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Alkylation

Chiral Inductive Diastereoconvergent Friedel–Crafts Alkylation Reaction of Diastereomixtures of Diarylmethanols with 2-Naphthol Derivatives Catalyzed by $SnBr_4$

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Abstract: A highly diastereoconvergent Friedel–Crafts alkylation reaction of 2-naphthol derivatives with diastereomixtures of diarymethanols bearing a designed chiral auxiliary was achieved by using tin(IV) bromide as a catalyst in nitromethane under mild reaction conditions. The effects of various substituents located on the chiral auxiliary were evaluated, and chiral induction was found to take place via a carbocation through the chelation effect of an oxygen atom in a stereoconvergent manner. The chiral auxiliary was easily deprotected under conventional hydrogenation conditions without affecting the chirality of the starting material. A variety of substrates were transformed successfully, with high yields and selectivities (diastereomeric ratios ≥ 20:1) obtained irrespective of the substitution pattern and the electronic nature of the substrate aromatic rings.

Introduction

The Lewis acid promoted Friedel–Crafts alkylation reaction[1] between arenes and alkyl halides is a fundamental method for the production of alkyl-substituted aromatic compounds. In a typical Friedel–Crafts alkylation reaction, the reaction proceeds in the presence of a catalytic amount of the Lewis acid (e.g., $AlCl_3$) with an alkyl halide to yield the desired product in addition to a hydrogen halide byproduct.[2,3] However, as environmental issues are a growing concern, atom-economical and environmentally friendly alternatives to the production of alkyl-substituted aromatic compounds are increasingly of interest. For example, the Friedel–Crafts-type dehydrative alkylation reaction employing free alcohols, instead of the corresponding halides, has attracted significant attention. However, problems have been encountered as a result of the challenging catalytic activation of the hydroxy moiety as a leaving group. Given that these reactions would produce water as the sole byproduct, such protocols are of particular interest in the context of green chemistry. Uemura et al. first achieved the $TeCl_4$-catalyzed Friedel–Crafts alkylation of arenes by using free alcohols in 1986.[4] Additional pioneering investigations into Friedel–Crafts alkylations with free alcohols were reported by Fukuzawa et al., who used a scandium(III) trifluoromethanesulfonate [$Sc(OTf)_3$] catalyst,[5] and Shimizu et al., who used a $Mo(CO)_6$ catalyst.[6] Significant efforts have since been devoted to the development of new synthetic methods for direct substitution of alcohols by using a catalytic amount of a Brønsted acid or Lewis acid, and many useful methods have been reported to date.[7,8] Among these reactions, we became interested in the development of a general method to provide a variety of diarylmethylated 2-naphthol derivatives by the Friedel–Crafts-type dehydrative alkylation reaction of diarylmethanols with substituted 2-naphthols, as the 2-naphthol moiety is present in a number of biologically active compounds,[9] photochromic compounds,[10] and asymmetric catalysts such as 2,2′-dihydroxy-1,1′-binaphthyl (BINOL)[11] and Betti base[12] (Figure 1).

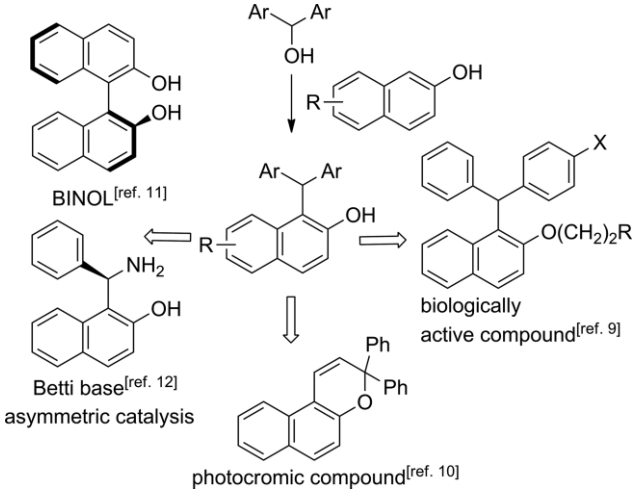

Figure 1. Examples of compounds containing the 2-naphthol moiety.

Although various methods for the preparation of such compounds have been reported with the use of a range of catalysts such as metal triflates,[13] H_2SO_4,[10] $NbCl_5$,[14] I_2,[15] surfactant-type Brønsted acids,[16] amberlyst-15,[17] pentafluorophenylboronic acid,[18] and $NaHSO_4/SiO_2$,[19] the substrate scope has

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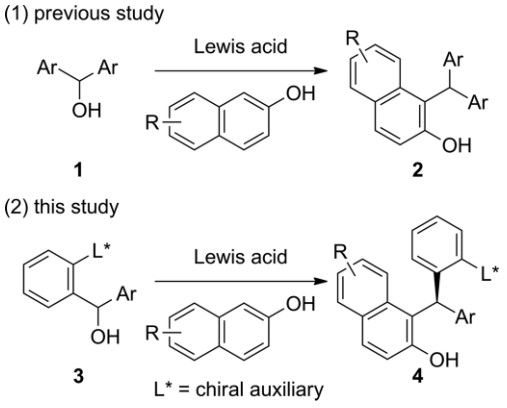
not yet been thoroughly investigated.[20] Recently, we developed a general method for the $SnBr_4$-promoted Friedel–Crafts-type dehydrative alkylation of diarylmethanols **1** with 2-naphthol derivatives to yield **2** under mild conditions by adjusting the catalyst loading and the reaction temperature according to the electronic nature of the substrates (Scheme 1, part 1).[21]

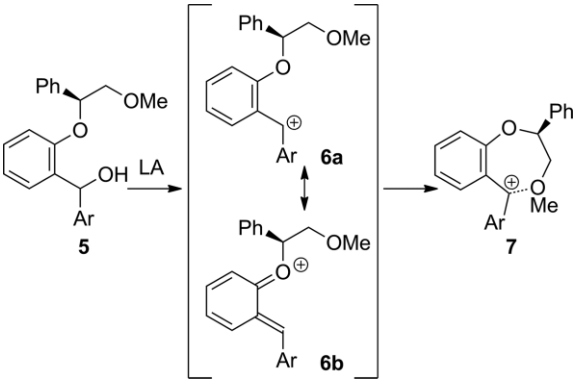


Scheme 1. (1) Reactions reported previously and (2) work examined in this study.

As the Friedel–Crafts-type reaction proceeds through a carbocation intermediate in an S_N1 fashion, it is generally difficult to control the reaction stereochemistry. Despite the number of useful catalytic asymmetric Friedel–Crafts reactions[22] that have been developed to date, the reaction of benzylic alcohols with arenes remains challenging. Recently, chiral phosphoric acid catalyzed asymmetric Friedel–Crafts-type reactions of naphthols with in situ generated *ortho*-[23,24] and *para*-[25] quinone methides[26] derived from the corresponding hydroxybenzhydryl alcohols were reported with good selectivity. However, these reports failed to carry out a systematic investigation of the substituent effects. Initially, pioneering investigations of substrate-controlled diastereoselective Friedel–Crafts reactions of acyclic chiral benzylic cations with arenes were reported by Bach et al.[27] and subsequently by Chung et al.,[28] who employed the Bach protocol. Later, Lautens et al.[29] achieved the diastereoselective benzylic arylation of cyclic benzylic cations through an asymmetric transition-metal-catalyzed ring-opening reaction of the corresponding *meso*-oxabicyclic alkenes.

Thus, as an alternative protocol, we herein describe the diastereoconvergent asymmetric Friedel–Crafts reaction of diarylmethanols **3** bearing a chiral auxiliary at the *ortho* position of the aromatic ring with 2-naphthol derivatives by using a catalytic amount of $SnBr_4$ (Scheme 1, part 2). In addition, we provide a systematic evaluation of the substituent effects to clarify the scope and limitations of this transformation to give **4** and consider the role of the chelation effect of the chiral auxiliary in achieving high selectivities.

In this work, we employ optically pure 2-methoxy-1-phenylethanol,[30] derived from commercially available (*R*)-mandelic acid, as a suitable chiral auxiliary according to the proposed reaction system shown in Scheme 2. We propose that dehydration takes place by treatment of **5** with a Lewis acid (LA) to furnish diarylmethyl cation **6a**, which exists in equilibrium with *ortho*-quinone methide cation **6b**.[23,24,26] We expect that the formation of seven-membered ring **7** will take place through chelation of the methoxy group on the chiral auxiliary at the dibenzylic position to determine the stereochemistry, with the direction of nucleophilic attack being determined by the position of the phenyl group on the stereogenic center, thus yielding high selectivities.

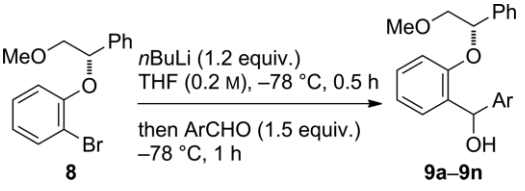


Scheme 2. Proposed reaction mechanism for the system examined herein.

Results and Discussion

To systematically evaluate the influence of the substrate aromatic ring substituents, we prepared a series of diarylmethanols bearing a chiral auxiliary through the reaction of aryl bromide **8** with the corresponding aromatic aldehydes to yield compounds **9a**–**n** (Table 1). Following lithiation of aryl bromide **8** by using *n*-butyllithium (*n*BuLi) in tetrahydrofuran (THF) at –78 °C for 30 min, the corresponding aromatic aldehydes were

Table 1. Preparation of diarylmethanols **9a**–**n** bearing a chiral auxiliary.



8 9a–9n

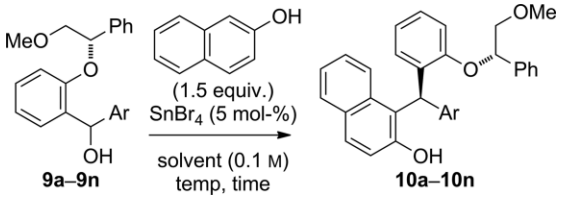
Entry	Ar	Yield of **9**[a] [%]	*dr*[b,c]
1	Ph (**a**)	86	62:38[d]
2	*o*-MeC_6H_4 (**b**)	82	60:40
3	*m*-MeC_6H_4 (**c**)	85	59:41
4	*p*-MeC_6H_4 (**d**)	82	61:39
5	3,4-$Me_2C_6H_3$ (**e**)	91	61:39
6	*o*-$MeOC_6H_4$ (**f**)	87	75:25
7	*m*-$MeOC_6H_4$ (**g**)	78	64:36
8	*p*-$MeOC_6H_4$ (**h**)	92	61:39
9	*o*-ClC_6H_4 (**i**)	83	58:42
10	*m*-ClC_6H_4 (**j**)	78	60:40
11	*p*-ClC_6H_4 (**k**)	81	60:40
12	*p*-FC_6H_4 (**l**)	87	58:42
13	α-Np[e] (**m**)	80	60:40
14	β-Np[e] (**n**)	78	57:43

[a] Yield of the isolated mixture of diastereomers. [b] The diastereomeric ratio (*dr*) was determined by ^1H NMR spectroscopy. [c] The absolute configuration was not determined unless otherwise noted. [d] Ratio [(*R*,*S*)-**9a**/(*S*,*S*)-**9a**] = 62:38. [e] Np: naphthyl.

added to the mixture to give diarylmethanols **9a**–**n** in good to high yields, regardless of the substituent types and patterns. In addition, with the exception of entry 6, diastereomeric ratios (*dr*) of ca. 60:40 were obtained for all reactions. These diastereomixtures were employed in subsequent reactions without prior separation of diastereomers.

With the series of diarylmethanols in hand, we carried out the diastereoselective Friedel–Crafts alkylation reaction of diastereomixtures of **9a**–**n** with 2-naphthol in the presence of $SnBr_4$ (5 mol-%). Optimization of the reaction conditions for each substrate was carried out by varying the reaction solvent, reaction temperature, and reaction time (Table 2). The reaction of **9a** was initially examined in CH_2Cl_2 at room temperature, as these represented the previously optimized conditions.[21] As a result, the reaction reached completion in 2 h and afforded desired compound **10a** in 88 % yield with 95:5 *dr* (Table 2, entry 1). Upon performing the same reaction at 0 °C, the selectivity improved slightly and the reactivity decreased significantly (Table 2, entry 2). Interestingly, upon changing the solvent from CH_2Cl_2 to $MeNO_2$, both the selectivity and reactivity were improved, and the reaction reached completion after 1 h at room temperature to afford **10a** in high yield and selectivity (Table 2, entry 3). Upon decreasing the reaction temperature to 0 °C, similar results were obtained with an extended reaction time of 24 h (Table 2, entry 4). In addition, similar results were also obtained in a mixed solvent of CH_2Cl_2/$MeNO_2$ (0.1 M, 1:1 volume ratio) at room temperature, although the yield dropped significantly with a reaction temperature of 0 °C (Table 2, entries 5 and 6). Considering the above results, we attempted the reaction in $MeNO_2$ at room temperature for 1 h. Upon applying these conditions to the reactions of **9b**–**e** bearing methyl and dimethyl substituents on the aromatic rings of the substrates, the reactions proceeded smoothly to afford corresponding target compounds **10b**–**e** in high yields with high selectivities (Table 2, entries 7–10). In addition, **9f**–**h** bearing methoxy substituents (Table 2, entries 11–15) exhibited enhanced reactivities, most likely due to stabilization of the corresponding carbocation intermediates by the electron-donating effect of the MeO group. At room temperature, these reactions reached completion within ca. 5 min, affording the target compounds in good yields and selectivities (Table 2, entries 11, 13, and 14). However, in the case of **9f**, the *dr* was slightly lower, and this issue was addressed by decreasing the reaction temperature to 0 °C without any reduction in the yield (Table 2, entries 11 and 12). Upon attempting the reaction of **9h** at 0 °C, the reactivity decreased and a prolonged reaction time of 6 h was required to complete the reaction (Table 2, entry 15). In addition, in the reactions of **9i**–**l** containing electron-withdrawing groups such as chloro and fluoro substituents, the selectivity was influenced by the substitution pattern (Table 2, entries 16–20). More specifically, the reaction of **9i** bearing an *ortho*-Cl substituent proceeded with moderate selectivity at both room temperature and 0 °C (Table 2, entries 16 and 17). A similar result was obtained for *meta*-Cl-substituted substrate **9j** (Table 2, entry 18).

Table 2. Chiral inductive diastereoconvergent Friedel–Crafts alkylation reaction of diastereomixtures of diarylmethanols **9a**–**n** with 2-naphthol.



Entry	Ar	Solvent	Temp. [°C]	Time [h]	Yield of **10**[a] [%]	*dr*[b]
1	Ph (**a**)	CH_2Cl_2	r.t.	2	88	95:5
2	Ph (**a**)	CH_2Cl_2	0	24	58	96:4
3	Ph (**a**)	$MeNO_2$	r.t.	1	90	97:3
4	Ph (**a**)	$MeNO_2$	0	24	88	97:3
5	Ph (**a**)	CH_2Cl_2/$MeNO_2$ (1:1)	r.t.	1	88	97:3
6	Ph (**a**)	CH_2Cl_2/$MeNO_2$ (1:1)	0	24	52	96:4
7	*o*-MeC_6H_4 (**b**)	$MeNO_2$	r.t.	1	94	97:3
8	*m*-MeC_6H_4 (**c**)	$MeNO_2$	r.t.	1	90	97:3
9	*p*-MeC_6H_4 (**d**)	$MeNO_2$	r.t.	1	94	97:3
10	3,4-$Me_2C_6H_3$ (**e**)	$MeNO_2$	r.t.	1	88	98:2
11	*o*-$MeOC_6H_4$ (**f**)	$MeNO_2$	r.t.	1	90	95:5
12	*o*-$MeOC_6H_4$ (**f**)	$MeNO_2$	0	1	87	97:3
13	*m*-$MeOC_6H_4$ (**g**)	$MeNO_2$	r.t.	1	96	97:3
14	*p*-$MeOC_6H_4$ (**h**)	$MeNO_2$	r.t.	1	93	98:2
15	*p*-$MeOC_6H_4$ (**h**)	$MeNO_2$	0	6	91	98:2
16	*o*-ClC_6H_4 (**i**)	$MeNO_2$	r.t.	1	93	92:8[c]
17	*o*-ClC_6H_4 (**i**)	$MeNO_2$	0	24	63	92:8[c]
18	*m*-ClC_6H_4 (**j**)	$MeNO_2$	r.t.	1	93	97:3
19	*p*-ClC_6H_4 (**k**)	$MeNO_2$	r.t.	1	95	99:1
20	*p*-FC_6H_4 (**l**)	$MeNO_2$	r.t.	1	96	99:1
21	α-Np (**m**)	$MeNO_2$	r.t.	1	90	97:3[c]
22	β-Np (**n**)	$MeNO_2$	r.t.	1	96	98:2

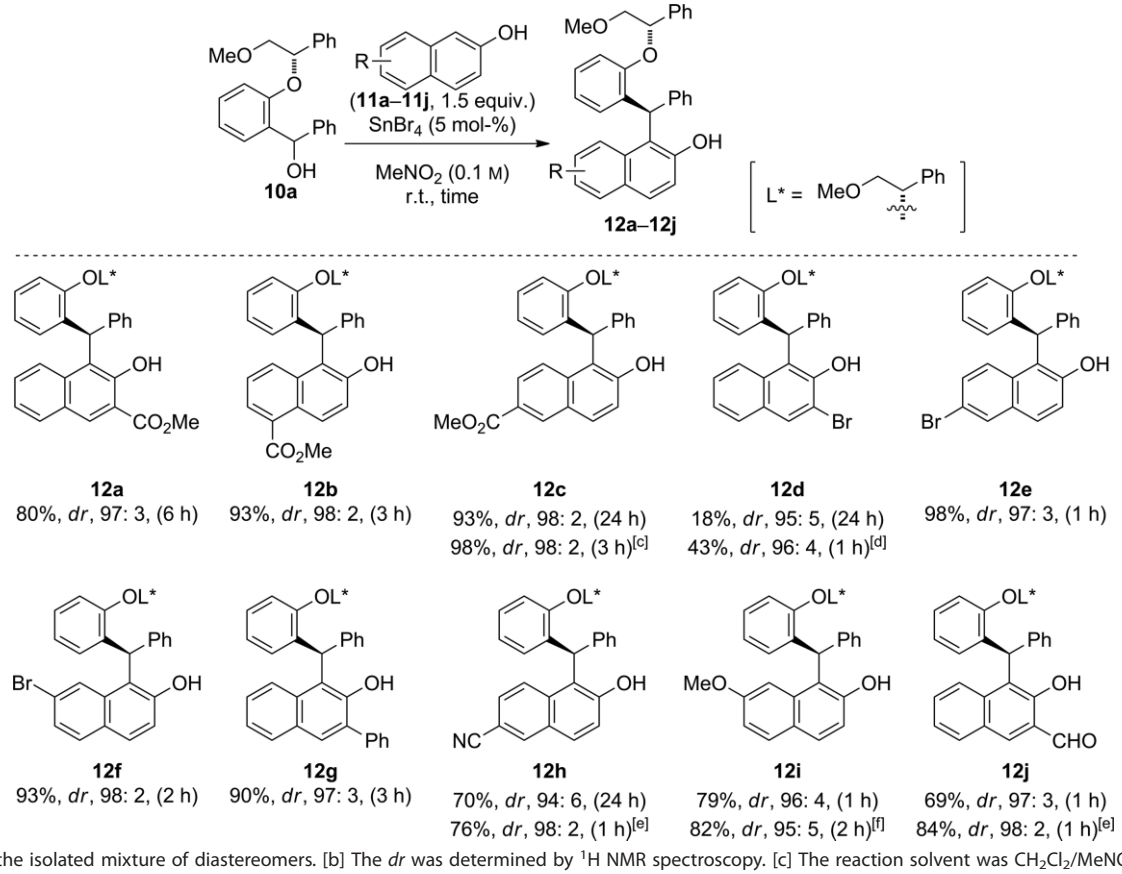
[a] Yield of the isolated mixture of diastereomers. [b] The *dr* was determined by ^1H NMR spectroscopy. [c] The *dr* was determined by HPLC analysis.

By contrast, the reactions of *para*-substituted **9k** and **9l** proceeded to give products with the highest selectivities (Table 2, entries 19 and 20), whereas **9m** and **9n** bearing naphthyl substituents afforded good results, regardless of the substitution pattern (Table 2, entries 21 and 22). Although a similar reaction[23] based on quinone methides and chiral Brønsted acid catalysts focused on substrates bearing electron-donating groups, it should be noted that the present method appears relatively unaffected by substituent effects.

We subsequently examined the reactions of diarylmethanol **10a** with 2-naphthol derivatives **11a–j** to elucidate the scope and limitations of the optimized reaction conditions, that is, in the presence of 5 mol-% catalyst in $MeNO_2$ at room temperature (Table 3). The reactions of compounds **11a–c** bearing a methyl ester on the naphthyl ring were examined, and they afforded products in good to high yields with high selectivities. Although a long reaction time of 24 h was required in the case of **11c** owing to its poor solubility in $MeNO_2$, the use of a mixture of $MeNO_2/CH_2Cl_2$ (1:1) improved the substrate solubility and the reaction time was reduced to 3 h. In the case of bromo-substituted 2-naphthol derivatives **11e** and **11f**, desired products **12e** and **12f** were obtained in high yields and selectivities within a few hours by using 6- and 7-bromo-2-naphthol derivatives. In contrast, 3-bromo-2-naphthol (**11d**) was furnished in a low yield under the optimized conditions; however, increasing the catalyst loading to 110 mol-% at 0 °C resulted in complete consumption of the starting material within 1 h and a slight increase in the yield of **12d**. Several other 2-naphthols (i.e., **11g–j**) were also examined, and desired compounds **12g–j** were produced in good to high yields with high selectivities. We considered it remarkable that such high diastereoselectivities were obtained regardless of the steric and electronic effects of the substituent groups on the naphthyl rings.

In the next step of our investigation, we attempted deprotection of the chiral auxiliary to produce optically chiral compounds (Scheme 3). As cleavage of *O*-α-methylbenzyl ethers was achieved previously under hydrogenation conditions by using Pd/C in EtOH,[31] we applied this method to compound **10a**. However, no reaction occurred and only starting material was recovered. We therefore examined the effect of the reaction solvent[32] and found THF to be the most suitable. Upon performing the hydrogenation reactions of **10a** and **10k** using $Pd(OH)_2$ in THF at room temperature under a hydrogen atmosphere, cleavage of the *O*-α-methoxymethylbenzyl ether was successful, giving corresponding deprotected compounds **13**[23b] and **14**[23a] in yields of 72 and 78 %, respectively, with enantiomeric excess (*ee*) values of 99 % [Scheme 3, Equations (1) and (2)]. The absolute configurations of **13** and **14** were determined by comparison of their previously reported optical rotations,[23] and the absolute configurations of the other products were assigned on the basis of these results. We also examined the use of BBr_3 to remove the chiral auxiliary;

Table 3. Chiral inductive asymmetric Friedel–Crafts alkylation reaction of diastereomixtures of **10a** with 2-naphthol derivatives **11a–j**.[a,b]



12a 80%, *dr*, 97: 3, (6 h)

12b 93%, *dr*, 98: 2, (3 h)

12c 93%, *dr*, 98: 2, (24 h); 98%, *dr*, 98: 2, (3 h)[c]

12d 18%, *dr*, 95: 5, (24 h); 43%, *dr*, 96: 4, (1 h)[d]

12e 98%, *dr*, 97: 3, (1 h)

12f 93%, *dr*, 98: 2, (2 h)

12g 90%, *dr*, 97: 3, (3 h)

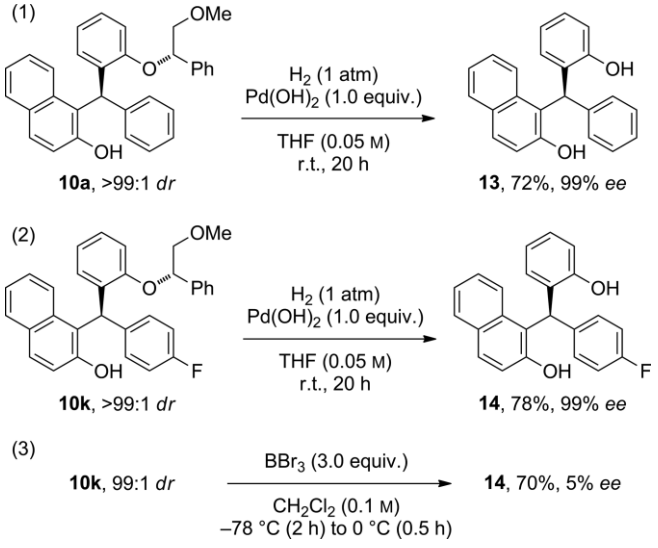
12h 70%, *dr*, 94: 6, (24 h); 76%, *dr*, 98: 2, (1 h)[e]

12i 79%, *dr*, 96: 4, (1 h); 82%, *dr*, 95: 5, (2 h)[f]

12j 69%, *dr*, 97: 3, (1 h); 84%, *dr*, 98: 2, (1 h)[e]

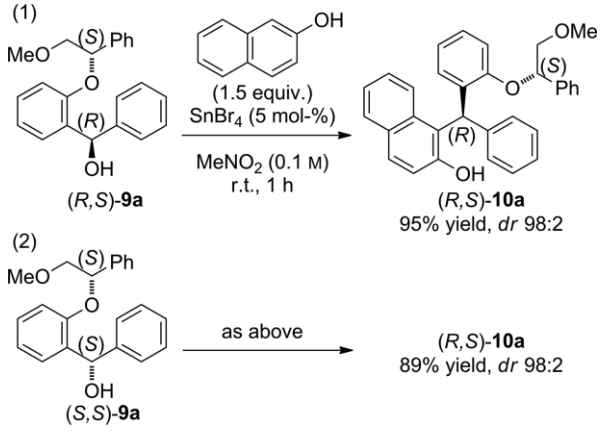
[a] Yield of the isolated mixture of diastereomers. [b] The *dr* was determined by ^1H NMR spectroscopy. [c] The reaction solvent was $CH_2Cl_2/MeNO_2$ (0.1 M, 1:1 volume ratio). [d] Using $SnBr_4$ (110 mol-%) at 0 °C. [e] Using $SnBr_4$ (30 mol-%) at 0 °C. [f] The reaction temperature was 0 °C.

however, upon treatment of **10k** with this reagent, cleavage of the ether bond to afford **14** in good yield was accompanied by racemization [Scheme 3, Equation (3)].



Scheme 3. Deprotection of the chiral auxiliary.

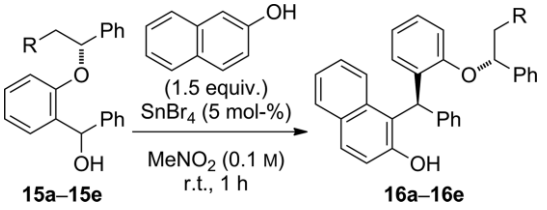
To elucidate the reaction mechanism, the reactions of single diastereomers (*R*,*S*)-**9a** and (*S*,*S*)-**9a**, the absolute configurations of which were determined by using the Mosher ester method,[33] were examined under the reaction conditions outlined in Table 2, entry 3 (Scheme 4). Both reactions afforded (*R*,*S*)-**10a** in high yields with high diastereoselectivities, results that are consistent with those obtained for the diastereomixture of **9a** (see Table 2, entry 3). These results indicate that the reaction proceeds via a dibenzyl cation in an S_N1 fashion, by which chiral induction takes place at the dibenzyl position owing to chelation effect of the methoxy group present on the chiral auxiliary.



Scheme 4. Stereoconvergent reactions of the two individual diastereomers of **9a**.

To verify the substituent effects on the chiral auxiliary, we examined the reactions of **15a**–**e** bearing a range of substituents under the optimized reaction conditions (Table 4). Interestingly, the reaction of **15b** bearing a free hydroxy group on the chiral auxiliary gave results comparable to those obtained for

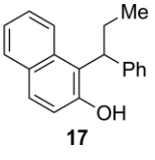
Table 4. Examination of the effect of the MeO group on the chiral auxiliary.



Entry	R	Yield of **16**[a] [%]	*dr*[b]
1[c,d]	OMe	90 (**16a** = **10a**)	97:3
2[e]	OH	87 (**16b**)	98:2
3[e]	OMOM	58[f] (**16c**)	95:5
4[e]	OTBS	8[g] (**16d**)	94:6
5[h]	CH_3	55[i] (**16e**)	55:45

[a] Yield of the isolated mixture of diastereomers. [b] The *dr* was determined by ^{1}H NMR spectroscopy. [c] As in Table 1, entry 3. [d] Substrate **15a**: 62:38 *dr*. [e] Substrates **15b**–**d**: 58:42 *dr*. [f] A diastereomixture of **16b** (93:7) was obtained in 21 % yield by deprotection of the MOM group. [g] A diastereomixture of **16b** (94:6) was obtained in 80 % yield by deprotection of the TBS group. [h] Substrate**15e**: 51:49 *dr*. [i] Compounds **13** and **17** were obtained in yields of 18 and 16 %, respectively.

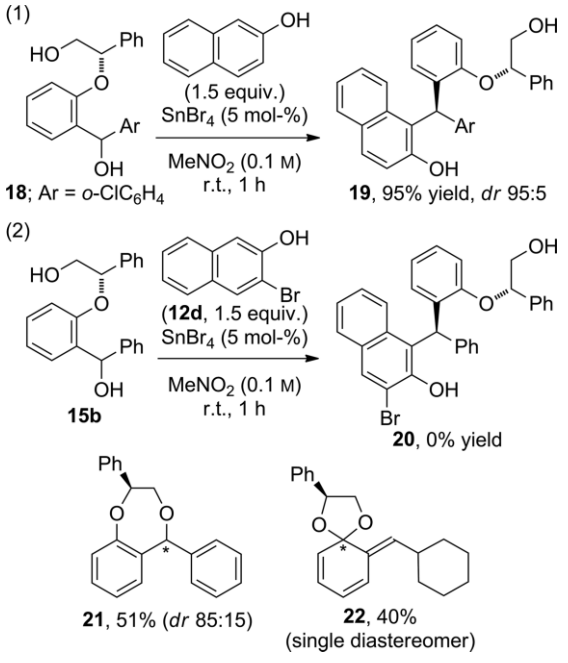
its methoxy equivalent (Table 4, entries 1 and 2). Upon examining the reaction of **15c** bearing a coordinating methoxymethyl (MOM) group, desired product **16c** was obtained in a moderate yield with 95:5 *dr*, which subsequently produced 21 % of the diastereomixture of **16b** (93:7) following deprotection of the methoxymethyl group (Table 4, entry 3). In the case of **15d** (R = OTBS, *tert*-butyldimethylsiloxy), although the selectivity of the reaction was high, deprotection of the TBS group yielded mainly **16b**, along with a very small amount of desired product **16d** (Table 4, entry 4). As anticipated, the reaction of **15e** containing no coordinating oxygen atom on the chiral auxiliary afforded **16e** in a moderate yield but with poor selectivity (Table 4, entry 5). Following cleavage of the ether bond, compounds **13** and **17** were obtained in yields of 18 and 16 %, respectively. These results therefore corroborated our initial working hypothesis regarding the chelation effect.



17

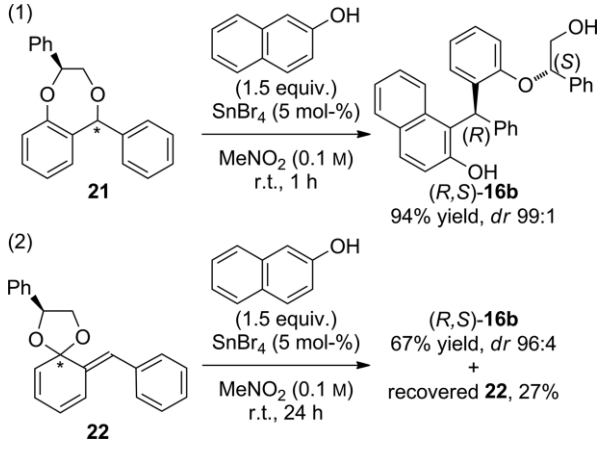
Taking into consideration that **15b** bearing a free hydroxy group on the chiral auxiliary was also found to be effective, as shown in Table 4, entry 2, we re-examined using its derivatives **18** and **15b** for reactions that previously did not furnish sufficient results, as shown in Scheme 5 (see Table 2, entry 16 and Table 3, **12d**). Although the reaction of **18** gave good results [Scheme 5, Equation (1)], desired compound **20** was not obtained in the reaction of **15b** upon using less-reactive 2-naphthol derivative **12d** [Scheme 5, Equation (2)]. Instead, the diastereomixtures of seven-membered ring compound **21** and the single diastereomer of spiro compound **22** (stereochemistries not assigned) were afforded in yields of 51 and 40 %, respectively. It is suggested that **21** and **22** were produced

through an intramolecular reaction between the free hydroxy group on the chiral auxiliary and the quinone methides promptly before the reaction with **12d**.



Scheme 5. Chiral inductive asymmetric Friedel–Crafts alkylation reaction of a diastereomixture of **18** and **15b** with 2-naphthol derivatives.

To confirm this proposed reaction mechanism, both seven-membered ring compound **21** and spiro compound **22** were subjected to the optimized reaction conditions in Scheme 6. Whereas the reaction of **21** reached completion in 1 h, the reaction of **22** was not complete in 24 h owing to its poor solubility in $MeNO_2$. Nevertheless, both reactions afforded the same product, (*R*,*S*)-**16b**, in almost identical high selectivities [Scheme 6, Equations (1) and (2)]. These results further indicate that the reactions proceed via the carbocation in an S_N1 manner, guided by stabilizing chelation of the chiral auxiliary.



Scheme 6. Examination of reaction intermediates **21** and **22**.

Considering the above results, a proposed transition state is illustrated in Figure 2. As indicated, the hydroxy oxygen atom of diarylmethanol **10a** is initially activated upon coordination with $SnBr_4$ to generate the cation, which is stabilized by chelation of the methoxy group on the chiral auxiliary to form seven-membered ring transition-state **23**. Subsequently, attack of the nucleophile occurs preferably through path b to avoid steric clash with the phenyl group on the stereogenic center. As a consequence, the diastereomixture of **10a** is converted into **15a** with high selectivity.

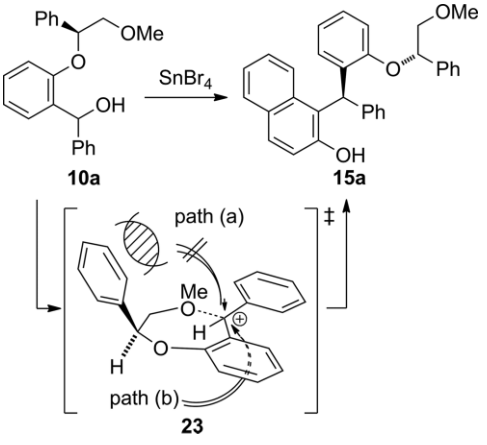
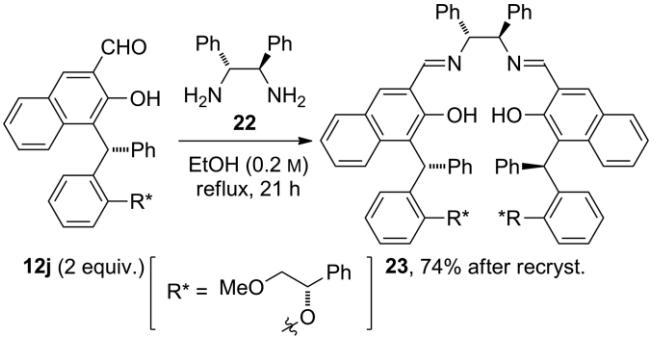


Figure 2. Proposed transition state for the transformation.

Finally, to demonstrate the applicability of this method, we examined the preparation of novel salen ligand **23**, as shown in Scheme 7. The reaction of 2 equivalents of **12j** with 1 equivalent of diamine **22** was carried out in EtOH at reflux (90 °C) in an oil bath for 21 h to afford **23** in 74 % yield after recrystallization. This result demonstrates the high utility of the present method for the synthesis of chiral ligands.



Scheme 7. Preparation of a novel salen ligand.

Conclusions

In summary, we herein reported the development of a $SnBr_4$-catalyzed highly diastereoconvergent Friedel–Crafts alkylation reaction of 2-naphthol derivatives with diarylmethanols bearing a chiral auxiliary. The reactions proceeded via a carbocation intermediate in an S_N1 manner, affording excellent selectivities towards a single diastereomer due to the chiral induction arising from the chelation effect imparted by the chiral auxiliary. In addition, the reactivities were enhanced by the chelation effect, and the majority of reactions reached completion within a few

hours under mild conditions. Furthermore, the effects of the substituents present on the substrates were systematically evaluated, and a fairly broad substrate range was confirmed as suitable for the reaction, as high yields and selectivities were obtained regardless of the substitution patterns and electronic natures of the substituents. The choice of solvent was also found to be important for subsequent deprotection of the chiral auxiliary, and its facile removal to yield the target chiral products was achieved under conventional hydrogenation conditions without any loss in chirality. Further studies are currently underway in our laboratory to expand the scope of this reaction and to develop novel chiral catalysts.

Experimental Section

General Information: ^{1}H NMR and ^{13}C NMR spectra were recorded with chloroform (in [D]chloroform) as an internal standard. Preparative thin-layer chromatography was performed on Wakogel B5F. All reactions were carried out under a nitrogen atmosphere in dried glassware. Dichloromethane was distilled from diphosphorus pentoxide and then calcium hydride and was dried with 4 Å molecular sieves. Toluene and THF were distilled from calcium hydride and were dried with 4 Å molecular sieves. All reagents were purchased from commercial suppliers and were used without further purification unless otherwise noted. $SnBr_4$ was purchased from Sigma–Aldrich. 2-Naphthol was recrystallized from $CHCl_3$ and hexane before use.

Typical Procedure for the Synthesis of Diarylmethanols: To a solution of **8** (255.7 mg, 0.832 mmol) in THF (4.25 mL) at –78 °C was added dropwise *n*BuLi (1.6 M in hexane, 638 μL, 1.02 mmol). The mixture was stirred for 30 min at the same temperature and then benzaldehyde (129 μL, 1.27 mmol) was slowly added. After the whole mixture was stirred for 1 h, the reaction was quenched with saturated aqueous NH_4Cl at –78 °C, and the mixture was diluted with EtOAc. After extraction with EtOAc, the combined organic layer was dried with Na_2SO_4, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexane/EtOAc = 9:1 to 4:1 to 1:1) to afford **9a** (239 mg, 86 % yield, 62:38 *dr*) as a pale-yellow oil. The diastereomixture was separated for analysis by preparative thin-layer chromatography on silica gel (hexane/EtOAc = 4:1 twice to 9:1) to provide (*R*,*S*)-**9a** and (*S*,*S*)-**9a** separately (see Table 1, entry 1). Data for (*R*,*S*)-**9a**: $[\alpha]_D^{22}$ = –4.89 (*c* = 0.86, $CHCl_3$). M.p. 110–111 °C. IR (KBr): $\tilde{\nu}$ = 3406, 1485, 1454, 1240, 1132, 1057, 756, 702 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 7.49 (d, *J* = 7.5 Hz, 2 H), 7.44–7.29 (m, 8 H), 7.04 (dt, *J* = 2.0, 8.0 Hz, 1 H), 6.84 (dd, *J* = 7.0, 1.5 Hz, 1 H), 6.81 (t, *J* = 7.5 Hz, 1 H), 6.63 (d, *J* = 8.0 Hz, 1 H), 6.32 (s, 1 H), 5.30 (dd, *J* = 9.5, 3.0 Hz, 1 H), 4.41 (br. s, 1 H), 3.80 (dd, *J* = 10.5, 9.5 Hz, 1 H), 3.59 (dd, *J* = 10.5, 3.0 Hz, 1 H), 3.45 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 156.4, 141.9, 138.0, 133.7, 128.8, 128.5, 128.24, 128.17, 127.9, 127.3, 127.2, 126.0, 121.1, 113.7, 80.8, 77.2, 71.2, 59.1 ppm. HRMS: calcd. for $C_{22}H_{22}O_3$ [M + Na]$^+$ 357.1461; found 357.1458. Data for (*S*,*S*)-**9a**: $[\alpha]_D^{23}$ = –101.4 (*c* = 1.14, $CHCl_3$). IR (neat): $\tilde{\nu}$ = 3447, 1489, 1452, 1236, 1121, 1022, 754, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 7.43 (d, *J* = 8.0 Hz, 2 H), 7.38–7.31 (m, 3 H), 7.29–7.22 (m, 4 H), 7.06 (dt, *J* = 1.5, 7.5 Hz, 1 H), 7,01–6.96 (m, 2 H), 6.92 (dt, *J* = 0.5, 7.5 Hz, 1 H), 6.56 (d, *J* = 8.0 Hz, 1 H), 5.83 (d, *J* = 10.0 Hz, 1 H), 5.23 (dd, *J* = 9.0, 3.5 Hz, 1 H), 4.51 (dd, *J* = 10.0, 1.5 Hz, 1 H), 3.55 (dd, *J* = 10.5, 9.0 Hz, 1 H), 3.49 (dd, *J* = 10.5, 3.5 Hz, 1 H), 3.45 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.5, 144.6, 137.6, 132.4, 129.3, 128.7, 128.6, 128.1, 127.8, 126.4, 125.8, 125.7, 120.9, 113.6, 79.3, 76.8, 58.8 ppm. HRMS: calcd. for $C_{22}H_{22}O_3$ [M + Na]$^+$ 357.1461; found 357.1452.

Typical Procedure for the Chiral Inductive Diastereoconvergent Friedel–Crafts Alkylation of a Diastereomixture of Diarylmethanols with 2-Naphthols: To a solution of $SnBr_4$ (3.4 mg. 7.76 μmol) in $MeNO_2$ (0.75 mL) at room temperature was successively added 2-naphthol (32.7 mg, 0.227 mmol) and diarylmethanol **9a** (50.8 mg, 0.152 mmol, 62:38 *dr*) in $MeNO_2$ [0.4 mL + 0.2 mL rinse (twice)]. The mixture was stirred for 1 h at room temperature. Then, the reaction was quenched with saturated aqueous $NaHCO_3$ at 0 °C, and the mixture was diluted with CH_2Cl_2. The organic layer was separated, and the aqueous layer was extracted with CH_2Cl_2. The combined organic layer was dried with Na_2SO_4. After filtration of the mixture and evaporation of the solvent, the crude product was purified by preparative thin-layer chromatography on silica gel (toluene/EtOAc = 20:1) to afford desired compound **10a** (63.1 mg, 90 %, 97:3 *dr*) as a pale-yellow oil (see Table 2, entry 3).

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(phenyl)methyl]naphthalen-2-ol (10a): The major diastereomer was separated from the minor diastereomer by recrystallization (CH_2Cl_2/hexane) to afford **10a** as a white solid $[\alpha]_D^{21}$ = –179.8 (*c* = 0.82, $CHCl_3$). M.p. 123–124 °C. IR (KBr): $\tilde{\nu}$ = 3287, 1622, 1599, 1483, 1450, 1288, 1236, 804, 752, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.12 (d, *J* = 9.5 Hz, 1 H), 7.19 (d, *J* = 8.0 Hz, 1 H), 7.74 (d, *J* = 8.5 Hz, 1 H), 7.46–7.39 (m, 1 H), 7.38–7.28 (m, 4 H), 7.25–7.20 (m, 5 H), 7.13–7.04 (m, 5 H), 6.86–6.75 (m, 3 H), 5.53 (br. s, 1 H), 5.33 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.44 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.36 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.24 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.5, 153.2, 142.0, 138.3, 133.7, 130.0, 129.9, 129.6, 129.3, 129.1, 128.8, 128.5, 128.3, 128.0, 127.1, 126.6, 126.2, 123.3, 123.0, 121.2, 120.0, 119.8, 113.1, 79.3, 76.7, 59.1, 43.0 ppm. HRMS: calcd. for $C_{32}H_{28}O_3$ [M + Na]$^+$ 483.1931; found 483.1928.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(*o*-tolyl)methyl]naphthalen-2-ol (10b): It was observed by NMR spectroscopy that an equilibrium exists among some rotamers. The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10b** as a pale-yellow solid. $[\alpha]_D^{18}$ = –278.9 (*c* = 1.10, $CHCl_3$). M.p. 119–120 °C. IR (KBr): $\tilde{\nu}$ = 3440, 1620, 1601, 1485, 1450, 1240, 1205, 818, 746, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.07 (br. s, 1 H), 7.80 (d, *J* = 8.0 Hz, 1 H), 7.74 (d, *J* = 9.0 Hz, 1 H), 7.46 (dd, *J* = 8.0, 7.5 Hz, 1 H), 7.40–7.15 (m, 7 H), 7.15–6.90 (m, 6 H), 6.90–6.72 (m, 3 H), 5.71 (br. s, 1 H), 5.26 (br. s, 1 H), 3.47 (br. s, 5 H), 2.18 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.2, 153.8, 140.6, 138.0, 137.8, 133.5, 131.3, 130.3, 129.8, 129.6, 129.3, 128.6, 128.4, 128.2, 127.9, 127.4, 126.81, 126.78, 126.1, 123.0, 122.9, 121.1, 119.7, 118.0, 113.2, 79.2, 77.3, 59.1, 41.5, 19.7 ppm. HRMS: calcd. for $C_{33}H_{30}O_3$ [M + Na]$^+$ 497.2087; found 497.2078.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(*m*-tolyl)methyl]naphthalen-2-ol (10c): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10c** as a pale-yellow solid. $[\alpha]_D^{21}$ = –180.9 (*c* = 1.18, $CHCl_3$). M.p. 71–72 °C. IR (KBr): $\tilde{\nu}$ = 3483, 1622, 1603, 1485, 1452, 1238, 1205, 814, 750, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.16 (*J* = 8.5 Hz, 1 H), 7.81 (d, *J* = 8.0 Hz, 1 H), 7.76 (d, *J* = 8.5 Hz, 1 H), 7.50–7.43 (m, 1 H), 7.35 (dd, *J* = 8.0, 7.0 Hz, 1 H), 7.31–7.21 (m, 4 H), 7.19–7.00 (m, 8 H), 6.88–6.76 (m, 3 H), 5.61 (br. s, 1 H), 5.37 (dd, *J* = 7.5, 4.0 Hz, 1 H), 3.50 (dd, *J* = 10.5, 7.5 Hz, 1 H), 3.41 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.30 (s, 3 H), 2.32 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.4, 153.2, 141.8, 138.9, 138.3, 133.7, 129.9, 129.5, 129.3, 129.2, 129.1, 128.5, 128.5, 128.2, 128.0, 127.9, 126.7, 126.2, 126.2, 125.7, 123.2, 123.0, 121.2, 120.1, 119.8, 79.2, 76.8, 59.2, 42.8, 21.5 ppm. HRMS: calcd. for $C_{33}H_{30}O_3$ [M + Na]$^+$ 497.2087; found 497.2071.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(*p*-tolyl)methyl]naphthalen-2-ol (10d): The major diastereomer was separated

from the minor diastereomer by recrystallization (CH_2Cl_2/EtOH) to afford **10d** as a white solid. $[\alpha]_D^{19}$ = –273.2 (*c* = 0.91, $CHCl_3$). M.p. 140–141 °C. IR (KBr): $\tilde{\nu}$ = 3440, 1620, 1599, 1483, 1452, 1242, 820, 764, 746, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.13 (d, *J* = 9.0 Hz, 1 H), 7.79 (d, *J* = 8.0 Hz, 1 H), 7.73 (d, *J* = 9.0 Hz, 1 H), 7.47–7.39 (m, 1 H), 7.32 (dd, *J* = 8.0, 7.0 Hz, 1 H), 7.25–7.19 (m, 3 H), 7.16 (d, *J* = 8.5 Hz, 2 H), 7.14–7.04 (m, 7 H), 6.85–6.74 (m, 3 H), 5.57 (br. s, 1 H), 5.34 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.47 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.38 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.27 (s, 3 H), 2.37 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.5, 153.2, 138.7, 138.4, 136.8, 133.7, 130.1, 129.9, 129.8, 129.5, 129.2, 128.6, 128.48, 128.45, 128.2, 127.9, 126.6, 126.2, 123.3, 123.0, 121.2, 120.2, 119.8, 113.1, 79.3, 76.8, 59.2, 42.6, 21.9 ppm. HRMS: calcd. for $C_{33}H_{30}O_3$ $[M + Na]^+$ 497.2087; found 497.2077.

1-[(*R*)-(3,4-Dimethylphenyl){2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}methyl]naphthalen-2-ol (10e): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10e** as a pale-yellow solid. $[\alpha]_D^{22}$ = –206.3 (*c* = 1.12, $CHCl_3$). M.p. 73–75 °C. IR (KBr): $\tilde{\nu}$ = 3474, 1622, 1601, 1485, 1452, 1238, 1202, 814, 750, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.13 (d, *J* = 8.5 Hz, 1 H), 7.78 (d, *J* = 8.0 Hz, 1 H), 7.73 (d, *J* = 9.0 Hz, 1 H), 7.44 (ddd, *J* = 8.5, 7.0, 1.0 Hz, 1 H), 7.32 (t, *J* = 7.5 Hz, 1 H), 7.26–7.17 (m, 3 H), 7.14–7.03 (m, 6 H), 6.99 (s, 1 H), 6.93 (d, *J* = 7.5 Hz, 1 H), 6.84–6.74 (m, 3 H), 5.62 (br. s, 1 H), 5.35 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.49 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.40 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.29 (s, 3 H), 2.27 (s, 3 H), 2.20 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.4, 153.3, 139.1, 138.4, 137.5, 135.5, 133.7, 130.4, 130.1, 129.9, 129.9, 129.5, 129.2, 128.5, 128.4, 128.1, 127.9, 126.7, 126.2, 126.0, 123.2, 123.0, 121.1, 120.3, 119.9, 113.0, 79.2, 76.8, 59.2, 42.5, 19.9, 19.4 ppm. HRMS: calcd. for $C_{34}H_{32}O_3$ $[M + H]^+$ 511.2244; found 511.2235.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(2-methoxy-phenyl)methyl]naphthalen-2-ol (10f): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10f** as a pale-yellow solid. $[\alpha]_D^{24}$ = –7.96 (*c* = 0.79, $CHCl_3$). M.p. 75–76 °C. IR (KBr): $\tilde{\nu}$ = 3476, 1599, 1487, 1452, 1240, 816, 752, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.08 (d, *J* = 9.0 Hz, 1 H), 7.76 (d, *J* = 8.0 Hz, 1 H), 7.69 (d, *J* = 8.5 Hz, 1 H), 7.44–7.38 (m, 1 H), 7.34–7.27 (m, 2 H), 7.24–7.18 (m, 3 H), 7.14–7.01 (m, 5 H), 7.01–6.94 (m, 3 H), 6.91 (t, *J* = 7.5 Hz, 1 H), 6.80 (t, *J* = 7.0 Hz, 1 H), 6.76 (d, *J* = 8.5 Hz,1 H), 5.77 (br. s, 1 H), 5.27 (dd, *J* = 4.5, 4.0 Hz, 1 H), 3.70 (s, 3 H), 3.20 (br. s, 2 H), 2.98 (br. s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 157.4, 155.5, 153.3, 138.4, 133.7, 130.7, 129.8, 129.8, 129.6, 128.9, 128.7, 128.42, 128.37, 128.25, 127.8, 126.4, 126.3, 126.3, 123.3, 122.8, 121.0, 121.0, 119.6, 119.3, 113.1, 111.1, 79.0, 76.4, 59.0, 55.7, 38.1 ppm. HRMS: calcd. for $C_{33}H_{30}O_4$ $[M + Na]^+$ 513.2036; found 513.2030.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(3-methoxy-phenyl)methyl]naphthalen-2-ol (10g): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10g** as a pale-yellow solid. $[\alpha]_D^{20}$ = –192.9 (*c* = 1.18, $CHCl_3$). M.p. 68–69 °C. IR (KBr): $\tilde{\nu}$ = 3481, 1599, 1582, 1485, 1452, 1238, 820, 750, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.12 (d, *J* = 8.5 Hz, 1 H), 7.79 (d, *J* = 8.0 Hz, 1 H), 7.74 (d, *J* = 9.0 Hz, 1 H), 7.48–7.40 (m, 1 H), 7.33 (dd, *J* = 7.5, 7.0 Hz, 1 H), 7.30–7.19 (m, 4 H), 7.14–7.04 (m, 5 H), 6.86 (dd, *J* = 8.0, 2.0 Hz, 1 H), 6.84–6.74 (m, 5 H), 5.17 (br. s, 1 H), 5.35 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.49 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.39 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.71 (s, 3 H), 3.29 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 160.3, 155.4, 153.3, 143.8, 138.3, 133.7, 130.1, 129.9, 129.8, 129.5, 129.3, 128.5, 128.5, 128.3, 128.0, 126.7, 126.2, 123.2, 123.0, 121.2, 120.9, 119.9, 119.8, 114.4, 113.1, 112.5, 79.3, 76.8, 59.2, 55.1, 42.9 ppm. HRMS: calcd. for $C_{33}H_{30}O_4$ $[M + Na]^+$ 513.2036; found 513.2030.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(4-methoxy-phenyl)methyl]naphthalen-2-ol (10h): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10h** as a pale-brownish solid. $[\alpha]_D^{22}$ = –191.6 (*c* = 1.09, $CHCl_3$). M.p. 70–71 °C. IR (KBr): $\tilde{\nu}$ = 3474, 1601, 1508, 1485, 1452, 1242, 816, 750, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.12 (d, *J* = 8.5 Hz, 1 H), 7.78 (d, *J* = 8.0 Hz, 1 H), 7.73 (d, *J* = 8.5 Hz, 1 H), 7.46–7.39 (m 1 H), 7.35–7.29 (m, 1 H), 7.25–7.19 (m, 3 H), 7.13 (d, *J* = 8.5 Hz, 2 H), 7.11–7.05 (m, 5 H), 6.89 (d, *J* = 9.0 Hz, 2 H), 6.85–6.75 (m, 3 H), 5.60 (br. s, 1 H), 5.33 (dd, *J* = 7.5, 4.0 Hz, 1 H), 3.43 (dd, *J* = 10.5, 7.5 Hz, 1 H), 3.37 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.82 (s, 3 H), 3.26 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 158.7, 155.5, 153.3, 138.4, 133.7, 133.6, 130.4, 129.8, 129.8, 129.6, 129.2, 128.50, 128.47, 128.2, 128.0, 126.6, 126.2, 123.3, 123.0, 121.2, 120.1, 119.8, 114.5, 113.1, 79.3, 76.8, 59.1, 55.3, 42.2 ppm. HRMS: calcd. for $C_{33}H_{30}O_4$ $[M + Na]^+$ 513.2036; found 513.2040.

1-[(*R*)-(2-Chlorophenyl){2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}methyl]naphthalen-2-ol (10i): The major diastereomer was separated from the minor diastereomer by preparative thin-layer chromatography on silica gel (hexane/$CHCl_3$/MeOH = 50:99:1 × 2) to afford **10i** as a brownish solid. $[\alpha]_D^{23}$ = +20.0 (*c* = 2.29, $CHCl_3$). M.p. 66–68 °C. IR (KBr): $\tilde{\nu}$ = 3483, 1622, 1599, 1485, 1452, 1238, 1205, 1126, 1049, 814, 748, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.18 (d, *J* = 8.5 Hz, 1 H), 7.78 (dd, *J* = 8.0, 1.5 Hz, 1 H), 7.73 (d, *J* = 8.5 Hz, 1 H), 7.51–7.41 (m, 2 H), 7.32 (ddd, *J* = 8.5, 7.0, 1.0 Hz, 1 H), 7.29–7.17 (m, 6 H), 7.16–7.03 (m, 4 H), 6.98 (s, 1 H), 6.92 (d, *J* = 7.0 Hz, 1 H), 6.84 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.78 (d, *J* = 8.0 Hz, 1 H), 5.57 (br. s, 1 H), 5.26 (d, *J* = 7.0, 4.0 Hz, 1 H), 3.20 (br. s, 2 H), 2.92 (br. s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.7, 153.3, 139.5, 138.2, 134.7, 133.6, 130.7, 130.2, 129.7, 129.5, 129.3, 129.0, 128.8, 128.6, 128.5, 128.4, 127.9, 127.2, 126.7, 126.2, 123.04, 122.96, 121.2, 119.6, 118.4, 113.4, 79.3, 76.5, 58.9, 41.9 ppm. HRMS: calcd. for $C_{32}H_{27}ClO_3$ $[M + Na]^+$ 517.1541; found 517.1543.

1-[(*R*)-(3-Chlorophenyl){2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}methyl]naphthalen-2-ol (10j): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10j** as a white solid. $[\alpha]_D^{25}$ = –280.7 (*c* = 0.56, $CHCl_3$). M.p. 80–81 °C. IR (KBr): $\tilde{\nu}$ = 3489, 1593, 1485, 1452, 1238, 814, 750, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.05 (d, *J* = 8.5 Hz, 1 H), 7.79 (dd, *J* = 8.0, 1.0 Hz, 1 H), 7.75 (d, *J* = 9.0 Hz, 1 H), 7.43 (ddd, *J* = 8.5, 7.0, 1.5 Hz, 1 H), 7.33 (ddd, *J* = 8.5, 7.0, 1.0 Hz, 1 H), 7.30–7.22 (m, 5 H), 7.21–7.17 (m, 1 H), 7.14–7.05 (m, 6 H), 6.83 (dt, *J* = 1.0, 8.0 Hz, 1 H), 6.78 (d, *J* = 8.0 Hz, 1 H), 6.76 (s, 1 H), 5.49 (br. s, 1 H), 5.30 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.39 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.31 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.19 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.6, 152.9, 144.4, 138.1, 134.9, 133.5, 130.1, 129.8, 129.7, 129.5, 129.3, 128.8, 128.6, 128.1, 127.1, 126.9, 126.7, 126.2, 123.3, 123.1, 121.4, 119.8, 119.5, 79.5, 76.6, 59.0, 42.8 ppm. HRMS: calcd. for $C_{32}H_{27}ClO_3$ $[M + Na]^+$ 517.1541; found 517.1531.

1-[(*R*)-(4-Chlorophenyl){2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}methyl]naphthalen-2-ol (10k): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10k** as a pale-yellow solid. $[\alpha]_D^{19}$ = –145.2 (*c* = 1.16, $CHCl_3$). M.p. 75–76 °C. IR (KBr): $\tilde{\nu}$ = 3503, 1622, 1599, 1487, 1452, 1238, 814, 750, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.06 (d, *J* = 9.0 Hz, 1 H), 7.80 (d, *J* = 8.5 Hz, 1 H), 7.75 (d, *J* = 8.5 Hz, 1 H), 7.43 (dt, *J* = 1.5, 8.0 Hz, 1 H), 7.37–7.20 (m, 6 H), 7.19–7.05 (m, 7 H), 6.87–6.78 (m, 2 H), 6.76 (s, 1 H), 5.53 (br. s, 1 H), 5.31 (dd, *J* = 7.5, 4.0 Hz, 1 H), 3.40 (dd, *J* = 10.5, 7.5 Hz, 1 H), 3.32 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.20 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.7, 153.0, 140.6, 138.2, 133.5, 132.6, 130.1, 129.8, 129.73, 129.68, 129.5, 129.0, 128.61, 128.57, 128.54, 128.1, 126.7, 126.2, 123.3, 123.1, 121.4, 119.8, 119.7, 113.4,

79.6, 76.6, 59.0, 42.5 ppm. HRMS: calcd. for $C_{32}H_{27}ClO_3$ [M + Na]$^+$ 517.1541; found 517.1525.

1-[(*R*)-(4-Fluorophenyl){2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}methyl]naphthalen-2-ol (10l): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10l** as a pale-yellow solid. $[\alpha]_D^{19}$ = –129.4 (*c* = 0.98, $CHCl_3$). M.p. 71–73 °C. IR (KBr): $\tilde{\nu}$ = 3489, 1622, 1601, 1506, 1485, 1452, 1236, 841, 814, 750, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.08 (d, *J* = 8.5 Hz, 1 H), 7.80 (dd, *J* = 8.0, 1.5 Hz, 1 H), 7.75 (d, *J* = 9.0 Hz, 1 H), 7.43 (ddd, *J* = 8.5, 7.0, 1.5 Hz, 1 H), 7.34 (ddd, *J* = 8.5, 7.0, 1.0 Hz, 1 H), 7.29–7.22 (m, 3 H), 7.21–7.16 (m, 2 H), 7.15–7.06 (m, 5 H), 7.06–6.99 (m, 2 H), 6.89 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.80 (d, *J* = 8.0 Hz, 1 H), 6.77 (s, 1 H), 5.52 (br. s, 1 H), 5.31 (dd, *J* = 7.5, 4.0 Hz, 1 H), 3.41 (dd, *J* = 10.5, 7.5 Hz, 1 H), 3.32 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.20 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 161.8 (d, *J* = 246 Hz), 155.6, 153.0, 138.2, 137.5 (d, *J* = 2.4 Hz), 133.5, 130.3 (d, *J* = 8.3 Hz), 130.2, 130.0, 129.7, 129.6, 129.4, 128.6, 128.5, 128.5, 128.1, 126.7, 126.2, 123.3, 123.1, 121.4, 119.82, 119.77, 115.8 (d, *J* = 21.6 Hz), 113.3, 79.5, 76.6, 59.0, 42.4 ppm. HRMS: calcd. for $C_{32}H_{27}FO_3$ [M + Na]$^+$ 501.1836; found 501.1831.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(naphthalen-1-yl)methyl]naphthalen-2-ol (10m): It was observed by NMR spectroscopy that an equilibrium exists among some rotamers. The major diastereomer was separated from the minor diastereomer by preparative thin-layer chromatography on silica gel (hexane/$CHCl_3$/MeOH = 100:99:1 × 4) to afford **10m** as a pale-brownish solid. $[\alpha]_D^{25}$ = –234.2 (*c* = 1.80, $CHCl_3$). M.p. 87–89 °C. IR (KBr): $\tilde{\nu}$ = 3474, 1622, 1599, 1485, 1452, 1238, 1205, 789, 750, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.42–6.76 (m, 23 H), 5.74 (br. s, 1 H), 5.33 (br. s, 1 H), 3.42 (br. s, 5 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.3, 154.3, 139.4, 138.2, 134.3, 133.3, 132.1, 130.2, 129.7, 129.3, 128.7, 128.4, 127.9, 127.0, 126.6, 126.1, 125.5, 124.0, 123.1, 122.9, 121.3, 119.6, 118.9, 113.4, 79.5, 76.1, 59.2, 40.9, 40.8 ppm. HRMS: calcd. for $C_{36}H_{30}O_3$ [M + Na]$^+$ 533.2087; found 533.2082.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}(naphthalen-2-yl)methyl]naphthalen-2-ol (10n): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **10n** as a pale-yellow solid. $[\alpha]_D^{22}$ = –189.2 (*c* = 0.80, $CHCl_3$). M.p. 87–88 °C. IR (KBr): $\tilde{\nu}$ = 3497, 1622, 1601, 1506, 1485, 1452, 1236, 841, 814, 750, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.17 (d, *J* = 8.5 Hz, 1 H), 7.90–7.80 (m, 3 H), 7.78 (d, *J* = 9.0 Hz, 1 H), 7.73–7.66 (m, 1 H), 7.55–7.41 (m, 5 H), 7.39–7.31 (m, 1 H), 7.22–7.07 (m, 6 H), 7.06–7.01 (m, 2 H), 6.99 (s, 1 H), 6.90–6.81 (m, 2 H), 5.70 (br. s, 1 H), 5.36 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.44 (dd, *J* = 11.0, 7.5 Hz, 1 H), 3.36 (dd, *J* = 11.0, 4.0 Hz, 1 H), 3.25 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.6, 153.4, 139.8, 138.2, 133.7, 133.6, 132.5, 130.0, 129.7, 129.6, 129.5, 129.0, 128.6, 128.5, 128.5, 128.4, 127.9, 127.6, 127.4, 126.74, 126.69, 126.25, 126.19, 126.0, 123.3, 123.1, 121.3, 119.8, 119.6, 113.2, 79.4, 76.8, 59.2, 43.2 ppm. HRMS: calcd. for $C_{36}H_{30}O_3$ [M + Na]$^+$ 533.2087; found 533.2083.

Methyl 3-Hydroxy-4-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}(phenyl)methyl]-2-naphthoate (12a): The major diastereomer was separated from the minor diastereomer by recrystallization (CH_2Cl_2/hexane) to afford **12a** as a pale-yellow solid. $[\alpha]_D^{22}$ = –119.0 (*c* = 0.80, $CHCl_3$). M.p. 158–159 °C. IR (KBr): $\tilde{\nu}$ = 3059, 1676, 1489, 1445, 1312, 1242, 1205, 793, 746, 723, 698 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 10.9 (s, 1 H), 8.54 (s, 1 H), 8.09 (d, *J* = 8.5 Hz, 1 H), 7.83 (d, *J* = 8.0 Hz, 1 H), 7.40 (t, *J* = 7.5 Hz, 1 H), 7.34–7.15 (m, 12 H), 7.05 (t, *J* = 7.5 Hz, 1 H), 6.98 (s, 1 H), 6.79 (t, *J* = 7.5 Hz, 1 H), 6.74 (d, *J* = 8.0 Hz, 1 H), 5.29 (dd, *J* = 6.5, 5.0 Hz, 1 H), 4.02 (d, *J* = 0.5 Hz, 3 H), 3.42–3.30 (m, 2 H), 3.21 (d, *J* = 1.0 Hz, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 170.7, 155.4, 154.6, 143.3, 138.8, 137.3, 132.0, 131.3, 130.7, 130.1, 128.9, 128.8, 128.4, 127.8, 127.8, 127.3, 127.2, 126.4, 125.6, 124.6, 123.7, 123.2, 120.3, 113.9, 112.3, 78.8, 76.7, 59.1, 52.6, 42.2 ppm. HRMS: calcd. for $C_{34}H_{30}O_5$ [M + Na]$^+$ 541.1985; found 541.1975.

Methyl 6-Hydroxy-5-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}(phenyl)methyl]-1-naphthoate (12b): $[\alpha]_D^{22}$ = –155.8 (*c* = 0.86, $CHCl_3$). M.p. 76–78 °C. IR (KBr): $\tilde{\nu}$ = 3483, 1717, 1599, 1485, 1452, 1259, 1236, 1099, 814, 752, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.76 (d, *J* = 9.5 Hz, 1 H), 8.33 (d, *J* = 9.0 Hz, 1 H), 7.95 (dd, *J* = 9.0 Hz, 1 H), 7.43 (dd, *J* = 9.0, 7.5 Hz, 1 H), 7.39–7.29 (m, 3 H), 7.26–7.18 (m, 6 H), 7.14–7.03 (m, 4 H), 6.86–6.80 (m, 2 H), 6.79 (d, *J* = 8.0 Hz, 1 H), 5.61 (br. s, 1 H), 5.33 (dd, *J* = 7.5, 4.0 Hz, 1 H), 3.99 (s, 3 H), 3.43 (dd, *J* = 10.5, 7.5 Hz, 1 H), 3.35 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.27 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 168.5, 155.5, 153.4, 141.7, 138.2, 134.3, 129.9, 129.9, 129.2, 129.2, 128.7, 128.52, 128.45, 128.2, 128.0, 127.4, 127.2, 126.8, 126.2, 126.2, 125.3, 121.5, 121.3, 120.4, 113.2, 79.4, 76.8, 59.1, 52.2, 43.3 ppm. HRMS: calcd. for $C_{34}H_{30}O_5$ [M + Na]$^+$ 541.1985; found 541.1983.

Methyl 6-Hydroxy-5-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}(phenyl)methyl]-2-naphthoate (12c): $[\alpha]_D^{22}$ = –139.7 (*c* = 0.77, $CHCl_3$). M.p. 81–83 °C. IR (KBr): $\tilde{\nu}$ = 3476, 1717, 1620, 1485, 1450, 1286, 1238, 1202, 1105, 814, 752, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.53 (d, *J* = 2.0 Hz, 1 H), 8.13 (d, *J* = 9.0 Hz, 1 H), 7.99 (dd, *J* = 9.0, 2.0 Hz, 1 H), 7.84 (d, *J* = 8.5 Hz, 1 H), 7.40–7.29 (m, 3 H), 7.25–7.18 (m, 5 H), 7.15 (d, *J* = 8.5 Hz, 1 H), 7.14–7.03 (m, 4 H), 6.86–6.80 (m, 2 H), 6.79 (d, *J* = 8.5 Hz, 1 H), 5.78 (br. s, 1 H), 5.33 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.95 (s, 3 H), 3.42 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.36 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.23 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 167.3, 155.6, 155.3, 141.5, 138.2, 136.2, 131.6, 130.7, 129.8, 129.7, 129.2, 129.2, 128.70, 128.66, 128.5, 128.0, 127.2, 126.2, 126.1, 124.5, 123.6, 121.3, 120.7, 120.3, 113.3, 79.4, 76.7, 59.1, 52.0, 43.1 ppm. HRMS: calcd. for $C_{34}H_{30}O_5$ [M + Na]$^+$ 541.1985; found 541.1987.

3-Bromo-1-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]phenyl}-(phenyl)methyl]naphthalen-2-ol (12d): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **12d** as a pale-brownish solid. $[\alpha]_D^{18}$ = –128.4 (*c* = 0.76, $CHCl_3$). M.p. 162–166 °C. IR (KBr): $\tilde{\nu}$ = 3437, 1597, 1585, 1485, 1447, 1244, 1126, 761, 746, 718, 698 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.11 (d, *J* = 9.0 Hz, 1 H), 8.07 (s, 1 H), 7.71 (dd, *J* = 8.0, 1.5 Hz, 1 H), 7.41 (ddd, *J* = 8.5, 7.0, 1.5 Hz, 1 H), 7.37–7.18 (m, 9 H), 7.14–7.05 (m, 4 H), 6.89 (s, 1 H), 6.82 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.78 (d, *J* = 8.0 Hz, 1 H), 5.99 (br. s, 1 H), 5.31 (dd, *J* = 7.5, 4.0 Hz, 1 H), 3.39 (dd, *J* = 10.5, 7.5 Hz, 1 H), 3.33 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.23 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.4, 148.7, 141.8, 138.4, 133.1, 131.4, 130.2, 130.1, 130.0, 128.9, 128.8, 128.5, 128.2, 128.0, 127.6, 126.83, 126.78, 126.3, 126.3, 124.0, 122.7, 121.0, 113.8, 112.9, 79.1, 76.6, 59.1, 43.7 ppm. HRMS: calcd. for $C_{32}H_{27}BrO_3$ [M + Na]$^+$ 561.1036; found 561.1022.

6-Bromo-1-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]phenyl}-(phenyl)methyl]naphthalen-2-ol (12e): The major diastereomer was separated from the minor diastereomer by preparative thin-layer chromatography on silica gel (toluene/EtOAc = 99:1 × 4) to afford **12e** as a pale-yellow solid. $[\alpha]_D^{23}$ = –149.8 (*c* = 0.96, $CHCl_3$). M.p. 66–68 °C. IR (KBr): $\tilde{\nu}$ = 3487, 1593, 1485, 1450, 1389, 1238, 1204, 1126, 954, 893, 752, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 7.98 (d, *J* = 9.0 Hz, 1 H), 7.93 (d, *J* = 2.5 Hz, 1 H), 7.64 (d, *J* = 8.5 Hz, 1 H), 7.46 (dd, *J* = 9.0, 2.5 Hz, 1 H), 7.39–7.29 (m, 3 H), 7.27–7.17 (m, 5 H), 7.14–7.03 (m, 5 H), 6.82 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.78 (d, *J* = 9.5 Hz, 1 H), 6.77 (s, 1 H), 5.60 (br. s, 1 H), 5.32 (dd, *J* = 8.0, 3.5 Hz, 1 H), 3.45 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.36 (dd, *J* = 10.5, 3.5 Hz, 1 H), 3.25 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.5, 153.5, 141.5, 138.2, 132.3, 130.9, 130.3, 129.8, 129.7, 129.2, 129.2, 128.7, 128.53, 128.46, 128.3, 128.0, 127.2, 126.2, 125.4, 121.3, 121.0, 120.4, 116.8, 113.3, 79.4, 76.7,

59.1, 42.9 ppm. HRMS: calcd. for $C_{32}H_{27}BrO_3$ [M + Na]$^+$ 561.1036; found 561.1029.

7-Bromo-1-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]phenyl}-(phenyl)methyl]naphthalen-2-ol (12f): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **12f** as a white solid. $[\alpha]_D^{22}$ = –140.2 (*c* = 1.07, $CHCl_3$). M.p. 67–68 °C. IR (KBr): $\tilde{\nu}$ = 3481, 1616, 1597, 1485, 1450, 1238, 833, 752, 698 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.24 (d, *J* = 1.0 Hz, 1 H), 7.69 (d, *J* = 8.5 Hz, 1 H), 7.65 (d, *J* = 8.5 Hz, 1 H), 7.41 (dd, *J* = 8.5, 1.5 Hz, 1 H), 7.39–7.29 (m, 3 H), 7.28–7.17 (m, 5 H), 7.16–7.02 (m, 5 H), 6.88–6.79 (m, 2 H), 6.70 (s, 1 H), 5.61 (br. s, 1 H), 5.34 (dd, *J* = 7.5, 4.0 Hz, 1 H), 3.46 (dd, *J* = 10.5, 7.5 Hz, 1 H), 3.39 (dd, *J* = 10.5 Hz, 1 H), 3.26 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.6, 154.1, 141.4, 138.4, 135.0, 130.1, 129.7, 129.5, 129.2, 129.2, 128.7, 128.5, 128.5, 128.0, 127.3, 126.4, 126.3, 125.6, 121.4, 121.3, 120.3, 120.3, 119.4 113.4, 79.4, 76.6, 59.2, 43.0 ppm. HRMS: calcd. for $C_{32}H_{27}BrO_3$ [M + Na]$^+$ 561.1036; found 561.1030.

1-[(*R*)-{2-[(*S*)-2-Methoxy-1-phenylethoxy]phenyl}-(phenyl)methyl]-3-phenylnaphthalen-2-ol (12g): The major diastereomer was separated from the minor diastereomer by preparative thin-layer chromatography on silica gel (toluene/EtOAc = 50:1 × 2) to afford **12g** as a pale-yellow solid. $[\alpha]_D^{21}$ = –169.8 (*c* = 0.49, $CHCl_3$). M.p. 76–78 °C. IR (KBr): $\tilde{\nu}$ = 3487, 1487, 1452, 1429, 1238, 1130, 750, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.15 (d, *J* = 9.0 Hz, 1 H), 7.81 (d, *J* = 8.0 Hz, 1 H), 7.77 (s, 1 H), 7.62–7.56 (m, 2 H), 7.46–7.40 (m, 3 H), 7.38–7.30 (m, 4 H), 7.30–7.21 (m, 6 H), 7.17 (dd, *J* = 7.5, 1.0 Hz, 1 H), 7.13–7.06 (m, 3 H), 6.94 (s, 1 H), 6.82 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.78 (d, *J* = 8.5 Hz, 1 H), 5.70 (br. s, 1 H), 5.33 (dd, *J* = 7.0, 4.0 Hz, 1 H), 3.45 (dd, *J* = 10.5, 7.0 Hz, 1 H), 3.36 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.23 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.5, 150.5, 142.2, 138.5, 138.3, 133.4, 132.0, 130.1, 129.69, 129.65, 129.4, 128.9, 128.9, 128.6, 128.5, 128.2, 128.1, 128.0, 127.4, 126.8, 126.6, 126.3, 126.3, 123.42, 123.35, 121.11, 121.09, 112.9, 79.2, 76.7, 59.2, 43.1 ppm. HRMS: calcd. for $C_{38}H_{32}O_3$ [M + Na]$^+$ 559.2244; found 559.2244.

6-Hydroxy-5-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]phenyl}-(phenyl)methyl]-2-naphthonitrile (12h): $[\alpha]_D^{22}$ = –159.2 (*c* = 0.97, $CHCl_3$). M.p. 80–82 °C. IR (KBr): $\tilde{\nu}$ = 3464, 2226, 1618, 1485, 1450, 1238, 822, 754, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.18 (d, *J* = 8.5 Hz, 1 H), 8.16 (d, *J* = 2.0 Hz, 1 H), 7.78 (d, *J* = 9.0 Hz, 1 H), 7.53 (dd, *J* = 9.0, 2.0 Hz, 1 H), 7.41–7.31 (m, 3 H), 7.28–7.16 (m, 6 H), 7.15–7.06 (m, 3 H), 7.04 (dd, *J* = 7.5, 1.5 Hz, 1 H), 6.84 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.81–6.76 (m, 2 H), 5.88 (br. s, 1 H), 5.33 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.46 (dd, *J* = 10.5, 8.0 Hz, 1 H), 3.37 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.25 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.9, 155.5, 141.1, 138.0, 135.5, 134.4, 129.74, 129.68, 129.3, 129.3, 128.7, 128.61, 128.57, 128.51, 128.1, 127.4, 127.3, 126.1, 124.7, 121.7, 121.4, 120.7, 119.5, 113.4, 106.2, 79.5, 76.8, 59.0, 42.9 ppm. HRMS: calcd. for $C_{33}H_{27}NO_3$ [M + Na]$^+$ 508.1883; found 508.1880.

7-Methoxy-1-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]-phenyl}(phenyl)methyl]naphthalen-2-ol (12i): The major diastereomer was separated from the minor diastereomer by recrystallization (EtOH) to afford **12i** as a brownish solid. $[\alpha]_D^{23}$ = –186.8 (*c* = 0.73, $CHCl_3$). M.p. 68–69 °C. IR (KBr): $\tilde{\nu}$ = 3489, 1624, 1516, 1485, 1450, 1225, 831, 752, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 7.66 (dd, *J* = 9.5, 8.5 Hz, 2 H), 7.39–7.28 (m, 4 H), 7.26–7.17 (m, 5 H), 7.14–7.07 (m, 2 H), 7.04 (d, *J* = 7.0 Hz, 2 H), 6.98 (dd, *J* = 9.0, 2.0 Hz, 1 H), 6.95 (d, *J* = 9.0 Hz, 1 H), 6.86–6.79 (m, 2 H), 6.73 (s, 1 H), 5.61 (br. s, 1 H), 5.34 (dd, *J* = 8.0, 4.0 Hz, 1 H), 3.74 (s, 3 H), 3.50 (ddd, *J* = 10.5, 8.0, 0.5 Hz, 1 H), 3.37 (ddd, *J* = 10.5, 4.0, 0.5 Hz, 1 H), 3.26 (d, *J* = 0.5 Hz, 1 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 158.2, 155.6, 153.9, 142.2, 138.3, 134.9, 130.07, 130.00, 129.92, 129.1, 128.9, 128.8, 128.5, 128.2, 128.0, 127.0, 126.3, 124.9, 121.3, 119.1, 117.1, 115.0, 113.3, 103.2, 79.4, 76.8, 59.1, 55.1, 43.3 ppm. HRMS: calcd. for $C_{33}H_{30}O_4$ [M + Na]$^+$ 513.2036; found 513.2033.

3-Hydroxy-4-[(*R*)-{2-[(*S*)-2-methoxy-1-phenylethoxy]phenyl}-(phenyl)methyl]-2-naphthaldehyde (12j): The major diastereomer was separated from the minor diastereomer by preparative thin-layer chromatography on silica gel (hexane/$CHCl_3$/MeOH = 100:99:1 × 3) to afford **12j** as a yellow oil. $[\alpha]_D^{24}$ = –136.3 (*c* = 0.82, $CHCl_3$). IR (neat): $\tilde{\nu}$ = 3466, 1655, 1630, 1487, 1450, 1238, 1117, 908, 733, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 10.7 (s, 1 H), 10.1 (s, 1 H), 8.14 (s, 1 H), 8.11 (d, *J* = 9.0 Hz, 1 H), 7.89 (d, *J* = 8.0 Hz, 1 H), 7.45 (dt, *J* = 1.0, 8.5 Hz, 1 H), 7.37–7.30 (m, 1 H), 7.30–7.13 (m, 11 H), 7.07–7.01 (m, 1 H), 6.93 (s, 1 H), 6.78 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.72 (d, *J* = 7.5 Hz, 1 H), 5.27 (dd, *J* = 7.0, 4.0 Hz, 1 H), 3.37 (dd, *J* = 10.5, 7.0 Hz, 1 H), 3.33 (dd, *J* = 10.5, 4.0 Hz, 1 H), 3.19 (s, 3 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 196.8, 155.4, 154.1, 142.9, 138.7, 137.7, 137.6, 131.1, 130.7, 130.3, 130.0, 129.0, 129.0, 128.4, 127.93, 127.89, 127.4, 126.4, 125.8, 124.9, 124.1, 123.7, 122.1, 120.3, 112.478.8, 76.8, 59.1, 41.9 ppm. HRMS: calcd. for $C_{33}H_{28}O_4$ [M + Na]$^+$ 511.1880; found 511.1886.

Typical Procedure for the Deprotection of the Chiral Auxiliary: To a solution of **10a** (23.0 mg, 0.05 mmol) in THF (1.0 mL) at room temperature was added $Pd(OH)_2$ (75 %, 0.05 mmol). The whole mixture was stirred at room temperature for 20 h under a hydrogen atmosphere. The reactant was filtered through a short pad of Na_2SO_4 with EtOAc and then a short pad of Celite with EtOAc. The filtrate was concentrated and purified by preparative thin-layer chromatography on silica gel (hexane/EtOAc = 4:1) to afford **13** (11.6 mg, 72 %, 99 % *ee*) as a colorless oil [see Scheme 3, Equation (1)].

(*R*)-1-[(2-Hydroxyphenyl)(phenyl)methyl]naphthalen-2-ol (13):[23b] $[\alpha]_D^{20}$ = –203.9 (*c* = 0.41, *i*PrOH); ref.[23b] $[\alpha]_D^{30}$ = +95.4 (*c* = 0.88, *i*PrOH), 55 % *ee* for *S*. HPLC (CHIRALPAK AD-3, *i*PrOH/hexane = 1:9, flow rate = 0.45 mL min^{-1}): t_R = 52.1 (0.1 %), 56.6 min (99.9 %).

(*R*)-1-[(4-Fluorophenyl)(2-hydroxyphenyl)methyl]naphthalen-2-ol (14):[23a] $[\alpha]_D^{25}$ = +64.3 (*c* = 0.36, $CHCl_3$); ref.[23a] $[\alpha]_D^{24}$ = +26.7 (*c* = 0.3, $CHCl_3$), 74 % *ee* for *R*. HPLC (CHIRALPAK IA-3, *i*PrOH/hexane = 1:9, flow rate = 0.50 mL min^{-1}): t_R = 35.4 (0.7 %), 37.3 min (99.3 %).

1-[(*R*)-{2-[(*S*)-2-Hydroxy-1-phenylethoxy]phenyl}-(phenyl)methyl]naphthalen-2-ol (16b): The major diastereomer was separated from the minor diastereomer by recrystallization ($CHCl_3$/petroleum ether) to afford **16b** as a pale-yellow solid. $[\alpha]_D^{21}$ = +81.2 (*c* = 0.87, $CHCl_3$). M.p. 99–101 °C. IR (KBr): $\tilde{\nu}$ = 3483, 1599, 1485, 1450, 1238, 1030, 814, 750, 700 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ = 8.13 (d, *J* = 8.5 Hz, 1 H), 7.83 (d, *J* = 7.0 Hz, 1 H), 7.77 (d, *J* = 9.0 Hz, 1 H), 7.47 (ddd, *J* = 8.5, 7.0, 1.0 Hz, 1 H), 7.42–7.22 (m, 9 H), 7.18–7.07 (m, 4 H), 7.01 (dd, *J* = 8.0, 1.0 Hz, 1 H), 6.87 (dt, *J* = 1.0, 7.5 Hz, 1 H), 6.70 (d, *J* = 8.5 Hz, 2 H), 5.59 (br. s, 1 H), 5.13 (dd, *J* = 8.0, 3.0 Hz, 1 H), 3.37–3.23 (m, 1 H), 3.18 (dd, *J* = 12.0, 8.0 Hz, 1 H), 0.83 (br. s, 1 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 155.5, 152.9, 140.6, 137.3, 132.9, 131.0, 129.5, 129.4, 129.3, 129.3, 129.0, 128.9, 128.7, 128.7, 128.2, 127.1, 127.0, 126.0, 123.4, 122.8, 121.3, 119.7, 119.6, 113.1, 80.9, 67.2, 44.1 ppm. HRMS: calcd. for $C_{31}H_{26}O_3$ [M + Na]$^+$ 469.1774; found 469.1769.

Procedure for the Preparation of Salen Ligand 23: To a solution of **12j** (216.0 mg, 0.44 mmol) in EtOH (2.2 mL) at room temperature was added (1*R*,2*R*)-1,2-diphenylethylenediamine (**22**; 46.6 mg, 0.22 mmol). The whole mixture was stirred at 90 °C for 21 h and then the solvent was evaporated. The crude mixture was purified by column chromatography on silica gel (hexane/EtOAc = 9:1 to 4:1 to 2:1), followed by recrystallization (EtOH/hexane) to afford salen

23 (186.5 mg, 74 %) as a yellow solid (see Scheme 7). $[\alpha]_D^{24}$ = –251.6 (c = 1.41, $CHCl_3$). M.p. 147–148 °C. IR (KBr): $\tilde{\nu}$ = 1630, 1485, 1452, 1236, 1121, 750, 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ = 13.0 (s, 2 H), 8.46 (s, 2 H), 7.93 (d, J = 8.0 Hz, 2 H), 7.55 (d, J = 8.0 Hz, 2 H), 7.50 (s, 2 H), 7.35–7.08 (m, 36 H), 7.08–7.03 (m, 2 H), 6.99 (s, 2 H), 6.72–6.78 (m, 4 H), 5.31 (dd, J = 7.0, 4.5 Hz, 2 H), 4.75 (s, 2 H), 3.35 (dd, J = 11.0, 7.0 Hz, 2 H), 3.30 (dd, J = 11.0, 4.5 Hz, 2 H), 3.14 (s, 6 H) ppm. ^{13}C NMR ($CDCl_3$): δ = 166.5, 155.6, 154.9, 143.9, 139.0, 135.5, 133.7, 131.3, 130.8, 129.3, 128.8, 128.4, 128.3, 128.1, 127.8, 127.8, 127.7, 127.6, 127.2, 126.5, 125.2, 124.7, 122.8, 122.6, 120.39, 120.35, 80.3, 79.1, 76.959.2, 41.7 ppm. HRMS: calcd. for $C_{33}H_{28}O_4$ $[M + Na]^+$ 1175.4970; found 1175.4967.

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Keywords: Alkylation · Carbocations · Chiral auxiliaries · Diastereoselectivity · Tin

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