STEREOISOMERIC DRUGS: UNRAVELLING THE IMPACT OF MOLECULAR MIRROR IMAGES ON MEDICINAL CHEMISTRY

Abstract

Stereoisomerism, a fundamental concept in chemistry, plays a pivotal role in drug design and development. While having the same chemical formula, stereoisomeric medications, which include enantiomers and diastereomers, have different three-dimensional atomic configurations. This review investigates the stereoisomeric drugs, examining how chirality has a significant impact on pharmacological characteristics, pharmacokinetics, and therapeutic results. It is essential for pharmaceutical researchers and healthcare providers to comprehend the importance of these modest structural differences. This review clarifies the tremendous effects of stereoisomerism on medication development, efficacy, safety, and personalised medicine by providing a brief summary of recent studies and examples across various drug classes. This review intends to advance our knowledge of medicinal chemistry and stimulate new developments in the field by shedding light on the complexity of stereoisomeric medicines.

Keywords: Stereoisomeric drugs, Stereoisomerism, Stereochemistry, Stereoisomers

Authors

Aman Naskar
Department of Pharmacy
Guru Ghasidas Vishwavidyalaya
(A Central University)
Bilaspur, Chhattisgarh, India.

Dipti Pal
Department of Pharmacy
Guru Ghasidas Vishwavidyalaya
(A Central University)
Bilaspur, Chhattisgarh, India.

Smita Suthar
Department of Pharmacy
Guru Ghasidas Vishwavidyalaya
(A Central University)
Bilaspur, Chhattisgarh, India.

Sanmati K. Jain*
Drug Discovery and Research Laboratory
Department of Pharmacy
Guru Ghasidas Vishwavidyalaya
(A Central University)
Bilaspur, Chhattisgarh, India.
sanmatijain72@yahoo.co.in

I. INTRODUCTION

The idea of stereochemistry has become an alluring and significant element in the field of pharmaceuticals, where accuracy and efficacy are crucial [1]. The fascinating group of medicinal substances known as stereoisomeric drugs, sometimes referred to as stereoisomers or enantiomers, has chemical formulas that are similar but differs in the spatial arrangement of its atoms. Due to this spatial arrangement, separate mirror-image structures emerge, giving rise to two or more enantiomers or chiral variants of the same molecule. The word "chiral" comes from the Greek word for "hand," since these isomers are comparable to left and right hands that cannot be superimposed upon one another. The fascinating realm of stereoisomers and their tremendous effects on drug development, pharmacokinetics, and therapeutic results are explored in this article. Deciphering the various biological effects, interactions, and potential adverse effects of medications has proven to be greatly aided by an understanding of their stereoisomeric nature. The importance of stereoisomeric medications is seen in their tremendous impact on pharmacological traits and biological functions. These isomers can interact with biological targets, enzymes, and receptors in the human body in radically varied ways despite having the identical chemical composition [2]. This dissimilarity can produce significantly different pharmacokinetic and pharmacodynamic profiles, altering the potency, effectiveness, metabolism, and toxicity of the drug [3]. The tremendous effects of stereoisomerism on medication action have fundamentally changed how drugs are designed as pharmaceutical researchers work to maximise the potential of these molecular wonders [4]. We shall examine the numerous stereoisomeric drugs in this review, covering both enantiomers and diastereomers. We will carefully study how chirality affects drug safety, effectiveness, and pharmacokinetics because even little changes in stereochemistry can have a variety of effects on metabolism, clearance, and drug-drug interactions. The importance of comprehending stereoisomeric medications cannot be understated as the study of pharmacology develops. We seek to increase our common understanding and appreciation of the interaction between chemistry and medicine by examining the intricate details of these molecules, which will ultimately influence the future course of pharmaceutical innovation.

II. STEREOCHEMISTRY AND STEREOISOMERS

The study of stereoisomers, or molecules with identically connected atoms but different arrangements of atoms in space, falls under the category of stereochemistry, a branch of chemistry that examines three-dimensional arrangements of atoms and molecules and their effects on biological systems [5]. The most common types of stereoisomers are the cis and trans versions of alkenes. Enantiomers and diastereomers are both form of stereoisomers. The former stereoisomers contain molecules that are non-superposable mirror images of one another, whereas the latter stereoisomers lack molecules which are mirror images to each other.

III. CHIRALITY AND ENANTIOMERS

The enantiomers are two chemical molecules that share a similar structure but exhibit significantly distinct biological behaviour and chirality of these molecules is a geometric characteristic that prevents them from superimposing with their mirror images [6]. On the other hand, achiral molecules are those that overlay with their mirror image. Simply put,

chirality refers to the right and left handed confirmation of most compounds. For example, The chiral molecule DNA rotates in a right-handed fashion. In 1848, Louis Pasteur made the first distinction between two isomers of sodium ammonium tartrate, and this was the beginning of chiral chemistry. Later, it was discovered that chirality not only affects plant and animal life, but also exhibits a significant impact on the pharmaceutical, agricultural, and other chemical industries.

The majority of medications are chiral, which means that even if one mirror form of a compound has the intended therapeutic effect, a second mirror form may be inactive, have undesirable therapeutic effects, or even have favourable therapeutic benefits. In some cases, the second mirror form may also have harmful effects. In the field of pharmaceutical science, 88% of the most recent medications were marketed as racemic mixtures of two equimolar enantiomers, with 56% of all drugs being chiral. Despite having identical molecular formulae, atom to atom connections, and bonding distances, simply chiral compounds have a distinctive architecture that prevents superposition [7].

Therefore, in the environment of biological systems where certain structural activity relationships are required for effect (like: enzymes, receptors, transporters, etc.), the physiochemical and biochemical properties of racemic mixes and individual stereoisomer vary substantially. Chemistry has advanced significantly in recent years, making it possible to distinguish between two medication enantiomers or between parent molecule and metabolites. The practise of "chiral switching" allows for the marketing of many medications as single enantiomers as opposed to their earlier racemic mixed form [8,9].

IV. RACEMIC MIXTURES

Approximately 25% of commercially available medications are racemic mixtures, which are combinations of more than one stereoisomer rather than a single chemical substance. The pharmacodynamics and pharmacokinetic characteristics of each stereoisomer present in the drug's racemic form vary from stereoisomer to stereoisomer [10]. Due to interactions between stereoisomers or for other reasons, racemic forms, which are present to provide superior therapeutic effects, may result in higher undesirable consequences [11].

V. NOMENCLATURE OF CHIRAL COMPOUNDS: THE R, S-SYSTEM

Three chemists, R. S. Cahn, C. K. Ingold, and V. Prelog, created the R, S system, also referred to as the Cahn-Ingold-Prelog criterion of designating chiral compounds. Both of these molecules, R and S, which stand for right and left, respectively, and are derivations of the Latin words rectus and sinister, respectively.

All of the atoms connected to the chiral centre are prioritised in the R, S system according to their atomic number. As the atomic number rises, the priority rises as well. Priority 1 is indicated by an arrow, followed by priority 2, and so on. The absolute configuration is R if the arrow moves in a clockwise direction, and S if it moves in an anticlockwise direction [12-14].

VI. STEREOISOMERIC DRUGS

1. **Thalidomide:** Thalidomide was initially marketed as a sedative and antiemetic (anti-nausea) drug in the late 1950s and early 1960s. It was eventually pulled off the market because it had been linked to serious teratogenic consequences, particularly when used during pregnancy, which led to limb abnormalities in new-borns [15]. Understanding the stereoisomerism of thalidomide is crucial for comprehending both its beneficial advantages and its terrible adverse effects. The chiral nature of thalidomide means that its mirror counterpart cannot be superimposed. The carbon atom, which is linked to four distinct groups, serves as the compound's sole chiral centre.

   A phthalimide ring and a glutarimide ring make up the two main components of thalidomide's structure. The carbon that joins these two rings is where the chiral centre is found. The 2,6-piperidine-2,6-dione ring of thalidomide contains one stereogenic centre, which gives rise to the enantiomeric pairs of (S)- and (R)-thalidomide (Figure 1). It is impossible to superimpose them because they are mirror pictures of one another. Despite having the same chemical formula, the two enantiomers differ in their three-dimensional arrangement of atoms [16].Strangely, while (S)-thalidomide was discovered to be a potent sedative and antiemetic, (R)-thalidomide was determined to be the cause of the teratogenic symptoms noticed during pregnancy. The medicine was sold as a racemic combination, which contained equal levels of both enantiomers [17].

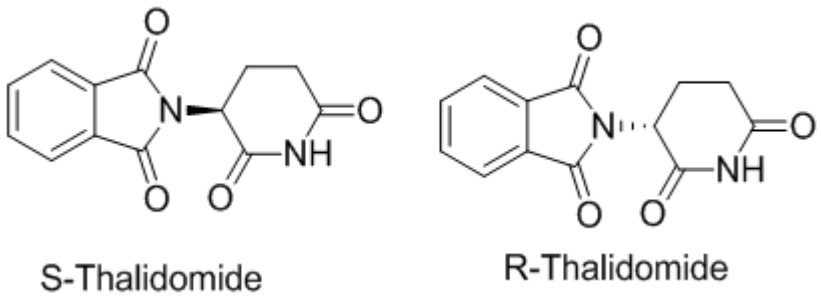


Figure 1: Thalidomide Enantiomers

2. **Ibuprofen:** A common nonsteroidal anti-inflammatory medicine (NSAID) in the class of propionic acid derivatives is ibuprofen. It is frequently used to lower fever, reduce inflammation, and relieve pain. The chemical name for ibuprofen is (RS)-2-(4-isobutylphenyl)propanoic acid [18]. In terms of its stereochemistry, ibuprofen contains a chiral center, which means it has the potential for two different stereoisomeric forms. The chiral center in ibuprofen arises from the carbon atom in its 2-position, which is part of the propionic acid moiety of the molecule. This chiral center gives rise to two possible stereoisomers: (R)-ibuprofen and (S)-ibuprofen (Figure 2).

   The (S)-ibuprofen and (R)-ibuprofen enantiomers exhibit different pharmacological activities. The majority of ibuprofen's therapeutic actions, such as its analgesic (pain-relieving), anti-inflammatory, as well as antipyretic (fever-reducing) qualities, are attributed to its (S)-ibuprofen isomer [19]. On the other hand, the (R)-ibuprofen isomer has shown to be less active or even inactive in terms of providing pain

relief and reducing inflammation. It is considered pharmacologically inactive or has much weaker activity compared to the (S)-ibuprofen. However, research has indicated that the (R)-ibuprofen isomer might have potential beneficial effects in other areas, such as neuroprotection and anticancer activity, which are not related to its traditional NSAID properties [20].

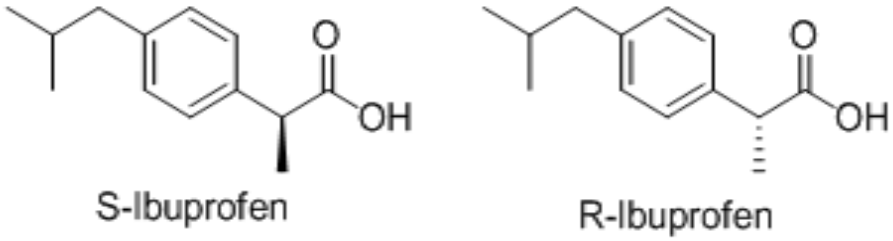


Figure 2: Ibuprofen Enantiomers

3. **DOPA:** DOPA, also known as L-DOPA (L-3,4-dihydroxyphenylalanine) is a naturally occurring amino acid and a precursor in the biosynthesis of several important neurotransmitters, including dopamine, norepinephrine, and epinephrine. It is used as a drug in the treatment of certain medical conditions, most notably Parkinson's disease [21]. It contains a chiral carbon atom, which means it can exist in two stereoisomeric forms: L-DOPA and D-DOPA (Figure 3). In the context of DOPA as a drug, L-DOPA is the form commonly used for therapeutic purposes.

   Due of its ability to pass the blood-brain barrier and turn into dopamine in the brain, it is given to individuals with Parkinson's disease. Dopamine is a neurotransmitter that is essential for controlling movement, and a lack of it is linked to Parkinson's disease's motor symptoms [22]. D-DOPA, on the other hand, is not typically used in medicine due to its lack of activity as a dopamine precursor and its limited ability to cross the blood-brain barrier. Instead, it is mostly used in research or as a reference compound [23].

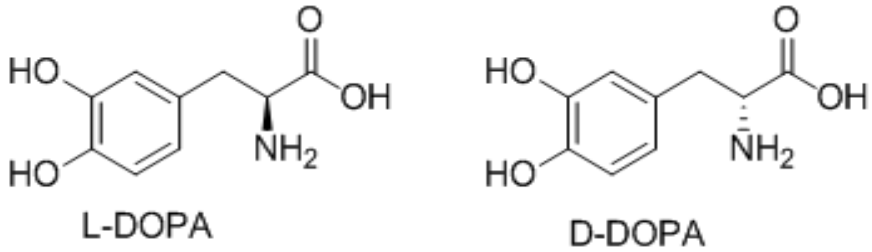


Figure 3: DOPA enantiomers

4. **Propranolol:** Propranolol is a medication used to treat various conditions, primarily hypertension (high blood pressure) and certain cardiovascular disorders. It is a member of the class of medications known as beta-adrenergic receptor antagonists, or beta-blockers [24]. Propranolol's stereochemistry describes how its atoms are arranged in three dimensions, specifically around its chiral centres. There are two potential

stereoisomers of propranolol because it has one chiral centre: (S)-propranolol and (R)-propranolol (Figure 4). The pharmacological effects of propranolol's two enantiomers are similar, yet there are several clear differences. The beta-blocker with greater potency is (S)-propranolol. The majority of beta-1 adrenergic receptors are situated in the heart, and it has greater affinity and selectivity for these receptors. (S)-propranolol is more successful at treating heart-related diseases like angina and arrhythmias because of its higher beta-1 blockage [25].

Compared to (S)-propranolol, (R)-propranolol is less effective and has lesser beta-blocking effects. For beta-2 adrenergic receptors, which are mostly present in the lungs and blood arteries, it exhibits better affinity and selectivity. For those who are sensitive, (R)-propranolol is more likely to result in bronchoconstriction (narrowing of the airways), which may not be ideal for those with respiratory diseases like asthma [26]. In order to provide a balanced and wider spectrum of therapeutic effects, the racemic mixture (a 1:1 combination of both enantiomers) is frequently utilised in clinical practise.

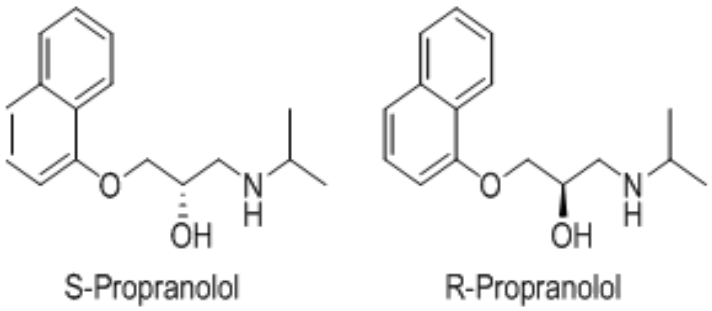


Figure 4: Propranolol Enantiomers

5. **Warfarin:** Warfarin is an anticoagulant medication used to prevent and treat blood clots. It belongs to a class of drugs known as vitamin K antagonists (VKAs) [27]. The primary mechanism of action of warfarin is its interference with the production of certain clotting factors in the liver, specifically factors II, VII, IX, and X, which are dependent on vitamin K for their synthesis [28]. By inhibiting these clotting factors, warfarin helps to prevent the formation of blood clots within the blood vessels, reducing the risk of conditions such as deep vein thrombosis (DVT), pulmonary embolism, and stroke [29].Warfarin has two enantiomers i.e., R-Warfarin and S-warfarin (Figure 5) because of the central chiral carbon atom present in its 3-(α-acetonylbenzyl)-4-hydroxycoumarin structure. (S)-Warfarin is the more potent enantiomer and is responsible for the anticoagulant effects of the drug. It acts as a vitamin K epoxide reductase inhibitor, blocking the recycling of vitamin K epoxide back to its active form. This prevents the synthesis of clotting factors II, VII, IX, and X, as well as anticoagulant proteins C and S, leading to a decrease in blood clotting activity [30].

(R)-Warfarin is much less potent than (S)-Warfarin and has weak anticoagulant activity. In fact, it can act as a competitive inhibitor for the active binding sites of the enzymes affected by (S)-Warfarin, potentially reducing the overall anticoagulant effect when present in the racemic mixture [31].Due to the differing therapeutic activities and potencies of the enantiomers, the use of warfarin as a racemic mixture allows for the

appropriate balance of anticoagulant effects while minimizing potential adverse effects. Individual patient responses to warfarin treatment can vary, and careful monitoring and dosage adjustments are necessary to achieve the desired therapeutic outcomes.

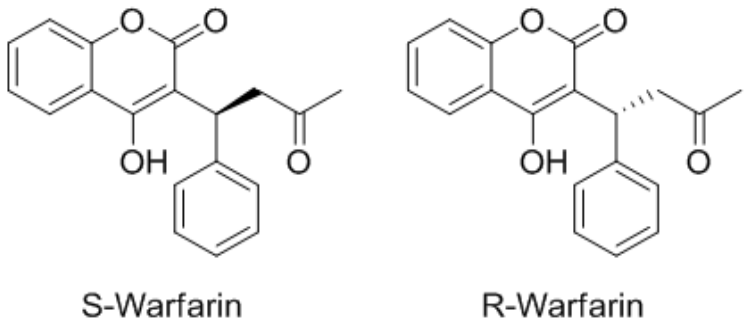


Figure 5: Warfarin Enantiomers

6. **Ketoprofen:** A nonsteroidal anti-inflammatory medicine (NSAID) called ketoprofen is frequently used to treat pain, lessen inflammation, and lower temperature. It is an NSAID from the class of propionic acid. Ketoprofen functions by preventing the body from producing prostaglandins, which are substances that cause pain, inflammation, and fever [32]. It is a racemic mixture, which means that both of its enantiomers are present in equal amounts: Ketoprofen (S) and ketoprofen (R) (Figure 6). The (S)-enantiomer of ketoprofen exhibits potent analgesic, anti-inflammatory, and antipyretic (fever-reducing) effects. It functions by preventing the production of prostaglandins, which cause pain and inflammation.

   Numerous illnesses, including rheumatoid arthritis, osteoarthritis, ankylosing spondylitis, and musculoskeletal problems, have been shown to respond favourably to treatment with the (S)-enantiomer [33]. On the other hand, the (R)-enantiomer of ketoprofen is generally considered to be less active or even inactive compared to the (S)-enantiomer. It may have some minor effects, but its contribution to the overall therapeutic activity of ketoprofen is generally considered negligible [34].

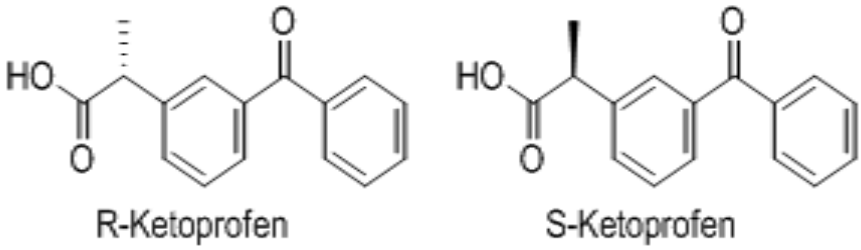


Figure 6: Ketoprofen Enantiomers

7. **Vigabatrin:** Vigabatrin, also known by its brand name Sabril, is an antiepileptic drug (AED) primarily used to treat certain types of seizures. It was approved by the U.S. Food and Drug Administration (FDA) in 2009 for the treatment of complex partial seizures in adult patients who have not responded adequately to other AEDs. It is also used to treat

infantile spasms (West syndrome) in children [35]. Vigabatrin works by inhibiting the enzyme gamma-aminobutyric acid (GABA) transaminase, which is responsible for breaking down GABA, a neurotransmitter that inhibits brain activity. By increasing GABA levels in the brain, vigabatrin helps to reduce abnormal electrical activity and prevent seizures [36]. Vigabatrin is a chiral molecule, meaning it exists in two enantiomeric forms that are mirror images of each other. These enantiomers are designated as (S)-vigabatrin and (R)-vigabatrin (Figure 7). The therapeutic activity of the enantiomers of vigabatrin is not equal. In the case of vigabatrin, only the (S)-enantiomer possesses antiepileptic activity. The (R)-enantiomer, on the other hand, does not have the same therapeutic effect and is considered inactive in terms of antiepileptic activity [37]. As a result, the pharmaceutical preparation of vigabatrin used for medical purposes is typically a mixture of both enantiomers, with the (S)-enantiomer being the active component responsible for the antiepileptic effects.

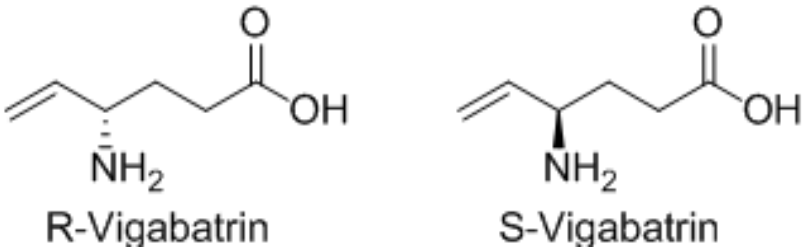


Figure 7: Vigabatrin Enantiomers

8. **Tiaprofenic Acid:** Tiaprofenic acid is a non-steroidal anti-inflammatory drug (NSAID) that is used to relieve pain and reduce inflammation. It belongs to the class of medications known as propionic acid derivatives [38]. Tiaprofenic acid works by inhibiting the production of certain chemicals in the body called prostaglandins. Prostaglandins are responsible for promoting pain, inflammation, and fever. By blocking their production, tiaprofenic acid helps to alleviate pain and reduce inflammation [39]. This medication is commonly used to treat conditions such as arthritis, including rheumatoid arthritis and osteoarthritis, as well as other inflammatory conditions like gout, tendonitis, bursitis, and menstrual pain. It is a chiral molecule, meaning it exists as two enantiomers, which are mirror images of each other. The two enantiomers of Tiaprofenic acid are designated as (S)-Tiaprofenic acid and (R)-Tiaprofenic acid, (Figure 8) based on their spatial arrangement around the chiral centre. (S)-Tiaprofenic acid is the active enantiomer responsible for the therapeutic effects of the drug. It exhibits potent anti-inflammatory, analgesic (pain-relieving), and antipyretic (fever-reducing) properties. By inhibiting the enzyme cyclooxygenase (COX), it prevents the production of prostaglandins, which are mediators of inflammation, pain, and fever. As a result, (S)-Tiaprofenic acid is effective in treating conditions like arthritis, musculoskeletal pain, and other inflammatory disorders [40]. (R)-Tiaprofenic acid is considered the inactive enantiomer, meaning it does not contribute significantly to the therapeutic activity of the drug. While it lacks substantial COX inhibition, it is still present in the drug formulation. However, it may not have significant pharmacological effects compared to the (S)-enantiomer [41].

It's important to note that commercial formulations of Tiaprofenic acid typically contain a racemic mixture of both enantiomers, as separating them can be challenging and costly. The therapeutic effects are primarily driven by the (S)-enantiomer, while the (R)-enantiomer may have minimal or negligible clinical impact.

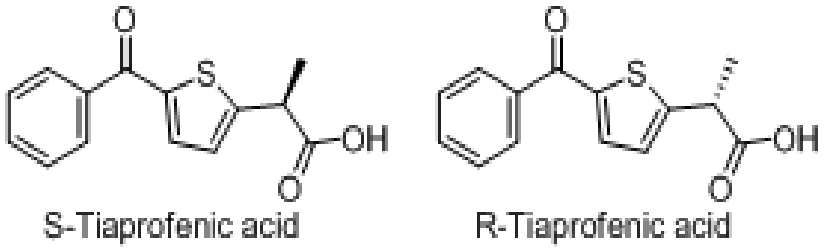


Figure 8: Tiaprofenic acid

9. **Tramadol:** A synthetic opioid painkiller called tramadol is used to relieve mild to moderately severe pain. It is offered under numerous brand names, including Conzip, Ultram, and others. In order to diminish pain perception and change the body's response to pain, tramadol binds to opioid receptors in the brain as well as spinal cord. Many painful illnesses, such as post-operative pain, chronic pain, and pain brought on by injuries, are treated with tramadol, which is frequently administered [42].

The cyclohexane ring of tramadol, also known as 2-(dimethylaminomethyl)-1-(3-methoxyphenyl)cyclohexanol, contains two stereogenic centres. As a result, the compound 2-(dimethylaminomethyl)-1-(3-methoxyphenyl)cyclohexanol can exist in four different configurational forms: (1R,2R), (1S,2S), (1R,2S), and (1S,2R). The primary byproducts of the synthesis route are the racemate (1:1 mixture) of (1R,2R)-isomer and the (1S,2S)-isomer (Figure 9). The (1R,2S)-isomer and the (1S,2R)-isomer's racemic mixture are also generated in trace amounts. The diastereomeric minor racemate [(1R,2S)-isomer and (1S,2R)-isomer] is separated into the (1R,2R)-isomer and the (1S,2S)-isomer by recrystallization of the hydrochlorides. Tramadol is a racemate of the (1R,2R) -(+)- and (1S,2S) -()-enantiomers' hydrochlorides. The main mechanism of action of the (+)-tramadol enantiomer is as a mild serotonin-norepinephrine reuptake inhibitor (SNRI), which prevents the reuptake of these neurotransmitters in the brain. It also contributes to the analgesic effects by raising levels of serotonin and norepinephrine. This enantiomer also exhibits weak affinity for the mu-opioid receptor, contributing to its opioid-like pain-relieving activity. The weak SNRI activity of (+)-tramadol may also contribute to some additional effects such as mood improvement and potential mild antidepressant-like effects [43]. The (-)-tramadol enantiomer has minimal affinity for the mu-opioid receptor and lacks significant opioid-like activity. This means it provides little to no analgesic effect through opioid receptor activation. However, it retains weak serotonin-norepinephrine reuptake inhibition (SNRI) activity, contributing to some degree of pain relief and other effects similar to (+)-tramadol [44].

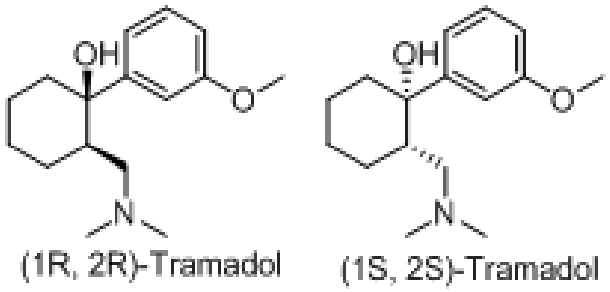


Figure 9: Tramadol Enantiomers

10. Flurbiprofen: Flurbiprofen is a nonsteroidal anti-inflammatory drug (NSAID) that is commonly used for the treatment of pain and inflammation. It belongs to the propionic acid class of NSAIDs [45]. Flurbiprofen works by inhibiting the production of certain chemicals in the body called prostaglandins, which are responsible for pain and inflammation. By reducing the levels of prostaglandins, flurbiprofen helps to alleviate pain, reduce swelling, and lower fever [46]. This medication is commonly used to relieve symptoms associated with various conditions, including osteoarthritis, rheumatoid arthritis, menstrual cramps, dental pain, sports injuries, and other musculoskeletal disorders. It is a chiral molecule, meaning it exists in two enantiomeric forms, namely (S)-flurbiprofen and (R)-flurbiprofen (Figure 10).

(S)-flurbiprofen is the active enantiomer and is responsible for most of the therapeutic effects of the drug, including its anti-inflammatory and analgesic activities. It inhibits the activity of cyclooxygenase enzymes (COX), particularly COX-1 and COX-2, which are involved in the production of prostaglandins that mediate pain and inflammation [47]. (R)-flurbiprofen, on the other hand, has much weaker COX inhibitory activity compared to the (S)-enantiomer. In fact, (R)-flurbiprofen is often considered an inactive enantiomer with minimal contribution to the therapeutic effects of the drug [48].

In summary, (S)-flurbiprofen is the pharmacologically active enantiomer responsible for the therapeutic effects of flurbiprofen, while (R)-flurbiprofen is considered relatively inactive in this context. All flurbiprofen formulations are now marketed as the racemate, despite the fact that the (S)-enantiomer has the majority of the beneficial anti-inflammatory activity and that both enantiomers may also have analgesic properties.

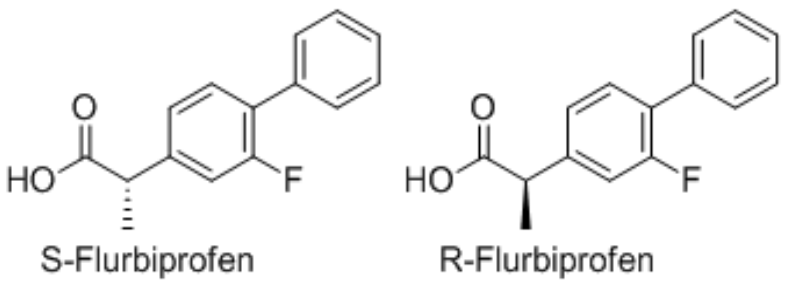


Figure 10: Flurbiprofen Enantiomers

11. Methadone: A synthetic opioid drug called methadone is primarily used to treat opioid dependence and manage chronic pain [49]. It was first developed in the 1930s and has since become an essential part of opioid addiction treatment programs. When someone is addicted to opioids like heroin or prescription medicines, methadone is frequently administered as a long-term maintenance drug. It aids in reducing cravings and withdrawal symptoms, helping people to stabilise their lives and make progress towards recovery. Although methadone has a longer duration of effect than other opioids, it nevertheless operates on the same opioid receptors in the brain [50]. Due to the chiral centre of methadone, it possesses two enantiomers: (R)-methadone and (S)-methadone (Figure 11). Both enantiomers of methadone contribute to its overall therapeutic effects, but they differ in their potency and pharmacokinetics.

(R)-methadone is considered more potent than the (S)-enantiomer and is primarily responsible for the analgesic effects of methadone. It has a longer half-life than (S)-methadone, which means it stays in the body for a longer duration [51].

(S)-methadone is less potent than the (R)-enantiomer and it plays a role in the overall pharmacological activity of the drug. It has a shorter half-life compared to (R)-methadone [52]. The clinical use of methadone typically involves a racemic mixture of both enantiomers, as this combination provides the most balanced therapeutic profile. The (R)-enantiomer contributes to analgesia and long-lasting effects, while the (S)-enantiomer helps with maintaining stable blood levels and reducing the risk of side effects.

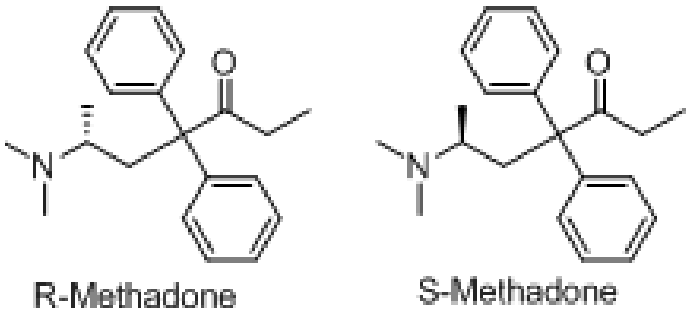


Figure 11: Methadone Enantiomers

12. Cetirizine: Cetirizine belongs to the group of drugs known as piperazines, which are compounds in which the nitrogen-attached hydrogens are changed to 4-chlorophenyl)(phenyl)methyl and 2-(carboxymethoxy)ethyl groups, respectively [53]. One of the most popular uses for this medication is for a condition known as allergic rhinitis. It is an orally active second-generation histamine H1 antagonist proved useful in the treatment of a variety of allergic symptoms, such as sneezing, coughing, nasal congestion, hives, and other symptoms [54]. Cetirizine is available as a racemic mixture, which contains equal amounts of two enantiomers: (R)-cetirizine and (S)-cetirizine (Figure 12). (R)-Cetirizine also known as levocetirizine is the active enantiomer of cetirizine and is responsible for its antihistamine effects.

It acts as a selective antagonist of histamine H1 receptors, which are involved in allergic responses. By blocking these receptors, (R)-cetirizine reduces the effects of

histamine, a chemical released during allergic reactions, thereby alleviating allergy symptoms. Compared to cetirizine, levocetirizine has a higher affinity for the histamine H1 receptor. The FDA approved levocetirizine in 1995 [55]. (S)-Cetirizine is considered inactive and does not contribute significantly to the therapeutic effects of cetirizine. However, it is not entirely without activity and may have some influence on the drug's overall pharmacokinetics [55].

In summary, the therapeutic activity of cetirizine is mainly attributed to its (R)-enantiomer, which acts as an antihistamine, providing relief from allergy symptoms. The (S)-enantiomer is less active but still present in the racemic mixture of cetirizine. Pharmaceutical formulations of cetirizine often contain only the active (R)-enantiomer to optimize its therapeutic effects while minimizing any unnecessary effects from the (S)-enantiomer.

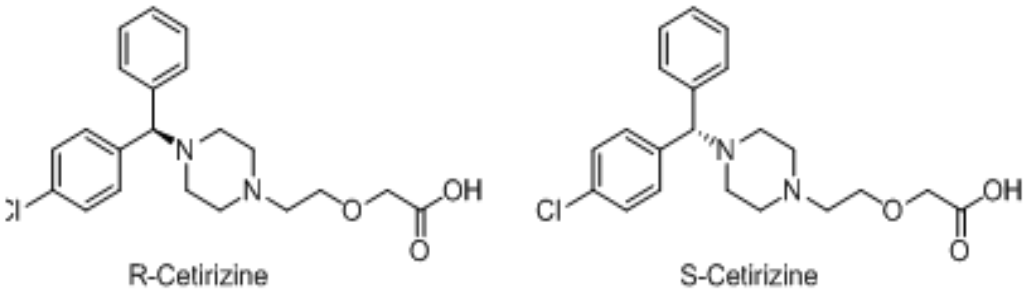


Figure 12: Cetirizine Enantiomers

13. **Morphine:** Morphine is an opioid alkaloid derived from the opium poppy plant (Papaver somniferum). It is a powerful analgesic (pain-relieving) drug and is used medically for pain management, especially in severe or chronic pain cases [56]. Morphine has a complex structure with several chiral centers, resulting in multiple stereoisomers. However, its most important chiral center is the C6 carbon atom, which gives rise to two enantiomers: (-)-morphine and (+)-morphine (Figure 13). Both enantiomers of morphine exhibit analgesic effects, but they can have different pharmacological properties. Generally, (-)-morphine is the more potent enantiomer and is responsible for most of the analgesic activity observed. It has a higher affinity for opioid receptors, particularly the mu-opioid receptor, which is primarily responsible for the analgesic effects of opioids [57]. On the other hand, (+)-morphine is less potent and has a lower affinity for opioid receptors compared to (-)-morphine. However, it can still contribute to the overall analgesic effect and may be involved in some of the side effects associated with morphine, such as respiratory depression and sedation [57].

In medical practice, morphine is used as a racemic mixture of both (-)- and (+)-morphine. The combination allows for a more balanced pharmacological profile, providing effective pain relief while minimizing certain side effects.

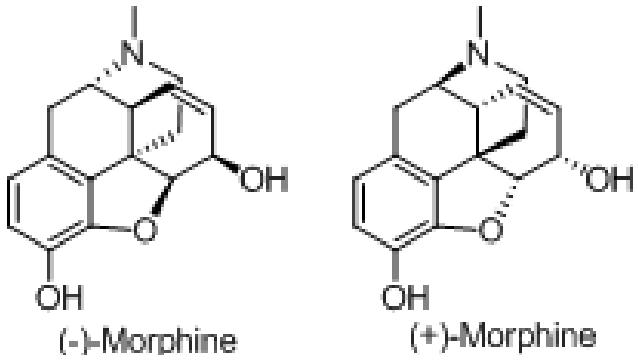


Figure 13: Morphine Enantiomers

14. Fluoxetine: The antidepressant drug fluoxetine is an SSRI (selective serotonin reuptake inhibitor). Various mental health issues can be treated with it; it is frequently prescribed under the trade name Prozac. Fluoxetine is most frequently used to treat major depressive disorder (MDD), obsessive-compulsive disorder (OCD), panic disorder, bulimia nervosa, and premenstrual dysphoric disorder (PMDD) [58]. Furthermore, it may be administered off-label for additional ailments. A neurotransmitter called serotonin is increased in the brain as a result of fluoxetine's action. R-fluoxetine and S-fluoxetine (Figure 14), two enantiomers of the drug fluoxetine, are combined in a racemic combination.

S-fluoxetine is the more active enantiomer responsible for the main therapeutic effects of fluoxetine. It boosts serotonin levels in the brain by blocking its reabsorption by nerve cells since it is a powerful and selective serotonin reuptake inhibitor. Increased serotonin availability is associated with improved mood and is the basis of fluoxetine's antidepressant action [59].

R-fluoxetine is less potent than the S-isomer in inhibiting serotonin reuptake. It is believed to have a weaker antidepressant effect compared to the S-enantiomer. However, R-fluoxetine does contribute to the overall therapeutic activity of the racemic mixture and may play a role in the drug's pharmacological effects [60].

The combination of R- and S-fluoxetine in the racemic mixture allows for a more balanced and effective antidepressant treatment compared to the individual enantiomers alone. While R-fluoxetine contributes to the overall effects, it is the S-enantiomer that plays the key role in the drug's therapeutic activity.

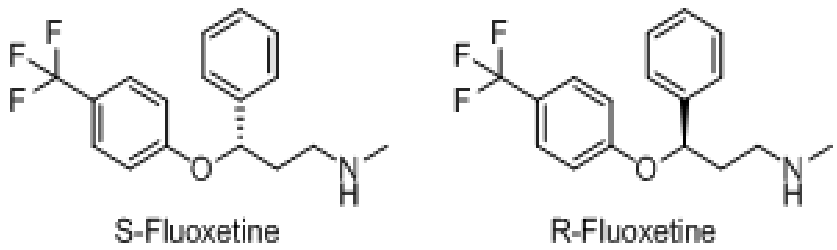


Figure 14: Fluoxetine Enantiomers

15. **Formoterol:** Formoterol is a long-acting beta-agonist (LABA) drug that is primarily used to treat asthma as well as chronic obstructive pulmonary disease (COPD) [61]. It facilitates breathing for those with COPD or asthma by relaxing the smooth muscles of the airways, which relieves bronchoconstriction. To exert its effects, formoterol binds to beta-2 adrenergic receptors found in the smooth muscle cells of the airways. This binding stimulates the receptors, causing the muscles to relax and the airways to widen, decreasing bronchoconstriction [62]. In the treatment of asthma and COPD, formoterol is frequently used as a maintenance drug. It is not meant for immediate relief of acute asthma attacks; instead, it is used to prevent and control symptoms over time. Formoterol exists as a racemic mixture of two enantiomers: (R, R)-formoterol and (S, S)-formoterol (Figure 15). Both enantiomers of formoterol, (R, R)-formoterol and (S, S)-formoterol, contribute to its therapeutic activity. However, (R, R)-formoterol is known to be the pharmacologically active enantiomer and is responsible for the majority of the bronchodilator effect [63]. The (S, S)-formoterol, although less active, also exhibits some bronchodilatory properties.

    The (R, R)-formoterol isomer has a higher affinity for the beta-2 adrenergic receptors in the lungs compared to the (S, S)-formoterol. This higher affinity results in a more potent and longer-lasting bronchodilatory effect, making it the desired enantiomer for treating asthma and COPD [64].

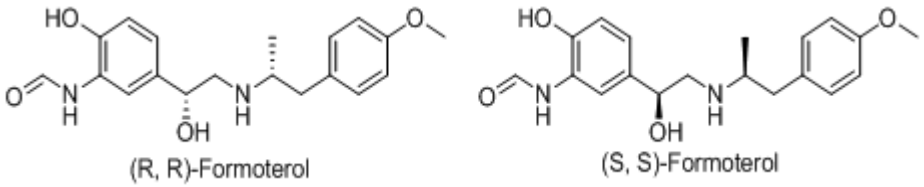


Figure 15: Formoterol Enantiomers

16. **Modafinil:** Modafinil is a medication that is primarily used to promote wakefulness in individuals with certain sleep disorders [65]. It was first approved by the U.S. Food and Drug Administration (FDA) in 1998 under the brand name "Provigil" and is classified as a eugeroic or wakefulness-promoting agent. Some of the common medical conditions for which modafinil may be prescribed include Narcolepsy, Obstructive Sleep Apnea (OSA), Shift Work Sleep Disorder (SWSD). Modafinil works by affecting certain chemicals in the brain that regulate sleep and wakefulness.

    It enhances wakefulness and alertness without causing significant stimulation or euphoria, unlike traditional stimulant drugs [66].It is a racemic compound, which means it consists of equal amounts of two enantiomers: R-modafinil (or armodafinil) and S-modafinil (Figure 16).

    Armodafinil is the (R)-enantiomer of modafinil and is marketed as a separate medication from the racemic mixture. It is believed to have a more potent effect compared to S-modafinil and is responsible for the majority of the wakefulness-promoting activity of modafinil. Armodafinil has a longer duration of action, allowing it to maintain its wakefulness-promoting effects for a longer period compared to S-

modafinil [67]. Armodafinil is used for the same therapeutic indications as modafinil, such as narcolepsy, obstructive sleep apnea, and shift work sleep disorder [67].

The (S)-enantiomer of modafinil (S-modafinil) is less potent than R-modafinil (armodafinil) and contributes less to the overall therapeutic activity of the racemic modafinil. However, it still contributes to the wakefulness-promoting effects of the drug to some extent [68].

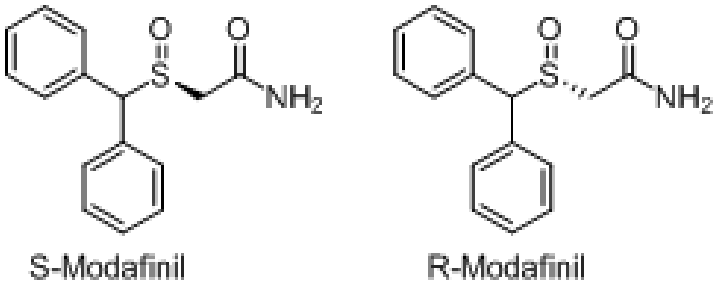


Figure 16: Modafinil Enantiomers

17. **Lansoprazole:** Lansoprazole is a medication that belongs to a class of drugs known as proton pump inhibitors (PPIs) [69]. It is commonly used to treat various gastrointestinal conditions, particularly those related to excess stomach acid production. Lansoprazole works by blocking the action of proton pumps in the stomach lining, which reduces the amount of acid produced [70]. Some of the conditions that lansoprazole is used to treat include Gastroesophageal reflux disease (GERD), Peptic ulcers, Zollinger-Ellison syndrome, Helicobacter pylori eradication. Lansoprazole is a chiral molecule, meaning it exists in two enantiomeric forms, known as (S)-lansoprazole and (R)-lansoprazole also known as dexlansoprazole (Figure 17). Both enantiomers of lansoprazole, (S)-lansoprazole and (R)-lansoprazole, contribute to the overall therapeutic effects of the drug.

However, the (S)-enantiomer is primarily responsible for the pharmacological activity, while the (R)-enantiomer is considered to be pharmacologically inactive. (S)-lansoprazole is a potent inhibitor of the gastric proton pump, H+/K+-ATPase, which is responsible for acid secretion in the stomach. By inhibiting this pump, (S)-lansoprazole reduces the production of gastric acid, providing relief from acid-related conditions like GERD and peptic ulcers [71].

The (R)-enantiomer, on the other hand, does not significantly contribute to the inhibition of gastric acid secretion and is mainly excreted unchanged in the urine [72].It's important to note that lansoprazole is usually administered as a racemic mixture of both enantiomers, as the (R)-enantiomer is considered to be relatively harmless and does not interfere with the therapeutic effects of the (S)-enantiomer. The (R)-enantiomer does not exhibit any clinically relevant pharmacological activity and is considered to be pharmacokinetically inert.

Therefore, both enantiomers are usually present in lansoprazole formulations, but the (S)-enantiomer is the one responsible for its therapeutic activity.

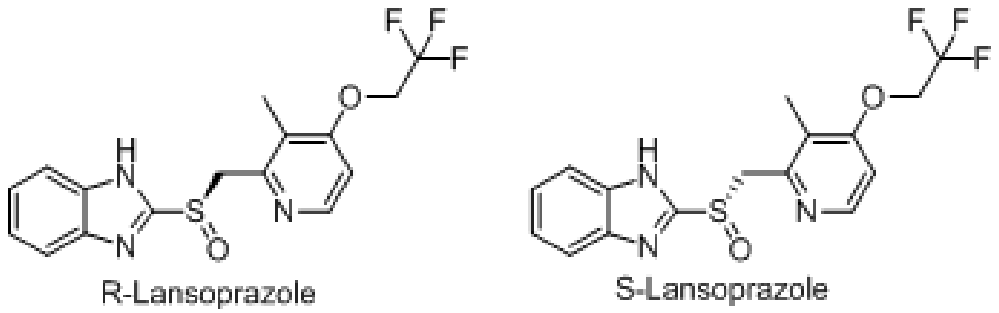


Figure 17: Lansoprazole Enantiomers

18. **Methylphenidate:** Methylphenidate is a central nervous system (CNS) stimulant and a medication used primarily to treat attention deficit hyperactivity disorder (ADHD) and narcolepsy [73]. It is sold under various brand names, including Ritalin, Concerta, Daytrana, and Metadate, among others. Methylphenidate works by increasing the levels of certain neurotransmitters, primarily dopamine and norepinephrine, in the brain. These neurotransmitters play a crucial role in regulating attention, focus, and impulse control [74].

    It exists as a racemic mixture of two enantiomers: dextromethylphenidate (D-MPH) and levomethylphenidate (L-MPH) (Figure 18). Dextromethylphenidate (D-MPH) is the more potent and therapeutically active enantiomer in methylphenidate. It is responsible for the desired effects in treating ADHD and narcolepsy. The mechanism of action involves blocking the reuptake of norepinephrine and dopamine, leading to increased concentrations of these neurotransmitters in the brain. This increase in neurotransmitter levels helps improve attention, focus, and impulse control in individuals with ADHD [75]. Levomethylphenidate (L-MPH) has some stimulant properties, but it is less potent and contributes minimally to the therapeutic effects of methylphenidate. It may have milder effects on norepinephrine and dopamine reuptake, but its activity is not as pronounced as the dextro- enantiomer [76].

    Overall, the therapeutic effects of methylphenidate are mainly attributed to dextromethylphenidate (D-MPH), which is more potent and clinically relevant, while levomethylphenidate (L-MPH) has limited therapeutic significance in the context of ADHD and narcolepsy treatment.

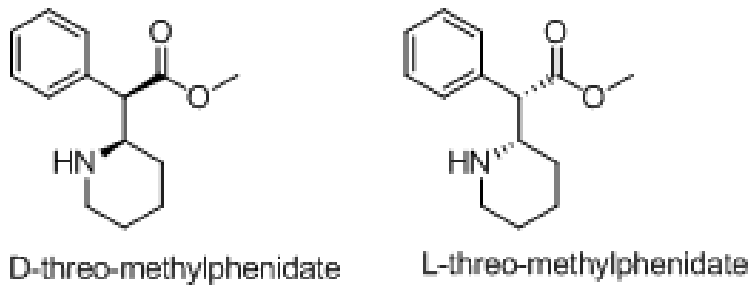


Figure 18: Methylphenidate Enantiomers

19. **Amphetamine:** Amphetamine is a central nervous system stimulant drug that belongs to the class of substances known as sympathomimetic amines [77]. It is a powerful psychoactive substance that can increase alertness, focus, and energy while also producing feelings of euphoria and heightened confidence. Amphetamines can be prescribed by doctors for specific medical conditions such as attention deficit hyperactivity disorder (ADHD) and narcolepsy, where they are used to improve attention, concentration, and manage excessive daytime sleepiness.

When taken, amphetamines stimulate the release of certain neurotransmitters, such as dopamine, norepinephrine, and serotonin, in the brain. This action increases brain activity, resulting in the heightened alertness and euphoria experienced by users [78]. Amphetamine is a chiral compound, meaning it exists in two different enantiomeric forms: (S)-amphetamine and (R)-amphetamine (Figure 19).

(S)-amphetamine (also known as dextroamphetamine or d-amphetamine) is a psychostimulant and central nervous system stimulant. It is used clinically to treat attention deficit hyperactivity disorder (ADHD), narcolepsy, and obesity (though it is rarely prescribed for the latter). (S)-amphetamine increases the levels of certain neurotransmitters, such as dopamine and norepinephrine, in the brain, leading to increased focus, alertness, and energy [79].

(R)-amphetamine (also known as levoamphetamine or l-amphetamine) is less potent than its (S)-enantiomer and has limited therapeutic use on its own [80]. However, it is sometimes present in combination formulations with (S)-amphetamine. The combination of both enantiomers is referred to as "mixed amphetamine salts" and is commonly used to treat ADHD and narcolepsy. The (R)-enantiomer contributes to the overall pharmacological effects, but the (S)-enantiomer is primarily responsible for the therapeutic activity.

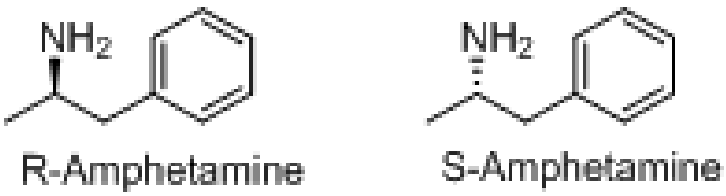


Figure 19: Amphetamine Enantiomers

20. **Citalopram:** The SSRI (selective serotonin reuptake inhibitor) pharmacological class includes citalopram as an antidepressant [81]. Increasing serotonin levels in the brain is the main method through which citalopram works. In order to control mood, emotions, and behaviour, serotonin, a neurotransmitter, is essential. Citalopram assists in maintaining higher amounts of serotonin in the brain by preventing its reuptake, which elevates mood and lessens depressive symptoms [82].

In order to treat depression, citalopram is typically utilised. It may also be given as a prescription for other diseases such panic disorder, social anxiety disorder (often known

as a social phobia), generalised anxiety disorder, and obsessive-compulsive disorder (OCD).

Citalopram is a chiral molecule, which means it has two stereoisomers or enantiomers that are mirror images of one another. The names of these enantiomers are (S)- and (R)-citalopram (Figure 20). The therapeutic activity of citalopram is primarily associated with the (S)-enantiomer, also known as escitalopram. Escitalopram is the active form that exerts the desired antidepressant effects [83]. As a result, the (S)-enantiomer is typically the one used in pharmaceutical preparations of citalopram.

The (R)-enantiomer, also known as R-citalopram, is considered inactive and does not contribute significantly to the therapeutic effects of the medication. In fact, it is believed that the (R)-enantiomer may even have a detrimental effect on the overall pharmacological profile of citalopram, potentially leading to certain side effects [84].

Due to the superior therapeutic activity and fewer side effects of (S)-citalopram (escitalopram), it is often marketed as a separate medication from citalopram, under the brand name Lexapro or Cipralex. Escitalopram is approved for the treatment of major depressive disorder and generalized anxiety disorder, among other conditions.

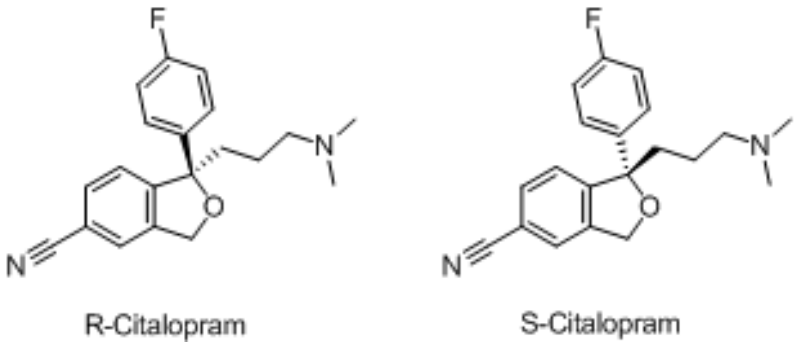


Figure 20: Citalopram Enantiomers

21. Omeprazole: The medicine omeprazole is a member of the proton pump inhibitors (PPIs) pharmacological class [85]. It is frequently used to treat ailments linked to overactive stomach acid production. The way omeprazole works is by lessening the amount of acid the stomach produces, which can aid in symptom relief and facilitate healing in a number of gastrointestinal diseases [86]. Omeprazole is frequently prescribed for conditions like Zollinger-Ellison syndrome, erosive esophagitis, peptic ulcers, and gastroesophageal reflux disease (GERD). There are four potential stereoisomers of omeprazole due to its two chiral centres. The marketed medicine, however, only contains two of the enantiomers because they are synthesised during the manufacturing process. Omeprazole comes in two enantiomers, S-Omeprazole and R-Omeprazole (Figure 21). Omeprazole is delivered as a racemic combination, which means that both enantiomers are present in equal amounts.

Esomeprazole is another name for the S-enantiomer. The medicinal benefits of omeprazole are brought on by its active enantiomer. It works by permanently blocking the

proton pump enzyme, or H+/K+-ATPase, in the parietal cells of the stomach. For the gastric mucosa to secrete acid, this enzyme is necessary. Esomeprazole decreases stomach acid production by blocking this enzyme, offering relief from illnesses caused by excess stomach acid [87]. It is frequently believed that the R-enantiomer is inert or has lower pharmacological activity than esomeprazole. It does not significantly impact omeprazole's therapeutic benefits. However, during metabolism, R-omeprazole is partially responsible for the overall effectiveness of omeprazole since it is partially converted to S-omeprazole in the liver [88].

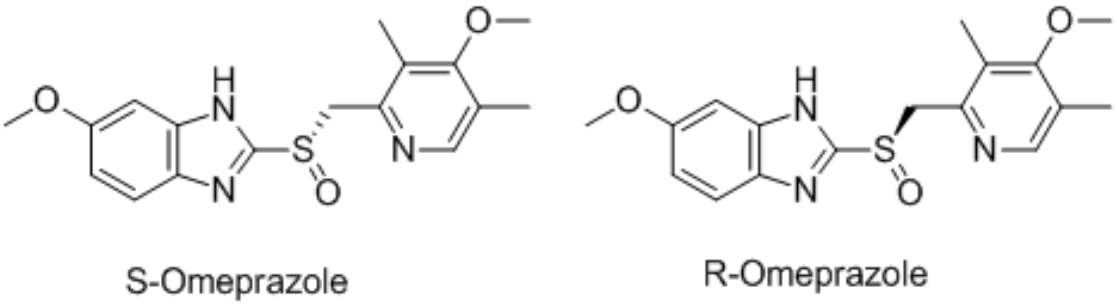


Figure 21: Omeprazole Enantiomers

22. Zopiclone: Zopiclone is a sedative-hypnotic medication that is used to treat insomnia. It belongs to a class of drugs known as cyclopyrrolones and is often prescribed to help individuals with difficulty falling asleep or staying asleep [89]. As a sedative, zopiclone works by enhancing the effects of gamma-aminobutyric acid (GABA), a neurotransmitter in the brain that has inhibitory effects. GABA helps reduce the activity of nerve cells, which in turn produces a calming effect, promoting sleep and reducing anxiety [90]. It is a racemic mixture, which means it contains equal amounts of two enantiomers: (S)-Zopiclone and (R)-Zopiclone (Figure 22).

(S)-Zopiclone also known as eszopiclone is considered the active form of the drug. It binds to specific receptors in the brain called GABA-A receptors, which are involved in the regulation of sleep and anxiety. By binding to these receptors, (S)-Zopiclone enhances the effects of gamma-aminobutyric acid (GABA), a neurotransmitter that inhibits brain activity, leading to sedative and sleep-inducing effects [91]. While (R)-Zopiclone does bind to GABA-A receptors, it does not exhibit the same level of therapeutic activity as the (S)-enantiomer. In fact, (R)-Zopiclone may even antagonize some of the effects of (S)-Zopiclone, reducing its overall potency [92].

Due to these differences in pharmacological activity, (S)-Zopiclone is primarily responsible for the therapeutic effects of Zopiclone in promoting sleep, while (R)-Zopiclone's contribution is considered negligible. Therefore, pharmaceutical formulations of Zopiclone often contain only the (S)-enantiomer to maximize the drug's efficacy while minimizing potential side effects associated with the (R)-enantiomer.

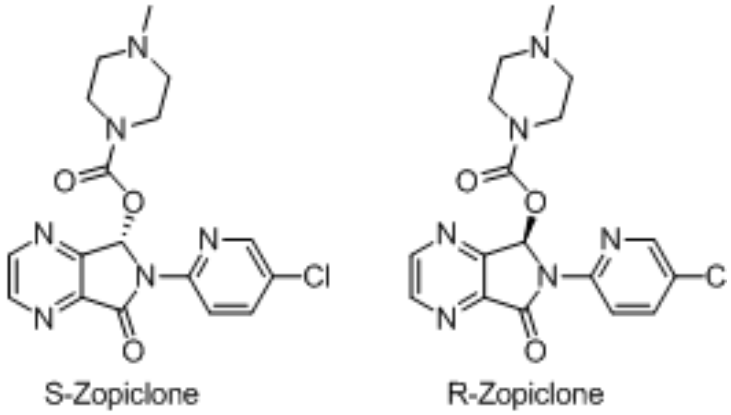


Figure 22: Zopiclone Enantiomers

23. Albuterol: The drug albuterol, usually referred to as salbutamol, is frequently prescribed to treat asthma as well as other respiratory ailments. It is a member of the group of medications known as bronchodilators or beta-2 adrenergic agonists [93]. Albuterol helps people with respiratory problems breathe more easily by relaxing and widening the airways in the lungs. The smooth muscles of the airways include beta-2 adrenergic receptors, which albuterol binds to. As a result of this binding, the bronchial passageways enlarge and the resistance of the airways decreases [94]. Asthma, chronic obstructive pulmonary disease (COPD), and other reversible obstructive airway illnesses are among the conditions for which albuterol is typically recommended for the treatment and prevention of bronchospasm.Albuterol is commonly administered as a racemic mixture of two enantiomers: (R)-albuterol (levalbuterol) and (S)-albuterol (Figure 23).

The therapeutic effects of albuterol are primarily attributed to its (R)-enantiomer, levalbuterol. Studies have shown that (R)-albuterol exhibits greater selectivity for the β2-adrenergic receptors, which are found in the smooth muscles of the airways. By selectively binding to these receptors, (R)-albuterol stimulates bronchial smooth muscle relaxation, leading to bronchodilation. This property makes it effective in relieving bronchospasm and improving airflow in conditions like asthma and COPD [95].

On the other hand, the (S)-enantiomer of albuterol, while still having some bronchodilatory activity, has been associated with increased cardiovascular side effects, such as tachycardia and palpitations, compared to the (R)-enantiomer. Due to these potential adverse effects, (S)-albuterol is considered less desirable for therapeutic use [96].

As a result, pharmaceutical formulations of albuterol often contain the (R)-enantiomer (levalbuterol) as the active ingredient, while minimizing the presence of the (S)-enantiomer to reduce side effects and optimize therapeutic efficacy.

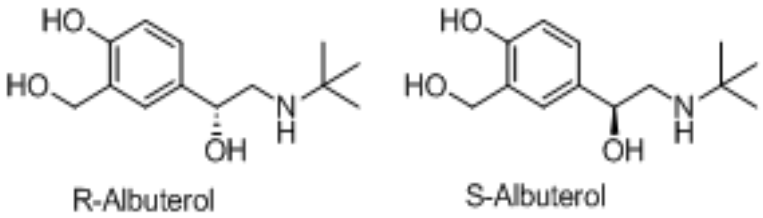


Figure 23: Albuterol Enantiomers

24. Betaxolol: Betaxolol is a medication that belongs to a class of drugs known as beta-blockers [97]. It is primarily used to treat various cardiovascular conditions, particularly hypertension (high blood pressure) and certain heart rhythm disorders like atrial fibrillation and atrial flutter. It acts as a selective beta-1 adrenergic receptor blocker, meaning it primarily targets the beta-1 receptors in the heart. By blocking these receptors, it reduces the influence of the sympathetic nervous system on the heart, resulting in a slower heart rate and reduced contractility, which helps to lower blood pressure and manage certain heart rhythm disorders [98].

Betaxolol has one chiral carbon resulting in two stereoisomers i.e., (R)-betaxolol and (S)-betaxolol (Figure 24). (R)-betaxolol also known as levobetaxolol is a selective beta-1 adrenergic receptor blocker. It primarily acts on beta-1 receptors found in the heart and helps to reduce the heart rate and myocardial contractility. By blocking these receptors, it decreases the force and rate of heart contractions, reducing the workload on the heart. This effect is beneficial in treating hypertension and various cardiovascular conditions [99]. (S)-betaxolol is also a beta-blocker, but it exhibits more non-selective activity, affecting both beta-1 and beta-2 adrenergic receptors. Beta-2 receptors are found in the bronchioles of the lungs and in blood vessels, among other places. Blocking these receptors can lead to bronchoconstriction and peripheral vasoconstriction, which may be less desirable for patients with certain respiratory conditions [100].

As a racemic mixture, betaxolol contains equal amounts of both enantiomers. The (R)-enantiomer's selective beta-1 blocking activity makes it the more desirable component for treating hypertension and certain cardiovascular conditions because it primarily targets the heart, minimizing unwanted side effects related to beta-2 receptor blockade.

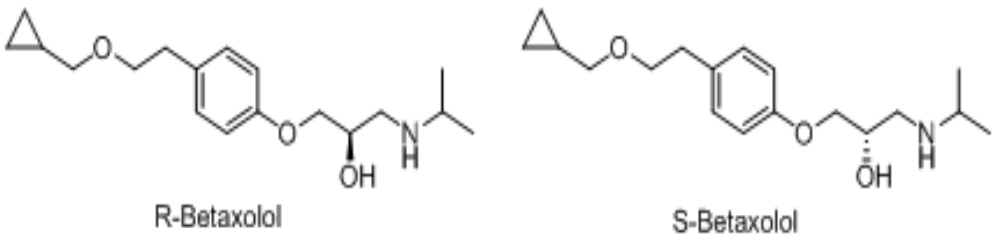


Figure 24: Betaxolol Enantiomers

25. **Bupivacaine:** Bupivacaine is a local anesthetic medication used to numb specific areas of the body during medical procedures or surgeries. It belongs to the amide class of local anaesthetics and is commonly used to provide regional anesthesia, such as nerve blocks, epidural anesthesia, and spinal anesthesia [101]. The primary mode of action of bupivacaine is to block the transmission of nerve impulses by inhibiting the influx of sodium ions through nerve cell membranes.

This action prevents the nerves from transmitting pain signals to the brain, leading to temporary loss of sensation in the area where the medication is administered [102]. Bupivacaine exists as a racemic mixture of two enantiomers: R-bupivacaine (levobupivacaine) and S-bupivacaine (dextrobupivacaine) (Figure 25). Levobupivacaine (S-enantiomer) is the more active and pharmacologically important enantiomer of bupivacaine.

Levobupivacaine provides potent and long-lasting local anesthesia, making it the preferred choice for various medical procedures. It has a similar profile of action to racemic bupivacaine but with potentially fewer cardiovascular side effects. Levobupivacaine's therapeutic activity is responsible for the analgesic effect and temporary loss of sensation in the targeted area [103].

Dextrobupivacaine (R-enantiomer) is less active as a local anesthetic compared to levobupivacaine. It has a lower potency and a shorter duration of action. Due to its reduced activity, it is not commonly used in clinical practice for regional anesthesia [104].

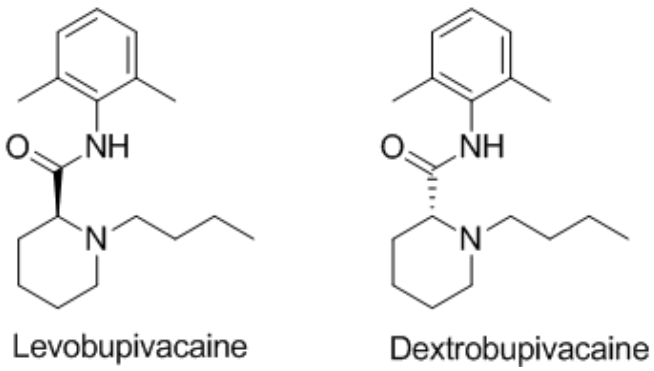


Figure 25: Bupivacaine Enantiomers

26. **Ofloxacin:** Ofloxacin is an antibiotic drug used to treat different bacterial infections. It is an antibiotic that belongs to the fluoroquinolone class and is efficient against a variety of bacteria [105]. By interfering with the process of bacterial DNA replication, ofloxacin prevents bacterial development and finally kills the bacterium. diseases in the respiratory tract, urinary tract, skin and soft tissues, sexually transmitted diseases, and gastrointestinal infections are among the conditions for which this drug is frequently recommended [106].

It exists as a racemic mixture of two enantiomers: (S)-Ofloxacin and (R)-Ofloxacin (Figure 26).Both enantiomers of ofloxacin contribute to the antibiotic activity

of the drug, but their potency and pharmacokinetic properties may vary. The (S)-ofloxacin enantiomer is generally considered to be more active against bacterial targets and is responsible for most of the antibacterial efficacy of the drug. It exhibits stronger binding to the bacterial enzymes responsible for inhibiting DNA gyrase and topoisomerase IV, which are essential for bacterial DNA replication and repair. This increased binding affinity leads to better bactericidal activity against a broader spectrum of bacteria [107].

On the other hand, the (R)-ofloxacin enantiomer has weaker antibacterial activity compared to (S)-ofloxacin. However, it still contributes to the overall efficacy of the drug, and its presence might help reduce the development of bacterial resistance and provide a broader spectrum of coverage [108].

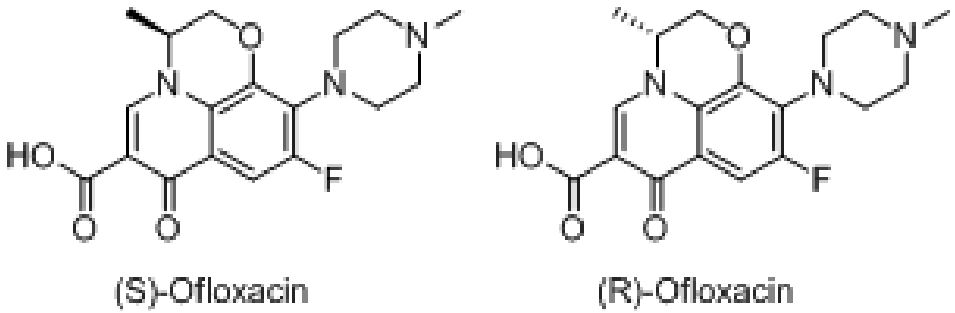


Figure 26: Ofloxacin Enantiomers

27. **Atenolol:** Atenolol is a medication that belongs to the class of drugs known as beta-blockers [109]. It is primarily used to treat certain cardiovascular conditions, particularly hypertension (high blood pressure) and angina (chest pain). Atenolol works by blocking the action of certain chemicals in the body, such as adrenaline, that can increase heart rate and blood pressure [110].

Atenolol is a chiral compound, which means it exists as two enantiomers (R)-atenolol and (S)-atenolol (Figure 27). (R)-atenolol is responsible for the desired beta-blockade activity, which helps to lower blood pressure and reduce the strain on the heart. It selectively blocks beta-1 adrenergic receptors in the heart, leading to decreased heart rate and force of contraction.

This results in reduced cardiac output and blood pressure, making it an effective treatment for hypertension and other cardiovascular conditions [111]. (S)-atenolol also has beta-blocking activity, but it is less potent compared to (R)-atenolol. In fact, (S)-atenolol may even exhibit some partial agonist activity, which means it could have stimulatory effects on beta-adrenergic receptors in certain situations. Due to its weaker beta-blocking activity, (S)-atenolol is considered less therapeutically relevant than the (R)-enantiomer [112].

The pharmaceutical formulation of atenolol typically contains a racemic mixture of both enantiomers, meaning it contains equal amounts of (R)-atenolol and (S)-atenolol. This is because the separation and synthesis of single enantiomers can be more complex

and expensive, and the therapeutic benefits of (R)-atenolol are considered to outweigh any potential drawbacks from the (S)-enantiomer.

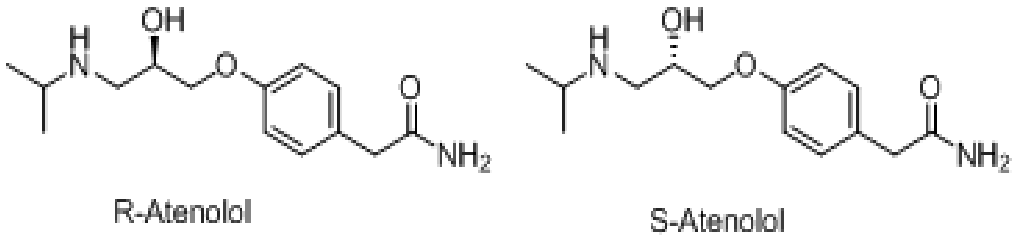


Figure 27: Atenolol Enantiomers

28. Ifosfamide: Ifosfamide is a medication used in cancer chemotherapy to treat various types of cancer. It belongs to a class of drugs known as alkylating agents [113]. Ifosfamide is particularly effective against certain types of cancers, such as testicular cancer, ovarian cancer, bladder cancer, and some types of soft tissue sarcomas. Ifosfamide works by damaging the DNA within cancer cells, interfering with their ability to grow and divide. It does this through a process called alkylation, where it attaches alkyl groups to the DNA molecules, leading to breaks in the DNA strands and preventing the cancer cells from replicating [114].

Ifosfamide has a chiral center, meaning it has two possible enantiomers: (R)-ifosfamide and (S)-ifosfamide (Figure 28). (R)-Ifosfamide is the more active form and is responsible for most of the drug's therapeutic effects. It is metabolized in the liver to form the active alkylating agent called 4-hydroxyifosfamide. This metabolite is responsible for the antitumor activity of the drug by crosslinking DNA and inhibiting cell division in cancer cells [115]. (S)-Ifosfamide is less pharmacologically active compared to its counterpart.

It is also metabolized in the liver, but the resulting metabolites are less effective as alkylating agents, leading to reduced antitumor activity [115].

The racemic mixture (a 1:1 mixture of both enantiomers) of ifosfamide is commonly used in clinical practice, where the (R)-enantiomer contributes to the therapeutic activity, while the (S)-enantiomer may have some limited effects.

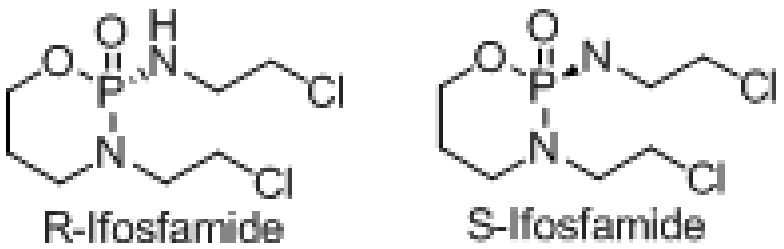


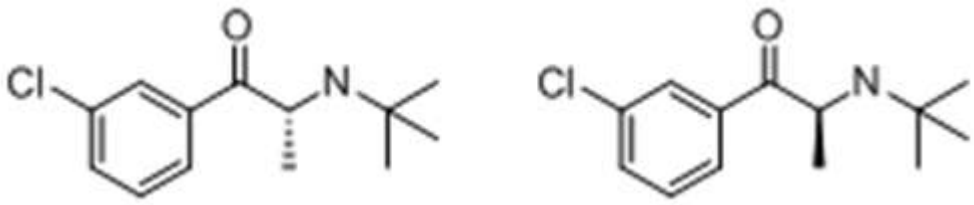
Figure 28: Ifosfamide Enantiomers

29. Bupropion: Bupropion, commonly known by its brand name Wellbutrin, is a medication primarily used as an antidepressant and smoking cessation aid. It belongs to the class of drugs known as atypical antidepressants or norepinephrine-dopamine reuptake inhibitors (NDRIs).

Bupropion works by affecting the levels of certain neurotransmitters in the brain, namely norepinephrine and dopamine. Bupropion works by inhibiting the reuptake of norepinephrine and dopamine, which leads to increased levels of these neurotransmitters in the brain. This, in turn, helps to regulate mood and reduce symptoms of depression [116].

Bupropion exists as a racemic mixture of two enantiomers, (R)-Bupropion and (S)-Bupropion (Figure 29). (R)-Bupropion primarily acts as a norepinephrine-dopamine reuptake inhibitor (NDRI). It inhibits the reuptake of norepinephrine and dopamine, leading to increased levels of these neurotransmitters in the brain. This is thought to be the main mechanism of its antidepressant and anti-addiction effects [117].

(S)-Bupropion also acts as a norepinephrine-dopamine reuptake inhibitor (NDRI), similar to its counterpart (R)-bupropion. However, (S)-bupropion is less potent in inhibiting the reuptake of these neurotransmitters compared to (R)-bupropion. It is believed that (S)-bupropion might contribute to the overall pharmacological profile of bupropion [117].



R-Bupropion S-Bupropion

Figure 29: Bupropion Enantiomers

30. Metoprolol: Metoprolol is a medication that belongs to the class of drugs known as beta-blockers. It is commonly prescribed to treat various cardiovascular conditions. Metoprolol works by blocking the action of adrenaline and similar stress hormones on the heart and blood vessels. By doing so, it decreases the heart rate and reduces the force with which the heart pumps blood, ultimately leading to a reduction in blood pressure and less strain on the heart [118]. It is available as a racemic mixture, containing two enantiomers: R-metoprolol and S-metoprolol (Figure 30).

R-metoprolol is responsible for the beta-blocking activity of metoprolol. It mainly acts as a selective beta-1 adrenergic receptor antagonist, meaning it primarily blocks the beta-1 receptors found in the heart. By blocking these receptors, R-metoprolol reduces the effects of adrenaline and noradrenaline on the heart, leading to decreased heart rate and contractility.

It is particularly effective in treating conditions such as hypertension and angina by reducing the workload on the heart and improving its oxygen supply-demand balance [119].

S-metoprolol also possesses beta-blocking activity, but it is less potent than R-metoprolol. However, it is noteworthy that S-metoprolol exhibits partial agonist activity on beta-1 adrenergic receptors, which means that it can produce some stimulatory effects on these receptors while also blocking them. This partial agonist activity may limit the overall therapeutic benefits of the racemic mixture of metoprolol, as it may reduce the net beta-blocking effect [120].

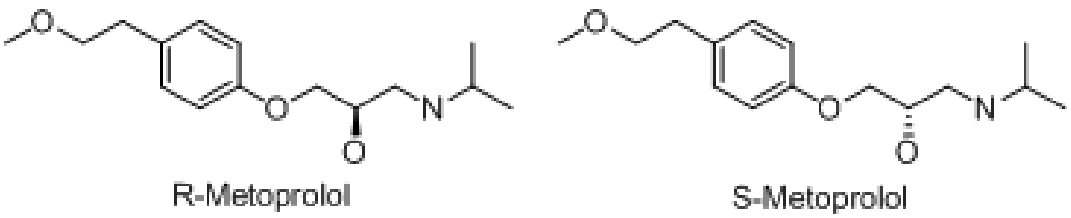


Figure 30: Metoprolol Enantiomers

31. Other Stereoisomeric Drugs: There are a huge number of stereoisomeric drugs available in the market and we have discussed 30 of them and few other drugs are shown in table no 1.

Table 1: Few other Stereoisomeric Drugs

Sl. No.	Drug	Biological Activity	Relative Activity of Enantiomers	Reference
01.	Naproxen	NSAID	S > R	[121]
02.	Pantoprazole	Proton pump inhibitors (PPIs)	R > S	[122]
03.	Fexofenadine	Antihistaminic	R > S	[123]
04.	Lamivudine	Nucleoside reverse transcriptase inhibitor (NRTI)	S > R	[124]
05.	Donepezil	Alzheimer's disease	R > S	[125]
06.	Methampheta mine	Central nervous system stimulant	D > L	[126]
07.	Ketamine	Anesthetic	S > R	[127]
08.	Ropivacaine	Local anesthetic	S > R	[128]
09.	Labetalol	Beta blocker	(S, S) - beta-blocking activity. (R, R) - alpha-blocking activity	[129]

10.	Carvedilol	Beta blocker	(S) - beta-blocking activity (R) - alpha-1 blocking activity	[130]
11.	Terbutaline	Bronchodilator	R > S	[131]
12.	Fluticasone	Respiratory diseases	S > R	[132]
13.	Ropinirole	Alzheimer's disease	S > R	[133]
14.	Promethazine	Antihistamine and antiemetic	S > R	[134]
15.	Methotrexate	Anti-cancer	S > R	[135]

VII. CONCLUSION

In conclusion, research on stereoisomeric medications illuminates the intriguing world of chemical structures and their influence on how drugs interact with the human body. The therapeutic efficacy and safety of these medications, which have identical chemical formulas but different spatial configurations, can demonstrate a remarkable diversity of outcomes. To improve medical treatments and guarantee patient wellbeing, it is essential to comprehend the role stereochemistry plays in drug development and administration. As this field of study develops, we can anticipate more precise and potent medications that take use of stereoisomerism's ability to enhance healthcare results.

REFERENCE

[1] J. McConathy, and M. J. Owens, "Stereochemistry in drug action," Prim Care Companion J Clin Psychiatry, 2003, 5(2), 70.
[2] J. Caldwell, "The importance of stereochemistry in drug action and disposition," J. Clin. Pharmacol., 1992, 32(10), 925-929.
[3] M. Eichelbaum, and A.S. Gross, "Stereochemical aspects of drug action and disposition," Advances in drug research ,1996, (Vol. 28, pp. 1-64). Academic Press.
[4] N. Chhabra, M.L. Aseri, and D. Padmanabhan, "A review of drug isomerism and its significance," International journal of applied and basic medical research, 2013, 3(1), 16.
[5] M. Simonyi, "Stereochemical Definitions and Nomenclature: Changing Signs?," Drug information journal, 1994, 28(2), 533-540.
[6] A. Nallamuthu, "Role of chirality in drugs, organic & medicinal chemistry," Int. J., 2018, 5.
[7] H. Alkadi, and R. Jbeily, "Role of Chirality in Drugs: An Overview," Infectious Disorders Drug Targets, 2018, 18(2), 88-95.
[8] I. Agranat, H. Caner, and J. Caldwell, "Putting chirality to work: the strategy of chiral switches," Nature Reviews Drug Discovery, 2002, 1(10), 753-768.
[9] B. Sharma, "Nature of chiral drugs and their occurrence in environment," Journal of Xenobiotics, 2014, 4(1), 2272.
[10] G.Q. Lin, J.G. Zhang, and J.F. Cheng, "Overview of chirality and chiral drugs," Chiral drugs: chemistry and biological action, 2011, 3-28.
[11] L.A. Nguyen, H. He, and C. Pham-Huy, "Chiral drugs: an overview," International journal of biomedical science: IJBS, 2006, 2(2), 85.
[12] J.C. Leffingwell, "Chirality & bioactivity I.: pharmacology," Leffingwell Reports, 2003, 3(1), 1-27.
[13] K.D. Tripathi, "Drug enantiomers: configuration and pharmacological implications," Indian journal of Pharmacology, 1993, 25(2), 73.

[14] R.H. Howland, "Understanding chirality and stereochemistry: Three-dimensional psychopharmacology," Journal of Psychosocial Nursing and Mental Health Services, 2009, 47(7), 15-18.
[15] M.E. Franks, G.R. Macpherson, and W.D. Figg, "Thalidomide," The Lancet, 2004, 363(9423), 1802-1811.
[16] M. Meyring, J. Mühlbacher, K. Messer, N. Kastner-Pustet, G. Bringmann, A. Mannschreck, and G. Blaschke, "In vitro biotransformation of (R)-and (S)-thalidomide: application of circular dichroism spectroscopy to the stereochemical characterization of the hydroxylated metabolites," Analytical chemistry, 2002, 74(15), 3726-3735.
[17] S. Wnendt, M. Finkam, W. Winter, J. Ossig, G. Raabe, and K. Zwingenberger, "Enantioselective inhibition of TNF- α release by thalidomide and thalidomide-analogues," Chirality, 1996, 8(5), 390-396.
[18] T.G. Kantor, "Ibuprofen," Annals of Internal Medicine, 1979, 91(6), 877-882.
[19] S.C. Tan, B.K. Patel, S.H. Jackson, C.G. Swift, and A.J. Hutt, "Ibuprofen stereochemistry: double-the-trouble?," Enantiomer, 1999, 4(3-4), 195-203.
[20] A.J. Romero, and C.T. Rhodes, "Stereochemical aspects of the molecular pharmaceutics of ibuprofen" Journal of pharmacy and pharmacology, 1993, 45(4), 258-262.
[21] B.P. Lee, J.L. Dalsin, and P.B. Messersmith, "Synthesis and gelation of DOPA-modified poly (ethylene glycol) hydrogels," Biomacromolecules, 2002, 3(5), 1038-1047.
[22] K.G. Lloyd, L. Davidson, and O. Hornykiewicz, "The neurochemistry of Parkinson's disease: effect of L-dopa therapy," Journal of Pharmacology and Experimental Therapeutics, 1975, 195(3), 453-464.
[23] T. Kawazoe, H. Tsuge, T. Imagawa, K. Aki, S. Kuramitsu, and K. Fukui, "Structural basis of D-DOPA oxidation by D-amino acid oxidase: alternative pathway for dopamine biosynthesis," Biochemical and biophysical research communications, 2007, 355(2), 385-391.
[24] D.G. Shand, "Propranolol," New England Journal of Medicine, 1975, 293(6), 280-285.
[25] B.E. Bleske, L.S. Welage, S. Rose, G.L. Amidon, and M.J. Shea, "The effect of dosage release formulations on the pharmacokinetics of propranolol stereoisomers in humans" The Journal of Clinical Pharmacology, 1995, 35(4), 374-378.
[26] J. Overman, F. Fontaine, J. Wylie-Sears, M. Moustaqil, L. Huang, M. Meurer, et al., "R-propranolol is a small molecule inhibitor of the SOX18 transcription factor in a rare vascular syndrome and hemangioma" Elife, 2019, 8, e43026.
[27] A.E. Rettie, and G. Tai, "The pharmocogenomics of warfarin," Molecular interventions, 2006, 6(4), 223.
[28] S. Patel, R. Singh, C.V. Preuss, and N. Patel, "Warfarin," In StatPearls [Internet]. StatPearls Publishing, 2022.
[29] J.P. Hanley, "Warfarin reversal," Journal of Clinical Pathology, 2004, 57(11), 1132-1139.
[30] J. Lindh, "Major determinants of outcome and dosing in warfarin treatment," Karolinska Institutet (Sweden), 2009.
[31] Z. Zhang, M.J. Fasco, Z. Huang, F.P. Guengerich, and L.S. Kaminsky, "Human cytochromes P4501A1 and P4501A2: R-warfarin metabolism as a probe," Drug metabolism and disposition, 1995, 23(12), 1339-1346.
[32] T.G. Kantor, "Ketoprofen: a review of its pharmacologic and clinical properties," Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy, 1986, 6(3), 93-102.
[33] M.I. Díaz-Reval, R. Ventura-Martínez, M. Déciga-Campos, J.A. Terrón, F. Cabré, and F.J. López-Muñoz, "Evidence for a central mechanism of action of S-(+)-ketoprofen," European journal of pharmacology, 2004, 483(2-3), 241-248.
[34] A.C. Rudy, Y. Liu, D.C. Brater, and S.D. Hall, "Stereoselective pharmacokinetics and inversion of (R)-ketoprofen in healthy volunteers," The Journal of Clinical Pharmacology, 1998, 38(2S), 3S-10S.
[35] E. Ben-Menachem, "Vigabatrin," Epilepsia, 1995, 36, S95-S104.
[36] P.J. Schechter, "Clinical pharmacology of vigabatrin" British Journal of Clinical Pharmacology, 1989, 27(S1), 19S-22S.
[37] L. Gram, O.M. Larsson, A. Johnsen, and A. Schousboe, "Experimental studies of the influence of vigabatrin on the GABA system," British journal of clinical pharmacology, 1989, 27(S1), 13S-17S.
[38] B. Poletto, "Tiaprofenic acid," Clinics in Rheumatic Diseases, 1984, 10(2), 333-351.
[39] E.M. Sorkin, and R.N. Brogden, "Tiaprofenic acid: a review of its pharmacological properties and therapeutic efficacy in rheumatic diseases and pain states," Drugs, 1985, 29, 208-235.
[40] N.N. Singh, F. Jamali, F.M. Pasutto, A.S. Russell, R.T. Coutts, and K.S. Drader, "Pharmacokinetics of the enantiomers of tiaprofenic acid in humans," Journal of pharmaceutical sciences, 1986, 75(5), 439-442.

[41] N.M. Davies, "Clinical pharmacokinetics of tiaprofenic acid and its enantiomers," Clinical pharmacokinetics, 1996, 31, 331-347.
[42] S. Grond, and A. Sablotzki, "Clinical pharmacology of tramadol," Clinical pharmacokinetics, 2004, 43, 879-923.
[43] G.E. Von Unruh, S. Hamm, W.D. Paar, and H.J. Dengler, "Isotope effects during metabolism of (+)-and (−)-trans tramadol isotopomers by human liver microsomes" Isotopes in Environmental and Health Studies, 1995, 31(3-4), 247-253.
[44] R.B. Raffa, E.L.M.A.R. Friderichs, W.O.L.F.G.A.N.G. Reimann, R.P. Shank, E.E. Codd, J.L. Vaught, et al., "Complementary and synergistic antinociceptive interaction between the enantiomers of tramadol," Journal of Pharmacology and Experimental Therapeutics, 1993, 267(1), 331-340.
[45] R.N. Brogden, R.C. Heel, T.M. Speight, and G.S. Avery, "Flurbiprofen: a review of its pharmacological properties and therapeutic use in rheumatic diseases," Drugs, 1979, 18, 417-438.
[46] F. Jamali, B.W. Berry, M.R. Tehrani, and A.S. Russell, "Stereoselective pharmacokinetics of flurbiprofen in humans and rats," Journal of pharmaceutical sciences, 1988, 77(8), 666-669.
[47] N.M. Davies, "Clinical pharmacokinetics of flurbiprofen and its enantiomers," Clinical pharmacokinetics, 1995, 28(2), 100-114.
[48] G. Geisslinger, and H.G. Schaible, "New insights into the site and mode of antinociceptive action of flurbiprofen enantiomers," The Journal of Clinical Pharmacology, 1996, 36(6), 513-520.
[49] R.A. Lugo, K.L. Satterfield, and S.E. Kern, "Pharmacokinetics of methadone," Journal of Pain & Palliative Care Pharmacotherapy, 2005, 19(4), 13-24.
[50] H. Joseph, S. Stancliff, and J. Langrod, "Methadone maintenance treatment (MMT): a review of historical and clinical issues," The Mount Sinai Journal of Medicine, New York, 2000, 67(5-6), 347-364.
[51] N. Ansermot, Ö. Albayrak, J. Schläpfer, S. Crettol, M. Croquette-Krokar, M. Bourquin, et al., "Substitution of (R, S)-methadone by (R)-methadone: impact on QTc interval," Archives of internal medicine, 2010, 170(6), 529-536.
[52] D.J. Foster, A.A. Somogyi, K.R. Dyer, J.M. White, and F. Bochner, "Steady-state pharmacokinetics of (R)-and (S)-methadone in methadone maintenance patients," British journal of clinical pharmacology, 2000, 50(5), 427-440.
[53] C. Lee Barnes, C.A. McKenzie, K.D. Webster, and K. Poinsett-Holmes, "Cetirizine: a new, nonsedating antihistamine," Annals of Pharmacotherapy, 1993, 27(4), 464-470.
[54] M.P. Curran, L.J. Scott, and C.M. Perry, "Cetirizine: a review of its use in allergic disorders," Drugs, 2004, 64, 523-561.
[55] D.Y. Wang, F. Hanotte, C. De Vos, and P. Clement, "Effect of cetirizine, levocetirizine, and dextrocetirizine on histamine-induced nasal response in healthy adult volunteers" Allergy, 2001, 56(4), 339-343.
[56] L.L. Christrup, "Morphine metabolites," Acta Anaesthesiologica Scandinavica, 1997, 41(1), 116-122.
[57] C. Y. Hong, N. Kado, and L.E. Overman, "Asymmetric synthesis of either enantiomer of opium alkaloids and morphinans. Total synthesis of (-)-and (+)-dihydrocodeinone and (-)-and (+)-morphine," Journal of the American Chemical Society, 115(23), 11028-11029.
[58] Gram, L. F. (1994). Fluoxetine. New England Journal of Medicine, 1993, 331(20), 1354-1361.
[59] D.T. Wong, R.W. Fuller, and D.W. Robertson, "Fluoxetine and its two enantiomers as selective serotonin uptake inhibitors," Acta pharmaceutica nordica, 1990, 2(3), 171-180.
[60] J. Magyar, Z. Rusznák, C. Harasztosi, Á. Körtvély, P. Pacher, T. Bányász, et al., "Differential effects of fluoxetine enantiomers in mammalian neural and cardiac tissues," International journal of molecular medicine, 2003, 11(4), 535-542.
[61] R.A. Bartow, R.N. Brogden, "Formoterol: c," Drugs, 1998, 55, 303-322.
[62] W. Szafranski, A. Cukier, A. Ramirez, G. Menga, R. Sansores, S. Nahabedian, et al., "Efficacy and safety of budesonide/formoterol in the management of chronic obstructive pulmonary disease," European Respiratory Journal, 2003, 21(1), 74-81.
[63] D. Schmidt, B.L. Källström, B. Waldeck, D. Branscheid, H. Magnussen, and K.F. Rabe, "The effect of the enantiomers of formoterol on inherent and induced tone in guinea-pig trachea and human bronchus," Naunyn-Schmiedeberg's Archives of Pharmacology, 2000, 361, 405-409.
[64] K. Kulhankova, C.S. George, J.N. Kline, and P.S. Thorne, "Pulmonary and systemic responses to inhaled allergens are aggravated by inhaled endotoxin," Journal of Allergy and Clinical Immunology, 2006, 117(2), S318.
[65] M.J. Minzenberg, and C.S. Carter, "Modafinil: a review of neurochemical actions and effects on cognition," Neuropsychopharmacology, 2008, 33(7), 1477-1502.

[66] P. Gerrard, and R. Malcolm, "Mechanisms of modafinil: a review of current research," Neuropsychiatric disease and treatment, 2007, 3(3), 349-364.
[67] C.J. Loland, M. Mereu, O.M. Okunola, J. Cao, T.E. Prisinzano, S. Mazier, et al., "R-modafinil (armodafinil): a unique dopamine uptake inhibitor and potential medication for psychostimulant abuse," Biological psychiatry, 2012, 72(5), 405-413.
[68] Y. In, K. Tomoo, T. Ishida, and Y. Sakamoto, "Crystal and molecular structure of an (S)-(+)-enantiomer of modafinil, a novel wake-promoting agent," Chemical and pharmaceutical bulletin, 2004, 52(10), 1186-1189.
[69] A.E. Zimmermann, and B.G. Katona, "Lansoprazole: a comprehensive review," Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy, 1997, 17(2), 308-326.
[70] B.D. Landes, J.P. Petite, and B. Flouvat, "Clinical pharmacokinetics of lansoprazole," Clinical pharmacokinetics, 1995, 28, 458-470.
[71] L. Sun, Y. Cao, H. Jiao, Y. Fang, Z. Yang, M. Bian, et al., "Enantioselective determination of (R) -and (S) -lansoprazole in human plasma by chiral liquid chromatography with mass spectrometry and its application to a stereoselective pharmacokinetic study," Journal of separation science, 2015, 38(21), 3696-3703.
[72] H. Katsuki, H. Yagi, K. Arimori, C. Nakamura, M. Nakano, S. Katafuchi, et al., "Determination of R (+)- and S (–)-lansoprazole using chiral stationary-phase liquid chromatography and their enantioselective pharmacokinetics in humans," Pharmaceutical research, 1996, 13, 611-615.
[73] Challman, D. Thomas and J.L. James, "Methylphenidate: its pharmacology and uses," Mayo Clinic Proceedings. Vol. 75. No. 7. Elsevier, 2000.
[74] H.C. Kimko, J.T. Cross, and D.R. Abernethy, "Pharmacokinetics and clinical effectiveness of methylphenidate," Clinical pharmacokinetics, 1999, 37, 457-470.
[75] S. Teo, D. Stirling, S. Thomas, A. Hoberman, A. Kiorpes, and V. Khetani, "A 90-day oral gavage toxicity study of d-methylphenidate and d, l-methylphenidate in Sprague–Dawley rats," Toxicology, 2002, 179(3), 183-196.
[76] R. Muniz, M. Brams, A. Mao, K. McCague, L. Pestreich, and R. Silva, "Efficacy and safety of extended-release dexmethylphenidate compared with d, l-methylphenidate and placebo in the treatment of children with attention-deficit/hyperactivity disorder: a 12-hour laboratory classroom study," Journal of child and adolescent psychopharmacology, 2008, 18(3), 248-256.
[77] P.H. Connell, "Amphetamine psychosis," British medical journal, 1957, 1(5018), 582.
[78] D.J. Heal, S.L. Smith, J. Gosden, and D.J. Nutt, "Amphetamine, past and present–a pharmacological and clinical perspective," Journal of psychopharmacology, 2013, 27(6), 479-496.
[79] T. Wang, B. Shen, Y. Shi, P. Xiang, and Z. Yu, "Chiral separation and determination of R/S-methamphetamine and its metabolite R/S-amphetamine in urine using LC–MS/MS," Forensic Science International, 2015, 246, 72-78.
[80] S. Hegstad, H. Havnen, A. Helland, O. Spigset, and J. Frost, "Enantiomeric separation and quantification of R/S-amphetamine in urine by ultra-high performance supercritical fluid chromatography tandem mass spectrometry," Journal of Chromatography B, 2018, 1077, 7-12.
[81] K. Bezchlibnyk-Butler, I. Aleksic, and S.H. Kennedy, "Citalopram--a review of pharmacological and clinical effects," Journal of Psychiatry and Neuroscience, 2000, 25(3), 241.
[82] B.G. Pollock, "Citalopram: a comprehensive review," Expert opinion on pharmacotherapy, 2001, 2(4), 681-698.
[83] J. Hyttel, K.P. Bøgesø, J. Perregaard, and C. Sanchez, "The pharmacological effect of citalopram resides in the (S)-(+)-enantiomer," Journal of Neural Transmission/General Section JNT, 1992, 88, 157-160.
[84] C. Sánchez, "The pharmacology of citalopram enantiomers: the antagonism by R-citalopram on the effect of S-citalopram," Basic & clinical pharmacology & toxicology, 2006, 99(2), 91-95.
[85] P.N. Maton, "Omeprazole," New England Journal of Medicine, 1991, 324(14), 965-975.
[86] C.W. Howden, "Clinical pharmacology of omeprazole," Clinical pharmacokinetics, 1991, 20(1), 38-49.
[87] A. Äbelö, T.B. Andersson, M. Antonsson, A.K. Naudot, I. Skånberg, and L. Weidolf, "Stereoselective metabolism of omeprazole by human cytochrome P450 enzymes," Drug Metabolism and Disposition, 2000, 28(8), 966-972.
[88] S. von Unge, V. Langer, and L. Sjölin, "Stereochemical assignment of the enantiomers of omeprazole from X-ray analysis of a fenchyloxymethyl derivative of (+)-(R)-omeprazole," Tetrahedron: Asymmetry, 1997, 8(12), 1967-1970.
[89] C. Fernandez, C. Martin, F. Gimenez, and R. Farinotti, "Clinical pharmacokinetics of zopiclone," Clinical pharmacokinetics, 1995, 29, 431-441.

[90] D.R. Drover, "Comparative pharmacokinetics and pharmacodynamics of short-acting hypnosedatives: zaleplon, zolpidem and zopiclone," Clinical pharmacokinetics, 2004, 43, 227-238.
[91] V. Georgiev, "(S)-Zopiclone Sepracor," Current Opinion in Investigational Drugs (London, England: 2000), 2001, 2(2), 271-273.
[92] H. Miyaguchi, and K. Kuwayama, "Enantioselective determination of (R)-zopiclone and (S)-zopiclone (eszopiclone) in human hair by micropulverized extraction and chiral liquid chromatography/high resolution mass spectrometry," Journal of Chromatography A, 2017, 1519, 55-63.
[93] A.M. Gadomski, R. Lichenstein, L. Horton, J. King, V. Keane, and T. Permutt, "Efficacy of albuterol in the management of bronchiolitis," Pediatrics, 1994, 93(6), 907-912.
[94] J.M. Drazen, E. Israel, H.A. Boushey, V.M. Chinchilli, J.V. Fahy, J.E. Fish, et al., "Comparison of regularly scheduled with as-needed use of albuterol in mild asthma," New England Journal of Medicine, 1996, 335(12), 841-847.
[95] C.P. Page, and J. Morley, "Contrasting properties of albuterol stereoisomers," Journal of allergy and clinical immunology, 1999, 104(2), S31-S41.
[96] R. Dhand, M. Goode, R. Reid, J.B. Fink, P.J. Fahey, and M.J. Tobin, "Preferential pulmonary retention of (S)-albuterol after inhalation of racemic albuterol," American journal of respiratory and critical care medicine, 1999, 160(4), 1136-1141.
[97] I. Goldberg, "Betaxolol," Australian and New Zealand Journal of Ophthalmology, 1989, 17(1), 9-13.
[98] R. Beresford, and R.C. Heel, "Betaxolol: a review of its pharmacodynamic and pharmacokinetic properties, and therapeutic efficacy in hypertension," Drugs, 1986, 31, 6-28.
[99] P.S. Kulkarni, and L. DeSantis, "Vasorelaxant effects of racemic betaxolol and its R-and S-isomers on bovine retinal vessels," Journal of Glaucoma, 2001, 10(5), 423-426.
[100] Y.H. Li, L.H. Huang, and H.M. Liu, "Chemoenzymatic Route to S-Betaxolol," Synthetic Communications, 2011, 41(16), 2468-2474.
[101] C.R. Babst, and B.N. Gilling, "Bupivacaine: a review," Anesthesia progress, 1978, 25(3), 87.
[102] W.A. Chambers, H.H. Edstrom, and D.B. Scott, "Effect of baricity on spinal anaesthesia with bupivacaine," British journal of anaesthesia, 1981, 53(3), 279-282.
[103] C.R. Cox, K.A. Faccenda, C. Gilhooly, J. Bannister, N.B. Scott, L.M. Morrison, "Extradural S (-)-bupivacaine: comparison with racemic RS-bupivacaine," British Journal of Anaesthesia, 1998, 80(3), 289-293.
[104] I.D. Welters, A. Menzebach, T.W. Langefeld, M. Menzebach, and G. Hempelmann, "Inhibitory effects of S- (−) and R- (+) bupivacaine on neutrophil function," Acta anaesthesiologica scandinavica, 2001, 45(5), 570-575.
[105] S. Flor, "Pharmacokinetics of ofloxacin. An overview," The American journal of medicine, 1989, 87(6C), 24S-30S.
[106] J.P. Monk, and D.M. Campoli-Richards, "Ofloxacin: a review of its antibacterial activity, pharmacokinetic properties and therapeutic use," Drugs, 1987, 33, 346-391.
[107] H.C. Neu, and N.X. Chin, "In vitro activity of S-ofloxacin," Antimicrobial agents and chemotherapy, 1989, 33(7), 1105-1107.
[108] L. Rabbaa, S. Dautrey, N. Colas-Linhart, C. Carbon, and R. Farinotti, "Absorption of ofloxacin isomers in the rat small intestine," Antimicrobial agents and chemotherapy, 1997, 41(10), 2274-2277.
[109] B. Carlberg, O. Samuelsson, and L.H. Lindholm, "Atenolol in hypertension: is it a wise choice?," The lancet, 2004, 364(9446), 1684-1689.
[110] P.R. Reeves, J. McAinsh, D.A. McIntosh, and M.J. Winrow, "Metabolism of atenolol in man," Xenobiotica, 1978, 8(5), 313-320.
[111] K. Stoschitzky, G. Egginger, G. Zernig, W. Klein, and W. Lindner, "Stereoselective features of (R) -and (S)-atenolol: Clinical pharmacological, pharmacokinetic, and radioligand binding studies," Chirality, 1993, 5(1), 15-19.
[112] K. Stoschitzky, W. Lindner, and W. Kiowski, "Stereoselective vascular effects of the (R)-and (S)-enantiomers of propranolol and atenolol," Journal of cardiovascular pharmacology, 1995, 25(2), 268-272.
[113] M. Furlanut, and L. Franceschi, "Pharmacology of ifosfamide," Oncology, 2003, 65(Suppl. 2), 2-6.
[114] W.P. Brade, K. Herdrich, and M. Varini, "Ifosfamide-pharmacology, safety and therapeutic potential," Cancer treatment reviews, 1985, 12(1), 1-47.
[115] C.S. Chen, Y. Jounaidi, and D.J. Waxman, "Enantioselective metabolism and cytotoxicity of R-ifosfamide and S-ifosfamide by tumor cell-expressed cytochromes P450," Drug metabolism and disposition, 2005, 33(9), 1261-1267.

[116] J.A. Ascher, J.O. Cole, J.N. Colin, J.P. Feighner, R.M. Ferris, H.C. Fibiger, et al., "Bupropion: a review of its mechanism of antidepressant activity," The Journal of clinical psychiatry, 1995, 56(9), 395-401.
[117] E.D. Kharasch, D. Mitchell, and R. Coles, "Stereoselective bupropion hydroxylation as an in vivo phenotypic probe for cytochrome P4502B6 (CYP2B6) activity," The Journal of Clinical Pharmacology, 2008, 48(4), 464-474.
[118] F. Waagstein, A. Hjalmarson, K. Swedberg, M.R. Bristow, E.M. Gilbert, F. Camerini, et al., "Beneficial effects of metoprolol in idiopathic dilated cardiomyopathy," The Lancet, 1993, 342(8885), 1441-1446.
[119] B.P. Jensen, C.F. Sharp, S.J. Gardiner, and E.J. Begg, "Development and validation of a stereoselective liquid chromatography–tandem mass spectrometry assay for quantification of S-and R-metoprolol in human plasma," Journal of Chromatography B, 2008, 865(1-2), 48-54.
[120] G. Wahlund, V. Nerme, T. Abrahamsson, and P.O. Sjöquist, "The β1 and β2-adrenoceptor affinity and β1-blocking potency of S-and R-metoprolol," British journal of pharmacology, 1990, 99(3), 592-596.
[121] S. Takaç, and M. Bakkal, "Impressive effect of immobilization conditions on the catalytic activity and enantioselectivity of Candida rugosa lipase toward S-Naproxen production," Process Biochemistry, 2007, 42(6), 1021-1027.
[122] H. Cao, M. Wang, J. Jia, Q. Wang, and M. Cheng, "Comparison of the effects of pantoprazole enantiomers on gastric mucosal lesions and gastric epithelial cells in rats," Journal of health science, 2004, 50(1), 1-8.
[123] M. Miura, and T. Uno, "Clinical pharmacokinetics of fexofenadine enantiomers," Expert Opinion on Drug Metabolism & Toxicology, 2010, 6(1), 69-74.
[124] J.M. Pluda, T.P. Cooley, J.S. Montaner, L.E. Shay, N.E. Reinhalter, S.N. Warthan, et al., "A phase I/II study of 2′-deoxy-3′-thiacytidine (lamivudine) in patients with advanced human immunodeficiency virus infection," Journal of Infectious Diseases, 1995, 171(6), 1438-1447.
[125] M.A. Radwan, H.H. Abdine, B.T. Al-Quadeb, H.Y. Aboul-Enein, and K. Nakashima, "Stereoselective HPLC assay of donepezil enantiomers with UV detection and its application to pharmacokinetics in rats," Journal of Chromatography B, 2006, 830(1), 114-119.
[126] J. Mendelson, N. Uemura, D. Harris, R.P. Nath, E. Fernandez, P. Jacob III, et al., "Human pharmacology of the methamphetamine stereoisomers," Clinical Pharmacology & Therapeutics, 2006, 80(4), 403-420.
[127] C. Yang, J. Yang, A. Luo, and K. Hashimoto, "Molecular and cellular mechanisms underlying the antidepressant effects of ketamine enantiomers and its metabolites," Translational psychiatry, 2019, 9(1), 280.
[128] G. Kuthiala, and G. Chaudhary, "Ropivacaine: A review of its pharmacology and clinical use," Indian journal of anaesthesia, 2011, 55(2), 104.
[129] B. Waldeck, "Biological significance of the enantiomeric purity of drugs," Chirality, 1993, 5(5), 350-355.
[130] W. Bartsch, G. Sponer, K. Strein, B. Müller-Beckmann, L. Kling, E. Böhm, et al., "Pharmacological characteristics of the stereoisomers of carvedilol," European journal of clinical pharmacology, 1990, 38, S104-S107.
[131] L. Borgstrom, L. Nyberg, S. Jonsson, C. Lindberg, and J. Paulson, "Pharmacokinetic evaluation in man of terbutaline given as separate enantiomers and as the racemate," British journal of clinical pharmacology, 1989, 27(1), 49-56.
[132] R. Fuller, M. Johnson, and A. Bye, "Fluticasone propionate—an update on preclinical and clinical experience," Respiratory medicine, 1995, 89, 3-18.
[133] M.J. Millan, D. Cussac, A. Gobert, F. Lejeune, J.M. Rivet, C.M. La Cour, et al., "S32504, a novel naphtoxazine agonist at dopamine D3/D2 receptors: I. Cellular, electrophysiological, and neurochemical profile in comparison with ropinirole. Journal of Pharmacology and Experimental Therapeutics, 2004, 309(3), 903-920.
[134] G.W. Ponder, and J.T. Stewart, "A liquid chromatographic method for the determination of promethazine enantiomers in human urine and serum using solid-phase extraction and fluorescence detection," Journal of pharmaceutical and biomedical analysis, 1995, 13(9), 1161-1166.
[135] R.I. Stefan, R.G. Bokretsion, J.F. van Staden, and H.Y. Aboul-Enein, "Determination of L-and D-enantiomers of methotrexate using amperometric biosensors," Talanta, 2003, 60(5), 983-990.

