

Conformational Control of Propeller-Like Chirality in Zn(II) Complexes: Tightly Balanced Steric Bias

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Received 23 June 1999; revised 9 August 1999; accepted 11 August 1999

Abstract: The conformational behavior of a series of chiral tripodal ligand-Zn(II) complexes was examined. The ligands adopt propeller-like conformations upon complexation of trigonal bipyramidal metal ions such as Zn(II), with the chirality of the propeller determined by the absolute configuration of a single chiral center in one of the tripod arms. Surprisingly, increasing the size of the substituent in the chiral arm did not improve the geometrical definition of the complexes, as indicated by the circular dichroism spectra of the complexes. © 1999 Elsevier Science Ltd. All rights reserved.

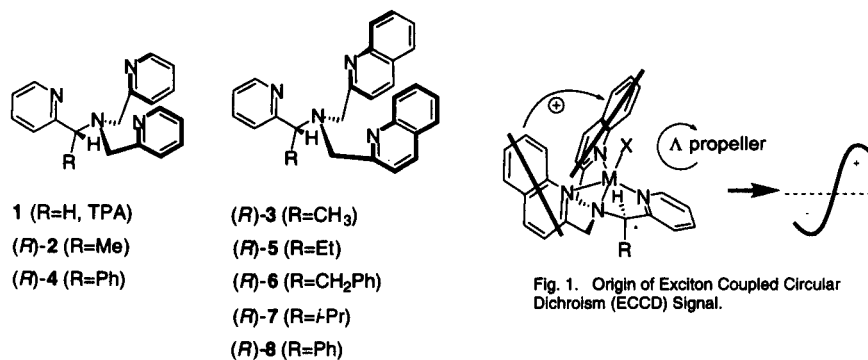
Keywords: Circular dichroism, Stereoisomerism, Conformation, Molecular devices

Chiral tripodal ligands related to tris-(2-pyridylmethyl)amine (TPA, **1**) with an asymmetric center in one arm (e.g., **2**)¹ have been used as chiral solvating agents¹ and for metal ion sensing with multiple signals.² Copper(II) complexes of the ligands have been shown to display redox-switched chiroptical properties with potential application in the development of molecular electronic devices.³ Related derivatives of α -amino acids and β -aminoalcohols have been used in assignment of their absolute configurations.⁴ The large amplitudes of the observed chiroptical spectra upon which these applications are based derive from a conformational bias that fixes the geometry of the heterocyclic chromophores, resulting in exciton-coupled circular dichroism (ECCD, Fig. 1).^{5,6} The complexation of a five-coordinate metal ion in a trigonal bipyramidal coordination geometry (e.g., $[M(L)X]^{n+}$, $M = \text{Zn(II)}$ or Cu(II) , $L = \mathbf{2}, \mathbf{3}$, or $\mathbf{4}$, $X =$ counterion or solvent) results in the formation of a propeller-like orientation of the heterocyclic rings, approximating an additional axial symmetry element (e.g., Fig. 2a). Complexation of metals with other coordination geometries does not generate the propeller structure and consequently does not result in strong CD spectra.¹ Of the various compounds reported so far, those with quinolines as heterocyclic ligating groups⁷ such as **3** have given the most dramatic ECCD spectra, due in part to the chromophoric properties of the quinolines.

Our previous studies examined complexes of **2-4** and single enantiomer complexes of **2** and **3**, with either a methyl or phenyl substituent on the asymmetric arm. We have suggested that two conformations were available to the substituted derivatives complexed with Zn(II) and Cu(II) metal ions, and that in the case of a methyl group (e.g., **3**), there is a preference for the anti conformation by 1-2 kcal/mol (Fig. 3).⁸ In the anti conformation, the saturated carbons taken together with the nitrogen atom represent a fairly crowded steric environment. However, in the syn conformation, the α -alkyl substituent encounters a high energy syn

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pentane-type interaction with a neighboring pyridine moiety. Thus, both metal ion-binding conformations are sterically crowded with the anti conformation being favored.⁸



While our conformational analysis, crystallographic structures, and chiroptical spectra painted a consistent picture of complexes of **2** and **3**, we desired to probe the question of whether similar observations would be made for a series of tripodal ligands in which the methyl substituent was changed to other alkyl- or aryl-groups. Preliminary examination of models and calculations had indicated that the new ligands **5-8** should adopt geometries similar to **2** and **3**, although at some point the substituent size would become too large and distort the propeller shape of the ligand due to the tight steric environment (Fig. 2b). The ECCD spectra should serve as probes of molecular geometry since the amplitude of the signal in the spectra depends on the relative orientation of the quinoline chromophores. We reported previously the synthesis and crystallographic structure of racemic [Zn(4)Cl]ClO₄,⁸ but we had not been able to prepare enantiomerically pure material for CD measurements.

Fig. 2. Stereochemical detail of [M(1)X]⁺.

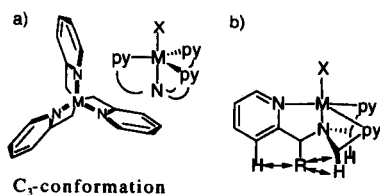
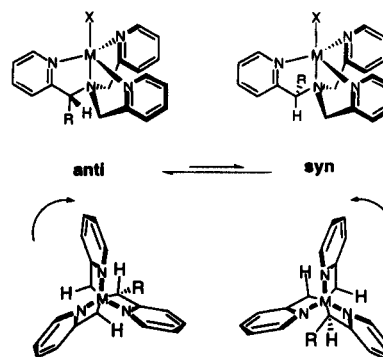


Fig. 3. Conformational interconversions.



RESULTS AND DISCUSSION

The phenyl substituted tripodal ligand **8** was reported previously in racemic form.⁸ Resolution of the requisite primary amine **12** by classical means failed, so the enantiomerically pure compound was prepared by asymmetric synthesis.

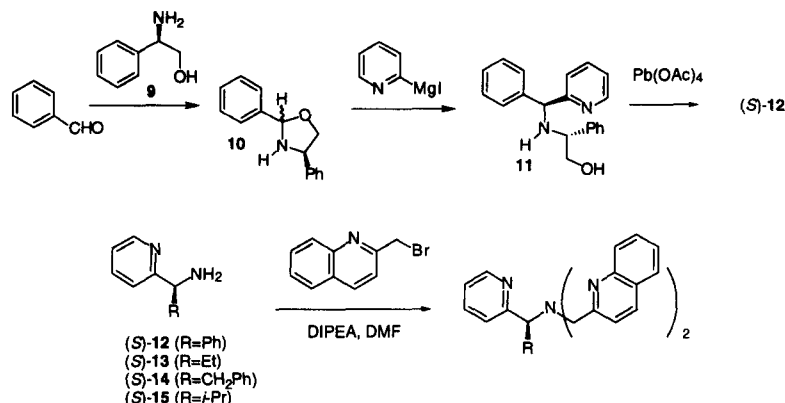


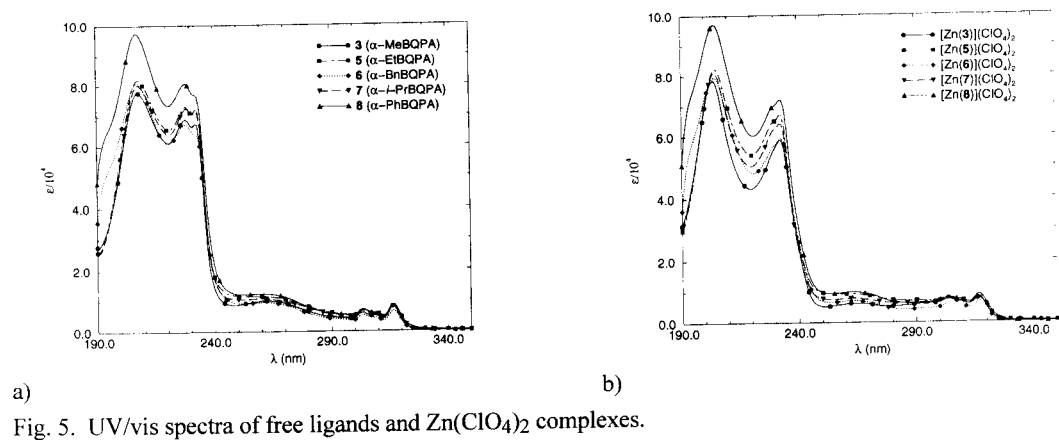
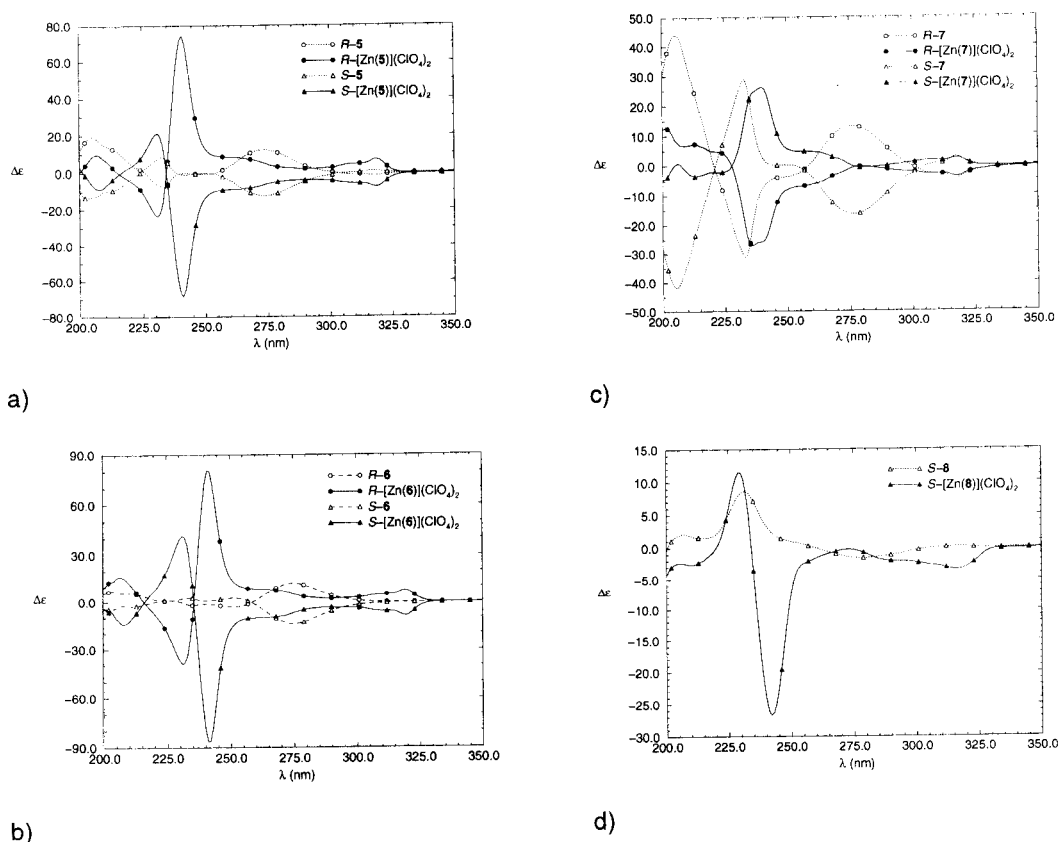
Fig. 4. Synthesis of Ligands.

Several methodologies for the synthesis of chiral primary amines using chiral auxiliaries have been reported.^{9,10} Thus, the Grignard reagent of 2-iodopyridine was prepared by reaction with EtMgBr (Fig. 4). Addition to the (*P*)-phenyl glycinol oxazolidine derivative of benzaldehyde **10** afforded compound **11**. Removal of the chiral auxiliary with Pb(OAc)₄ afforded amine **12** in moderate yield with 81% ee. The alternative synthesis of **11** by addition of PhMgCl to the oxazolidine of picolylaldehyde gave a 1:1 mixture of diastereomers. While this manuscript was in preparation, a variation of this method using valinol in place of phenylglycinol was reported.¹¹ Subsequent alkylation of **12** with 2-bromomethylquinoline (prepared from 2-quinolinecarbaldehyde) in aqueous NaOH afforded the target compound **8** in 42% yield.

Primary amines **13-15** were prepared as described¹² from the appropriate enantiomer of pinanone.¹³ The obtained ee was typically around 85%, but a single recrystallization of amine hydrochloric acid salt gave >95% ee. The ligands **5-8** were synthesized by reacting the chiral amine with 2-bromomethylquinoline in the presence of diisopropylethylamine in DMF.⁷ The ee of compounds was tested for compounds **5** and **6** and confirmed to be similar to that determined for the primary amines **13** and **14**.

Spectroscopic studies

Diagnostic information for zinc complex formation was observed in ¹H NMR spectra of free ligands and complexes in CDCl₃. Two AB doublets appear (*J*~15 Hz) in the region δ 4.5-3.5 for the free ligands corresponding to the diastereotopic protons of the CH₂ groups. Spectra of the Zn(ClO₄)₂ complexes display

Fig. 5. UV/vis spectra of free ligands and Zn(ClO₄)₂ complexes.Fig. 6. Circular dichroism spectra of free ligands and Zn(ClO₄)₂ complexes.

doublets (δ 5.5–4.0) for each of the four protons of the two methylenes, indicative of freezing the nitrogen atom inversion by coordination to the zinc. Also characteristic of zinc complex formation are three extremely downfield resonances (δ 9.8–9.2) corresponding to one proton on each of the heterocycles.

The UV-VIS spectra (Fig. 5) of the free ligands are very similar to one another, presenting peaks at 207 nm ($\epsilon=77000$ – 97000), bands at 228 nm ($\epsilon=67000$ – 81000) with a poorly resolved accompanying band or shoulder at 233 nm ($\epsilon=64000$ – 77000), and broad bands at 250–325 nm (317 nm, $\epsilon=9000$). The peaks at 207 nm originate from both pyridyl and quinolyl moieties, while the ones at 233 nm derive mainly from the quinolyl chromophores.⁵ The spectra of zinc complexes show small shifts compared to the free ligands, with maxima at 204 nm and 233 nm. The longitudinal transition at 233 nm is responsible for the bisignate signals in the circular dichroism spectra.⁵

The circular dichroism spectra (Fig. 6) of $Zn(ClO_4)_2$ complexes of **5**, **6**, and **8** present bisignate CD spectra, centered around the 233 nm absorption peak observed in the UV-VIS spectra. These arise from the exciton interaction through space of strong electric transition moments of the quinolyl chromophores. In each case, the sequence of the signs of the paired Cotton effects (CEs) correlates with the chirality of the initial primary amines from which the ligands were prepared: For example, the ligands with *R* configuration give split CD curves having first positive CE at 241 nm, followed by a negative CE at 231 nm, resulting from a positive exciton coupling. The curves are nonconservative, possibly due to overlap with contributions from chromophore transitions from the pyridine moieties or other quinoline transitions with different orientations.

Table 1. Summary of Circular Dichroism Data for $Zn(L)(ClO_4)_2$ Complexes.¹

		3 ²	5	6	8	7
λ_{max}^1 ($\Delta\epsilon$)	R isomer	241 (204)	241 (74.0)	241 (80.6)	--	3
	S isomer		241 (-68.4)	241 (-86.4)	242 (-26.8)	
λ_{max}^2 ($\Delta\epsilon$)	R isomer	231 (-60.6)	231 (-23.5)	231 (-38.9)	--	3
	S isomer		231 (21.1)	231 (41.4)	231 (11.4)	
A ($\Delta\Delta\epsilon$)	R isomer	+264.6	+97.52	+119.55	--	3
	S isomer		-89.58	-127.87	-38.19	

¹Units: λ in nm, $\Delta\epsilon$ in $L\ mol^{-1}\ cm^{-1}$. ²Reference 1. ³No apparent couplet.

The amplitudes (A values in $\Delta\epsilon$) are listed in Table 1. Surprisingly, none of the CD spectra show amplitudes as large as that of the zinc complex of **3**. This result may be rationalized by consideration of the tight steric environment around the group present on the chiral arm, with the alkyl group being somewhat eclipsed with the pyridine C_3 -H bond (Fig. 2b). In crystallographic structures of complexes related to **1** in the C_3 conformation (including α -substituted ligand complexes), the C_{py3} - C_{py2} - C_{CH2} -H (or C_{py3} - C_{py2} - C_{CHR} - C_α) torsion angle is between 8° and 40° , which is significantly smaller than the 60° angle that would be expected if the C_{py3} - C_{py2} bond bisected the H-C-R angle.⁸ This latter interaction determines the tilt of the heterocyclic ring with respect to the absolute configuration of the chiral arm. We conclude that the nonrigid complex is

sensitive to steric bulk in this environment, and that bulky substituents in the α -position may distort the torsional angles that normally give rise to the propeller twist of the heterocycle rings.

The results obtained with the ligand **7** support this analysis. Although the UV-vis spectrum of the $\text{Zn}(\text{ClO}_4)_2$ complex of **7** is very similar to the other $\text{Zn}(\text{L})$ complexes, the CD spectrum is entirely different from the others, with no bisignate signal. Another clue was found in the chemical shift in the ^1H NMR spectrum corresponding to the pyridyl-6 proton, which in the $\text{Zn}(\mathbf{7})(\text{ClO}_4)_2$ spectrum appears at δ 9.24 (overlap with a quinolyl proton) while the same proton appears downfield at 9.52 in the $\text{Zn}(\text{II})$ complexes of the other ligands. This behavior is consistent with weaker coordination to the electrophilic $\text{Zn}(\text{II})$ ion.

To probe this effect further, the CD spectrum of the $\text{Cu}(\text{SCN})_2$ complex of **7** was measured.³ The result was an ECCD spectrum (R-isomer, $\Delta\epsilon_1$ 239 nm (-139), $\Delta\epsilon_2$ 231 (17.8)) with a sign that is completely reversed from that of the analogous complex of **3** (R-isomer, $\Delta\epsilon_1$ 239 nm (200), $\Delta\epsilon_2$ 229 (-42.9)). The reversal of chirality is due to the inability of the pyridine moiety to coordinate to the copper, which results in rotation of the uncoordinated arm such that the pyridyl points down. The rotation induces conformational changes in the other two arms, affording inversion of the propeller, the chirality of the bisquinoline coupling, and thus the ECCD signal. To further test this hypothesis, the commercially available α -phenethylamine was alkylated with bromomethylquinoline and the CD spectrum was recorded.⁴ A clean ECCD spectrum was observed, with the R-amine giving a negative ECCD couplet.

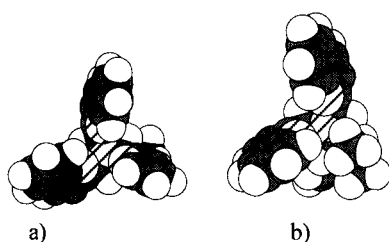


Fig. 7. Space-Filling Model Depictions of Energy-Minimized Structures of Tetradentate (a) and Tridentate (b) Ligand Conformations in $[\text{Zn}(\mathbf{7})\text{Cl}]^+$ (Zn, Cl omitted for clarity).

Thus, the isopropyl substituent in ligand **7** is too bulky to be accommodated in either the anti or syn conformations in complexes with $\text{Cu}(\text{II})$, and the pyridine arm is distorted out of coordination with the metal ion. The resulting tridentate coordination of the metal is well-precedented; for example, $\text{Zn}(\text{II})$ and $\text{Cu}(\text{II})$ complexes of dipicolylamine are well-known.¹⁴ Decoordination of the pyridine then results in a rotation about the tertiary carbon-nitrogen bond to position the isopropyl group away from the steric crowding. This induces bond rotations in the other two arms, inverting the orientation of the two quinoline rings and generating a CD spectrum of opposite sign. Fig. 7 shows space-filling model representations of energy minimized tetradentate and tridentate ligand conformations of $[\text{Zn}(\mathbf{7})\text{Cl}]^+$. The complete structure of the tridentate $\text{Zn}(\mathbf{7})$ and $\text{Cu}(\mathbf{7})$ complexes (i.e., coordination of solvent to the metal or formation of bridged complexes) cannot be ascertained

from the present data, but the ECCD data indicate the orientation of the two quinolines, which is rationalized by the proposed conformational interchange.

CONCLUSIONS

The present results show that the conformational bias argument developed to explain the large chiroptical properties of Zn(II) and Cu(II) complexes of **2** is also valid to explain the behavior of **5**, **6**, and **8**. However, the amplitudes of the ECCD spectra are reduced, probably as a result of steric interactions between the C α -R substituent and the nearly eclipsed pyridyl-C $_3$ -H bond or the protons of the methylene groups on the other two arms. For compound **7**, the large α -substituent distorts the complex, impairing the coordination of the pyridine moiety to the metal ion, resulting in no ECCD spectrum for Zn(**7**)(ClO $_4$) $_2$ or an ECCD spectrum of opposite sign for Cu(**7**)(SCN) $_2$.

EXPERIMENTAL SECTION

General.¹⁵ MALDI-TOF mass spectra were measured with a Kratos MALDI-I spectrometer using the matrix sinapinic acid. ESI-MS experiments were performed with 1% acetic acid/methanol and a Vestec model 200 spectrometer as previously described.¹⁶ Enantiomeric purity of primary amines was determined with a CROWNPAK CR(+)¹⁷ column. Enantiomeric purity of compounds **5** and **6** was determined with a CHIRALPAK AD¹⁷ column.

***N*-(*S*)-(2-hydroxy-1-phenylethyl)-(*R*)-1-phenyl-(2-pyridine)methanamine 11.** To a solution of 5 mL of THF under nitrogen and 3.16 g (15.4 mmol) of 2-iodopyridine was added 15.4 mL of ethyl magnesium bromide (1.0 M solution in THF) dropwise at room temperature. After stirring the green solution for 25 min at room temp, 1.39 g (6.18 mmol) of oxazolidine **10**¹⁸ (prepared from (*R*)-phenyl glycinol) dissolved in 3 mL of THF was added. The solution was heated to reflux for 5 h. After cooling to ambient temp, 20 mL of water was added and the resulting precipitate was removed by filtration. The filtrate was diluted with ether (50 mL), and the layers were separated and dried with MgSO $_4$. The solvent was evaporated and the residue was purified by silica gel chromatography (7 hexanes : 3 EtOAc) to yield 820 mg (44 %) of alcohol **11**. ^1H NMR (200 MHz, CDCl $_3$): δ 8.65 (d, 1 H), 7.65 (t, 1 H), 7.4-7.1 (m, 12 H), 4.9 (m, 1 H), 3.8-3.6 (m, 3H), 3.45 (br s, 2H). ^{13}C NMR (50 MHz, CDCl $_3$): δ 162.5, 149.8, 143.5, 141.3, 137.2, 129.1, 129.0, 128.0, 127.9, 127.7, 123.3, 122.6, 67.7, 65.4, 63.1. MS (ESI-MS, m/e): 304. Anal. Calcd (mass %) for C $_{20}$ H $_{20}$ N $_2$ O•H $_2$ O: C, 74.51; H, 6.88; N, 8.69. Found: C, 74.89; H, 6.87; N, 8.69.

(*S*)-1-Phenyl-(2-pyridine)methanamine 12. Lead tetraacetate (1.65 g, 3.72 mmol) was added to the amino alcohol **11** (0.870 g, 2.86 mmol) dissolved in 18.8 mL of CH $_2$ Cl $_2$ and 9.4 mL of MeOH at 0°C. The reaction mixture was stirred for 40 min at 0°C. The solvent was evaporated in vacuo. The crude residue was then dissolved in 15 mL of ethanol and 15 mL of 3N HCl and stirred for 48 h at ambient temp. The layers were separated and the aqueous phase was made basic by addition of Na $_2$ CO $_3$ and extracted with ether several times. The organic extracts were combined, dried with MgSO $_4$ and evaporated. The crude residue was

chromatographed on silica (7 hexanes : 3 EtOAc followed by methanol), affording the amine in 38% yield (200 mg). The ee was determined to be 81% by HPLC (CROWNPAK CR(+), 50% 0.1 M HClO₄/MeOH). ¹H NMR, ¹³C NMR, and MS spectra were identical to the spectra previously reported for the racemic material.⁸

(S)-N,N-Bis(2-quinolylmethyl)-1-phenyl-(2-pyridine)methanamine 8. Amine **12** (0.1 g, 0.54 mmol) dissolved in 8 mL of water and 2-bromomethylquinoline (0.24 g, 1.09 mmol) and 10 M NaOH (4 equiv) were combined and heated to 70°C for 3 h. Extractive isolation with chloroform including washing with brine and drying over MgSO₄ followed by chromatography on alumina (2 CH₂Cl₂ : 1 EtOAc followed by EtOAc) yielded compound **8** in 42% yield. ¹H NMR (200 MHz, CDCl₃): δ 8.3 (m, 1H), 8.1-7.1 (m, 20H), 5.25 (s, 1H), 4.15 (s, 4H). ¹³C NMR (50.3 MHz, CDCl₃): δ 161.1, 160.8, 149.8, 148.3, 140.7, 136.6, 136.5, 129.8, 129.6, 129.55, 128.7, 127.8, 127.7, 126.4, 124.6, 122.5, 121.6, 71.1, 58.6. UV-vis (AN, nm): λ_{max} = 207 (84024), 228 (69787). High resolution MS (FAB, NBA, m/e) Calcd for C₃₂H₂₇N₄ (M+H): 467.2236. Found: 467.2239.

2-Bromomethylquinoline. 2-Quinolinecarbaldehyde (10.18 g, 64.77 mmol) was dissolved in 125 mL of methanol. To the solution was added 1.23 g (32.4 mmol) of sodium borohydride over a period of 20 min. The quantity 30 mL of 5% HCl aqueous solution was added to the reaction mixture which was then evaporated to ca. 20 mL. Extractive isolation with CH₂Cl₂ gave a yellow powder, 9.74 g (61.26 mmol, 95%), mp 63-64°C. The solid was used without further purification.

The alcohol (9.66 g, 60.75 mmol) was dissolved in 150 mL of benzene. To the solution was added thionyl bromide (11.8 mL, 151.9 mmol) from an addition funnel over 15 min. The solution was heated to 100-110°C for 1 h. The solvent was evaporated and 100 mL of CH₂Cl₂ and 100 mL of water was added to the residue. The solution was basified with potassium carbonate. Extractive isolation and evaporation of the solvent gave a brownish powder (12.1 g, 90%) that gave a ¹H NMR spectrum identical to that obtained with an authentic sample prepared by a literature method.¹⁹

General procedure for 5-8. A solution of (*R*) or (*S*)-amine **13-15** (0.66 mmol), 2-bromomethylquinoline (293 mg, 1.32 mmol) and diisopropylethylamine (257 mg, 1.99 mmol, 2 eq.) in 5 mL of DMF was stirred at 100-110°C for 4 h. The solvent was evaporated and 20 mL of ether and 20 mL of water were added. The ether layer was separated, dried over sodium sulfate, decolorized by charcoal, and evaporated to give a thick brown oil. The crude product was dissolved in CH₂Cl₂ and extracted with 5% HCl. The aqueous layer was washed with CH₂Cl₂, basified with KHCO₃, and extracted with CH₂Cl₂. The organic layer was washed with brine and dried over magnesium sulfate. Removal of solvent gave the pure product.

General procedure for the synthesis of zinc complexes for ¹H NMR studies. To 0.24 mmol of ligand in 0.5 mL of boiling MeOH was added Zn(ClO₄)₂·6H₂O (89.6 mg, 0.24 mmol). The mixture was stirred for 2 min. One eq. of NaCl (aq) (14.3 mg in 0.4 mL of water) was added to the mixture, followed by stirring for 2 min. The solvent was removed, affording a brown solid.

(S)-N,N-Bis(2-quinolylmethyl)-1-(2-pyridine)propanamine 5. 51% yield, 95.0% ee. ¹H-NMR (200 MHz, CDCl₃) δ 8.69 (d, J=4.4 Hz, 1H), 8.10-7.96 (m, 4H), 7.82-7.10 (m, 12H), 4.26 (d, J=14.5 Hz, 2H).

3.83 (d, $J=14.7$ Hz, 2H), 3.71 (dd, $J=13.6, 13.6$ Hz, 2H), 2.27–2.05 (m, 2H), 0.88 (t, $J=8$ Hz, 1H). ^{13}C -NMR (50 MHz, CDCl_3) δ 161.7, 159.4, 149.6, 147.9, 136.6, 136.3, 129.7, 129.5, 127.9, 127.8, 126.5, 125.3, 122.5, 121.6, 67.0, 58.1, 23.9, 12.2. MS (MALDI-TOF, m/e): 419.4. UV-vis (AN, nm): $\lambda_{\text{max}} = 208$ (97288), 228 (86580). Anal. Calcd (mass %) for $\text{C}_{28}\text{H}_{26}\text{N}_4 \cdot 1.5\text{H}_2\text{O}$: C, 75.48; H, 6.56; N, 12.57. Found: C, 75.39; H, 6.20; N, 12.43. Complex with $\text{Zn}(\text{ClO}_4)_2$: ^1H -NMR (200 MHz, CDCl_3): δ 9.64 (d, $J=9.1$, 1H), 9.52–9.50 (m, 1H), 9.24 (d, $J=8.4$, 1H), 8.43–8.38 (m, 2H), 8.10–7.50 (m, 11H), 4.85 (d, $J=18.3$, 1H), 4.80 (d, $J=17.6$, 1H), 4.68–4.57 (m, 1H), 4.47 (d, $J=18.3$, 1H), 4.45 (d, $J=17.6$, 1H), 2.40–2.12 (m, 2H), 0.93 (t, $J=7.2$, 3H).

(R)-N,N-Bis(2-quinolylmethyl)-1-(2-pyridine)propanamine 5. 30% yield, 97.2% ee. Anal. Calcd (mass %) for $\text{C}_{28}\text{H}_{26}\text{N}_4$: C, 80.35; H, 6.26; N, 13.39. Found: C, 80.59; H, 6.33; N, 13.38.

(S)-N,N-Bis(2-quinolylmethyl)-1-(phenylmethyl)-(2-pyridine)methanamine 6. Yellow solid. 48% yield, 99.2% ee, mp 62–64°C. ^1H -NMR (200 MHz, CDCl_3) δ 8.69 (d, $J=4.4$ Hz, 1H), 8.10–7.96 (m, 4H), 7.82–6.95 (m, 16H), 4.31 (d, $J=14.7$ Hz, 2H), 4.13 (dd, $J=13.6, 13.6$ Hz, 2H), 3.83 (d, $J=14.7$ Hz, 2H), 3.59 (dd, $J=13.6, 7.5$ Hz, 1H), 3.38 (dd, $J=13.6, 7.5$ Hz, 1H). ^{13}C -NMR (50 MHz, CDCl_3) δ 161.3, 158.5, 149.6, 147.9, 140.4, 136.6, 136.4, 130.2, 129.7, 129.4, 128.5, 127.9, 127.6, 126.5, 126.3, 125.5, 122.7, 121.5, 66.2, 57.8, 36.9. MS (MALDI-TOF, m/e): 480.9. UV-vis (AN, nm): $\lambda_{\text{max}} = 208$ (86852), 228 (75070). Anal. Calcd (mass %) for $\text{C}_{33}\text{H}_{28}\text{N}_4$: C, 82.47; H, 5.87; N, 11.66. Found: C, 82.23; H, 6.01; N, 11.73. Complex with $\text{Zn}(\text{ClO}_4)_2$ (53% yield): ^1H -NMR (200 MHz, CDCl_3) δ 9.71 (d, $J=8.5$ Hz, 1H), 9.52 (d, $J=8.1$ Hz, 1H), 9.27 (d, $J=9.2$ Hz, 1H), 8.42 (d, $J=8.4$ Hz, 2H), 8.10–7.40 (m, 10H), 7.16–7.08 (m, 3H), 7.05–6.85 (m, 3H), 5.17 (d, $J=18.3$ Hz, 1H), 4.88 (d, $J=17.7$ Hz, 1H), 4.83 (dd, $J=11, 3.4$ Hz, 1H), 4.58 (d, $J=18.3$ Hz, 1H), 4.37 (d, $J=17.7$ Hz, 1H), 3.65 (dd, $J=12, 3.4$ Hz, 1H), 2.54 (dd, $J=12, 11$ Hz, 1H).

(R)-N,N-Bis(2-quinolylmethyl)-1-(phenylmethyl)-(2-pyridine)methanamine 6. 39% yield, 97.9% ee. Anal. Calcd (mass %) for $\text{C}_{33}\text{H}_{28}\text{N}_4 \cdot \text{H}_2\text{O}$: C, 79.49; H, 6.06; N, 11.24. Found: C, 79.10; H, 5.69; N, 11.09.

(S)-N,N-Bis(2-quinolylmethyl)-1-(2-pyridyl)-2-methylpropanamine 7. Yellow solid, 15% yield, 96.0% ee, mp 125–127°C. ^1H -NMR (200 MHz, CDCl_3) δ 8.71 (d, $J=4.04$ Hz, 1H), 8.20–8.00 (m, 4H), 7.89–7.60 (m, 7H), 7.57–7.45 (m, 2H), 7.33–7.16 (m, 2H), 4.31 (d, $J=14.60$ Hz, 2H), 3.63 (d, $J=14.6$ Hz, 2H), 3.24 (d, $J=10.66$ Hz, 1H), 2.89–2.68 (m, 1H), 1.28 (d, $J=6.44$ Hz, 3H), 0.59 (d, $J=6.44$ Hz, 3H). ^{13}C -NMR (50 MHz, CDCl_3) δ 161.1, 157.7, 149.9, 148.0, 136.6, 136.2, 129.7, 129.5, 127.9, 127.8, 126.5, 126.2, 122.4, 121.7, 71.7, 57.9, 28.6, 21.4, 21.3. MS (MALDI-TOF, m/e): 432.6. UV-vis (AN, nm): $\lambda_{\text{max}} = 208$ (85106), 228 (76607). Anal. Calcd (mass %) for $\text{C}_{29}\text{H}_{28}\text{N}_4$: C, 80.52; H, 6.52; N, 12.96. Found: C, 80.65; H, 6.64; N, 13.01. Complex with $\text{Zn}(\text{ClO}_4)_2$ (79% yield). ^1H -NMR (200 MHz, CDCl_3) δ 9.76 (d, $J=8.80$ Hz, 1H), 9.26–9.22 (m, 2H), 8.37 (d, 8.68 Hz, 1H), 8.27 (d, 8.52 Hz, 1H), 8.05–7.80 (m, 5H), 7.70–7.40 (m, 6H), 5.16 (d, $J=18.0$ Hz, 1H), 4.97 (d, $J=18.0$ Hz, 1H), 4.82 (d, $J=2.32$ Hz, 1H), 4.50 (d, $J=18.0$ Hz, 1H), 4.38 (d, $J=18.0$ Hz, 1H), 2.61–2.40 (m, 1H), 1.12 (d, $J=6.76$ Hz, 3H), 0.40 (d, $J=6.76$ Hz, 3H).

(*R*)-*N,N*-Bis(2-quinolylmethyl)-1-(2-pyridyl)-2-methylpropanamine **7**. 13% yield, 96.6% ee. Anal. Calcd (mass %) for C₂₉H₂₈N₄: C, 80.52; H, 6.52; N, 12.95. Found: C, 80.31; H, 6.36; N, 12.71.

Spectroscopic studies: UV-VIS spectra of the compounds were acquired with 10 μM solution in acetonitrile on a Perkin Elmer Lambda 5 spectrophotometer. CD spectra were obtained with 0.3 mM solution in acetonitrile on an Aviv 62DS spectrometer. The zinc complexes were generated by adding 1.1 eq. of zinc perchlorate in acetonitrile to the free ligands in acetonitrile solution. Previous work demonstrated that spectra obtained in this way were identical to those obtained from preformed, fully characterized zinc complexes.⁵ All ligands and complexes used to measure the spectra shown in Fig. 6 were >95% ee except for **8** which was 81% ee.

Acknowledgment. We thank the National Institutes of Health (GM 49170) for support of this research. We are grateful to Jesus Castagnetto for help with calculations. EI, FAB, and high-resolution mass spectra were obtained at the Michigan State University Mass Spectrometry Facility (supported in part by grant DRR-00480, from the Biotechnology Research Technology Program, NCRS, NIH). We are grateful to Professor Nina Berova for helpful discussions. We thank Chiral Technologies, Inc. for determination of the enantiomeric purity of **5** and **6**.

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