [³H]paroxetine binding (Table 1), show that the diequatorial isomers, (1*R*)-2α,3β-4b and (1*S*)-2α,3β-4e, are substantially less potent than the diaxial isomers, (1*R*)-2β,3α-4c and (1*S*)-2β,3α-4f, demonstrating that conformation C_{eq}, which may well be the low-energy conformation of paroxetine, is not well accommodated by the receptor at the 5-HT transporter. The most potent of the isomers is (1*R*)-2β,3α-4c, suggesting that its conformation best mimics the conformation of paroxetine which is recognized by the receptor. Since the preferred conformation of the piperidine ring of (1*R*)-2β,3α-4c is a substantially flattened boat, it appears that a relatively flat conformation may be required for paroxetine to bind the receptor at the 5-HT transporter. Such a conformation could resemble both the (1*R*)- and the (1*S*)-isomers of 2β,3α-4c, and indeed, the potency of (1*R*)-2β,3α-4c is only 3.4 times greater than that of the (1*S*)-isomer. The more than 1 order of magnitude lower potency of (1*R*)-2β,3α-4c (IC₅₀ = 5.62 nM) relative to paroxetine (IC₅₀ = 0.28 nM) may be due to steric inhibition of binding by the ethylene bridge in (1*R*)-2β,3α-4c.

The fact that several 3β-(para-substituted phenyl)-tropane-2β-carboxylic acid methyl esters, which possess the natural (1*R*)-cocaine stereochemistry, have high affinity at the 5-HT site³⁸ suggested that (1*R*)-2β,3β-4a (i.e., an analogue of the *cis* isomer of paroxetine) might also possess high affinity at the 5-HT transporter. Additionally, it had been shown that N-demethylation of 3β-(*p*-fluorophenyl)-2β-carbomethoxytropane (WIN 35,428) to give the *N*-nor analogue (RTI-142) resulted in increased affinity at the DA, 5-HT, and NE transporters.³⁹ The data in the Table indicate that these observations do not generalize to this set of compounds. In other words, N-demethylation leads to increased potency at 5-HT transporters only for the isomers which preferentially exist in a boat conformation; the effect on potency at DA and NE transporters appears to be random. In addition, it was surprising

to note that both (1*R*)-2β,3β-4a and (1*S*)-2β,3β-4d had low affinity for all three transporters. The low affinity of (1*R*)-2β,3β-7a and its *N*-nor analogue (1*R*)-2β,3β-4a at the DAT relative to the (1*R*)-2β,3α-isomers is particularly striking. Thus, since the ratio of potencies to inhibit radioligand binding at the DAT for cocaine, which has the (1*R*)-2β,3β configuration, to allococaine, which has (1*R*)-2β,3α configuration, is 59,⁴⁰ it might have been expected that the potency of the (1*R*)-2β,3β-7a and (1*R*)-2β,3β-4a would exceed that of their (1*R*)-2β,3α-isomers. Instead, the ratio is 0.01 for (1*R*)-2β,3β-7a to (1*R*)-2β,3α-7c and 0.005 for (1*R*)-2β,3β-4a to (1*R*)-2β,3α-4c. This unexpected result may be attributable to the flattened boat conformation of (1*R*)-2β,3α-7c and (1*R*)-2β,3α-4c. A less striking but similar situation had been observed for the isomeric 3-phenyl-2-(3-methyl-1,2,4-oxadiazol-5-yl)tropanes, where the potency of the 2β,3α isomer, which exists in a boat conformation, was only slightly lower (1.48) than that of the 2β,3β isomer, which exists in a chair conformation.³⁷

Conclusions

Six of the possible eight stereoisomers of 3-(4-fluorophenyl)-2-[[3,4-(methylenedioxy)phenoxy]methyl]-nortropane (4) have been prepared as analogues of paroxetine. Ligand binding data show that (1*R*)-2β,3α-4c, which is one of the isomers that has the same relative stereochemistry as paroxetine, has the highest affinity for the 5-HT transporter. Since this isomer exists in a flattened boat conformation with pseudo-equatorial substituents, it appears that a flattened boat conformation of paroxetine is recognized by the binding site at the 5-HT transporter. The order of magnitude lower potency of (1*S*)-2α,3β-4e, which is the other isomer that has the same relative stereochemistry as paroxetine, confirms that a chair conformation with two equatorial substituents is not recognized by the 5-HT transporter-associated receptor. The good affinity of (1*R*)-2β,3α-4c and (1*R*)-2β,3α-7c at the DA transporter suggests that tropane analogues which exist in a flat-

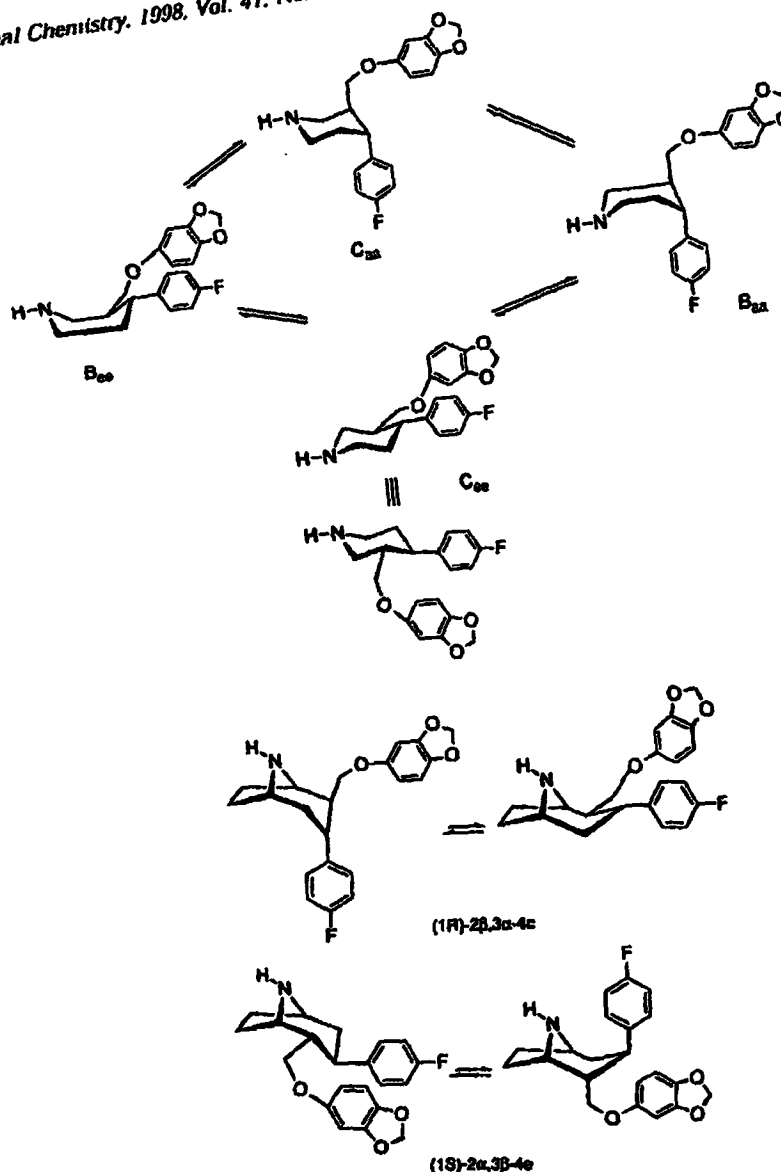


Figure 2. Chair and boat conformations.

tened boat conformation with pseudoequatorial substituents are well recognized by the DAT-associated binding site.

Experimental Section

Melting points were determined on a Thomas-Hoover capillary tube apparatus. All optical rotations were determined at the sodium D line using a Rudolph Research Autopol III polarimeter (1 dm cell). Thin-layer chromatography was carried out on Whatman silica gel 60 TLC plates, and flash chromatography was conducted on silica gel 60 (230–400 mesh). Visualization was accomplished under UV or in an iodine chamber. Microanalyses were carried out by Atlantic Microlab, Inc. Tropinone was purchased from Lancaster Synthesis, Inc., and samarium iodide was from Fluka Chemical Corp. All other chemicals were purchased from Aldrich Chemical Co, Inc. THF and ether were freshly distilled from sodium benzophenone. All other reagents were used without further purification.

Nuclear Magnetic Resonance Studies. Routine NMR spectra were obtained on a Bruker AM-250 spectrometer. COSY, NOESY, and HMQC spectra were recorded on a Bruker

AMX-500 spectrometer operating at 500.13 MHz for ^1H using a Bruker 5 mm inverse detect broadband probe. The double quantum filtered phase sensitive COSY²¹ and NOESY²² were acquired as 1024 × 512 data points with a spectral width of 4800 Hz in both dimensions. The data were apodized with a squared sine function and zero filled to 2K × 2K data points prior to Fourier transformation. NOESY spectra were obtained with a 1200 ms mixing time and a recycle delay of 4 s. Heteronuclear multiple quantum correlation (HMQC)²³ spectra were acquired as 1024 × 256 data points with a spectral width of 4800 Hz in F2 and 24 375 Hz in F1. An average coupling constant of 145 Hz was used to optimize $1/2J_{\text{CH}}$ delays. The data were apodized with a squared sine function and zero filled to 2048 × 512 data points prior to Fourier transformation.

Molecular Modeling Studies. Molecular modeling was performed on a SGI O2 using Sybyl 6.3⁴¹ and Spartan.⁴² Minimum energy structures were obtained using the simulated annealing module in Sybyl. For each structure, 50 cycles were calculated with a simulated temperature of 500 K for 500 fs and then annealed to 200 K for 500 fs with an exponential ramping function. The overall boat or chair conformation was maintained during the annealing procedure by placing a

penalty function on the N-C3 torsional angle with an equilibrium value of 0° for the boat conformation and 65° for the chair conformation. The lowest energy structures for each conformation were transferred to Spartan where the structures were further optimized using MM3; then the heats of formation were obtained from semiempirical (AM1) quantum mechanics calculations.

General Synthesis of 3-(4-Fluorophenyl)-2-(hydroxymethyl)tropane (6). A solution of 5 (3.0 mmol) in 10 mL of Et₂O was added dropwise to a cooled slurry (0 °C) of lithium aluminum hydride (5.0 mmol) in 20 mL of anhydrous Et₂O. The reaction mixture was stirred at room temperature for 2 h and then cooled to 0 °C and quenched with NH₄Cl (~3 mL). Water was added, and the layers were separated. The aqueous layer was extracted with Et₂O. The organic layers were combined, and the solvent was removed to afford a white solid which was recrystallized from hexanes or EtOAc. Results from each isomer are described in the following experiments.

(1*R*)-3β-(4-Fluorophenyl)-2β-(hydroxymethyl)tropane [(1*R*)-2β,3β-6]. Recrystallization from hexanes gave 0.745 g (83%) of white solid: mp 75–78 °C; [α]_D²⁰ –59.8° (c 0.5, CHCl₃); ¹H NMR (CDCl₃) δ 1.46 (m, 1H), 1.58–1.67 (m, 1H), 1.72 (s, 1H), 1.75 (s, 1H), 2.16 (m, 2H), 2.28 (s, 3H), 2.50 (m, 1H), 3.07 (m, 1H), 3.35 (m, 2H), 3.46 (m, 1H), 3.75 (m, 1H), 7.01 (m, 2H), 7.32 (m, 2H). Anal. (C₁₅H₂₀FNO) C, H, N.

(1*R*)-3β-(4-Fluorophenyl)-2α-(hydroxymethyl)tropane [(1*R*)-2α,3β-6]. Recrystallization from EtOAc gave 0.494 g (79%) of white solid: mp 174–176 °C; [α]_D²⁰ +26.3° (c 0.62, CHCl₃); ¹H NMR (CDCl₃) δ 1.54–1.62 (m, 2H), 1.70–2.22 (m, 6H), 2.27–2.35 (m, 1H), 2.35 (s, 3H), 3.20–3.41 (m, 4H), 6.96 (m, 2H), 7.18 (m, 2H); ¹³C NMR (CDCl₃) δ 162.33 (d), 139.21, 128.77, 128.64, 115.08, 114.74, 62.41, 61.43, 48.58, 40.84, 40.59, 37.19, 25.48, 21.26. Anal. (C₁₅H₂₀FNO) C, H, N. The alcohol was converted to the D-tartrate salt. Recrystallization from MeOH/Et₂O gave a white hygroscopic powder: mp 89 °C (fusion); ¹H NMR (CD₃OD) δ 1.88–2.39 (m, 7H), 2.72 (m, 1H), 2.87 (s, 3H), 3.25 (dd, 2H), 3.96 (m, 1H), 4.07 (m, 1H), 7.05 (m, 2H), 7.31 (m, 2H); [α]_D²⁵ +3.5° (c 0.20, CH₃OH). Anal. (C₁₆H₂₄FNO₇) C, H, N.

(1*R*)-3α-(4-Fluorophenyl)-2β-(hydroxymethyl)tropane [(1*R*)-2β,3α-6]. Recrystallization from hexanes gave 0.681 g (64%, two steps from oxadiazole 10) of white solid: mp 83–84 °C; ¹H NMR (CDCl₃) δ 1.43–1.56 (m, 2H), 1.74 (m, 1H), 1.84 (m, 1H), 2.01–2.13 (m, 2H), 2.23 (s, 3H), 2.46 (m, 1H), 2.95 (m, 1H), 3.24 (m, 2H), 3.64 (m, 1H), 3.83 (m, 1H), 6.96 (m, 2H), 7.24 (m, 2H); ¹³C NMR (CDCl₃) δ 163.27 (d), 142.79, 128.66, 128.54, 115.09, 114.75, 69.11, 65.21, 62.07, 49.62, 40.88, 37.82, 35.53, 26.95, 26.53; [α]_D²⁰ –41.9° (c 0.31, CHCl₃). Anal. (C₁₅H₂₀FNO) C, H, N. The product was converted to the D-tartrate salt. Recrystallization from (CH₃)₂CHOH/Et₂O gave a hygroscopic off-white solid: mp 79 °C (fusion); ¹H NMR (CD₃OD) δ 1.86 (m, 1H), 2.02–2.13 (m, 3H), 2.30–2.72 (m, 3H), 2.78 (s, 3H), 3.01 (m, 1H), 3.51 (m, 2H), 3.88 (m, 1H), 7.06 (m, 2H), 7.35 (m, 2H); [α]_D²⁰ –24.0° (c 0.48, CH₃OH). Anal. (C₁₆H₂₄FNO₇·0.5 H₂O) C, H, N.

(1*S*)-3β-(4-Fluorophenyl)-2β-(hydroxymethyl)tropane [(1*S*)-2β,3β-6]. Recrystallization from hexanes gave 1.18 g (70%) of white solid: mp 77–79 °C; ¹H NMR (CDCl₃) δ 1.46 (m, 1H), 1.67–1.58 (m, 1H), 1.72 (s, 1H), 1.75 (s, 1H), 2.16 (m, 2H), 2.28 (s, 3H), 2.50 (m, 1H), 3.07 (m, 2H), 3.35 (m, 2H), 3.46 (m, 1H), 3.75 (m, 1H), 7.01 (m, 2H), 7.32 (m, 2H); ¹³C NMR (CDCl₃) δ 161.42, 138.41, 129.86, 129.73, 115.13, 114.80, 68.56, 65.21, 61.96, 45.49, 41.19, 37.32, 36.19, 26.29, 25.18. [α]_D²⁰ +58.9° (c 0.54, CHCl₃). Anal. (C₁₅H₂₀FNO) C, H, N.

(1*S*)-3β-(4-Fluorophenyl)-2α-(hydroxymethyl)tropane [(1*S*)-2α,3β-6]. Recrystallization from EtOAc gave 0.88 g (66%) of white solid: mp 173–175 °C; ¹H NMR (CDCl₃) δ 1.54–1.62 (m, 2H), 1.70–2.22 (m, 6H), 2.27–2.35 (m, 1H), 2.36 (s, 3H), 3.20–3.41 (m, 4H), 6.96 (m, 2H), 7.18 (m, 2H); ¹³C NMR (CDCl₃) δ 161.42 (d), 139.69, 129.22, 129.09, 115.44, 115.11, 62.71, 62.15, 61.90, 49.28, 41.20, 41.00, 37.53, 25.84, 21.62; [α]_D²⁰ –24.7° (c 0.51, CHCl₃). Anal. (C₁₅H₂₀FNO) C, H, N.

(1*S*)-3α-(4-Fluorophenyl)-2β-(hydroxymethyl)tropane [(1*S*)-2β,3α-6]. Recrystallization from Et₂O/hexanes

gave 0.540 g (72%) of white solid: mp 83–85 °C; ¹H NMR (CDCl₃) δ 1.49 (m, 2H), 1.74 (m, 2H), 2.05 (m, 2H), 2.23 (s, 3H), 2.47 (m, 1H), 2.94 (m, 2H), 3.23 (m, 2H), 3.65 (m, 1H), 3.85 (m, 1H), 6.96 (m, 2H), 7.25 (m, 2H); ¹³C NMR (CDCl₃) δ 160.99 (d), 141.98, 128.63, 128.57, 114.93, 114.77, 68.69, 64.94, 60.16, 49.88, 40.83, 38.01, 35.49, 27.07, 26.62; [α]_D²⁰ +38.6° (c 0.29, CHCl₃). Anal. (C₁₅H₂₀FNO·0.5H₂O) C, H, N.

Procedure for the General Synthesis of 3-(4-Fluorophenyl)-2-[[3,4-(methylenedioxy)phenoxy]methyl]tropane (7). A solution of the appropriate isomer of 6 (2.0 mmol) in 15 mL of CH₂Cl₂ was cooled to 0 °C, and methanesulfonyl chloride (2.5 mmol) was added. Et₃N (2.0 mmol) was then added dropwise. The reaction mixture was stirred at 0 °C for 0.5 h and then at room temperature. After 3 h, CH₂Cl₂ and water were added. The reaction was basified to pH 10 with NH₄OH, and the layers were separated. The aqueous layer was extracted with CH₂Cl₂. The organic layers were combined, washed with 1 N NaOH, water, NH₄Cl solution, water, and NaCl solution, and dried over Na₂SO₄. The solvent was removed to give a colorless, slightly cloudy oil which was used without further purification.

Sodium hydride (60% dispersion, 4.0 mmol) was washed twice with hexanes under nitrogen gas. Anhydrous THF (10 mL) was added, and the slurry was cooled to 0 °C. A solution of sesamol (4.0 mmol) in 10 mL of THF was added dropwise. Eventually the mixture cleared and became yellow. The alkoxide was warmed to room temperature and refluxed for 45 min. The mesylate and 18-crown-6 ether (~5 mg) were dissolved in 10 mL of a mixture of THF and 2 mL of DMF and added dropwise over 10 min. The reaction was warmed to room temperature after the addition was complete, refluxed for 3 h, and then stirred at room temperature for 2 h. The reaction mixture was cooled to 0 °C and quenched with water. THF was removed under reduced pressure, water and NH₄OH were added, and the aqueous layer (pH 10) was extracted with CH₂Cl₂. The organic layers were combined, washed with 1 N NaOH, water, and NaCl solution, and dried over MgSO₄. The solvent was removed to give a light yellow oil which was purified by flash chromatography on silica gel, eluting with Et₂O/Ft₃N/hexanes (27:3:70).

(1*R*)-3β-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)phenoxy]methyl]tropane [(1*R*)-2β,3β-7a]. Purification by flash chromatography gave 0.33 g (44%) of the pure product as an oil: ¹H NMR (C₆D₆) δ 1.59 (m, 1H), 1.81 (m, 2H), 2.09 (m, 2H), 2.14 (m, 1H), 2.20 (ddd, 1H, J = 14.3, 5.8, 5.8 Hz), 2.38 (ddd, 1H, J = 11.6, 1.6, 1.6 Hz), 2.40 (s, 3H), 2.98 (dd, 1H, J = 11.6, 6.2 Hz), 3.01 (ddd, 1H, J = 6.2, 6.2, 1.6 Hz), 3.42 (dd, 1H, J = 10.6, 5.8 Hz), 4.31 (ddd, 1H, J = 9.7, 1.8, 1.8 Hz), 5.89 (s, 2H), 6.32 (dd, 1H, J = 8.6, 2.3 Hz), 6.48 (d, 1H, J = 2.3 Hz), 6.66 (d, 1H, J = 8.6 Hz), 6.95 (dd, 2H, J = 8.8, 8.8 Hz), 7.39 (dd, 2H, J = 8.8, 5.8 Hz); ¹³C NMR (CDCl₃) δ 163.06, 159.20, 152.75, 148.28, 143.23, 141.82, 129.45, 129.33, 115.12, 114.78, 108.57, 108.09, 101.15, 99.90, 83.74, 55.25, 50.49, 54.52, 42.89, 33.96, 31.96, 26.98, 23.38. The D-tartrate salt recrystallized from 2-propanol/ethyl ether yielded a white powder which had mp 97 °C (fusion): ¹H NMR (CD₃OD) δ 2.00–2.43 (m, 7H), 2.95 (s, 3H), 3.48 (m, 2H), 3.68 (m, 2H), 4.61 (m, 1H), 5.86 (s, 2H), 6.39 (dd, 1H), 6.49 (d, 1H), 6.68 (dd, 1H), 7.03 (m, 2H), 7.36 (m, 2H); [α]_D²⁰ +11.8° (c 0.27, CH₃OH). Anal. (C₂₀H₂₆FNO₃) C, H, N.

3β-(4-Fluorophenyl)-2α-[[3,4-(methylenedioxy)phenoxy]methyl]tropane [(1*R*)-2α,3β-7b]. Fractions were pooled to give 0.34 g (51%) of the product as a colorless oil: ¹H NMR (C₆D₆) δ 1.37 (ddd, 1H, J = 12.0, 9.6, 4.8 Hz), 1.44 (ddd, 1H, J = 12.0, 5.7, 3.0 Hz), 1.71 (m, 1H), 1.77 (m, 1H), 1.87 (ddd, 1H, J = 12.0, 6.4, 6.4 Hz), 1.94 (ddd, 1H, J = 12.0, 5.7, 1.8 Hz), 2.20 (s, 3H), 2.31 (ddd, 1H, J = 12.0, 12.0, 5.7 Hz), 2.65 (ddd, 1H, J = 12.0, 9.6, 3.5 Hz), 3.00 (dd, 1H, J = 6.4, 6.4, 3.0 Hz), 3.40 (dd, 1H, J = 9.6, 9.6 Hz), 3.49 (dd, 1H, J = 9.6, 3.5 Hz), 3.52 (dd, 1H, J = 6.7, 3.0 Hz), 5.33 (s, 2H), 6.12 (dd, 1H, J = 8.5, 2.5 Hz), 6.49 (d, 1H, J = 2.5 Hz), 6.56 (d, 1H, J = 8.5 Hz), 6.79 (dd, 2H, J = 8.7, 8.7 Hz), 6.94 (dd, 2H, J = 8.7, 5.5 Hz); ¹³C NMR (CDCl₃) δ 154.45, 148.30, 144.66, 139.53, 129.33, 129.20, 115.73, 115.40, 107.98, 105.68.

101.23, 98.14, 70.84, 68.91, 63.28, 62.01, 46.23, 41.55, 41.23, 37.54, 26.10, 22.07. The compound was converted to the D-tartrate salt. Recrystallization from EtOH/Et₂O gave a hygroscopic off-white powder: mp 105 °C (fusion); ¹H NMR (CD₃OD) δ 1.95 (m, 1H), 2.13–2.46 (m, 5H), 2.77–3.00 (m, 2H), 2.89 (s, 3H), 3.46–3.70 (m, 2H), 3.99 (m, 1H), 4.14 (m, 1H), 4.43 (s, 2H), 5.84 (s, 2H), 6.15 (dd, 1H), 6.35 (d, 1H), 6.62 (d, 1H), 7.06 (m, 2H), 7.35 (m, 2H); [α]_D²⁵ +32.8° (c 0.29, CH₃OH). Anal. (C₂₈H₃₀FNO₆) C, H, N.

3α-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)phenoxy]methyl]tropane [(1*R*)-2β,3α-7c]. Fractions were pooled to give 0.312 g (12%) of the product as a light yellow oil: ¹H NMR (C₆D₆N) δ 1.25 (dd, 1H, *J* = 13.2, 10.8 Hz), 1.50 (ddd, 1H, *J* = 12.5, 9.5, 3.4 Hz), 1.59 (ddd, 1H, *J* = 17.0, 12.1, 4.9 Hz), 1.87 (ddd, 1H, *J* = 10.8, 10.8, 3.5 Hz), 2.13 (ddd, 1H, *J* = 17.0, 12.1, 5.8 Hz), 2.29 (m, 4H), 2.46 (ddd, 1H, *J* = 13.2, 8.6, 8.3 Hz), 2.62 (ddd, 1H, *J* = 10.8, 10.3, 8.3 Hz), 3.29 (m, 2H), 3.59 (dd, 1H, *J* = 10.8, 3.5 Hz), 3.75 (dd, 1H, *J* = 10.8, 10.8 Hz), 5.87 (s, 2H), 6.18 (dd, 1H, *J* = 8.5, 2.5 Hz), 6.38 (d, 1H, *J* = 2.5 Hz), 6.63 (d, 1H, *J* = 8.5 Hz), 6.96 (dd, 2H, *J* = 8.6, 8.6 Hz), 7.16 (dd, 2H, *J* = 8.6, 5.6 Hz); ¹³C NMR (CDCl₃) δ 163.29, 159.39, 154.48, 148.111, 141.39, 140.73, 140.68, 129.47, 129.28, 115.32, 114.99, 107.85, 105.53, 101.05, 97.98, 71.33, 62.73, 59.48, 50.89, 41.45, 41.11, 36.12, 29.43, 28.48. The product was converted to the D-tartrate salt. Recrystallization from EtOH/Et₂O gave a hygroscopic off-white solid: mp 84 °C (fusion); ¹H NMR (CD₃OD) δ 1.82 (m, 1H), 2.07–2.19 (m, 2H), 2.30–2.76 (m, 4H), 2.82 (s, 3H), 3.02–3.15 (m, 1H), 3.76 (m, 2H), 3.96 (m, 2H), 5.87 (s, 2H), 6.30 (dd, 1H), 6.51 (d, 1H), 6.65 (d, 1H), 7.07 (m, 2H), 7.35 (m, 2H); [α]_D²⁵ –48.3° (c 0.29, CH₃OH). Anal. (C₂₈H₃₀FNO₆·0.5H₂O) C, H, N.

(1*S*)-3β-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)phenoxy]methyl]tropane [(1*S*)-2β,3β-7d]. Fractions were pooled to give 1.02 g (69%) of the pure product. ¹H and ¹³C NMR are identical with the (1*R*)-enantiomer. The product was converted to the D-tartrate salt. Recrystallization from 2-propanol/ethyl ether yielded a white powder: mp 90 °C (fusion); ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer; [α]_D²⁵ –26.8° (c 0.63, CH₃OH). Anal. (C₂₈H₃₀FNO₆) C, H, N.

(1*S*)-3β-(4-Fluorophenyl)-2α-[[3,4-(methylenedioxy)phenoxy]methyl]tropane [(1*S*)-2α,3β-7e]. Fractions were pooled to give 0.76 g (64%) of the product as a slightly yellow oil. ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer. The compound was converted to the D-tartrate salt. Recrystallization from MeOH/Et₂O gave a hygroscopic off-white powder: mp 95 °C (fusion); ¹H and ¹³C NMR are identical with the (1*R*)-enantiomer; [α]_D²⁵ –50.8° (c 0.50, CH₃OH). Anal. (C₂₈H₃₀FNO₆) C, H, N.

(1*S*)-3α-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)phenoxy]methyl]tropane [(1*S*)-2β,3α-7f]. Fractions were pooled to give 0.24 g (32%) of the product as a light yellow oil. ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer. The product was converted to the D-tartrate salt. Recrystallization from MeOH/Et₂O gave a hygroscopic white solid: mp 56 °C dec. ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer; [α]_D²⁵ +38.2° (c 0.33, CH₃OH). Anal. (C₂₈H₃₀FNO₆·0.25H₂O) C, H, N.

General Procedure for Demethylation of 3-(4-Fluorophenyl)-2-[[3,4-(methylenedioxy)phenoxy]methyl]tropane (7). Method A. The appropriate isomer of 7 (1.0 mmol) was dissolved in 15 mL of dichloroethane under nitrogen gas. Proton Sponge [1,8-bis(dimethylamino)naphthalene, 0.14 mmol; Aldrich] was added, and the solution was stirred for 0.5 h at room temperature. ACE-Cl (6.0 mmol) was added, and the reaction mixture was refluxed for 24 h. The reaction mixture was cooled and the solvent removed under reduced pressure. MeOH (10 mL) was added, and the reaction mixture was refluxed for 24 h. The solvent was removed under reduced pressure to afford a dark orange/red oil. Water was added, and the reaction mixture was basified with NH₄OH. The aqueous layer was extracted with CH₂Cl₂. The solvent was removed under reduced pressure, and the product was purified by flash chromatography

Method B. The appropriate isomer of 7 (1.0 mmol) was dissolved in 10 mL of toluene under nitrogen gas. Potassium carbonate (0.4 mmol) was added, and the solution was refluxed for 0.5 h. Trichloromethyl chloroformate (3.8 mmol) was added, and the reaction was refluxed for 24 h. Additional chloroformate was added, and the reaction was refluxed for 24 h. Water and CHCl₃ were added, and the reaction mixture was basified with NH₄OH. The layers were separated, and the aqueous layer was extracted with CHCl₃. The combined organic layers were dried over Na₂SO₄. The solvent was removed to afford a brown oil. The carbonate was dissolved in glacial acetic acid (6.0 mL), and Zn dust (1.00 g) was added in small portions. The mixture was stirred for 12 h at room temperature. Water and CHCl₃ were added, and the reaction was filtered through Celite. After basifying with NH₄OH and extracting with CHCl₃, the organic layers were dried over K₂CO₃. The product was purified by flash chromatography on silica gel, first eluting with Et₂O/Et₃N (9:1) followed by CHCl₃/CH₃OH/NH₄OH (90:9:1).

3β-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)phenoxy]methyl]nortropane [(1*R*)-2β,3β-4a]. Method A. Purification afforded 0.083 g (62%) of the product as a pink oil: ¹H NMR (C₆D₆N) δ 1.67 (dd, 1H, *J* = 12.0, 3.5 Hz), 1.91 (m, 2H), 2.05 (ddd, 1H, *J* = 13.9, 10.9, 1.9 Hz), 2.15 (m, 3H), 2.93 (dd, 1H, *J* = 12.3, 1.9 Hz), 3.28 (dd, 1H, *J* = 12.3, 5.5 Hz), 3.32 (m, 1H), 3.60 (dd, 1H, *J* = 10.6, 6.2 Hz), 4.55 (ddd, 1H, *J* = 9.5, 5.5, 1.9 Hz), 5.93 (s, 2H), 6.58 (dd, 1H, *J* = 8.4, 2.4 Hz), 6.86 (d, 1H, *J* = 8.4 Hz), 6.87 (d, 1H, *J* = 2.4 Hz), 7.06 (dd, 2H, *J* = 8.7, 8.7 Hz), 7.49 (dd, 2H, *J* = 8.7, 5.4 Hz); ¹³C NMR (CDCl₃) δ 163.18, 159.20, 152.51, 148.34, 142.14, 141.93, 129.11, 128.99, 115.40, 115.06, 108.42, 108.10, 101.08, 99.82, 83.05, 47.72, 46.21, 42.18, 39.84, 33.54, 31.31, 27.02. The product was converted to the D-tartrate salt. Recrystallization from EtOH/Et₂O gave a white hygroscopic powder: mp 183–185 °C dec; ¹H NMR (CD₃OD) δ 1.98–2.37 (m, 7H), 3.24–3.42 (m, 2H), 3.72 (m, 1H), 3.87 (br s, 1H), 4.42 (s, 2H), 4.55 (bs, 1H), 5.7 (s, 2H), 6.39 (dd, 1H), 6.58 (d, 1H), 6.68 (d, 1H), 7.05 (m, 2H), 7.33 (m, 2H); [α]_D²⁵ +10.6° (c 0.36, CH₃OH). Anal. (C₂₅H₂₈FNO₅) C, H, N.

(1*R*)-3β-(4-Fluorophenyl)-2α-[[3,4-(methylenedioxy)phenoxy]methyl]nortropane [(1*R*)-2α,3β-4b]. Method A. Fractions were pooled to afford 0.19 g (55%) of pink oil: ¹H NMR (C₆D₆N) δ 1.68 (m, 3H), 1.78 (m, 1H), 1.87 (ddd, 1H, *J* = 12.6, 12.6, 2.2 Hz), 1.97 (m, 1H), 2.58 (m, 1H), 2.73 (ddd, 1H, *J* = 11.9, 11.9, 5.5 Hz), 3.58 (ddd, 1H, *J* = 6.6, 3.2, 3.2 Hz), 3.69 (s, 1H), 3.71 (d, 1H, *J* = 1.9 Hz), 3.96 (dd, 1H, *J* = 6.4, 2.2 Hz), 5.90 (s, 2H), 6.32 (dd, 1H, *J* = 8.3, 2.5 Hz), 6.62 (d, 1H, *J* = 2.5 Hz), 6.78 (d, 1H, *J* = 8.3 Hz), 7.11 (dd, 2H, *J* = 8.7, 8.7 Hz), 7.32 (dd, 2H, *J* = 8.7, 5.5 Hz); ¹³C NMR (CDCl₃) δ 163.96, 159.66, 154.13, 148.14, 141.57, 138.91, 129.10, 128.98, 115.66, 115.33, 107.81, 105.44, 101.08, 97.91, 68.57, 56.35, 55.16, 46.48, 46.21, 41.24, 37.89, 28.98, 24.99. The product was converted to the D-tartrate salt. Recrystallization from MeOH/Et₂O gave a hygroscopic light yellow powder: mp 140 °C (fusion); ¹H NMR (CD₃OD) δ 1.88–2.45 (m, 6H), 2.66 (m, 1H), 3.00 (m, 1H), 3.53–3.70 (m, 2H), 4.13 (m, 1H), 4.28 (m, 1H), 4.42 (s, 2H), 5.84 (s, 2H), 6.14 (dd, 1H), 6.34 (d, 1H), 6.60 (d, 1H), 7.06 (m, 2H), 7.33 (m, 2H); [α]_D²⁵ +36.0° (c 0.30, CH₃OH). Anal. (C₂₅H₂₈FNO₅·0.5H₂O) C, H, N.

(1*R*)-3α-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)phenoxy]methyl]nortropane [(1*R*)-2β,3α-4c]. Method A. Fractions were pooled to afford 0.069 g (55%) of yellow oil: ¹H NMR (C₆D₆N) δ 1.51 (m, 1H), 1.65 (m, 2H), 1.92 (m, 2H), 2.23 (ddd, 1H, *J* = 13.8, 9.1, 7.4 Hz), 2.80 (ddd, 1H, *J* = 11.1, 11.1, 7.4 Hz), 3.52 (m, 2H), 3.71 (d, 1H, *J* = 3.3 Hz), 3.75 (dd, 1H, *J* = 9.1, 3.7 Hz), 3.91 (dd, 1H, *J* = 9.1, 9.1 Hz), 5.85 (s, 2H), 6.35 (dd, 1H, *J* = 8.4, 2.3 Hz), 6.65 (d, 1H, *J* = 2.4 Hz), 6.77 (d, 1H, *J* = 8.5 Hz), 7.09 (dd, 1H, *J* = 8.6 Hz), 7.25 (dd, 1H, *J* = 8.4, 5.6 Hz); ¹³C NMR (CDCl₃) δ 163.61, 154.52, 148.07, 141.62, 140.39, 129.47, 115.37, 115.03, 107.87, 105.60, 101.08, 98.03, 71.11, 55.25, 51.96, 49.84, 39.12, 35.92, 34.33, 32.30. The product was converted to the D-tartrate salt. Recrystallization from 2-propanol/Et₂O gave a hygroscopic white crystalline solid: mp 174 °C dec; ¹H NMR (CD₃OD) δ 1.72 (m, 1H),

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2.01–2.24 (m, 5H), 2.58 (m, 1H), 2.94 (m, 1H), 3.69 (m, 2H), 4.11 (m, 2H), 5.86 (s, 1H), 62.8 (dd, 1H), 6.50 (d, 1H), 6.65 (d, 1H), 7.06 (m, 2H), 7.33 (m, 2H); $[\alpha]_D^{25} -79.7^\circ$ (c 0.32, CH₂OH). Anal. (C₂₅H₂₈FNO₃) C, H, N.

(1*S*)-3β-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)-phenoxy]methyl]nortropine [(1*S*)-2β,3β-4*f*]. Method B. Flash chromatography gave 0.098 g (26%) of the product. Another fraction contained 0.118 g of the *N*-methyl starting material. ¹H and ¹³C NMR are identical with the (1*R*)-enantiomer. The product was converted to the *L*-tartrate salt. Recrystallization from EtOH/Et₂O gave a light tan hygroscopic powder; mp 180–184 °C dec; ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer; $[\alpha]_D^{25} -10.3^\circ$ (c 0.30, CH₂OH). Anal. (C₂₅H₂₈FNO₃) C, H, N.

(1*S*)-3β-(4-Fluorophenyl)-2α-[[3,4-(methylenedioxy)-phenoxy]methyl]nortropine [(1*S*)-2α,3β-4*f*]. Method A. Fractions were pooled to afford 0.135 g (40%) of pink oil. ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer. The product was converted to the *D*-tartrate salt. Recrystallization from MeOH/Et₂O gave a hygroscopic tan powder; mp 170 °C (fusion); ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer; $[\alpha]_D^{25} -52.4^\circ$ (c 0.50, CH₂OH). Anal. (C₂₅H₂₈FNO₃·0.25H₂O) C, H, N.

(1*S*)-3α-(4-Fluorophenyl)-2β-[[3,4-(methylenedioxy)-phenoxy]methyl]nortropine [(1*S*)-2β,3α-4*f*]. Method B. Flash chromatography afforded 0.095 g (55%) of the product as a brown oil. ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer. The product was converted to the *L*-tartaric acid salt. Recrystallization from EtOH/Et₂O gave a light tan hygroscopic powder; mp 163–166 °C dec; ¹H and ¹³C NMR are identical with those of the (1*R*)-enantiomer; $[\alpha]_D^{25} +76.3^\circ$ (c 0.27, CH₂OH). Anal. (C₂₅H₂₈FNO₃·0.5H₂O) C, H, N.

(1*R*)-3α-(4-Fluorophenyl)-2α-(3-methyl-1,2,4-oxadiazol-5-yl)tropane (10). To a cooled solution (–78 °C) of bromofluorobenzene (0.64 g, 3.66 mmol) in 10 mL of anhydrous Et₂O was added *t*-BuLi (1.0 M in pentane, 6.0 mL, 6.00 mmol) dropwise. After the mixture was stirred for 20 min at –78 °C, a solution of 9 (0.31 g, 1.51 mmol) in 20 mL of Et₂O was added slowly. The reaction was stirred at –78 °C for 2 h and then at –40 °C for 1 h. The reaction was treated with ethereal TFA over 5 min, allowed to warm to 0 °C, and diluted with ether. The mixture was basified with dilute NH₄OH and the layers were separated. After the organic layer was dried over Na₂SO₄, the solvent was removed to give 0.44 g of oil. Flash chromatography [EtOAc/Et₃N/hexanes (27:3:70)] gave 0.28 g of product as a white solid. Recrystallization from hexanes afforded 0.158 g (35%) of white crystals; mp 101–103 °C; ¹H NMR (CDCl₃) δ 1.52–1.67 (m, 2H), 1.83–2.15 (m, 3H), 2.25 (s, 3H), 2.32 (s, 3H), 2.47 (m, 1H), 3.35 (m, 1H), 3.56 (m, 1H), 3.65 (m, 1H), 4.18 (m, 1H), 6.84 (m, 2H), 7.06 (m, 2H); ¹³C NMR (CDCl₃) δ 179.41, 166.49, 137.41, 129.28, 129.16, 114.89, 114.55, 62.24, 59.63, 44.31, 40.48, 35.33, 34.69, 28.39, 23.10, 11.49; $[\alpha]_D^{25} +52.0^\circ$ (c 0.60, CHCl₃). Anal. (C₁₇H₂₂FNO₃) C, H, N.

(1*R*)-3α-(4-Fluorophenyl)-2β-carbomethoxytropane [(*R*)-2β,3α-5]. To a solution of nickel acetate (5.33 g, 21.43 mmol) in 50 mL of MeOH was added slowly a slurry of NaBH₄ (0.801 g, 21.43 mmol) in 25 mL of MeOH. A solution of the oxadiazolyltropane 10 (1.29 g, 4.28 mmol) and HCl (12 N, 1.78 mL, 21.43 mmol) in 50 mL of MeOH was added slowly to the black slurry. The reaction mixture was stirred at room temperature for 2 h and then refluxed for 3 h. The reaction mixture was cooled and then Et₂O and saturated NaHCO₃ were added. The reaction was basified with NH₄OH to pH 10. The layers were separated, and the blue aqueous layer was extracted with Et₂O several times. The solvent was removed to afford 1.03 g of clear oil; ¹H NMR (C₆D₆) δ 1.03–1.18 (m, 2H), 1.27–1.33 (m, 1H), 1.70–1.92 (m, 2H), 2.02 (s, 3H), 2.25 (m, 1H), 2.38 (m, 1H), 2.88 (m, 1H), 3.25 (s, 3H), 3.31 (m, 1H), 3.55–3.66 (m, 1H), 6.77 (m, 2H), 6.91 (m, 2H). The ester was characterized as the *D*-tartrate salt;¹⁷ $[\alpha]_D^{25} -34.4^\circ$ (c 0.54, CH₂OH); mp 65 °C. Anal. (C₂₀H₂₂FNO₃·0.5H₂O) C, H, N.

(1*S*)-2-Carbomethoxy-3-[[[(trifluoromethyl)sulfonyl]oxy]tropane (12). Carbomethoxytropinone^{19,40,43} (6.01 g, 30.5 mmol) was dissolved in 150 mL of anhydrous THF under N₂. After the mixture was cooled to –78 °C, bis(trimethylsilyl)-amide (1.0 M solution in THF, 40.0 mL, 40.0 mmol) was added dropwise by an addition funnel. The mixture was stirred at –78 °C for 0.5 h. The triflimide (13.03 g, 36.5 mmol) was dissolved in 100 mL of anhydrous THF and added dropwise. The reaction was stirred for 10 min at –78 °C, then warmed to 0 °C, and stirred for 2 h. The reaction vessel was fitted with a drying tube and allowed to remain at 5 °C for 36 h. The reaction was quenched with H₂O and extracted with CH₂Cl₂. After the mixture was dried over Na₂SO₄, solvent was removed from the solution to afford 11.77 g of brown oil. Purification by flash chromatography (hexane/EtOAc, 3:2) gave 8.07 g (80%) of triflate 12 as a golden oil; ¹H NMR (CDCl₃) δ 1.60 (m, 1H), 2.00 (m, 2H), 2.20 (m, 2H), 2.40 (s, 3H), 2.85 (m, 1H), 3.43 (m, 1H), 3.82 (s, 3H), 3.93 (d, 1H); ¹³C NMR (CDCl₃) δ 163.79, 149.10, 125.19, 118.21 (q), 60.08, 57.40, 52.05, 34.86, 34.66, 33.03, 29.96; $[\alpha]_D^{25} -7.8^\circ$ (c 1.0, CHCl₃). Anal. (C₁₁H₁₄F₃O₅) C, H, N.

(1*S*)-Anhydroecognine Methyl Ester (13). The triflate 12 (11.36 g, 34.5 mmol) was dissolved in 250 mL of anhydrous THF under N₂. Next, Pd(OAc)₂ (0.177 g, 0.788 mmol), PPh₃ (0.461 g, 1.76 mmol), and Et₃N (14.4 mL, 10.45 g, 103.3 mmol) were added. The reaction was stirred for 5 min, HCO₂H (2.60 mL, 3.17 g, 68.9 mmol) was added dropwise, and the mixture was refluxed for 1 h. After to room temperature, water was added. The reaction was extracted with CHCl₃ and dried over Na₂SO₄. Purification by flash chromatography (Et₂O/Et₃N/hexane, 9:1:10) gave 5.43 g (87%; 75%, 2 steps from 11) of 13; ¹H NMR (CDCl₃) δ 1.49 (m, 1H), 1.86 (m, 2H), 2.14 (m, 2H), 2.34 (s, 3H), 2.62 (m, 1H), 3.24 (m, 1H), 3.74 (s, 3H), 3.79 (m, 1H), 6.82 (m, 1H); $[\alpha]_D^{25} +35.5^\circ$ (c 1.0, CHCl₃) [lit.⁴³ $[\alpha]_D^{25} +38.3^\circ$ (c 1.0, CH₂OH)].

(1*S*)-3β-(4-Fluorophenyl)tropane-2β-carboxylic Acid Methyl Ester [(1*S*)-2β,3β-5]. The synthesis of this compound has been described previously.⁴³ The fractions were pooled to give 4.22 g (51%) of product as a white solid; mp 92–93 °C (lit.⁴³ mp 94–96 °C). A second fraction (1.48 g) contained the α-isomer; ¹H NMR (CDCl₃) δ 7.22 (m, 2H), 6.95 (m, 2H), 3.57 (m, 1H), 3.50 (s, 3H), 3.36 (m, 1H), 2.95 (m, 1H), 2.86 (m, 1H), 2.57 (m, 1H), 2.22 (s, 3H), 2.15 (m, 2H), 1.57–1.75 (m, 3H); $[\alpha]_D^{25} +49.2^\circ$ (c 0.52, CH₂OH) [lit.⁴³ for the naphthalene-1,5-disulfonate $[\alpha]_D^{25} +84.5^\circ$ (c 1.0, H₂O)].

(1*S*)-3β-(4-Fluorophenyl)tropane-2α-carboxylic Acid Methyl Ester [(1*S*)-2α,3β-5]. A white solid was obtained which was recrystallized to give white crystals; mp 68–70 °C (lit.⁴³ mp 71.5–73.5 °C); ¹H NMR (CDCl₃) δ 1.56–2.15 (m, 6H), 2.40 (s, 3H), 3.00–3.14 (m, 2H), 3.23 (m, 1H), 3.41 (m, 1H), 3.50 (s, 3H), 6.97 (m, 2H), 7.21 (m, 2H); ¹³C NMR (CDCl₃) δ 173.30, 161.40 (d), 139.38, 129.19, 129.07, 115.30, 114.97, 63.62, 61.12, 51.49, 51.42, 39.65, 38.76, 36.14, 26.40, 23.20; $[\alpha]_D^{25} -14.5^\circ$ (c 0.55, CH₂OH) [lit.⁴³ $[\alpha]_D^{25} -1.2^\circ$ (c 5.0, CHCl₃)].

(1*S*)-2-Carbomethoxy-3-(4-fluorophenyl)tropane (14). To a round-bottom flask was added the triflate 12 (1.51 g, 4.59 mmol), LiCl (0.402 g, 9.57 mmol), tris(dibenzylideneacetone)dipalladium(0) (0.170 g), Na₂CO₃ (2.0 M soln in H₂O, 4.5 mL, 9.0 mmol), and diethoxymethane (10 mL). The mixture was stirred vigorously, and (*p*-fluorophenyl)boronic acid (0.852 g, 6.08 mmol) was added. The reaction was refluxed and monitored by TLC (Et₂O/Et₃N, 9:1). After 1 h, the reaction was filtered through Celite. Et₂O and H₂O were added, and the mixture was basified to pH 10 with NH₄OH. The layers were separated, and the aqueous layer was extracted with CHCl₃. The organic layers were combined and dried over Na₂SO₄. The solvent was removed from the dried solution to afford a dark yellow oil. Purification by flash chromatography (silica gel, Et₂O/Et₃N/hexane, 9:1:10) afforded 1.09 g (86%) of the tropane as a yellow oil which solidified upon standing; mp 56–58 °C; ¹H NMR (CDCl₃) δ 7.13–6.97 (m, 4H), standing; mp 56–58 °C; ¹H NMR (CDCl₃) δ 7.13–6.97 (m, 4H), 3.85 (d, 1H), 3.50 (s, 3H), 3.35 (m, 1H), 2.74 (m, 1H), 2.44 (s, 3H), 1.94–2.24 (m, 4H), 1.64 (m, 1H); ¹³C NMR (CDCl₃) δ 168.21, 162.12 (d), 142.77, 137.15, 131.02, 128.52, 128.40,