Synthesis and Applications of 3-[6-(Hydroxymethyl)pyridin-2-yl]-1,1′-bi-2-naphthols or 3,3′-Bis[6-(hydroxymethyl)pyridin-2-yl]-1,1′-bi-2-naphthols

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Abstract: A series of new 1,1′-bi-2-naphthol (BINOL) derived ligands, 3-[6-(hydroxymethyl)pyridin-2-yl]-BINOLs or 3,3′-bis[6-(hydroxymethyl)pyridin-2-yl]-BINOLs, bearing one or two chiral pyridinylmethanols attached to a binaphthyl skeleton, have been synthesized using the Suzuki cross-coupling reaction. The resulting compounds have been used as ligands in the enantioselective addition of diethylzinc to aldehydes; the products were obtained with up to 96% ee.

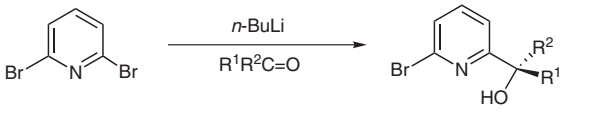
Key word: pyridin-2-ylmethanol, BINOL, Suzuki cross-coupling reaction, asymmetric catalysis

As an important C_2-symmetric ligand, 1,1′-bi-2-naphthol (BINOL) and its derivatives have been used extensively in asymmetric catalysis and chiral recognition and they also exhibit outstanding chiral induction in many processes.[1,2] In particular, BINOL derivatives bearing one or two chiral group at the 3- or 3,3′-positions have presented high enantioselective catalysis activity in various enantioselective reactions such as oxidative coupling reactions,[3a–c] 1,3-dipolar cycloadditions,[3d] and sulfoxidations.[3e] The introduction of a chiral group, utilizing natural resources such as amino acids and amino alcohols, has revealed interesting properties such as: (1) the stereogenic centers are adjustable (to give matched and mismatched combinations); (2) the steric effects are tunable (by modification of the R group, Scheme 1); (3) the effect of axial chirality of BINOL and chirality at the carbon center is also easily adjusted for good enantioselectivity.

C_1-Symmetric chiral pyridinylmethanols have been found extensive application[4] as chiral auxiliaries and ligands in asymmetric catalysis and can also be easily prepared by reaction of 2-lithiopyridine with optically active naturally occurring ketones, such as (–)-fenchone, (–)-camphor, and (–)-menthone. By introducing optically active pyridinylmethanols stemming from these naturally occurring ketones into the 3- or 3,3′-positions of BINOLs, we expect to obtain a potentially useful chiral ligand for asymmetric synthesis.

Our group has already reported the synthesis of BINOL ligands substituted by heteraromatic groups, such as 3-pyridinyl-BINOLs and 3,3′-bis(pyridinyl)-BINOLs, by Suzuki cross-coupling reactions.[5] Herein, we report a series of BINOL derivatives with substituted by chiral groups, 3-[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **9a–c** or 3,3′-bis[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **8a–c** that were also synthesized by Suzuki cross-coupling reactions of both enantiomeric forms of 3-(1,3,2-dioxaborolan-2-yl)-BINOLs **5** or 3,3′-bis(1,3,2-dioxaborolan-2-yl)-BINOLs **4** with chiral 6-bromopyridin-2-ylmethanols **2a–c**; their reactivity and enantioselectivity were tested in the enantioselective addition of diethylzinc to aldehydes.

According to the known procedure,[4a] the 6-bromopyridin-2-ylmethanols **2a–c** were prepared by monolithiation of 2,6-dibromopyridine in diethyl ether followed by trapping with (–)-fenchone, (+)-camphor, or (–)-menthone (Scheme 1). Compounds **2a–c** were obtained as single diastereomers according to NMR analysis of the product. The yields were 42–90% based on 2,6-dibromopyridine, depending mostly on the nature of the ketone. (–)-Fenchone, hindered but not enolizable, gives a good indication of the nucleophilicity of 2-lithiopyridine. For the other two ketones, partially hindered, the enolization reaction competes and limits the addition reaction, hence give a moderate yield.[6]



a R^1, R^2 = (–)-fenchyl
b R^1, R^2 = (+)-camphan-2-yl
c R^1, R^2 = (–)-*p*-menth-2-yl

Scheme 1 Synthesis of 6-bromopyridin-2-ylmethanols **2a–c**.

Formally, **8** and **9** are Suzuki cross-coupling products of **4** and **5** with **2a–c**.[5b] The availability of both enantiomeric forms of **4** and **5** allows the introduction of a considerable degree of structural diversity following a short reaction sequence. The reagents and the reaction conditions, which have been applied in the synthesis of **8** and **9**, are depicted in Scheme 2.

The synthesis of **8** and **9** started from commercially available (*S*)- or (*R*)-BINOL. The hydroxy groups of (*S*)- or (*R*)-BINOL were protected as methoxymethyl (MOM) ethers (96%). The resulting compound, 2,2′-bis(methoxymethoxy)-1,1′-binaphthalene **3**, was subjected to either 4 or 1.1 equivalents of both *N*,*N*,*N*′,*N*′-tetramethyl-

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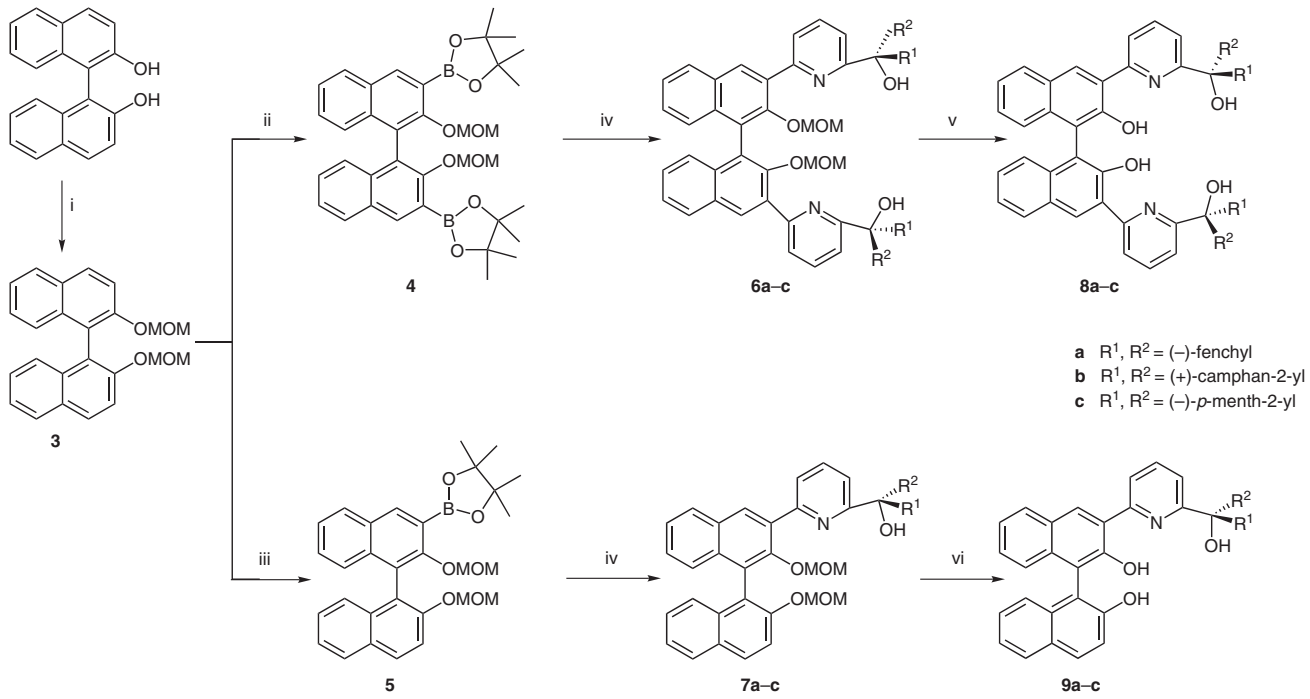


Scheme 2 Synthesis of 3-[6-(hydroxymethyl)pyridin-2-yl]-BINOL **9** or 3,3′-bis[6-(hydroxymethyl)pyridin-2-yl]-BINOL **8**: (i) NaH, MOM-Cl, DMF–THF, 0 °C; (ii) (a) *n*-BuLi (4 equiv), TMEDA (4 equiv), Et_2O, r.t. 3 h; (b) 2-isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (8 equiv), –78 °C, then r.t., overnight; (iii) (a) *n*-BuLi (1.1 equiv), TMEDA (1.1 equiv), Et_2O, r.t., 3 h; (b) 2-isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (3 equiv), –78 °C, then r.t., overnight; (iv) **2a–c**, 5% $Pd(PPh_3)_4$, Na_2CO_3 (12 equiv), toluene–H_2O, reflux, 48 h. (v) concd HCl, EtOH–CH_2Cl_2, r.t., 24 h. (vi) concd HCl, EtOH–CH_2Cl_2, 40–50 °C, 6 h.

ethylenediamine and *n*-butyllithium, followed by addition of 2-isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane at –78 °C, and subsequent quenching of the reaction with saturated aqueous ammonium chloride to give **4** or **5** in 80% or 81% yields, respectively, in both enantiomeric forms. In the synthesis of **5**, unreacted **3** could be recovered and recycled. Suzuki coupling of both enantiomeric forms of **4** and **5** with **2a–c** by refluxing in the presence of sodium carbonate and tetrakis(triphenylphosphine)palladium(0) (5%) in toluene and water for 48 hours afforded diastereomers of 3-[6-(hydroxymethyl)pyridin-2-yl]-MOM-BINOLs **7a–c** or 3,3′-bis[6-(hydroxymethyl)pyridin-2-yl]-MOM-BINOLs **6a–c** in 78–84% yield. The diastereomers of **8a–c** and **9a–c** were obtained by deprotection of **6a–c** and **7a–c**. Treatment of **6a–c** with concentrated hydrochloric acid in ethanol–dichloromethane at room temperature for 24 hours gave **8a–c** quantitatively, but under the same conditions **7a–c** gave the product with only one methoxymethyl group removed.[7] However, treatment **7a–c** with concentrated hydrochloric acid in ethanol–dichloromethane at 40–50 °C for six hours gave **9a–c** in high yield (91–95%).

All the intermediates and the diastereomers of **8a–c** and **9a–c** discussed have been characterized by ^1H NMR, ^{13}C NMR, and ESI-MS. In Figures 1 and 2 the structures of all compounds are depicted and the overall yields (after four steps, referring to the initial amount of BINOL) are given.

The diastereomerically pure 3-[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **9a–c** or 3,3′-bis[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **8a–c** were employed in the enantioselective addition of diethylzinc to aldehydes, a standard reaction to test the efficiency of chiral ligands. Notably, it was possible to modify the structural features of the ligand, either by adjusting the configurations of the two stereogenic centers or by changing the substituent on the pyridine ring. Moreover, the twelve 3-[6-(hydroxymethyl)pyridin-2-yl]-BINOLs or 3,3′-bis[6-(hydroxymethyl)pyridin-2-yl]-BINOLs were synthesized in as pairs of diastereomers, thus allowing evaluation of possible 'match–mismatch' effects to be displayed during the catalytic reaction.

In order to evaluate the capability of **9a–c** or **8a–c** as chiral ligands in the enantioselective addition of diethylzinc to benzaldehyde,[8] several common factors such as the solvent, reaction temperature, ligand/metal molar ratio, etc., were initially examined. The reaction was found to have a reasonable yield and enantiomeric excess of 1-phenylpropan-1-ol in toluene at 0 °C with 20 mol% of (*S*,2*R*)-**8a** as its titanium complex (Table 1).

The effectiveness of the twelve ligands in the enantioselective addition of diethylzinc to benzaldehyde was tested. As shown by the results summarized in Table 2, (*R*,2*R*)-**8a** and (*S*,1*S*)-**8c** both gave 1-phenylpropan-1-ol with higher enantioselectivity (90% and 95%, respectively) (Table 2, entries 2 and 5). Overall C_1-symmetrical 3-substituted BINOLs **9a–c** gave lower enantioselectivity than C_2-symmetrical 3,3′-disubstituted BINOLs **8a–c**, indicating that symmetrically substituted ligands are more suit-

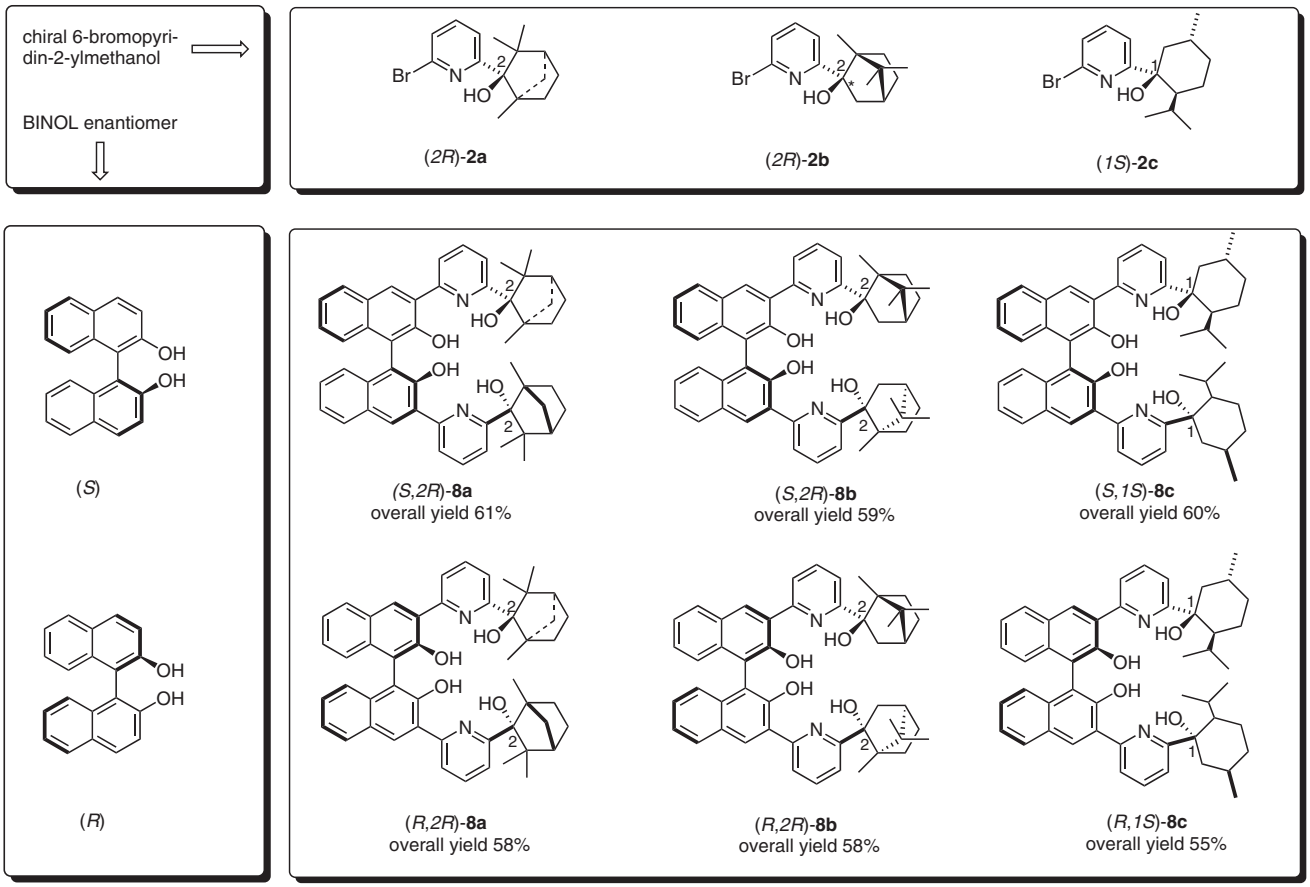
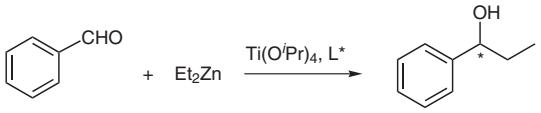


Figure 1 Diastereomerically pure 3,3′-bis[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **8a–c** prepared by the combination of (*S*)- and (*R*)-BINOL with three chiral 6-bromopyridin-2-ylmethanols **2a–c**.

able for this reaction than unsymmetrically substituted ligands. For the C_2-symmetrical 3,3′-disubstituted BINOLs, the use of (*R*,2*R*)-**8a**, (*R*,2*R*)-**8b**, and (*S*,1*S*)-**8c**, which are each one of a pair of diastereomers, resulted in much higher enantioselectivity. From this result, it was apparent that the same configured ligands (*R*,*R*) or (*S*,*S*), giving a matched combination, achieved better results than the opposite configured ligands (*S*,*R*) or (*R*,*S*), giving a dismatched combination. Interestingly, application of each pair of diastereomers of **8a–c**, whether the binaphthyl subunit has the *S*- or *R*-configuration, gave the same enantiomeric product, but with different enantioselectivity. The steric effect of the substituent on the pyridine ring was compared in the ligands that had matched combinations. The reaction using menthyl-substituted (*S*,1*S*)-**8c**, which is sterically more hindered, gave the best enantioselectivity, while the products from the reaction with camphanyl-substituted (*R*,2*R*)-**8b** gave lower enantiomeric excesses.

The high enantioselectivity of ligands (*R*,2*R*)-**8a** and (*S*,1*S*)-**8c** for the addition of diethylzinc to benzaldehyde prompted us to examine their use for the reaction of various aromatic aldehydes. The results are summarized in Table 3. Highest enantioselectivity (up to 96% ee) was observed for ligand (*S*,1*S*)-**8c** with *p*-anisaldehyde.

Table 1 Enantioselective Addition of Diethylzinc to Benzaldehyde Catalyzed by Ligand (*S*,2*R*)-**8a**[a]



Entry	Solvent	Temp (°C)	Amount of ligand (mol%)	Yield[b] (%)	ee (%)[c]
1	CH_2Cl_2	20	20	–	–
2	THF	20	20	–	–
3	toluene	20	20	72	63
4[d]	toluene	20	20	60	41
5	toluene	0	10	69	62
6	toluene	0	20	70	70

[a] Time: 5 h.
[b] Isolated yields after chromatography.
[c] Determined by GC analysis using a chiral column (Chrompack Chirasil-DEX-CB column).
[d] Reaction was run without Ti(O*i*-Pr)$_4$.

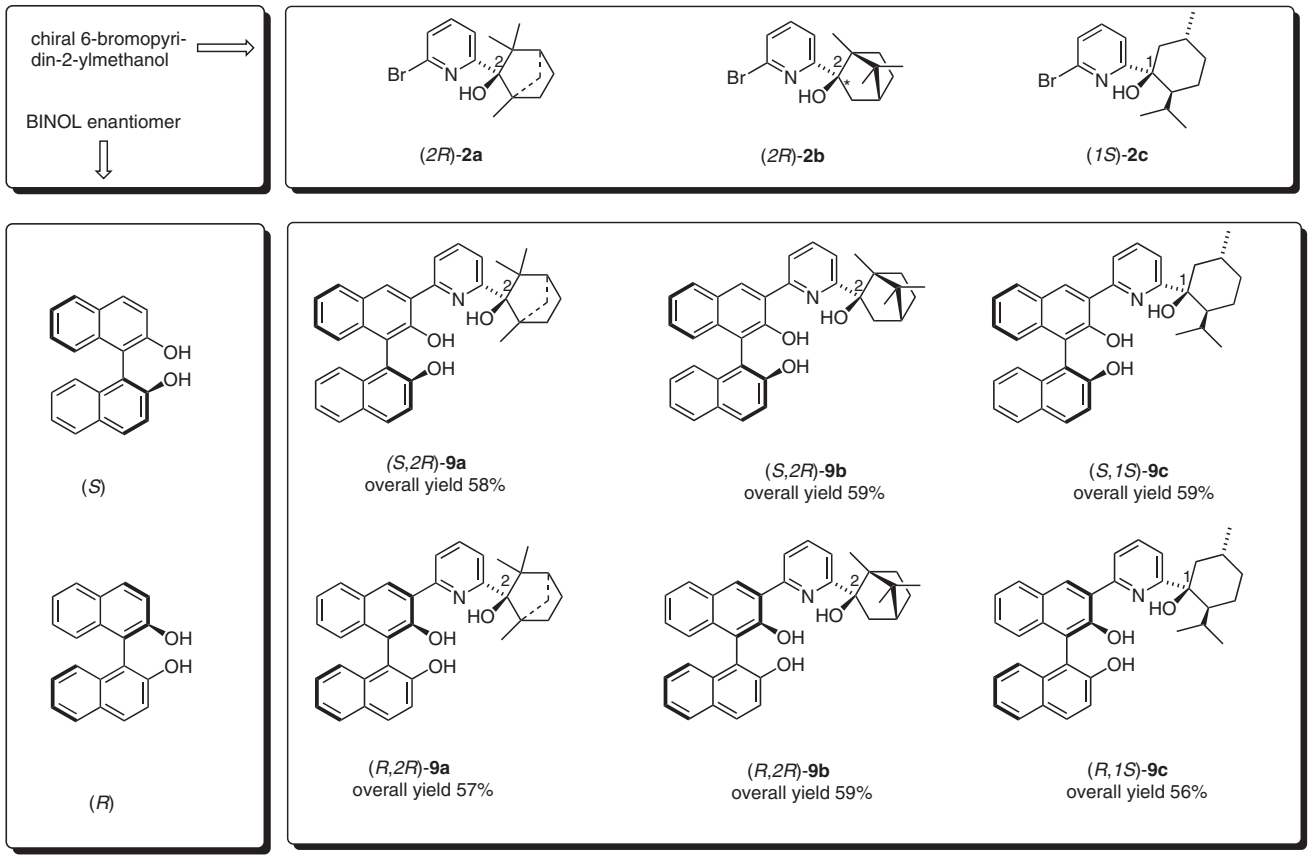


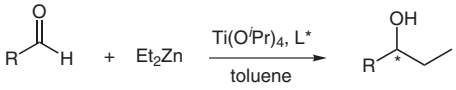
Figure 2 Diastereomerically pure 3-[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **9a–c** prepared by the combination of (*S*)- and (*R*)-BINOL with three chiral 6-bromopyridin-2-ylmethanols **2a–c**.

Table 2 Enantioselective Addition of Diethylzinc to Benzaldehyde by Ligands **8a–c** and **9a–c**[a] in Toluene

Entry	Ligand	Yield[b] (%)	ee[c] (%)	Config[d]
1	(*S*,2*R*)-**8a**	70	70	*R*
2	(*R*,2*R*)-**8a**	83	90	*R*
3	(*S*,2*R*)-**8b**	71	74	*R*
4	(*R*,2*R*)-**8b**	75	81	*R*
5	(*S*,1*S*)-**8c**	85	95	*S*
6	(*R*,1*S*)-**8c**	76	81	*S*
7	(*S*,2*R*)-**9a**	69	49	*S*
8	(*R*,2*R*)-**9a**	74	79	*R*
9	(*S*,2*R*)-**9b**	62	55	*R*
10	(*R*,2*R*)-**9b**	66	26	*R*
11	(*S*,1*S*)-**9c**	64	43	*S*
12	(*R*,1*S*)-**9c**	70	67	*R*

[a] L*/Ti(O*i*-Pr)$_4$/Et$_2$Zn/benzaldehyde 0.2:1.4:3:1, 0 °C, 5 h.
[b] Isolated yields after chromatography.
[c] Determined by GC analysis using a chiral column (Chrompack Chirasil-DEX-CB column).
[d] Absolute configuration was determined by comparison to literature values.[9]

Table 3 Enantioselective Addition of Diethylzinc to Benzaldehyde Catalyzed by Ligands (*R*,2*R*)-**8a** and (*S*,1*S*)-**8c**[a]



Entry	R	Ligand	Yield[b] (%)	ee[c] (%)	Config
1	4-ClC_6H_4	(*R*,2*R*)-**8a**	69	69	*R*
2	Ph	(*R*,2*R*)-**8a**	83	90	*R*
3	4-MeOC_6H_4	(*R*,2*R*)-**8a**	79	60	*R*
4	1-naphthyl	(*R*,2*R*)-**8a**	74	69	*R*
5	2-naphthyl	(*R*,2*R*)-**8a**	80	89	*R*
6	4-ClC_6H_4	(*S*,1*S*)-**8c**	70	71	*S*
7	Ph	(*S*,1*S*)-**8c**	85	95	*S*
8	4-MeOC_6H_4	(*S*,1*S*)-**8c**	84	96	*S*
9	1-naphthyl	(*S*,1*S*)-**8c**	76	65	*S*
10	2-naphthyl	(*S*,1*S*)-**8c**	81	94	*S*

[a] L*/Ti(O*i*-Pr)$_4$/Et$_2$Zn/benzaldehyde 0.2:1.4:3:1, 0 °C, 5 h.
[b] Isolated yields after chromatography.
[c] Determined by GC analysis using a chiral column (Chrompack Chirasil-DEX-CB column) or by HPLC analysis using a chiral column (OD-H column). Absolute configuration was determined by comparison to literature values.[9]

In summary, the twelve diastereomers of 3-[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **9a–c** and 3,3′-[6-(hydroxymethyl)pyridin-2-yl]-BINOLs **8a–c** have been prepared from BINOL and natural occurring ketones. The capability of these compounds to serve as ligands in asymmetric catalysis was demonstrated in the enantioselective addition of diethylzinc to benzaldehyde; enantiomeric excesses of up to 96% were observed. The further investigations of the utilization and properties of these ligands are in progress.

^{1}H and ^{13}C NMR spectra were recorded at 300, 400, 600 MHz and 100 MHz on Bruker-AV spectrometers. IR spectra were recorded on a Bio-Rad FTS135 infrared spectrophotometer. ESI-MS measurements were conducted with a LCQ instrument. Melting points were measured with a hot-stage microscope XT-4. Elemental analyses were carried out with a VarioEL instrument. Optical rotations were measured on a 341LC polarimeter. GC measurements were carried out on a Shimadzu GC-2010A instrument. HPLC utilized a Shimadzu LC-6AD pump, a Shimadzu SPD-10A UV detector, and Shimadzu Class-VP system controller software. Reactions were carried out in anhydrous solvents under an argon atmosphere, unless otherwise stated. Et_2O, toluene, and THF were distilled from Na benzophenone ketyl. CH_2Cl_2 were dried over CaH_2. (–)-Fenchone, (+)-camphor, and (–)-menthone were purchased from Acros and used without further purification and other chemicals were also purchased from commercial suppliers. All products were purified by column chromatography on silica gel (230–400 mesh).

Optically Active 6-Bromopyridin-2-ylmethanols 2; General Procedure

To an Et_2O soln (250 mL) of 2,6-dibromopyridine (11.8 g, 0.05 mol) was added 1.6 M *n*-BuLi in hexane (35 mL, 0.055 mol) at –78 °C over 30 min, and the mixture was allowed to react for a further 30 min at this temperature. Chiral ketone (0.05 mol) in anhyd Et_2O (20 mL) was then added dropwise over 15 min and H_2O (100 mL) was then added. The layers were separated and the aqueous layer was extracted with EtOAc (2 × 100 mL). The combined organic layers were washed with 10% NaOH and brine and then dried ($MgSO_4$). The solvent was removed under reduced pressure and the crude product was purified by column chromatography (petroleum ether–EtOAc, 20:1). All ligands were characterized by ^{1}H NMR spectra.

(1*R*,2*R*,4*S*)-2-(6-Bromopyridin-2-yl)-1,3,3-trimethylbicyclo[2.2.1]heptan-2-ol [(2*R*)-2a]

Yield: 13.9 g (90%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53 (t, *J* = 7.8 Hz, 1 H), 7.31 (d, *J* = 8.0 Hz, 1 H), 6.99 (d, *J* = 7.6 Hz, 1 H), 6.20 (s, 1 H), 2.23 (d, *J* = 10 Hz, 1 H), 1.85 (m, 1 H), 1.79 (d, *J* = 4 Hz, 1 H), 1.48 (m, 1 H), 1.15 (d, *J* = 10.4 Hz, 1 H), 1.13 (m, 1 H), 0.9 (s, 3 H), 0.91 (s, 3 H), 0.45 (s, 3 H).

(1*R*,2*R*,4*R*)-2-(6-Bromopyridin-2-yl)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol [(2*R*)-2b]

Yield: 6.5 g (42%).

^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.51 (t, *J* = 7.8 Hz, 1 H), 7.39 (d, *J* = 7.2 Hz, 1 H), 7.36 (d, *J* = 7.8 Hz, 1 H), 2.26 (m, 1 H), 2.14 (d, *J* = 13.8 Hz, 1 H), 1.90 (t, *J* = 8.4 Hz, 1 H), 1.78 (m, 1 H), 1.28 (m, 1 H), 1.24 (s, 3 H), 1.24 (s, 1 H), 0.90 (s, 3 H), 0.85 (s, 3 H), 0.75 (m, 1 H).

(1*S*,2*S*,5*R*)-1-(6-Bromopyridin-2-yl)-2-isopropyl-5-methylcyclohexan-1-ol [(1*S*)-2c]

Yield: 10 g (68%).

^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.55 (t, *J* = 7.8 Hz, 1 H), 7.36 (d, *J* = 7.2 Hz, 1 H), 7.33 (d, *J* = 7.8 Hz, 1 H), 1.98 (m, 1 H), 1.86 (m, 1 H), 1.67 (m, 3 H), 1.56 (m, 1 H), 1.43 (m, 1 H), 1.25 (m, 1 H), 1.05 (m, 1 H), 0.89 (d, *J* = 6.0 Hz, 3 H), 0.84 (d, *J* = 6.0 Hz, 3 H), 0.71 (d, *J* = 7.2 Hz, 3 H).

(*S*)- or (*R*)-2,2′-Bis(methoxymethoxy)-3,3′-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,1′-binaphthyl [(*S*)-4 or (*R*)-4]

To a flame-dried, 500-mL 3-necked flask equipped with an N_2 inlet was added anhyd Et_2O (250 mL), TMEDA (16 mL, 0.104 mol) and (*S*)- or (*R*)-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*)-**3** or (*R*)-**3**, 10 g, 0.026 mol] [synthesized from BINOL and MOMCl]. To this soln was added 1.6 M *n*-BuLi in hexane (65 mL, 0.104 mol) was added over 30 min and then the mixture was stirred at r.t. for 3 h. It was then cooled to –78 °C and 2-isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (42 mL, 0.208 mol) was added via syringe over a period of 30 min. The soln was allowed to warm to r.t. and was stirred overnight. Sat. NH_4Cl (200 mL) was added and the mixture was stirred for 1 h. The organic phase was separated and washed with sat. aq NaCl (200 mL) and dried (Na_2SO_4). The filtrate was removed under reduced pressure and the crude product was purified by column chromatography (petroleum ether–EtOAc, 10:1) to give (*S*)-**4** or (*R*)-**4** as white solids; yield: 12.9 g (80%).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.49 (s, 1 H), 7.92 (d, *J* = 8.1 Hz, 1 H), 7.40 (t, *J* = 6.9 Hz, 1 H), 7.29 (t, *J* = 6.6 Hz, 1 H), 7.22 (d, *J* = 8.1 Hz, 1 H), 4.9 (s, 2 H), 2.32 (s, 3 H), 1.42 (s, 12 H).

(*S*)- or (*R*)-2,2′-Bis(methoxymethoxy)-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,1′-binaphthyl [(*S*)-5 or (*R*)-5]

To a flame-dried, 500-mL 3-necked flask equipped with an N_2 inlet was added anhyd Et_2O (300 mL), TMEDA (9.2 mL, 0.0615 mol) and (*S*)- or (*R*)-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*)-**3** or (*R*)-**3**, 5.6 g, 0.015 mol] [synthesized from BINOL and MOMCl]. To this soln was added 1.6 M *n*-BuLi in hexane (10 mL, 0.0165 mol) was added over 15 min. The mixture was stirred at r.t. for 3 h, after which time it had become pale-green. It was then cooled to –78 °C and 2-isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (9.2 mL, 0.045 mol) was added via syringe over a period of 15 min. The soln was allowed to warm to r.t. and was stirred overnight. Sat. NH_4Cl (200 mL) was added and the mixture was stirred for 0.5 h. The organic phase was separated and washed with sat. aq NaCl (200 mL) and dried (Na_2SO_4). The filtrate was removed under reduced pressure and the crude product was purified by column chromatography (petroleum ether–CH_2Cl_2, 2:1) to give (*S*)-**5** or (*R*)-**5** as white solids (3.9 g, 81%) and 2,2′-bis(methoxymethoxy)-1,1′-binaphthyl (2.0 g).

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.4 (s, 1 H), 8.07–8.04 (m, 2 H), 7.94 (d, *J* = 8.0 Hz, 1 H), 7.63 (d, *J* = 9.2 Hz, 1 H), 7.43 (t, *J* = 7.2 Hz, 1 H), 7.41–7.31 (m, 2 H), 7.25 (t, *J* = 7.2 Hz, 1 H), 7.01 (s, *J* = 8.4 Hz, 1 H), 6.94 (d, *J* = 8.4 Hz, 1 H), 5.19 (d, *J* = 6.8 Hz, 1 H), 5.04 (d, *J* = 6.8 Hz, 1 H), 4.77 (d, *J* = 5.6 Hz, 1 H), 4.71 (d, *J* = 6.0 Hz, 1 H), 3.07 (s, 3 H), 2.40 (s, 3 H), 1.37 (s, 12 H).

3,3′-Bis{6-substituted pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyls 6; General Procedure

To a degassed soln of **2** (2 mmol) in toluene (20 mL) was added $Pd(PPh_3)_4$ (0.05 mmol). The mixture was stirred at r.t. for 10 min, and then a soln of aq 1 M Na_2CO_3 (12 mL, 12 mmol) and **4** (0.63 g, 1 mmol) were added and the mixture was refluxed for 24 h. The organic phase was separated and the aqueous phase was extracted with EtOAc (2 × 20 mL). The combined organic phases were dried ($MgSO_4$). The crude product was purified by column chromatography (petroleum ether–EtOAc, 20:1) to yield **6** as white solids.

(*S*)-3,3′-Bis{6-[(1*R*,2*R*,4*S*)-2-hydroxy-1,3,3-trimethylbicyclo [2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*,2*R*)-6a]
Yield: 0.70 g (84%); mp 134–136 °C; $[\alpha]_D$ –34.3 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2390, 1465, 976 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.30 (s, 1 H), 8.10 (d, *J* = 8.4 Hz, 1 H), 7.87 (t, *J* = 8.0 Hz, 1 H), 7.70 (d, *J* = 8.0 Hz, 2 H), 7.50 (t, *J* = 8.0 Hz, 1 H), 7.37 (t, *J* = 7.8 Hz, 1 H), 7.17 (d, *J* = 8.4 Hz, 1 H), 4.39 (d, *J* = 5.6 Hz, 1 H), 4.29 (d, *J* = 5.6 Hz, 1 H), 2.31 (s, 3 H), 2.24 (m, 1 H), 1.76 (m, 2 H), 1.48 (m, 1 H), 1.26 (d, *J* = 9.2 Hz, 1 H), 1.07 (m, 2 H), 1.01 (s, 3 H), 0.98 (s, 3 H), 0.57 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.1, 153.3, 151.1, 135.3, 134.2, 133.4, 131.5, 130.8, 128.5, 126.9, 126.4, 126.3, 125.4, 122.8, 121.7, 98.9, 83.8, 56.1, 51.9, 48.8, 46.1, 42.1, 32.6, 29.4, 24.5, 22.4, 17.3.

ESI-MS: *m*/*z* (%) = 833.1 (100) [M^+].

Anal. Calcd for $C_{54}H_{60}N_2O_6$: C, 77.85; H, 7.26; N, 3.36. Found: C, 77.49; H, 7.33; N, 3.32.

(*R*)-3,3′-Bis{6-[(1*R*,2*R*,4*S*)-2-hydroxy-1,3,3-trimethylbicyclo [2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*R*,2*R*)-6a]
Yield: 0.67 g (81%); mp 194–196 °C; $[\alpha]_D$ –90.2 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2928, 1463, 973 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.30 (s, 1 H), 8.08 (d, *J* = 8.0 Hz, 1 H), 7.86 (t, *J* = 7.6 Hz, 1 H), 7.70 (d, *J* = 8.0 Hz, 2 H), 7.50 (t, *J* = 7.6 Hz, 1 H), 7.39 (t, *J* = 7.6 Hz, 1 H), 7.21 (d, *J* = 8.4 Hz, 1 H), 4.41 (d, *J* = 5.6 Hz, 1 H), 4.33 (d, *J* = 5.2 Hz, 1 H), 2.34 (s, 3 H), 2.50 (m., 1 H), 1.73–1.75 (m, 2 H), 1.42–1.48 (m, 1 H), 1.27–1.24 (m, 1 H), 1.08 (s, 3 H), 1.02–1.04 (m, 2 H), 0.98 (s, 3 H), 0.52 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.2, 153.4, 151.1, 135.4, 134.1, 133.5, 131.5, 130.8, 128.5, 127.0, 126.4, 126.3, 125.4, 122.8, 121.6, 98.9, 83.8, 56.2, 48.9, 46.1, 42.1, 32.6, 29.6, 24.5, 22.5, 17.3.

ESI-MS: *m*/*z* (%) = 833.1 (100) [M^+].

Anal. Calcd for $C_{54}H_{60}N_2O_6$: C, 77.85; H, 7.26; N, 3.36. Found: C, 77.79; H, 7.34; N, 3.37.

(*S*)-3,3′-Bis{6-[(1*R*,2*R*,4*R*)-2-hydroxy-1,7,7-trimethylbicyclo [2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*,2*R*)-6b]
Yield: 0.68 g (82%); mp 136–138 °C; $[\alpha]_D$ –38.8 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2955, 1458, 974 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.37 (s, 1 H), 8.07 (d, *J* = 8.0 Hz, 1 H), 7.90 (t, *J* = 7.8 Hz, 1 H), 7.80 (d, *J* = 7.8 Hz, 1 H), 7.65 (d, *J* = 7.8 Hz, 1 H), 7.50 (t, *J* = 7.6 Hz, 1 H), 7.36 (t, *J* = 7.6 Hz, 1 H), 7.19 (d, *J* = 8.8 Hz, 1 H), 5.23 (s, 1 H), 4.44 (d, *J* = 5.6 Hz, 1 H), 4.31 (d, *J* = 5.6 Hz, 1 H), 2.91 (d, *J* = 12.8 Hz, 1 H), 2.33 (s, 3 H), 2.08 (m, 1 H), 1.86 (m, 1 H), 1.67 (m, 1 H), 1.57 (m, 1 H), 1.27 (s, 3 H), 1.17 (m, 1 H), 0.88 (s, 6 H), 0.76 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 163.3, 154.0, 151.2, 135.8, 134.2, 133.6, 131.6, 130.8, 128.5, 127.0, 126.3, 125.4, 123.1, 119.2, 99.0, 82.9, 56.2, 53.6, 50.6, 45.5, 44.5, 30.9, 27.1, 21.4, 21.2, 10.2.

ESI-MS: *m*/*z* (%) = 833.1 (100) [M^+].

Anal. Calcd for $C_{54}H_{60}N_2O_6$: C, 77.85; H, 7.26; N, 3.36. Found: C, 77.77; H, 7.19; N, 3.42.

(*R*)-3,3′-Bis{6-[(1*R*,2*R*,4*R*)-2-hydroxy-1,7,7-trimethylbicyclo [2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*R*,2*R*)-6b]
Yield: 0.67 g (80%); mp 138–140 °C; $[\alpha]_D$ –45.6 (*c* 0.4, CH_2Cl_2).

IR (KBr): 2956, 1458, 974 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.34 (s, 1 H), 8.05 (d, *J* = 8.4 Hz, 1 H), 7.89 (t, *J* = 8.0 Hz, 1 H), 7.79 (d, *J* = 7.6 Hz, 1 H), 7.64 (d, *J* = 7.6 Hz, 1 H), 7.50 (t, *J* = 8.0 Hz, 1 H), 7.37 (t, *J* = 7.6 Hz, 1 H), 7.17 (d, *J* = 8.8 Hz, 1 H), 5.23 (s, 1 H), 4.42 (d, *J* = 5.6 Hz, 1 H), 4.30 (d, *J* = 5.6 Hz, 1 H), 2.89 (d, *J* = 8.8 Hz, 1 H), 2.32 (s, 3 H), 2.04–2.07 (m, 1 H), 1.85–1.86 (m, 1 H), 1.66 (m, 1 H), 1.55 (m, 1 H), 1.26 (s, 3 H), 1.34–1.16 (m, 1 H), 0.87 (s, 3 H), 0.87 (s, 3 H), 0.73–0.75 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 163.3, 154.0, 151.2, 135.8, 134.2, 133.6, 131.6, 130.8, 128.5, 127.0, 126.3, 125.4, 123.1, 119.2, 99.0, 82.9, 56.2, 53.6, 50.6, 45.5, 44.5, 30.9, 27.1, 21.4, 21.2, 10.2.

ESI-MS: *m*/*z* (%) = 833.1 (100) [M^+].

Anal. Calcd for $C_{54}H_{60}N_2O_6$: C, 77.85; H, 7.26; N, 3.36. Found: C, 77.99; H, 7.31; N, 3.31.

(*S*)-3,3′-Bis{6-[(1*S*,2*S*,5*R*)-1-hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*,1*S*)-6c]
Yield: 0.68 g (82%); mp 106–108 °C; $[\alpha]_D$ +11.3 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2951, 1461, 974 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.29 (s, 1 H), 8.11 (d, *J* = 8.4 Hz, 1 H), 7.91 (t, *J* = 7.8 Hz, 1 H), 7.68 (dd, *J* = 4.8 Hz, 2 H), 7.50 (t, *J* = 8.0 Hz, 1 H), 7.37 (t, *J* = 8.0 Hz, 1 H), 7.16 (d, *J* = 8.4 Hz, 1 H), 5.01 (s, 1 H), 4.47 (d, *J* = 5.6 Hz, 1 H), 3.39 (d, *J* = 5.6 Hz, 1 H), 2.36 (s, 3 H), 1.88–1.91 (m, 2 H), 1.74–1.80 (m, 2 H), 1.66–1.65 (m, 1 H), 1.52–1.57 (m, 2 H), 1.26–1.33 (m, 1 H), 1.03–1.09 (m, 1 H), 0.87 (d, *J* = 6.4 Hz, 3 H), 0.84 (d, *J* = 6.0 Hz, 3 H), 0.62 (d, *J* = 6.8 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 165.3, 153.7, 151.1, 137.1, 134.2, 133.5, 131.7, 130.8, 128.5, 127.1, 126.5, 126.3, 125.4, 122.9, 117.7, 99.0, 77.2, 56.2, 50.9, 50.2, 35.5, 28.6, 27.7, 23.7, 22.4, 22.1, 18.6.

ESI-MS: *m*/*z* (%) = 837.1 (100) [M^+].

Anal. Calcd for $C_{54}H_{64}N_2O_6$: C, 77.48; H, 7.71; N, 3.35. Found: C, 77.51; H, 7.75; N, 3.31.

(*R*)-3,3′-Bis{6-[(1*S*,2*S*,5*R*)-1-hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*R*,1*S*)-6c]
Yield: 0.66 g (79%); mp 100–104 °C; $[\alpha]_D$ –53.3 (*c* 0.4, CH_2Cl_2).

IR (KBr): 2950, 1461, 974 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.28 (s, 1 H), 8.09 (d, *J* = 8.4 Hz, 1 H), 7.91 (t, *J* = 8.0 Hz, 1 H), 7.70 (d, *J* = 8.0 Hz, 2 H), 7.68 (d, *J* = 8.0 Hz, 1 H), 7.50 (t, *J* = 7.6 Hz, 1 H), 7.37 (t, *J* = 7.6 Hz, 1 H), 7.15 (d, *J* = 8.4 Hz, 1 H), 5.03 (s, 1 H), 4.48 (d, *J* = 5.2 Hz, 1 H), 4.32 (d, *J* = 5.2 Hz, 1 H), 2.34 (s, 3 H), 1.98–2.01 (m, 1 H), 1.90–1.92 (m, 1 H), 1.78–1.81 (m, 1 H), 1.63–1.69 (m, 2 H), 1.52–1.57 (m, 1 H), 1.31–1.35 (m, 1 H), 1.02–1.09 (m, 1 H), 0.85 (d, *J* = 6.8 Hz, 3 H), 0.82 (d, *J* = 7.2 Hz, 3 H), 0.70 (d, *J* = 7.2 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 165.3, 153.6, 151.2, 137.2, 134.2, 133.5, 131.7, 130.8, 128.5, 127.1, 126.5, 126.3, 125.4, 123.0, 117.8, 99.1, 77.2, 56.2, 50.9, 50.2, 35.4, 28.7, 27.6, 23.7, 22.4, 22.2, 18.7.

ESI-MS: *m*/*z* (%) = 837.1 (100) [M^+].

Anal. Calcd for $C_{54}H_{64}N_2O_6$: C, 77.48; H, 7.71; N, 3.35. Found: C, 77.59; H, 7.69; N, 3.50.

3-{6-Substituted pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyls 7; General Procedure
To a degassed soln of **2** (1.3 mmol) in toluene (20 mL) was added $Pd(PPh_3)_4$ (0.06 mmol). The mixture was stirred at r.t. for 10 min, a soln of aq 1 M Na_2CO_3 (15 mL, 14.4 mmol) and **5** (0.60 g, 1.2 mmol) was added, and it was refluxed for 24 h. The organic phase was separated and the aqueous phase was extracted with EtOAc

(2 × 20 mL). The combined organic phases were dried ($MgSO_4$). The crude product was purified by column chromatography (petroleum ether–EtOAc, 20:1) to yield **7** as white solids.

(*S*)-3-{6-[(1*R*,2*R*,4*S*)-2-Hydroxy-1,3,3-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*,2*R*)-7a]
Yield: 0.56 g (78%); mp 160–162 °C; $[\alpha]_D$ –128.8 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2931, 1159, 1012 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.27 (s, 1 H), 8.10 (d, *J* = 9.2 Hz, 1 H), 8.07 (d, *J* = 8.4 Hz, 1 H), 7.98 (d, *J* = 8.0 Hz, 1 H), 7.84 (t, *J* = 7.6 Hz, 1 H), 7.66–7.70 (m, 3 H), 7.48 (t, *J* = 7.6 Hz, 1 H), 7.30–7.41 (m, 3 H), 7.13 (d, *J* = 8.4 Hz, 1 H), 7.08 (d, *J* = 8.4 Hz, 1 H), 5.21 (t, *J* = 7.6 Hz, 2 H), 4.31 (d, *J* = 5.6 Hz, 1 H), 4.26 (d, *J* = 5.6 Hz, 1 H), 3.19 (s, 3 H), 2.35 (s, 3 H), 2.25 (m, 1 H), 1.74 (m, 2 H), 1.42–1.49 (m, 1 H), 1.25–1.28 (m, 1 H), 1.03–1.09 (m, 1 H), 1.06 (s, 3 H), 0.98 (s, 3 H), 0.53 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.0, 153.3, 153.0, 150.9, 135.2, 134.1, 133.9, 133.5, 131.2, 130.9, 129.7, 128.6, 127.8, 126.8, 126.5, 126.4, 125.9, 125.3, 124.1, 122.8, 121.5, 121.1, 116.8, 99.0, 95.1, 83.8, 56.2, 56.0, 51.9, 48.9, 46.1, 42.1, 32.6, 29.5, 24.5, 22.4, 17.3.

ESI-MS: *m*/*z* (%) = 603.7 (100) [M^+].

Anal. Calcd for $C_{39}H_{41}N_1O_5$: C, 77.59; H, 6.85; N, 2.32. Found: C, 77.35; H, 6.79; N, 2.32.

(*R*)-3-{6-[(1*R*,2*R*,4*S*)-2-Hydroxy-1,3,3-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*R*,2*R*)-7a]
Yield: 0.58 g (80%); mp 144–146 °C; $[\alpha]_D$ +45.6 (*c* 0.4, CH_2Cl_2).

IR (KBr): 2929, 1149, 1013 cm^{-1}.

^1H NMR (600 MHz, DMSO-d_6): δ = 8.24 (s, 1 H), 8.10 (d, *J* = 9.0 Hz, 1 H), 8.06 (d, *J* = 9.0 Hz, 1 H), 7.98 (d, *J* = 7.8 Hz, 1 H), 7.84 (s, 1 H), 7.66–7.69 (m, 3 H), 7.48 (t, *J* = 7.2 Hz, 1 H), 7.39 (t, *J* = 7.8 Hz, 1 H), 7.31–7.36 (m, 2 H), 7.15 (d, *J* = 8.4 Hz, 1 H), 7.09 (d, *J* = 9.0 Hz, 1 H), 5.20 (dd, *J* = 6.6 Hz, 2 H), 4.35 (d, *J* = 5.4 Hz, 1 H), 4.26 (d, *J* = 6.0 Hz, 1 H), 3.19 (s, 3 H), 2.34 (s, 3 H), 2.24 (m, 1 H), 1.75 (m, 2 H), 1.45 (m, 1 H), 1.24 (m, 1 H), 1.10 (m, 2 H), 1.02 (s, 3 H), 0.97 (s, 3 H), 0.55 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.0, 153.5, 153.0, 150.8, 135.2, 134.0, 133.9, 133.6, 131.2, 130.9, 129.8, 129.7, 128.6, 127.8, 126.8, 126.7, 126.4, 125.8, 125.7, 125.3, 124.1, 122.9, 121.5, 120.7, 116.4, 99.1, 94.9, 83.8, 56.4, 56.0, 51.9, 48.9, 46.1, 42.1, 32.6, 29.5, 24.5, 22.5, 17.3.

ESI-MS: *m*/*z* (%) = 603.7 (100) [M^+].

Anal. Calcd for $C_{39}H_{41}NO_5$: C, 77.59; H, 6.85; N, 2.32. Found: C, 77.61; H, 6.76; N, 2.35.

(*S*)-3-{6-[(1*R*,2*R*,4*R*)-2-Hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*,2*R*)-7b]
Yield: 0.59 g (82%); mp 80–84 °C; $[\alpha]_D$ –125.7 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2956, 1150, 1014 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.34 (s, 1 H), 8.10 (d, *J* = 9.2 Hz, 1 H), 8.06 (d, *J* = 8.0 Hz, 1 H), 7.98 (d, *J* = 8.0 Hz, 1 H), 7.87 (t, *J* = 8.0 Hz, 1 H), 7.76 (d, *J* = 7.2 Hz, 1 H), 7.67 (d, *J* = 9.2 Hz, 1 H), 7.64 (d, *J* = 7.2 Hz, 1 H), 7.47 (t, *J* = 7.2 Hz, 1 H), 7.29–7.41 (m, 3 H), 7.11 (d, *J* = 8.4 Hz, 1 H), 7.08 (d, *J* = 8.4 Hz, 1 H), 5.21 (t, *J* = 4.0 Hz, 2 H), 4.35 (d, *J* = 5.2 Hz, 1 H), 4.30 (d, *J* = 5.6 Hz, 1 H), 3.19 (s, 3 H), 2.93 (d, *J* = 9.2 Hz, 1 H), 2.34 (s, 3 H), 2.06–2.09 (m, 1 H), 1.86 (t, *J* = 4.0 Hz, 1 H), 1.62–1.65 (m, 1 H), 1.53–1.57 (m, 1 H), 1.27 (s, 3 H), 1.13–1.16 (m, 1 H), 0.88 (s, 6 H), 0.74–0.76 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 163.3, 154.2, 153.0, 150.9, 135.7, 134.1, 134.0, 133.7, 131.2, 130.9, 129.8, 129.7, 128.6, 127.8, 126.8, 126.6, 126.4, 125.9, 125.8, 125.3, 124.1, 123.2, 120.9, 119.0, 116.7, 99.1, 95.1, 82.9, 56.2, 56.0, 53.6, 50.6, 45.5, 44.3, 30.8, 27.1, 21.4, 21.2, 10.2.

ESI-MS: *m*/*z* (%) = 603.7 (100) [M^+].

Anal. Calcd for $C_{39}H_{41}NO_5$: C, 77.59; H, 6.85; N, 2.32. Found: C, 77.71; H, 6.81; N, 2.34.

(*R*)-3-{6-[(1*R*,2*R*,4*R*)-2-Hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*R*,2*R*)-7b]
Yield: 0.58 g (81%); mp 162–164 °C; $[\alpha]_D$ +51.4 (*c* 0.4, CH_2Cl_2).

IR (KBr): 2958, 1150, 1014 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.33 (s, 1 H), 8.10 (d, *J* = 9.2 Hz, 1 H), 8.05 (d, *J* = 8.0 Hz, 1 H), 7.98 (d, *J* = 8.0 Hz, 1 H), 7.87 (t, *J* = 8.0 Hz, 1 H), 7.75 (d, *J* = 7.6 Hz, 1 H), 7.67 (d, *J* = 9.2 Hz, 1 H), 7.64 (d, *J* = 8.0 Hz, 1 H), 7.48 (t, *J* = 8.0 Hz, 1 H), 7.31–7.41 (m, 3 H), 7.14 (d, *J* = 8.4 Hz, 1 H), 7.09 (d, *J* = 8.4 Hz, 1 H), 5.23 (s, 1 H), 5.20 (dd, *J* = 6.8 Hz, 2 H), 4.38 (d, *J* = 5.6 Hz, 1 H), 4.30 (d, *J* = 5.6 Hz, 1 H), 3.19 (s, 3 H), 2.87 (d, *J* = 13.2 Hz, 1 H), 2.35 (s, 3 H), 2.06–2.09 (m, 1 H), 1.86 (t, *J* = 4.0 Hz, 1 H), 1.66 (m, 1 H), 1.55 (m, 1 H), 1.27 (s, 3 H), 1.36–1.19 (m, 1 H), 0.88 (s, 3 H), 0.87 (s, 3 H), 0.76–0.77 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 163.4, 154.2, 153.0, 150.8, 135.7, 134.0, 133.9, 133.8, 131.2, 130.9 129.8, 129.7, 128.6, 127.8, 126.8, 126.7, 126.4, 125.8, 125.7, 125.3, 124.2, 123.3, 120.8, 119.0, 116.6, 99.2, 95.0, 82.8, 56.3, 56.0, 53.6, 50.6, 45.5, 44.4, 30.9, 27.1, 21.4, 21.2, 10.2.

ESI-MS: *m*/*z* (%) = 603.7 (100) [M^+].

Anal. Calcd for $C_{39}H_{41}NO_5$: C, 77.59; H, 6.85; N, 2.32. Found: C, 77.67; H, 6.91; N, 2.33.

(*S*)-3-{6-[(1*S*,2*S*,5*R*)-1-Hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*S*,1*S*)-7c]
Yield: 0.6 g (82%); mp 82–86 °C; $[\alpha]_D$ –111.2 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2951, 1150, 1014 cm^{-1}.

^1H NMR (600 MHz, DMSO-d_6): δ = 8.23 (s, 1 H), 8.10 (d, *J* = 9.0 Hz, 1 H), 8.07 (d, *J* = 7.8 Hz, 1 H), 7.98 (d, *J* = 8.4 Hz, 1 H), 7.89 (t, *J* = 7.8 Hz, 1 H), 7.64–7.68 (m, 3 H), 7.48 (t, *J* = 8.4 Hz, 1 H), 7.39 (d, *J* = 8.4 Hz, 1 H), 7.31–7.34 (m, 2 H), 7.12 (d, *J* = 8.4 Hz, 1 H), 7.08 (d, *J* = 8.4 Hz, 1 H), 5.20 (dd, *J* = 7.2 Hz, 2 H), 5.06 (s, 1 H), 4.41 (d, *J* = 6.6 Hz, 1 H), 4.28 (d, *J* = 6.6 Hz, 1 H), 3.18 (s, 3 H), 2.31 (s, 3 H), 1.93–1.95 (m, 2 H), 1.80 (d, *J* = 12.0 Hz, 1 H), 1.52–1.71 (m, 4 H), 1.30–1.32 (m, 1 H), 1.04–1.08 (m, 1 H), 0.86 (d, *J* = 6.6 Hz, 3 H), 0.81 (d, *J* = 6.6 Hz, 3 H), 0.67 (d, *J* = 7.2 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 165.2, 153.7, 153.0, 150.8, 137.0, 134.0, 133.6, 131.3, 130.9, 129.8, 129.7, 128.6, 127.8, 126.8, 126.7, 126.5, 125.8, 125.6, 125.3, 124.1, 123.1, 120.7, 117.6, 116.4, 99.1, 94.9, 77.2, 56.3, 56.0, 50.9, 50.2, 35.4, 28.6, 27.6, 23.7, 22.4, 22.1, 18.7.

ESI-MS: *m*/*z* (%) = 607.8 (100) [M^+].

Anal. Calcd for $C_{39}H_{43}NO_5$: C, 77.07; H, 7.13; N, 2.30. Found: C, 77.16; H, 7.21; N, 2.25.

(*R*)-3-{6-[(1*S*,2*S*,5*R*)-1-Hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-2,2′-bis(methoxymethoxy)-1,1′-binaphthyl [(*R*,1*S*)-7c]
Yield: 0.58 g (79%); mp 80–84 °C; $[\alpha]_D$ +64.9 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2950, 1150, 1014 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.24 (s, 1 H), 8.10 (d, *J* = 9.2 Hz, 1 H), 8.07 (d, *J* = 8.4 Hz, 1 H), 7.98 (d, *J* = 8.0 Hz, 1 H), 7.89 (t, *J* = 7.6 Hz, 1 H), 7.64–7.68 (m, 3 H), 7.75 (t, *J* = 7.6 Hz, 1 H), 7.29–7.41 (m, 3 H), 7.11 (d, *J* = 8.4 Hz, 1 H), 7.07 (d, *J* = 8.4 Hz, 1 H), 5.21 (t, *J* = 8.0 Hz, 2 H), 5.02 (s, 1 H), 4.32 (dd, *J* = 5.6 Hz, 2 H), 3.19 (s, 3 H), 2.30 (s, 3 H), 1.91–1.94 (m, 2 H), 1.63–1.82 (m, 3 H), 1.53–1.56 (m, 2 H), 1.29–1.31 (m, 1 H), 1.02–1.06 (m, 1 H), 0.87 (d, *J* = 8.4 Hz, 3 H), 0.82 (d, *J* = 6.8 Hz, 3 H), 0.66 (d, *J* = 6.8 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 165.2, 153.7, 153.0, 150.8, 137.0, 134.1, 134.0, 133.5, 131.3, 130.9, 129.8, 129.7, 128.6, 127.8, 126.8, 126.6, 126.4, 125.8, 125.8, 125.3, 124.1, 123.1, 121.0, 117.6, 116.8, 99.1, 95.1, 77.2, 56.2, 56.0, 50.9, 50.2, 35.4, 28.6, 27.6, 23.7, 22.5, 22.2, 18.7.

ESI-MS: *m*/*z* (%) = 607.8 (100) [M$^+$].

Anal. Calcd for $C_{39}H_{43}NO_5$: C, 77.07; H, 7.13; N, 2.30. Found: C, 77.12; H, 7.11; N, 2.35.

Deprotection of the MOM Groups; General Procedure

Method A: To a soln of **6** (0.6 mmol) in EtOH (10 mL) and CH_2Cl_2 (10 mL) was added concd HCl (0.5 mL) and the mixture was stirred at r.t. for 24 h. The mixture was washed with aq Na_2CO_3 and extracted with CH_2Cl_2 (2 ×). The combined organic layers were washed with brine, dried ($MgSO_4$), and concentrated in vacuo. The crude product was purified by column chromatography (petroleum ether–EtOAc, 5:1) to yield **8** as yellow solids.

Method B: To a soln of **7** (0.8 mmol) in EtOH (10 mL) and CH_2Cl_2 (10 mL) was added concd HCl (0.5 mL) and the mixture was stirred at 40–50 °C for 6 h. The mixture was washed with aq Na_2CO_3 and extracted with CH_2Cl_2 (2 ×). The combined organic layers were washed with brine, dried ($MgSO_4$), and concentrated in vacuo. The crude product was purified by column chromatography (petroleum ether–EtOAc 5:1) to yield **9** as yellow solids.

(*S*)-3,3′-Bis{6-[(1*R*,2*R*,4*S*)-2-hydroxy-1,3,3-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*S*,2*R*)-8a]

According to method A; yield: 0.42 g (95%); mp 204–206 °C; $[\alpha]_D$ –53.5 (*c* 0.4, CH_2Cl_2).

IR (KBr): 2930, 1580, 1461 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 13.80 (s, 1 H), 8.83 (s, 1 H), 8.38 (d, *J* = 8.0 Hz, 1 H), 8.07 (t, *J* = 8.0 Hz, 1 H), 8.03 (d, *J* = 8.0 Hz, 1 H), 7.78 (s, 1 H), 7.30 (t, *J* = 7.2 Hz, 1 H), 7.22 (t, *J* = 7.2 Hz, 1 H), 6.98 (d, *J* = 8.4 Hz, 1 H), 4.97 (s, 1 H), 2.27–2.30 (m, 1 H), 2.15 (m, 1 H), 1.63 (m, 2 H), 1.33 (m, 1 H), 1.18–1.10 (m, 1 H), 1.07 (s, 3 H), 1.01–0.95 (m, 1 H), 0.92 (s, 3 H), 0.39 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 161.7, 156.1, 153.1, 137.2, 135.0, 128.6, 128.4, 128.0, 127.2, 125.0, 123.4, 123.2, 121.5, 119.6, 117.6, 84.5, 52.3, 48.9, 46.3, 41.7, 32.9, 29.1, 24.1, 21.9, 17.1.

ESI-MS: *m*/*z* (%) = 745.0 (100) [M$^+$].

Anal. Calcd for $C_{50}H_{52}N_2O_4$: C, 80.61; H, 7.04; N, 3.76. Found: C, 80.49; H, 7.01; N, 3.79.

(*R*)-3,3′-Bis{6-[(1*R*,2*R*,4*S*)-2-hydroxy-1,3,3-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*R*,2*R*)-8a]

According to method A; yield: 0.41 g (93%); mp 208–210 °C; $[\alpha]_D$ –124.1 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2930, 1582, 1461 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 13.80 (s, 1 H), 8.83 (s, 1 H), 8.38 (d, *J* = 8.0 Hz, 1 H), 8.08 (t, *J* = 8.0 Hz, 1 H), 8.03 (d, *J* = 8.4 Hz, 1 H), 7.80 (d, *J* = 7.6 Hz, 1 H), 7.30 (t, *J* = 7.2 Hz, 1 H), 7.23 (t, *J* = 7.2 Hz, 1 H), 6.98 (d, *J* = 8.4 Hz, 1 H), 4.99 (s, 1 H), 2.42–2.44 (m, 1 H), 2.14 (m, 1 H), 1.62–1.65 (m, 1 H), 1.29–1.35 (m, 1 H), 1.07–1.11 (m, 1 H), 1.01 (s, 3 H), 0.93–0.98 (m, 1 H), 0.92 (s, 3 H), 0.40 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 161.7, 155.9, 153.2, 137.2, 135.1, 128.6, 128.4, 128.0, 127.1, 125.1, 123.3, 123.1, 121.5, 119.6, 117.6, 84.6, 52.5, 49.0, 46.4, 41.8, 33.0, 29.1, 24.1, 21.8, 17.1.

ESI-MS: *m*/*z* (%) = 745.0 (100) [M$^+$].

Anal. Calcd for $C_{50}H_{52}N_2O_4$: C, 80.61; H, 7.04; N, 3.76. Found: C, 80.52; H, 7.10; N, 3.90.

(*S*)-3,3′-Bis{6-[(1*R*,2*R*,4*R*)-2-hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*S*,2*R*)-8b]

According to method A; yield: 0.42 g (94%); mp 219–221 °C; $[\alpha]_D$ –21.1 (*c* 0.4, CH_2Cl_2).

IR (KBr): 2956, 1581, 1458 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.4 (s, 1 H), 8.87 (s, 1 H), 8.44–8.46 (m, 1 H), 8.11–8.14 (m, 1 H), 8.03 (d, *J* = 8.4 Hz, 1 H), 7.73 (d, *J* = 7.8 Hz, 1 H), 7.30 (t, *J* = 7.2 Hz, 1 H), 7.23 (t, *J* = 7.2 Hz, 1 H), 7.01 (d, *J* = 8.4 Hz, 1 H), 5.35 (d, *J* = 3.6 Hz, 1 H), 2.38 (d, *J* = 7.2 Hz, 1 H), 2.01–2.03 (m, 1 H), 1.71 (t, *J* = 3.6 Hz, 1 H), 1.44–1.46 (m, 1 H), 1.24–1.85 (m, 1 H), 1.17 (s, 3 H), 1.09–1.12 (m, 1 H), 0.87 (s, 3 H), 0.79 (s, 3 H), 0.53 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.9, 156.3, 154.0, 137.9, 135.1, 128.7, 127.9, 127.0, 124.9, 122.9, 122.1, 120.5, 119.4, 118.0, 84.3, 54.0, 50.5, 45.4, 43.9, 30.8, 26.0, 21.3, 21.2, 10.0.

ESI-MS: *m*/*z* (%) = 745.0 (100) [M$^+$].

Anal. Calcd for $C_{50}H_{52}N_2O_4$: C, 80.61; H, 7.04; N, 3.76. Found: C, 80.72; H, 7.09; N, 3.84.

(*R*)-3,3′-Bis{6-[(1*R*,2*R*,4*R*)-2-hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*R*,2*R*)-8b]

According to method A; yield: 0.42 g (95%); mp 216–218 °C; $[\alpha]_D$ –22.5 (*c* 0.4, CH_2Cl_2).

IR (KBr): 2955, 1580, 1458 cm^{-1}.

^{1}H NMR (600 MHz, DMSO-d_6): δ = 14.40 (s, 1 H), 8.87 (s, 1 H), 8.46 (d, *J* = 8.4 Hz, 1 H), 8.13 (t, *J* = 7.8 Hz, 1 H), 8.03 (d, *J* = 8.4 Hz, 1 H), 7.73 (d, *J* = 7.8 Hz, 1 H), 7.30 (t, *J* = 7.2 Hz, 1 H), 7.23 (t, *J* = 7.2 Hz, 1 H), 7.01 (d, *J* = 3.6 Hz, 1 H), 5.35 (s, 1 H), 2.38 (d, *J* = 7.2 Hz, 1 H), 2.02 (m, 1 H), 1.71 (t, *J* = 3.6 Hz, 1 H), 1.46 (m, 1 H), 1.17 (s, 3 H), 1.07–1.15 (m, 2 H), 0.87 (s, 3 H), 0.79 (s, 3 H), 0.51–0.54 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 161.8, 156.2, 154.0, 137.9, 135.1, 128.7, 127.9, 127.8, 126.9, 124.8, 122.9, 122.1, 120.5, 119.4, 118.0, 84.3, 54.0, 50.5, 45.4, 43.9, 30.8, 26.0, 21.3, 21.2, 10.0.

ESI-MS: *m*/*z* (%) = 745.0 (100) [M$^+$].

Anal. Calcd for $C_{50}H_{52}N_2O_4$: C, 80.61; H, 7.04; N, 3.76. Found: C, 80.76; H, 7.20; N, 3.62.

(*S*)-3,3′-Bis{6-[(1*S*,2*S*,5*R*)-1-hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*S*,1*S*)-8c]

According to method A; yield: 0.43 g (96%); mp 198–201 °C; $[\alpha]_D$ +62.6 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2952, 1580, 1461 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.31 (s, 1 H), 8.89 (s, 1 H), 8.42 (d, *J* = 8.4 Hz, 1 H), 8.14 (t, *J* = 8.0 Hz, 1 H), 8.04 (d, *J* = 8.4 Hz, 1 H), 7.78 (d, *J* = 7.6 Hz, 1 H), 7.31 (t, *J* = 7.2 Hz, 1 H), 7.23 (t, *J* = 7.2 Hz, 1 H), 6.93 (d, *J* = 8.4 Hz, 1 H), 5.04 (s, 1 H), 1.86 (m, 1 H), 1.57–1.68 (m, 4 H), 1.33–1.41 (m, 2 H), 1.21–1.26 (m, 1 H), 0.87–0.84 (m, 1 H), 0.74 (d, *J* = 7.2 Hz, 3 H), 0.72 (d, *J* = 6.8 Hz, 3 H), 0.55 (d, *J* = 7.2 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 164.7, 157.1, 154.4, 138.3, 135.3, 128.7, 127.8, 127.7, 127.2, 125.0, 123.0, 122.4, 118.7, 118.2, 118.0, 79.2, 49.7, 48.3, 34.4, 28.3, 27.5, 23.6, 21.9, 21.5, 18.6.

ESI-MS: *m*/*z* (%) = 749.0 (100) [M$^+$].

Anal. Calcd for $C_{50}H_{56}N_2O_4$: C, 80.18; H, 7.54; N, 3.74. Found: C, 80.11; H, 7.48; N, 3.69.

(*R*)-3,3′-Bis{6-[(1*S*,2*S*,5*R*)-1-hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*R*,1*S*)-8c]

According to method A; yield: 0.41 g (91%); mp 186–190 °C; $[\alpha]_D$ +103.3 (*c* 0.5, CH_2Cl_2).

IR (KBr): 2951, 1580, 1461 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.3 (s, 1 H), 8.89 (s, 1 H), 8.43 (d, *J* = 8.0 Hz, 1 H), 8.14 (t, *J* = 8.0 Hz, 1 H), 8.02 (d, *J* = 8.4 Hz, 1 H), 7.75 (d, *J* = 7.2 Hz, 1 H), 7.29 (t, *J* = 7.6 Hz, 1 H), 7.19 (t, *J* = 7.2 Hz, 1 H), 7.01 (d, *J* = 8.8 Hz, 1 H), 5.05 (s, 1 H), 1.85–1.87 (m, 1 H), 1.56–1.70 (m, 4 H), 1.36–1.40 (m, 1 H), 1.23–1.26 (m, 1 H), 0.84–0.87 (m, 1 H), 0.75 (t, *J* = 8.4 Hz, 6 H), 0.53 (d, *J* = 6.8 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 164.7, 156.9, 154.2, 138.4, 135.1, 128.6, 127.8, 127.1, 125.1, 123.1, 122.2, 118.6, 118.3, 118.1, 79.3, 49.8, 48.2, 34.4, 28.3, 27.5, 23.5, 21.9, 21.4, 18.6.

ESI-MS: *m*/*z* (%) = 749.0 (100) [M$^+$].

Anal. Calcd for $C_{50}H_{56}N_2O_4$: C, 80.18; H, 7.54; N, 3.74. Found: C, 80.01; H, 7.49; N, 3.76.

(*S*)-3-{6-[(1*R*,2*R*,4*S*)-2-Hydroxy-1,3,3-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*S*,2*R*)-9a]

According to method B; yield: 0.39 g (95%); mp 222–224 °C; $[\alpha]_D$ –132.8 (*c* 0.5, CH_2Cl_2).

IR (KBr): 3533, 2957, 1584, 815, 753 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 13.7 (s, 1 H), 9.24 (s, 1 H), 8.97 (s, 1 H), 8.35 (d, *J* = 8.0 Hz, 1 H), 8.06 (t, *J* = 8.0 Hz, 1 H), 8.02 (d, *J* = 8.0 Hz, 1 H), 7.88 (t, *J* = 7.2 Hz, 2 H), 7.77 (s, 1 H), 7.35 (d, *J* = 9.2 Hz, 1 H), 7.30–7.15 (m, 4 H), 7.01 (d, *J* = 8.4 Hz, 1 H), 6.89 (d, *J* = 8.4 Hz, 1 H), 4.97 (s, 1 H), 2.29 (d, *J* = 10.0 Hz, 1 H), 2.15 (m, 1 H), 1.64 (m, 2 H), 1.37–1.33 (m, 1 H), 1.17–1.16 (m, 1 H), 1.07 (s, 3 H), 1.03–0.96 (m, 1 H), 0.92 (s, 3 H), 0.39 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.3, 155.4, 154.4, 151.7, 137.5, 135.0, 133.8, 129.7, 129.3, 129.0, 128.8, 128.1, 127.9, 126.3, 125.2, 124.7, 123.7, 123.1, 122.7, 122.0, 118.9, 118.0, 115.4, 114.3, 84.7, 52.4, 48.8, 46.4, 41.7, 33.0, 29.0, 24.0, 21.7, 17.0.

ESI-MS: *m*/*z* (%) = 515.6 (100) [M$^+$].

Anal. Calcd for $C_{35}H_{33}NO_3$: C, 81.53; H, 6.45; N, 2.72. Found: C, 81.49; H, 6.37; N, 2.72.

(*R*)-3-{6-[(1*R*,2*R*,4*S*)-2-Hydroxy-1,3,3-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*R*,2*R*)-9a]

According to method B; yield: 0.38 g (91%); mp 216–218 °C; $[\alpha]_D$ +44.0 (*c* 0.4, CH_2Cl_2).

IR (KBr): 3491, 2931, 1589, 817, 746 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 13.8 (s, 1 H), 9.24 (s, 1 H), 8.79 (s, 1 H), 8.36 (d, *J* = 8.0 Hz, 1 H), 8.06 (t, *J* = 8.0 Hz, 1 H), 8.00 (d, *J* = 7.6 Hz, 1 H), 7.88 (t, *J* = 8.0 Hz, 2 H), 7.78 (d, *J* = 6.0 Hz, 1 H), 7.35 (d, *J* = 8.0 Hz, 1 H), 7.30–7.15 (m, 4 H), 7.02 (d, *J* = 8.0 Hz, 1 H), 6.88 (d, *J* = 8.4 Hz, 1 H), 4.99 (s, 1 H), 2.34 (d, *J* = 10.0 Hz), 2.15 (m, 1 H), 1.66 (m, 2 H), 1.38–1.32 (m, 1 H), 1.19–1.16 (m, 1 H), 1.02 (s, 3 H), 0.98–0.95 (m, 1 H), 0.93 (s, 3 H), 0.41 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.3, 155.3, 154.4, 151.6, 137.5, 135.0, 133.8, 129.7, 129.3, 129.1, 128.8, 128.1, 128.0, 126.2, 125.3, 124.7, 123.8, 123.1, 122.7, 122.0, 118.9, 118.0, 115.3, 114.2, 84.7, 52.5, 48.9, 46.4, 41.7, 33.0, 29.0, 24.0, 21.7, 17.0.

ESI-MS: *m*/*z* (%) = 515.6 (100) [M$^+$].

Anal. Calcd for $C_{35}H_{33}NO_3$: C, 81.53; H, 6.45; N, 2.72. Found: C, 81.72; H, 6.38; N, 2.66.

(*S*)-3-{6-[(1*R*,2*R*,4*R*)-2-Hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*S*,2*R*)-9b]

According to method B; yield: 0.38 g (92%); mp 236–238 °C; $[\alpha]_D$ –103.7 (*c* 0.5, CH_2Cl_2).

IR (KBr): 3533, 2957, 1585, 816, 748 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.37 (s, 1 H), 9.24 (s, 1 H), 8.82 (s, 1 H), 8.43 (d, *J* = 8.0 Hz, 1 H), 8.11 (t, *J* = 8.0 Hz, 1 H), 8.01 (d, *J* = 7.6 Hz, 1 H), 7.88 (t, *J* = 8.0 Hz, 2 H), 7.34 (d, *J* = 8.8 Hz, 1 H), 7.21–7.31 (m, 3 H), 7.16 (t, *J* = 7.6 Hz, 1 H), 7.02 (d, *J* = 8.4 Hz, 1 H), 6.90 (d, *J* = 8.0 Hz, 1 H), 5.34 (s, 1 H), 2.40 (d, *J* = 9.2 Hz, 1 H), 2.03–2.06 (m, 1 H), 1.73 (t, *J* = 4.0 Hz, 1 H), 1.45 (m, 1 H), 1.19 (s, 3 H), 1.17–1.06 (m, 2 H), 0.88 (s, 3 H), 0.80 (s, 3 H), 0.49–0.55 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.6, 155.7, 154.9, 151.6, 138.0, 135.1, 133.8, 129.8, 129.3, 128.9, 128.8, 128.1, 128.0, 126.3, 125.3, 124.6, 123.8, 123.2, 122.3, 121.0, 119.1, 117.9, 115.4, 114.3, 84.2, 54.1, 50.6, 45.4, 44.0, 30.8, 26.3, 21.3 21.2, 10.1.

ESI-MS: *m*/*z* (%) = 515.6 (100) [M$^+$].

Anal. Calcd for $C_{35}H_{33}NO_3$: C, 81.53; H, 6.45; N, 2.72. Found: C, 81.71; H, 6.55; N, 2.69.

(*R*)-3-{6-[(1*R*,2*R*,4*R*)-2-Hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*R*,2*R*)-9b]

According to method B; yield: 0.39 g (94%); mp 168–170 °C; $[\alpha]_D$ +106.0 (*c* 0.5, CH_2Cl_2).

IR (KBr): 3534, 2955, 1587, 816, 746 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.44 (s, 1 H), 9.25 (s, 1 H), 8.85 (s, 1 H), 8.45 (d, *J* = 8.0 Hz, 1 H), 8.12 (t, *J* = 8.0 Hz, 1 H), 8.01 (d, *J* = 8.0 Hz, 1 H), 7.89 (t, *J* = 7.2 Hz, 2 H), 7.72 (d, *J* = 8.0 Hz, 1 H), 7.35 (d, *J* = 8.8 Hz, 1 H), 7.18–7.33 (m, 3 H), 7.17 (t, *J* = 7.2 Hz, 1 H), 7.01 (d, *J* = 8.4 Hz, 1 H), 6.92 (d, *J* = 8.4 Hz, 1 H), 5.32 (s, 1 H), 2.40 (d, *J* = 9.6 Hz, 1 H), 1.99–2.00 (m, 1 H), 1.76 (t, *J* = 4.0 Hz, 1 H), 1.50–1.53 (m, 1 H), 1.19 (s, 3 H), 1.16–1.09 (m, 2 H), 0.9 (s, 3 H), 0.81 (s, 3 H), 0.50–0.54 (m, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.6, 155.6, 154.9, 151.7, 138.1, 135.2, 133.8, 129.8, 129.3, 128.9, 128.8, 128.2, 128.1, 128.0, 126.3, 125.1, 124.7, 123.8, 123.1, 122.2, 121.2, 119.1, 118.0, 115.3, 114.3, 84.3, 54.1, 50.6, 45.4, 44.0, 30.8, 26.3, 21.3, 21.2, 10.0.

ESI-MS: *m*/*z* (%) = 515.6 (100) [M$^+$].

Anal. Calcd for $C_{35}H_{33}NO_3$: C, 81.53; H, 6.45; N, 2.72. Found: C, 81.39; H, 6.43; N, 2.83.

(*S*)-3-{6-[(1*S*,2*S*,5*R*)-1-Hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*S*,1*S*)-9c]

According to method B; yield: 0.39 g (93%); mp 148–150 °C; $[\alpha]_D$ –46.2 (*c* 0.4, CH_2Cl_2).

IR (KBr): 3533, 2952, 1591, 814, 744 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.10 (s, 1 H), 9.23 (s, 1 H), 8.84 (s, 1 H), 8.39 (d, *J* = 8.0 Hz, 1 H), 8.12 (t, *J* = 8.0 Hz, 1 H), 8.00 (d, *J* = 8.0 Hz, 1 H), 7.88 (t, *J* = 7.2 Hz, 2 H), 7.75 (d, *J* = 7.6 Hz, 1 H), 7.35 (d, *J* = 6.8 Hz, 1 H), 7.34–7.16 (m, 4 H), 7.00 (d, *J* = 8.4 Hz, 1 H), 6.87 (d, *J* = 8.4 Hz, 1 H), 5.03 (s, 1 H), 1.87 (m, 1 H), 1.72–1.56 (m, 4 H), 1.46–1.49 (m, 1 H), 1.38 (m, 1 H), 1.28 (m,

1 H), 0.84 (m, 1 H), 0.76 (t, *J* = 6.8 Hz, 6 H), 0.60 (d, *J* = 6.8 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 164.9, 156.3, 155.3, 151.8, 138.7, 135.3, 133.8, 129.8, 129.3, 128.8, 128.7, 128.2, 128.0, 127.9, 126.3, 125.3, 124.8, 123.7, 123.2, 122.0, 118.9, 118.3, 118.1, 115.5, 114.4, 79.3, 49.7, 48.5, 34.3, 28.3, 27.6, 23.5, 21.8, 21.4, 18.6.

ESI-MS: *m*/*z* (%) = 517.6 (100) [M^+].

Anal. Calcd for $C_{35}H_{35}NO_3$: C, 81.22; H, 6.82; N, 2.71. Found: C, 81.03; H, 6.60; N, 2.65.

(*R*)-3-{6-[(1*S*,2*S*,5*R*)-1-Hydroxy-2-isopropyl-5-methylcyclohexyl]pyridin-2-yl}-1,1′-bi-2-naphthol [(*R*,1*S*)-9c]
According to method B; yield: 0.38 g (92%); mp 140–144 °C; $[\alpha]_D$ +130.9 (*c* 0.4, CH_2Cl_2).

IR (KBr): 3532, 2952, 1591, 813, 744 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.21 (s, 1 H), 9.24 (s, 1 H), 8.85 (s, 1 H), 8.40 (d, *J* = 8.0 Hz, 1 H), 8.12 (t, *J* = 8.0 Hz, 1 H), 8.00 (d, *J* = 8.0 Hz, 1 H), 7.88 (t, *J* = 8.0 Hz, 2 H), 7.75 (d, *J* = 8.0 Hz, 1 H), 7.35 (d, *J* = 8.0 Hz, 1 H), 7.29 (t, *J* = 6.8 Hz, 1 H), 7.24 (t, *J* = 8.0 Hz, 2 H), 7.13 (t, *J* = 8.8 Hz, 1 H), 7.01 (d, *J* = 8.8 Hz, 1 H), 6.92 (d, *J* = 8.4 Hz, 1 H), 5.01 (s, 1 H), 1.87 (s, 1 H), 1.72–1.57 (m, 4 H), 1.43–1.36 (m, 2 H) 1.24–1.22 (m, 1 H), 0.91–0.84 (m, 1 H), 0.79 (d, *J* = 6.4 Hz, 3 H), 0.75 (d, *J* = 6.8 Hz, 3 H), 0.52 (d, *J* = 6.8 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 164.8, 156.3, 155.5, 151.6, 138.7, 135.1, 133.8, 129.8, 129.3, 128.8, 128.7, 128.1, 127.9, 126.2, 125.3, 124.5, 123.7, 123.2, 121.9, 118.9, 118.3, 117.9, 115.5, 114.3, 79.3, 49.7, 48.5, 34.3, 28.3, 27.6, 23.4, 21.9, 21.4, 18.6.

ESI-MS: *m*/*z* (%) = 517.6 (100) [M^+].

Anal. Calcd for $C_{35}H_{35}NO_3$: C, 81.22; H, 6.82; N, 2.71. Found: C, 81.31; H, 6.71; N, 2.68.

Addition of Diethylzinc to Benzaldehydes; General Procedure
Chiral ligand (0.005 mmol) in anhyd toluene (3 mL) was cooled to 0 °C and Ti(O*i*-Pr)$_4$ (0.35 mmol) was added. After 5 min, 1 M Et_2Zn in hexane (0.75 mmol) was added slowly. The mixture was allowed to stir at 0 °C for 30 min. Freshly distilled aldehyde (0.25 mmol) was added to the soln and the mixture was allowed to stir at 0 °C for 5 h. The reaction was stopped by the addition of 1 M HCl (3.0 mL) and the product was extracted with EtOAc (3.0 mL). The extract was dried ($MgSO_4$) and concentrated in vacuo. The residue was purified by column chromatography. The enantiomeric excess of the product was determined by chiral GC with a Chrompack Chirasil-DEX CB column or chiral HPLC with a OD-H column.

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