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A study of substituent effects on the enantioselective trimethylsilylcyanation of benzaldehyde catalyzed by chiral Schiff base–titanium(IV) complexes

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Received 3 December 2004; accepted 5 January 2005

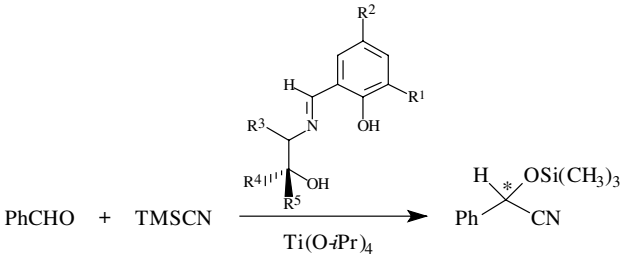
Abstract—New chiral Schiff base ligands derived from *tert*-butyl salicylaldehydes bearing electron withdrawing and donating groups were synthesized by reaction with various substituted chiral amino alcohols. These ligands were used with titanium tetraisopropoxide to study steric and electronic effects on the enantioselectivity of the trimethylsilylcyanation of benzaldehyde. ZINDO calculations are in agreement with the experimental results on the intermediate complexes, which indicate that the steric effects of the substituents are more important than the electronic ones.

1. Introduction

Enantioselective trimethylsilylcyanation of a carbonyl group is a synthetically useful transformation, wherein a new carbon–carbon bond and a stereocenter are created. This transformation has been achieved by using a chiral ligand–metal complex as a Lewis acid catalyst to promote the addition of trimethylsilylcyanide (TMSCN) to a carbonyl compound.[1,2] The types of chiral ligands used for this purpose include tetradentate, tridentate, and bidentate ligands. Metals such as magnesium,[3,4] boron,[5] aluminum,[5–9] tin,[10] bismuth,[11] rhenium,[12] titanium,[13–24] vanadium,[25] and the lanthanides[26–28] have been employed in these complexes. Recently we described the use of tridentate Schiff base ligands of the [ONO] type in combination with titanium tetraisopropoxide to catalyze the trimethylsilylcyanation of benzaldehyde, to give the cyanohydrins in moderate to good enantioselectivities (40–85%).[29] These ligands were inspired by the initial studies by Oguni et al. on the enantioselective trimethylsilylcyanation of aldehydes.[19]

2. Results and discussion

We were interested in studying the effects of substituents on the Schiff base ligand and how they influence the enantioselectivity of the addition of TMSCN to aldehydes. Therefore, subtle changes in the size of substituents, R^1–R^5, of ligand **I** (Scheme 1) were made. These ligands were then tested in Eq. 1.



(1)

In our earlier work we have shown that a *tert*-butyl group at R^1, *ortho* to the phenolic –OH inhibits the formation of the catalytically inactive species L_2^*Ti, resulting in a product of higher enantiomeric excess.[29] In a subsequent study, we have also shown that bulky substituents at R^1 and R^3 (Scheme 2, structure **II**) are essential for obtaining good enantioselectivities in the

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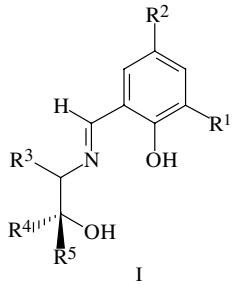
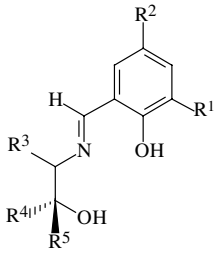
doi:10.1016/j.tetasy.2005.01.030



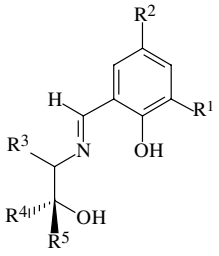
I

Scheme 1. Structure **I**.

cyanohydration of aldehydes.[30] However, if R^1 was larger than *tert*-butyl, it led to poor enantioselectivities (Scheme 2, structure **III**).[30] In this study we concluded that Schiff base with R_1 = *tert*-butyl, R^3 = *tert*-butyl or isopropyl, or R^3, R^4 = rigid cyclic five-membered ring was the best combination to obtain high enantioselectivities in the trimethylsilylcyanation of benzaldehyde.



II



III

$R^1 = C(CH_3)_3$
$R^3 = C(CH_3)_3$, $CH(CH_3)_2$
R^3-$R^4 = CH_2C_6H_4$

$R^1 = C(CH_3)_2CH_2CH_3$, $R^3 = C(CH_3)_3$
$R^1 = C(CH_3)_2CH_2CH_3$, R^3-$R^4 = CH_2C_6H_4$
$R^1 = C(CH_3)_2Ph$, $R^3 = C(CH_3)_3$
$R^1 = C(CH_3)_2Ph$, R^3-$R^4 = CH_2C_6H_4$
R^1 = Adamantyl, $R^3 = C(CH_3)_3$
R^1 = Adamantyl, R^3-$R^4 = CH_2C_6H_4$

Scheme 2. Structures for **II** and **III**.

In designing chiral Schiff base ligands **I** for the trimethylsilylcyanation of aldehydes, we emphasized the size of the substituents R^1, R^3, and the relative stereochemistry at R^3. However, little attention was paid to the substituents R^4 and R^5, and the alkoxy group on the titanium and their influence on the enantioselectivity of the cyanohydration reaction. In our previous work, having a rigid five-membered ring with two stereogenic centers (R^3 and R^4) gave an enantioselectivity of 85% in the trimethylsilylcyanation of benzaldehyde.[29] Therefore, it was of interest to investigate whether this high enantioselectivity was due to either the steric effects, the additional stereogenic center on the ligand, or both. To test this, we synthesized a number of Schiff base ligands (**2**, **5**, **6**, **8**, **10**, **12**, Table 1) with two stereogenic centers as shown in Eq. 2. These ligands were then tested in Eq. 1 (Table 1). When comparing the enantioselectivities obtained with these ligands to their parent ligand ($R^4 = R^5 = H$), it was found that the enantiomeric excess of the final product decreased. Interestingly, when $R^3 = R^4 = Ph$ (ligands **10**, **12**, and results from previous work[30]) the enantioselectivity of the cyanohydrin was comparable to when $R^3 = Ph$, $R^4 = R^5 = H$.[19] This is probably due to π-stacking between the phenyl rings, thus enabling the [ON] coordination to the metal. This is supported by similar π-stacking in the amino alcohol ligands used in the asymmetric transfer hydrogenation reaction.[31] However, when $R^3 = CH_3$, $R^4 = Ph$, and $R^5 = H$, the enantioselectivity decreased, even though the ligand had an additional stereogenic center (ligands **2**, **5**, and **6**, Table 1). The decrease in enantioselectivity is probably due to repulsion between R^3 and R^4. Introducing an additional substituent R^5 on the Schiff base, resulted in poor yield and lower ee of the cyanohydrin product (ligands **6** and **8**), due to overcrowding around the metal center. Further, ligand modification with imine replaced by phenyl (indane ring system in the R^3 and R^4 positions) also led to poor yields and low enantioselectivities. This study also showed that substituent R^2 had little or no influence on the final enantioselectivity of the reaction (ligands **4**, **5**, **11**, and **12**). The overall decreasing trend in the enantioselectivity can be ratio-

Table 1. Enantioselective addition of trimethylsilylcyanide to benzaldehyde promoted by chiral Schiff base–titanium complexes: steric effects[a]

Schiff base	Config.	R^1	R^2	R^3	R^4	R^5	Yield (%)	Ee[b] (%) (config.)
1	(*S*)	$C(CH_3)_3$	H	CH_3	H	H	60	60 (*R*)[c]
2	(*R*,*S*)	$C(CH_3)_3$	H	CH_3	Ph	H	30	34 (*R*)
3	(*R*)	$C(CH_3)_3$	H	H	CH_3	H	60	63 (*S*)
4	(*R*)	$C(CH_3)_3$	$C(CH_3)_3$	H	CH_3	H	60	58 (*S*)
5	(*R*,*S*)	$C(CH_3)_3$	$C(CH_3)_3$	CH_3	Ph	H	35	35 (*R*)
6	(*S*)	$C(CH_3)_3$	H	CH_3	Ph	Ph	20	18 (*R*)
7	(*S*)	$C(CH_3)_3$	H	$CH(CH_3)_2$	H	H	67	85 (*R*)[c]
8	(*S*)	$C(CH_3)_3$	H	$CH(CH_3)_2$	Ph	Ph	54	64 (*R*)[c]
9	(*R*)	$C(CH_3)_3$	H	Ph	H	H	41	40 (*S*)[c]
10	(*S*,*R*)	$C(CH_3)_3$	H	Ph	Ph	H	30	36 (*R*)
11	(*R*)	$C(CH_3)_3$	$C(CH_3)_3$	Ph	H	H	40	45 (*S*)
12	(*R*,*S*)	$C(CH_3)_3$	$C(CH_3)_3$	Ph	Ph	H	85	53 (*S*)[d]

[a] All reactions were performed using 20 mol % titanium tetraisopropoxide at −78 °C in dichloromethane for 36 h. Each ee value is the result of a minimum of two runs.
[b] Enantioselectivities were determined as described in Section 4.
[c] Ref. 19.
[d] Ref. 22.

nalized in terms of steric repulsion between substituents R^3 and R^4 (R^5), thus making the [ONO] coordination to titanium difficult and thus distorting the intermediate titanium complex.

To understand better the factors that control the enantioselective addition of cyanide to the metal-coordinated aldehyde, we modeled the titanium Schiff base complex using molecular mechanics and the semi-empirical program, ZINDO.[32] Oguni's and our own studies have given the highest enantioselectivities when R^1 = *tert*-butyl and R^3 = isopropyl or *tert*-butyl. The choice of the alkoxy group is also important. Oguni et al. demonstrated that Schiff base ligand (R^1 = *tert*-butyl, R^3 = isopropyl), and Ti(O-*i*-Pr)$_4$ exhibited the highest reactivity and enantioselectivity in the cyanosilylation of aldehydes. In contrast, Ti(O-*t*-Bu)$_4$ and Ti(OEt)$_4$ gave 29% and 36% ee's, respectively,[19] suggesting that the ligand with R^3 = *tert*-butyl or isopropyl and isopropoxy (on titanium) appears to be the optimal combination to achieve high ee's. In our computational study the *tert*-butyl group was chosen for both R^1 and R^3 and isopropoxide for the alkoxide group. Using these groups, we formed two sets of isomeric complexes. The first set was based on the Schiff base, benzaldehyde, and two isopropoxides complexed to titanium, giving a total of 12 isomers. Recently, Shibasaki has shown using Schiff base, Ti(O-*i*-Pr)$_4$ and TMSCN, that the cyanide ion displaces one of the isopropoxides on the titanium center. Furthermore, the cyanide from the metal is not transferred to the carbonyl group.[16] Thus, a second set of complexes were also examined replacing one of the titanium isopropoxide groups with a cyanide group, forming a total of 24 possible isomeric compounds. The molecular mechanics calculations gave the same basic *mer* complex as the lowest energy isomer for both the diisopropoxide and the cyano isopropoxide complexes (Fig. 1). The complexed benzaldehyde is orientated in these two compounds with the aldehyde hydrogen pointed toward the Schiff base. The R^3 *tert*-butyl group blocks the *re* face of the aldehyde, allowing the attack to proceed on the *si* face forming the observed product. These same two sets of complexes were also examined at the semi-empirical level using ZINDO. Again, the lowest energy complexes were two related *fac* complexes containing a diisopropoxide or cyano isopropoxide groups (Fig. 2) with the aldehyde hydrogen again pointed toward the Schiff base. The calculated ZINDO energies for the *fac* complexes were significantly lower than for the *mer* complexes found in the molecular mechanics calculations. As before, the *tert*-butyl R^3 group allows preferential attack of the cyanide anion on the *si* face of the complexed benzaldehyde yielding the observed product. The majority of the other complexes showed little differentiation in either product configuration. In addition, our calculations also showed that substituents R^1 and R^2 have minimal contribution to the face selection by cyanide.

Interestingly, the electronic effects have seldom been reported for the vast number of chiral ligands used for the trimethylsilylcyanation reaction. In spite of this fact, electronic effects and the fine tuning of chiral ligands

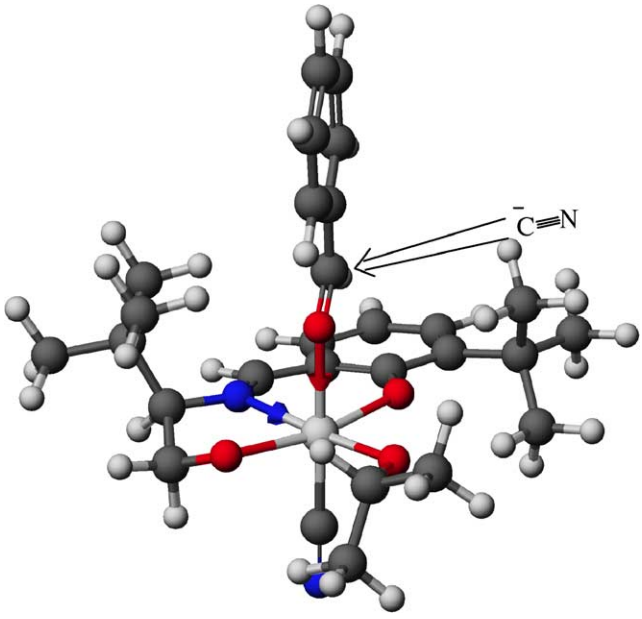


Figure 1. Lowest energy *mer* isomer by MM2 for the octahedral titanium complex transition state in the trimethylsilylcyanation of benzaldehyde.

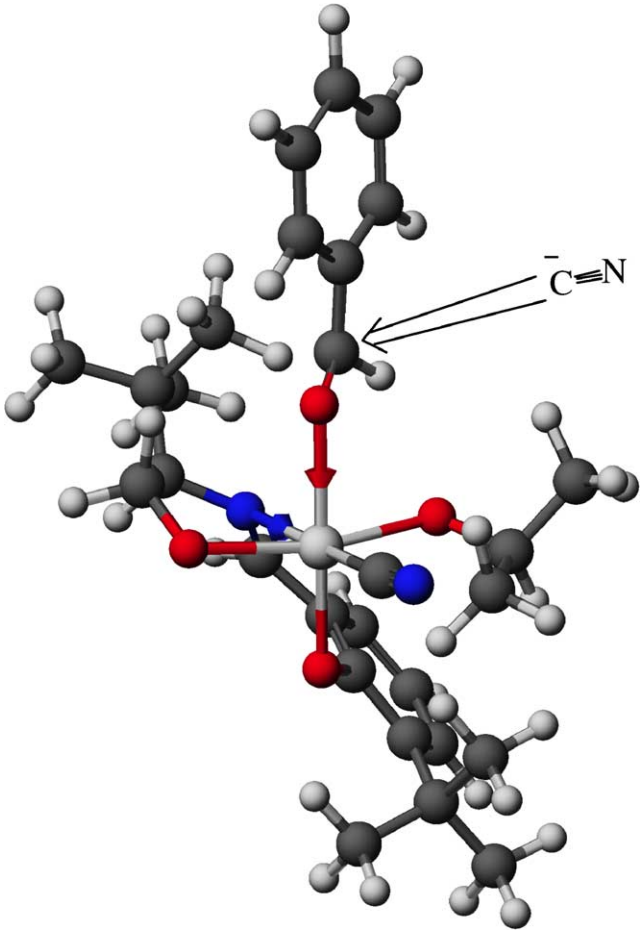


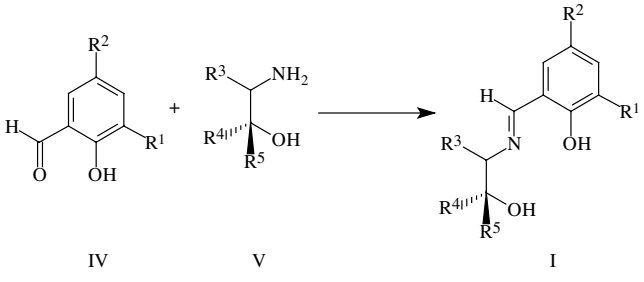
Figure 2. Lowest energy *fac* isomer by ZINDO for the octahedral titanium complex transition state in the trimethylsilylcyanation of benzaldehyde.

Table 2. Enantioselective addition of trimethylsilylcyanide to benzaldehyde promoted by chiral Schiff base–titanium complexes: electronic effects[a]

Schiff base	Config.	R^1	R^2	R^3	R^4	R^5	Yields (%)	Ee (%)[b] (config.)
13	(1*S*,2*R*)	$C(CH_3)_3$	NO_2	$CH_2C_6H_4$		H	52	39 (*S*)
14	(1*R*,2*S*)	$C(CH_3)_3$	Br	$CH_2C_6H_4$		H	59	56 (*R*)
15	(1*R*,2*S*)	$C(CH_3)_3$	OCH_3	$CH_2C_6H_4$		H	58	48 (*R*)
16	(1*R*,2*S*)	OCH_3	H	$CH_2C_6H_4$		H	73	38 (*R*)[c]
17	(1*R*,2*S*)	Br	Br	$CH_2C_6H_4$		H	16	12 (*R*)[c]
18	(*S*)	$C(CH_3)_3$	NO_2	$C(CH_3)_3$	H	H	29	44 (*R*)
19	(*S*)	$C(CH_3)_3$	Br	$C(CH_3)_3$	H	H	52	77 (*R*)
20	(*S*)	$C(CH_3)_3$	OCH_3	$C(CH_3)_3$	H	H	49	67 (*R*)
21	(*R*)	$C(CH_3)_3$	NO_2	C_6H_5	H	H	60	22 (*S*)
22	(*R*)	$C(CH_3)_3$	Br	C_6H_5	H	H	50	48 (*S*)
23	(*R*)	$C(CH_3)_3$	OCH_3	C_6H_5	H	H	54	46 (*S*)
24	(1*S*,2*R*)	$C(CH_3)_3$	NO_2	C_6H_5	C_6H_5	H	55	24 (*S*)
25	(1*S*,2*R*)	$C(CH_3)_3$	Br	C_6H_5	C_6H_5	H	47	53 (*S*)
26	(1*S*,2*R*)	$C(CH_3)_3$	OCH_3	C_6H_5	C_6H_5	H	48	58 (*S*)
27	(*S*)	$C(CH_3)_3$	NO_2	$CH(CH_3)_2$	H	H	25	40 (*R*)
28	(*S*)	$C(CH_3)_3$	Br	$CH(CH_3)_2$	H	H	60	53 (*R*)
29	(*S*)	$C(CH_3)_3$	OCH_3	$CH(CH_3)_2$	H	H	65	56 (*R*)

[a] All reactions were performed using 20 mol % titanium tetraisopropoxide at −78 °C in dichloromethane for 36 h. Each ee value is the result of a minimum of two runs.
[b] Enantioselectivities were determined as described in Section 4.
[c] Ref. 29.

for asymmetric transformations is gradually beginning to be recognized as a useful factor to enhance enantioselectivity.[33–36] Having studied the steric effects of Schiff base ligands our next goal was to study the electronic effect of substituents on the ligand and how it affects the enantioselectivity in the TMSCN (Eq. 1). In our initial studies using ligands with $R^1 = OCH_3$ **16** (Table 2) and $R^1 = R^2 = Br$ (**17**), we obtained ee's of 38% and 12%, respectively. This prompted us to investigate the electronic effect of substituents on the Schiff base ligands in more detail. Based on our previous work, we synthesized the starting aldehydes **IV** with R^1 = *tert*-butyl group *ortho* to the phenolic –OH and R^2 = electron donating or withdrawing groups using literature methods.[29,37,38] The aldehydes **IV** were then coupled with different amino alcohols **V** to give the corresponding Schiff base ligands **I** in excellent yields (Eq. 2).



IV V I (2)

The ligands were then used with Ti(O-*i*-Pr)$_4$ as catalysts to add TMSCN to benzaldehyde (Eq. 1) and the product analyzed as reported in earlier papers.[29,30] The results of our findings are shown in Table 2.

In designing ligands **I**, our assumption was that an electron withdrawing group (R^2) placed *para* to the phenolic –OH, would make the titanium center more Lewis acidic and the titanium–oxygen bond (of benzaldehyde) shorter and stronger in the intermediate, resulting in a higher enantioselectivity in the final cyanohydrin product. Contrary to our assumption, the strong electron withdrawing nitro group led to consistently low ee's (Table 2, ligands **13**, **18**, **21**, **24**, and **27**). However, replacing the nitro group with a less powerful electron withdrawing bromine atom or electron donating methoxy group (both π donors) with $R^1 = R^3$ = *tert*-butyl, led to reasonably good ee's (Table 2, ligands **19** and **20**). Our results are in agreement with Jiang's observation with salen ligands used with Ti(O-*i*-Pr)$_4$ as catalyst in the trimethylsilylcyanation of aldehydes, where –NO_2, –Cl, and –Br substituents in the same position gave 6%, 30%, and 39% ee's, respectively.[39] The low enantioselectivity observed with the nitro group could be due to several reasons, the electron withdrawing nitro could alter the conformation of the transition state or favor an earlier transition state with the CN^- further from the chiral environment of the titanium–Schiff base. In contrast, the methoxy and bromo substituents lead to a late transition state in which there is a greater interaction of the CN^- with the catalyst–substrate complex, leading to high ee's.

3. Conclusion

In conclusion, our results show that the efficiency of a Schiff base ligand–titanium complex in the asymmetric trimethylsilylcyanation of benzaldehyde depends largely on steric interaction between the ligand, aldehyde, and metal. Increasing the number of stereogenic centers around the metal, does not necessarily increase the enantioselectivity. Preliminary computational modeling of the complexes showed that the R^3 substituent plays a large role in determining the enantioselectivity of the catalyst. Furthermore, the electron density on the carbonyl carbon showed very little change, whether the substituent *para* to the phenolic –OH was –NO_2, –Br, or –OCH_3 (assuming the aldehyde coordinates orthogonal to the phenoxy ring).

4. Experimental

Details of the general procedure for the synthesis of the Schiff bases, the trimethylsilylcyanation reaction and the analysis procedures have been reported in a previous work.[29]

4.1. Data for (*R*,*S*)-(+)-2-*tert*-butyl-6-[(2-hydroxy-1-methyl-2-phenyl-ethylamino)-methyl]-phenol, 2

Yellow liquid (0.66 g, 80%); $[\alpha]_D^{25} = +95$ (*c* 0.09, CH_2Cl_2); IR (neat) 3393, 2959, 1630, 1436, 1388, 1268, 1199, 1144, 1025, 752, and 703 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 13.74 (br s, 1H), 8.23 (s, 1H), 7.22–7.34 (m, 6H), 7.02 (dd, $J_1 = 7.8$ Hz, $J_2 = 1.7$ Hz, 1H), 6.77 (t, $J = 7.7$ Hz, 1H), 4.79 (d, $J = 5.1$ Hz, 1H), 3.65 (q, $J = 6.5$ Hz, 1H), 1.41 (s, 9H), 1.28 (d, $J = 6.6$ Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 165.35, 160.43, 140.98, 137.39, 129.81, 129.43, 128.18, 127.78, 127.53, 126.86, 126.49, 118.58, 117.74, 77.61, 69.97, 34.82, 29.31, and 17.50 ppm. Anal. Calcd for $C_{20}H_{25}NO_2$: C, 77.14; H, 8.09. Found: C, 77.22; H, 8.17.

4.2. Data for (*R*)-(−)-2-*tert*-butyl-6-[(2-hydroxy-propyl-imino)-methyl]-phenol, 3

Yellow liquid (1.36 g, 85%); $[\alpha]_D^{25} = -27$ (*c* 0.03, CH_2Cl_2); IR (neat) 3364, 2881, 1633, 1433, 1267, 1145, 1038, and 751 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 13.79 (br s, 1H), 8.38 (s, 1H), 7.35 (dd, $J_1 = 7.7$ Hz, $J_2 = 1.6$ Hz, 1H), 7.12 (dd, $J_1 = 7.6$ Hz, $J_2 = 1.7$ Hz, 1H), 6.83 (t, $J = 7.7$ Hz, 1H), 4.14 (dq, $J = 3.9$ Hz, 1H), 3.72 (dd, $J_1 = 3.9$ Hz, $J_2 = 1.4$ Hz, 1H), 3.49 (dd, $J_1 = 7.2$ Hz, $J_2 = 1.0$ Hz, 1H), 2.02 (br s, 1H), 1.45 (s, 9H), 1.31 (d, $J = 6.4$ Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 167.58, 160.43, 137.49, 129.84, 129.61, 118.58, 117.95, 67.36, 67.10, 34.82, 29.34, 20.85 ppm. Anal. Calcd for $C_{14}H_{21}NO_2$: C, 71.46; H, 8.99. Found: C, 71.45; H, 9.02.

4.3. Data for (*R*)-2,4-di-*tert*-butyl-6-[(2-hydroxy-propyl-imino)-methyl]-phenol, 4

Yellow liquid (1.5 g, 80%); $[\alpha]_D^{25} = -11$ (*c* 0.08, CH_2Cl_2); IR (neat) 3357, 2961, 1635, 1441, 1361, 1174, 1044, and 772 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 13.35 (br s, 1H), 8.35 (s, 1H), 7.40 (d, $J = 2.3$ Hz, 1H), 7.10 (d, $J = 2.3$ Hz, 1H), 4.10 (m, 1H), 3.70 (dd, $J_1 = 12.1$ Hz, $J_2 = 0.7$ Hz, 1H), 2.48 (dd, $J_1 = 12.2$ Hz, $J_2 = 7.2$ Hz, 1H), 1.44 (s, 9H), 1.31 (s, 9H), 1.28 (d, $J = 6.4$ Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 167.97, 158.07, 140.22, 136.78, 127.16, 126.07, 117.80, 67.41, 67.17, 35.03, 34.13, 31.48, 29.44, and 20.81 ppm. Anal. Calcd for $C_{18}H_{29}NO_2$: C, 74.18; H, 10.03. Found: C, 74.44; H, 10.33.

4.4. Data for (*R*,*S*)-2,4-di-*tert*-butyl-6-[(2-hydroxy-1-methyl-2-phenyl-ethylimino)-methyl]-phenol, 5

Yellow liquid (0.6 g, 82%); $[\alpha]_D^{25} = +68$ (*c* 0.01, CH_2Cl_2); IR (neat) 3372, 2959, 1633, and 1440 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.29 (s, 1H), 7.39–7.22 (m, 6H), 7.02 (d, $J = 2.0$ Hz, 1H), 4.80 (d, $J = 4.0$ Hz, 1H), 3.65 (q, $J = 6.0$ Hz, 1H), 1.44 (s, 9H), 1.29 (s, 9H), 1.40 (d, $J = 6.5$ Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 165.83, 158.11, 141.06, 140.08, 136.74, 128.24, 127.79, 127.06, 126.91, 126.10, 117.85, 77.64, 69.96, 39.97, 34.05, 31.43, 29.36, 17.39 ppm. Anal. Calcd for $C_{24}H_{33}NO_2$: C, 78.43; H, 9.05. Found: C, 78.49; H, 9.06.

4.5. Data for (*S*)-(+)-2-*tert*-butyl-6-[(2-hydroxy-1-methyl-2,2-diphenyl-ethylimino)-methyl]-phenol, 6

Yellow liquid (0.14 g, 80%); $[\alpha]_D^{25} = +82$ (*c* 0.01, CH_2Cl_2); IR (neat) 3564, 2957, 1622, 1436, 1267, 1140, 1003, and 752 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 13.12 (br s, 1H), 8.34 (s, 1H), 7.55 (dd, $J_1 = 8.6$ Hz, $J_2 = 1.4$ Hz, 1H), 7.49 (dd, $J_1 = 8.4$ Hz, $J_2 = 1.2$ Hz, 1H), 7.31 (t, $J = 7.4$ Hz, 1H), 7.27 (dd, $J_1 = 7.7$ Hz, $J_2 = 1.6$ Hz, 4H), 7.23 (t, $J = 7.5$ Hz, 4H), 7.20 (t, $J = 7.3$ Hz, 2H), 1.38 (s, 9H), 1.24 (d, $J = 6.5$ Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 166.20, 159.74, 145.71, 144.32, 137.32, 129.93, 129.59, 128.17, 126.81, 126.34, 126.05, 118.65, 117.89, 79.69, 70.29, 34.79, 29.30, 17.48 ppm. Anal. Calcd for $C_{26}H_{29}NO_2$: C, 80.59; H, 7.54. Found: C, 80.64; H, 7.60.

4.6. Data for (*S*,*R*)-(−)-2-*tert*-butyl-6-[(2-hydroxy-1,2-diphenyl-ethylimino)-methyl]-phenol, 10

Yellow amorphous solid (0.86 g, 82%); $[\alpha]_D^{25} = -19$ (*c* 0.04, CH_2Cl_2); IR (neat) 3424, 2942, 1619, 1439, 1266, 1199, 1043, 754, and 702 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 13.60 (br s, 1H), 8.07 (s, 1H), 7.22–7.40 (m, 11H), 6.93 (dd, $J_1 = 7.5$ Hz, $J_2 = 1.5$ Hz, 1H), 6.73 (t, $J = 7.5$ Hz, 1H), 5.05 (d, $J = 6.8$ Hz, 1H), 3.90 (d, $J = 6.8$ Hz, 1H), 1.43 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 166.61, 160.26, 140.19, 139.45, 137.31, 130.12, 129.65, 128.72, 128.12, 128.08, 128.01, 127.22, 118.59, 117.82, 80.22, 78.39, 34.84, 29.33 ppm. Anal. Calcd for $C_{23}H_{25}NO_2$: C, 79.51; H, 7.25. Found: C, 79.70; H, 7.30.

4.7. Data for (*R*)-(+)-2,4-di-*tert*-Butyl-6-[(2-hydroxy-1-phenyl-ethylimino)-methyl]-phenol, 11

Yellow solid (1.53 g, 86%); mp 62–65 °C; $[\alpha]_D^{25} = +118$ (*c* 0.01, CH_2Cl_2); IR (KBr) 3381, 2955, 1629, 1361, 1248, 1172, 879, and 698 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 11.63 (br s, 1H), 8.47 (s, 1H), 7.42–7.20 (m, 6H), 7.11 (d, $J = 2.0$ Hz, 1H), 4.40 (t, $J = 12.0$ Hz, 1H), 3.84 (dd, $J_1 = 6.0$ Hz, $J_2 = 4.0$ Hz, 2H), 1.46 (s, 9H), 1.27 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 167.54, 158.00, 140.40, 139.57, 136.75, 128.75, 127.74, 127.35, 127.18, 126.41, 117.87, 75.18, 67.58, 31.39, 31.21, 29.38, and 29.20 ppm. Anal. Calcd for $C_{23}H_{31}NO_2$: C, 78.24; H, 8.84. Found: C, 78.24; H, 8.90.

4.8. Data for (*R*,*S*)-(+)-2,4-di-*tert*-Butyl-6-[(2-hydroxy-1,2-diphenyl-ethylimino)-methyl]-phenol, 12

Yellow solid (0.8 g, 80%); mp 66–70 °C; $[\alpha]_D^{25} = +11$ (*c* 0.02, CH_2Cl_2); IR (KBr) 3433, 2953, 1627, 1445, 1173,

1034, and 897 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.13 (s, 1H), 8.07 (s, 1H), 7.31–7.22 (m, 11H), 6.92 (d, $J = 2.0$ Hz, 1H), 5.02 (d, $J = 7.9$ Hz, 1H), 4.49 (d, $J = 7.9$ Hz, 1H), 2.11 (br s, 1H), 1.45 (s, 9H), 1.24 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 167.12, 158.01, 140.30, 140.09, 139.66, 136.63, 128.64, 128.07, 127.94, 127.89, 127.28, 126.31, 117.88, 79.96, 77.0, 34.97, 33.99, 31.78, and 29.36 ppm. Anal. Calcd for $C_{29}H_{35}NO_2$: C, 81.08; H, 8.21. Found: C, 81.11; H, 8.25.

4.9. Data for (1*S*,2*R*)-(−)-1-[(3-*tert*-butyl-2-hydroxy-5-nitro-benzylidene)-amino]-indan-2-ol, 13

Yellow solid (0.48 g, 40%); mp 72–78 °C; $[\alpha]_D^{25} = -29.3$ (*c* 0.50, CH_2Cl_2); IR (KBr): 3419, 3108, 2952, 1638, 1600, 1557, 1316, and 748 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 8.53 (s, 1H), 8.22 (d, 1H, $J = 2.80$ Hz), 8.16 (d, 1H, $J = 3.00$ Hz), 7.36–7.20 (m, 4H), 4.95 (d, 1H, $J = 5.2$ Hz), 4.76 (q, 1H, $J = 5.4$ Hz), 3.30 (dd, 1H, $J_1 = 6.0$ Hz, $J_2 = 16.0$ Hz), 3.11 (dd, 1H, $J = 5.0$ Hz, $J = 16.0$ Hz), and 1.42 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 165.04, 169.10, 140.37, 140.44, 139.24, 138.30, 129.24, 127.48, 127.21, 125.81, 125.54, 125.03, 116.70, 74.92, 73.45, 39.47, 35.21, and 28.89 ppm. EIMS (*m*/*e*): 354 [M^+] (82), 337(18), 221(43), 207(37), 179(42), 133(100), 105(53), 91(31), and 77(39). HREIMS *m*/*z* calcd for $C_{20}H_{22}N_2O_4$ 354.1573, found 354.1579.

4.10. Data for (1*R*,2*S*)-(+)-1-[(5-bromo-3-*tert*-butyl-2-hydoxy-benzylidene)-amino]-indan-2-ol, 14

Yellow liquid (1.13 g, 87%); $[\alpha]_D^{25} = +11.0$ (*c* 0.50, CH_2Cl_2); IR (neat): 3374, 29.51, 1625, 749, and 600 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 8.47 (s, 1H), 7.44 (d, $J = 2.6$ Hz, 1H), 7.32 (d, $J = 2.6$ Hz, 1H) 7.34–7.21 (m, 4H), 4.73 (d, $J = 5.2$ Hz, 1H), 4.61 (q, $J = 5.2$ Hz, 1H), 3.18 (dd, $J = 5.6$ Hz, $J = 15.8$ Hz, 1H), 3.05 (dd, $J = 5.2$ Hz, 1H), and 1.36 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 165.56, 159.57, 140.42, 140.05, 139.98, 132.47, 131.69, 128.34, 126.75, 125.18, 124.57, 119.53, 109.54, 74.88, 74.78, 50.28, 39.26, 34.94, 29.22, and 29.00 ppm. EIMS (*m*/*e*): 387 [M^+] (69), 240(24), 133(100), 103(77), and 77(77). HREIMS *m*/*z* calcd for $C_{20}H_{22}NO_2Br$ 387.0834, found 387.0834.

4.11. Data for (1*R*,2*S*)-(+)-1-[(3-*tert*-butyl-2-hydroxy-5-methoxy-benzylidene)-amino]-indan-2-ol, 15

Brown liquid (0.86 g, 82%); $[\alpha]_D^{25} = +27.1$ (*c* 0.50, CH_2Cl_2); IR (neat): 3383, 2953, 1629, 1206, and 752 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 8.53 (s, 1H), 7.29–7.17 (m, 4H), 7.01 (d, 1H, $J = 5.6$ Hz), 4.65 (q, $J = 5.6$ Hz, 1H), 3.77 (s 3H), 3.22 (dd, $J_1 = 5.4$ Hz, $J_2 = 16.8$ Hz, 1H), 3.10 (dd, $J_1 = 5.2$ Hz, $J_2 = 14.0$ Hz, 1H), and 1.38 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 167.54, 155.28, 151.59, 141.19, 141.13, 139.4, 128.78, 127.27, 125.73, 125.17, 119.19, 118.21, 112.08, 75.74, 75.43, 56.05, 39.79, 35.24, and 29.54 ppm. EIMS (*m*/*e*): 339 [M^+] (53), 221(32), 192(92), 133(61), 80(28), and 57(100). HREIMS *m*/*z* calcd for $C_{21}H_{25}NO_3$ 339.1825, found 339.1834.

4.12. Data for (*S*)-(−)-2-*tert*-butyl-6-[(1-hydroxymethyl-2,2-dimethyl-propylimino)-methyl]-4-nitro-phenol, 18

Yellow solid (0.22 g, 30%); mp 130–133 °C; $[\alpha]_D^{25} = -40$ (*c* 0.01, CH_2Cl_2); IR (KBr) 3415, 2962, 1632, 1479, 1325 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.51 (s, 1H), 8.27 (d, $J = 2.8$ Hz, 1H), 8.15 (d, $J = 2.6$ Hz, 1H), 4.00 (dd, $J_1 = 11.4$ Hz, $J_2 = 2.8$ Hz, 1H), 3.66 (t, $J = 9.4$ Hz, 1H), 3.21 (dd, $J_1 = 2.8$ Hz, $J_2 = 9.4$ Hz, 1H) and 1.43 (s, 9H), 1.05 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 173.97, 168.05, 142.33, 138.23, 129.73, 126.01, 117.31, 79.15, 62.23, 36.22, 34.05, 29.53, and 27.32 ppm. Anal. Calcd for $C_{17}H_{26}N_2O_4$: C, 63.35; H, 8.07. Found: C, 63.41; H, 8.10.

4.13. Data for (*S*)-(−)-4-bromo-2-*tert*-butyl-6-[(1-hydroxymethyl-2,2-dimethyl-propylimino)-methyl]-phenol 19

Yellow solid (0.37 g, 89%); mp 141–143 °C; $[\alpha]_D^{25} = -37$ (*c* 0.03, CH_2Cl_2); IR (KBr) 3441, 2962, and 1626 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 13.95 (s, 1H), 8.22 (s, 1H), 7.30 (d, $J = 2.4$ Hz, 1H), 7.22 (d, $J = 2.4$ Hz, 1H), 3.92 (dd, $J = 2.6$ Hz, $J = 11.10$ Hz, 1H), 3.72 (t, $J = 9.7$ Hz, 1H), 2.93 (dd, $J_1 = 2.8$ Hz, $J_2 = 9.5$ Hz, 1H), 1.40 (s, 9H), and 1.00 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 165.60, 159.88, 140.35, 132.58, 131.99, 120.01, 110.01, 81.49, 62.62, 35.32, 33.44, 29.40, and 27.27 ppm. Anal. Calcd for $C_{17}H_{26}BrNO_2$: C, 57.30; H, 7.30. Found: C, 57.33; H, 7.34.

4.14. Data for (*S*)-(−)-2-*tert*-butyl-6-[(1-hydroxymethyl-2,2-dimethyl-propylimino)-methyl]-4-methoxy-phenol, 20

Yellow solid (0.33 g, 80%); mp 122–125 °C; $[\alpha]_D^{25} = -62$ (*c* 0.001, CH_2Cl_2); IR (KBr) 3461, 2959, 1631, 1056, and 783 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 8.31 (s, 1H), 6.99 (d, $J = 3.2$ Hz, 1H), 6.65 (d, $J = 3.2$ Hz, 1H), 3.94 (dd, $J_1 = 3.2$ Hz, $J_2 = 11.2$ Hz, 1H), 3.78 (s, 3H), 3.72 (m, 1H), 2.93 (dd, $J_1 = 2.8$ Hz, $J_2 = 9.2$ Hz, 1H), 1.43 (s, 9H), and 0.98 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 166.83, 155.32, 151.61, 139.37, 118.68, 118.06, 112.01, 81.70, 62.76, 56.05, 35.19, 33.42, 29.46, and 27.26 ppm. Anal. Calcd for $C_{18}H_{29}NO_3$: C, 70.34; H, 9.44. Found: C, 70.39; H, 9.45.

4.15. Data for (*R*)-(+)-2-*tert*-butyl-6-[(2-hydroxy-1-phenyl-ethylimino)-methyl]-4-nitro-phenol, 21

Yellow solid (0.13 g, 91%); mp 57–59 °C; $[\alpha]_D^{25} = +19.3$ (*c* 0.02, CH_2Cl_2); IR (KBr) 3416, 2959, 2871, 1635, 750, and 699 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.50 (s, 1H), 8.20 (d, $J = 3.0$ Hz, 1H), 8.12 (d, $J = 3.0$ Hz, 1H), 7.25–7.41 (m, 5H) 4.58 (t, $J = 6.6$ Hz, 1H), 3.97 (d, $J = 6.6$ Hz, 2H), and 1.45 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 167.53, 165.76, 139.89, 138.91, 138.30, 129.28, 128.55, 127.36, 126.75,

125.32, 117.38, 74.98, 67.33, 35.45, and 28.18 ppm. Anal. Calcd for $C_{19}H_{22}N_2O_4$: C, 66.66; H, 6.43. Found: C, 66.71; H, 6.47.

4.16. Data for (*R*)-(+)-4-bromo-2-*tert*-butyl-6-[(2-hydroxy-1-phenyl-ethylimino)-methyl]-phenol, 22

Yellow liquid (0.15 g, 79%); $[\alpha]_D^{25} = +78$ (*c* 0.02, CH_2Cl_2); IR (neat) 3374, 2955, 2872, 1632, 1065, 870, and 700 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.32 (s, 1H), 7.38 (d, $J = 2.4$ Hz, 1H), 7.39–7.20 (m, 5H), 7.20 (d, $J = 2.4$ Hz, 1H) 4.39 (t, 1H, $J = 6.0$ Hz, 1H), 3.80 (d, $J = 5.4$ Hz, 2H), 1.40 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 165.97, 159.68, 139.19, 132.91, 132.16, 129.11, 128.20, 127.38, 120.10, 110.21, 110.21, 75.77, 67.56, 35.17, and 29.27 ppm. Anal. Calcd for $C_{19}H_{22}NO_2Br$: C, 60.63; H, 5.85. Found: C, 60.67; H, 5.88.

4.17. Data for (*R*)-(−)-2-*tert*-butyl-6-[(2-hydroxy-1-phenyl-ethylimino)-methyl]-4-methoxy-phenol, 23

Colorless liquid, (0.43 g, 93%); $[\alpha]_D^{25} = +98$ (*c* 0.01, CH_2Cl_2); IR (neat) 3411, 2957, 2870, 1633, 1059, and 700 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.44 (s, 1H), 7.39–7.37 (m, 5H), 6.99 (d, $J = 3.0$ Hz, 1H), 6.61 (d, $J = 3.0$ Hz, 1H), 4.44 (t, $J = 7.0$ Hz, 1H), 3.92 (m, 2H), 3.75 (s, 3H), and 1.44 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 167.19, 155.11, 151.69, 139.69, 139.37, 129.08, 128.11, 127.47, 118.99, 118.18, 112.12, 76.15, 68.38, 67.90, 55.99, 35.15, and 29.44 ppm. Anal. Calcd for $C_{20}H_{25}NO_3$: C, 73.39; H, 7.64. Found: C, 73.44; H, 7.68.

4.18. Data for (1*S*,2*R*)-(−)-2-*tert*-butyl-6-[(2-hydroxy-1,2-diphenyl-ethylimino)-methyl]-4-nitro-phenol, 24

Yellow solid (0.15 g, 97%); mp 55–58 °C; $[\alpha]_D^{25} = -727$ (*c* 0.01, CH_2Cl_2); IR (KBr) 3446, 2959, 2871, 1635, and 705 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.19 (d, $J = 3.0$ Hz, 1H), 8.12 (s, 1H), 7.93 (d, $J = 3.0$ Hz, 1H), 7.44–7.32 (m, 5H), 7.31–7.18 (m, 5H), 5.08 (d, $J = 6.6$ Hz, 1H), 4.60 (d, $J = 6.6$ Hz, 1H), 1.45 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 167.30, 165.40, 139.89, 138.46, 129.14, 128.61, 128.44, 128.21, 127.33, 126.54, 125.25, 117.37, 79.47, 78.33, 35.46, 33.46, 31.09, and 29.15 ppm. Anal. Calcd for $C_{27}H_{26}N_2O_4$: C, 71.76; H, 6.22. Found: C, 71.76; H, 6.25.

4.19. Data for (1*S*,2*R*)-(−)-4-bromo-2-*tert*-butyl-6-[(2-hydroxy-1,2-diphenyl-ethylimino)-methyl]-phenol, 25

Yellow solid (0.25 g, 93%); mp 56–58 °C; $[\alpha]_D^{25} = -33.0$ (*c* 0.11, CH_2Cl_2); IR (KBr) 3424, 2952, 2878, 1631, 1045, and 705 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.0 (s, 1H), 7.35–7.29 (m, 11H), 7.00 (d, $J = 3.0$ Hz, 1H), 5.00 (d, $J = 7.0$ Hz, 1H), 4.47 (d, $J = 7.0$ Hz, 1H), and 1.41 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 165.59, 159.66, 140.29, 132.78, 132.06, 129.04, 128.38, 127.42, 120.08, 109.97, 80.27, 78.48, 35.23, and 29.26 ppm. Anal. Calcd for $C_{25}H_{26}BrNO_2$: C, 66.37; H, 5.75. Found: C, 66.40; H, 5.77.

4.20. Data for (1*S*,2*R*)-(−)-2-*tert*-butyl-6-[(2-hydroxy-1,2-diphenyl-ethylimino)-methyl]-4-methoxy-phenol, 26

Yellow liquid (0.43 g, 75%); $[\alpha]_D^{25} = -21$ (*c* 0.01, CH_2Cl_2); IR (neat) 3422, 2960, 1633, 1065, and 700 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.03 (s, 1H), 7.36–7.21 (m, 10H), 6.94 (d, $J = 3.0$ Hz, 1H), 6.40 (d, $J = 3.0$ Hz, 1H), 5.01 (d, $J = 6.8$ Hz, 1H), 4.50 (d, $J = 6.8$ Hz, 1H), 3.68 (s, 3H), and 1.43 (s, 9H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 166.65, 155.10, 151.42, 140.47, 139.72, 139.17, 128.92, 128.37, 128.27, 128.20, 127.47, 118.74, 118.12, 112.03, 80.41, 78.52, 55.91, 35.13, and 29.39 ppm. Anal. Calcd for $C_{26}H_{29}NO_3$: C, 77.41; H, 7.19. Found: C, 77.45; H, 7.22.

4.21. Data for (*S*)-(−)-2-*tert*-butyl-6-[(1-hydroxmethyl-2-methyl-propylimino)-methyl]-4-nitro-phenol, 27

Yellow solid (0.21 g, 30.0%); mp 82–86 °C; $[\alpha]_D^{25} = -26$ (*c* 0.01, CH_2Cl_2); IR (KBr) 3418, 2964, 1634, 1480 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.37 (s, 1H), 8.18 (d, $J = 2.8$ Hz, 1H), 8.12 (d, $J = 2.8$ Hz, 1H), 3.90 (dd, $J_1 = 3.5$ Hz and $J_2 = 11.2$ Hz, 1H), 3.79 (dd, $J_1 = 8.7$ Hz, $J_2 = 11.2$ Hz, 1H), 3.18 (m, 1H), 2.20 (sept, 1H), 1.44 (s, 9H), 0.99 (d, 6H, $J = 3.1$ Hz) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 169.36, 165.60, 140.35, 138.24, 127.06, 125.18, 116.70, 76.22, 64.14, 35.44, 31.63, 29.19, 19.94, 18.79.

4.22. Data for (*S*)-(−)-4-bromo-2-*tert*-butyl-6-[(1-hydroxymethyl-2-methyl-propylimino)-methyl]-phenol, 28

Yellow liquid (0.53 g, 60%); $[\alpha]_D^{25} = -57$ (*c* 0.01, CH_2Cl_2); IR (neat) 3353, 2960, 2871, 1635, and 772 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.24 (s, 1H), 7.39 (d, $J = 2.4$ Hz, 1H), 7.25 (d, $J = 2.4$ Hz, 1H), 3.74 (m, 2H), 3.00 (m, 1H), 1.92 (sept, $J = 6.4$ Hz, 1H), 1.41 (s, 9H), 0.92 (d, $J = 6.6$ Hz, 6H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 165.51, 160.09, 140.40, 132.60, 131.97, 120.00, 109.94, 69.43, 77.62, 64.43, 35.17, 30.10, 29.28, 19.86, and 18.68 ppm. Anal. Calcd for $C_{16}H_{24}NO_2Br$: C, 56.14; H, 7.01. Found: C, 56.15; H, 7.04.

4.23. Data for (*S*)-(−)-2-*tert*-butyl-6-[(1-hydroxymethyl-2-methyl-propylimino)-methyl]-4-methoxy-phenol, 29

Yellow solid (0.36 g, 62%); mp 72–74 °C $[\alpha]_D^{25} = -41$ (*c* 0.002, CH_2Cl_2); IR (KBr) 3453, 2965, 2873, 1634, 1068, and 783 cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 8.30 (s, 1H), 6.98 (d, $J = 3.0$ Hz, 1H), 6.63 (d, $J = 3.2$ Hz, 1H), 3.76 (s, 3H), 3.79–3.68 (m, 1H), 3.05–2.96 (m, 1H), 2.00–1.74 (sept, $J_1 = 6.8$ Hz, 1H), 1.43 (s, 9H), 0.94 (d, $J = 6.8$ Hz, 6H) ppm; $^{13}C\{^1H\}$ NMR (50 MHz, $CDCl_3$): δ 166.54, 155.29, 151.50, 139.29, 118.57, 118.08, 111.93, 77.94, 64.63, 55.96, 35.09, 30.18, 29.41, 19.89 and 18.79 ppm. Anal. Calcd for $C_{17}H_{27}NO_3$: C, 69.62; H, 9.21. Found: C, 69.66; H, 9.24.

Acknowledgements

We gratefully acknowledge support for this project by Consejo del Sistema Nacional de Educación Tecnológica (COSNET grant 498.01) 2002, Consejo Nacional de Ciencia y Tecnología (CONACyT grant 37827-E) 2001, and graduate fellowship by CONACyT for A.G.

References

1. Gregory, R. J. H. *Chem. Rev.* **1999**, *99*, 3649–3682.
2. North, M. In *Comprehensive Organic Functional Group Transformations*; Katrizky, A. R., Meth-Cohn, O., Rees, C. W., Pattenden, G., Eds.; Pergamon: Oxford, 1995; Vol. 3, Chapter 18.
3. Corey, E. J.; Wang, Z. *Tetrahedron Lett.* **1993**, *34*, 4001–4004.
4. Ward, D. E.; Hrapchak, M. J.; Sales, M. *Org. Lett.* **2000**, *2*, 57–60.
5. Reetz, M. T.; Kyung, S. H.; Bolm, C.; Zierke, T. *Chem. Ind.* **1986**, 824–826.
6. Ohno, H.; Nitta, H.; Tanaka, K.; Mori, A.; Inoue, S. L. *J. Org. Chem.* **1992**, *57*, 6778–6783.
7. Hamashima, Y.; Sawada, D.; Kanai, M.; Shibasaki, M. *J. Am. Chem. Soc.* **1999**, *121*, 2641–2642.
8. Hamashima, Y.; Sawada, D.; Nogami, H.; Kanai, M.; Shibasaki, M. *Tetrahedron* **2001**, *57*, 805–814.
9. Deng, H.; Isler, M. P.; Snapper, M. L.; Hoveyda, A. H. *Angew. Chem., Int. Ed.* **2002**, *41*, 1009–1012.
10. Kobayashi, S.; Tsuchiya, Y.; Mukaiyama, T. *Chem. Lett.* **1991**, 541–544.
11. Wade, M.; Takahashi, T.; Domae, T.; Fukuma, T.; Miyoshi, N.; Smith, K. T. *Tetrahedron: Asymmetry* **1997**, *8*, 3939–3946.
12. Garner, C. M.; Fernandez, J. M.; Gladysz, J. A. *Tetrahedron Lett.* **1989**, *30*, 3931–3934.
13. Nitta, H.; Yu, D.; Kudo, M.; Mori, A.; Inoue, S. *J. Am. Chem. Soc.* **1992**, *114*, 7969–7975.
14. Hwang, C. D.; Hwang, D. R.; Uang, B. J. *J. Org. Chem.* **1998**, *63*, 6762–6763.
15. Belokon, Y. N.; Caveda-Cepas, S.; Green, B.; Ikonnikov, N. S.; Khrustalev, V. N.; Larichev, V. S.; Moscalenko, M. A.; North, M.; Orizu, C.; Tararov, V. I.; Tasinazzo, M.; Timofeeva, G. I.; Yashkina, L. V. *J. Am. Chem. Soc.* **1999**, *121*, 3968–3973.
16. Hamashima, Y.; Kanai, M.; Shibasaki, M. *J. Am. Chem. Soc.* **2000**, *122*, 7412–7413.
17. Liang, S.; Bu, X. R. *J. Org. Chem.* **2002**, *67*, 2702–2704.
18. Hamashima, Y.; Kanai, M.; Shibasaki, M. *Tetrahedron Lett.* **2001**, *42*, 691–694.
19. Hayashi, M.; Miyamoto, Y.; Inoue, T.; Oguni, N. *J. Org. Chem.* **1993**, *58*, 1515–1522.
20. Belokon, Y. N.; Gutanov, A. V.; Moskalenko, M. A.; Yashikina, L. V.; Lesovoy, D. E.; Ikonnikov, N. S.; Larichev, V. S.; North, M. *Chem. Commun.* **2002**, 244–245.
21. Jiang, Y.; Zhou, X.; Hu, W.; Wu, L.; Mi, A. *Tetrahedron: Asymmetry* **1995**, *6*, 405–408.
22. Yaozhong, J.; Xiangge, Z.; Wenhao, H.; Zhi, L.; Alqiao, M. *Tetrahedron: Asymmetry* **1995**, *6*, 2915–2916.
23. Belokon, Y. N.; Green, B.; Ikonnikov, N. S.; North, M.; Parsons, T.; Tararov, V. I. *Tetrahedron* **2001**, *57*, 771–779.
24. Chang, C. W.; Yang, C. T.; Hwang, C. D.; Uang, B. J. *Chem. Commun.* **2002**, 54–55.
25. Belokon, Y. N.; North, M.; Parsons, T. *Org. Lett.* **2000**, *2*, 1617–1619.
26. Qian, C.; Zhu, C.; Huang, T. *J. Chem. Soc., Perkin Trans. 1* **1998**, 2131–2132.
27. Yabu, K.; Masumoto, S.; Kanai, M.; Curran, D. P.; Shibasaki, M. *Tetrahedron Lett.* **2002**, *43*, 2923–2926.
28. Masumoto, S.; Yabu, K.; Kanai, M.; Shibasaki, M. *Tetrahedron Lett.* **2002**, *43*, 2919–2922.
29. Flores-López, L. Z.; Parra-Hake, M.; Somanathan, R.; Walsh, P. J. *Organometallics* **2000**, *19*, 2153–2160.
30. Gama, A.; Flores-López, L. Z.; Aguirre, G.; Parra-Hake, M.; Somanathan, R.; Walsh, P. J. *Tetrahedron: Asymmetry* **2002**, *13*, 149–154.
31. Everaere, K.; Mortreux, A.; Bulliard, M.; Brussee, J.; van der Gen, A.; Nowogrocki; Carpentier, J.-F. *Eur. J. Org. Chem.* **2001**, 275–291.
32. Calculations were conducted using a Macintosh computer with CAChe version 4.9.3 suite of programs. The structures and relative energies were calculated using Augmented molecular mechanics force field and ZINDO with INDO/1 parameters.
33. Palucki, M.; Finney, N. S.; Popisil, P. J.; Ishida, T.; Jacobsen, E. J. *J. Am. Chem. Soc.* **1998**, *120*, 948–954.
34. RajanBabu, T. V.; Ayers, T. A.; Halliday, T. A.; You, K. K.; Calabrese, J. C. *J. Org. Chem.* **1997**, *62*, 6012–6028.
35. Zhang, H.; Xue, F.; Mak, T. C. W.; Chan, K. S. *J. Org. Chem.* **1996**, *61*, 8002–8003.
36. RajanBabu, T. V.; Casalnuovo, A. L. *J. Am. Chem. Soc.* **1996**, *118*, 6325–6326.
37. Larrow, J. F.; Jacobsen, E. N.; Gao, Y.; Hong, Y.; Nie, X.; Zepp, C. M. S. *J. Org. Chem.* **1994**, *59*, 1939–1942.
38. Cogan, D. A.; Liu, G.; Ellman, J. A. *J. Am. Chem. Soc.* **1998**, *120*, 8011–8019.
39. Jiang, Y.; Gong, L.; Feng, X.; Hu, W. H.; Pan, W. P.; Li, Z.; Mi, A. *Tetrahedron* **1997**, *53*, 14327–14338.