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Supporting Information

Asymmetric cyclopropanation of 2,5-dimethyl-2,4-hexadiene by copper catalysts bearing new bisoxazoline ligands

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I. General Information.

Unless otherwise noted, all reactions were carried out under a nitrogen atmosphere.

MeOH (anhydrous), CH₂Cl₂ (anhydrous), THF (anhydrous), and xylene (anhydrous) as the solvents were dehydrated by molecular sieves 4A before use. The bisoxazoline compounds **5**, **7**, **8**, **9**, and **10** are commercially available. The bisoxazoline compound **6**

was prepared from *L*-valinol by adaptation of a procedure for **5**.^{1a,b} The compound **11a** was prepared based on Corey's method.² Optical rotations were measured on a JASCO DIP-370. Melting points were measured with a METTLER TOLEDO TYPE FP62. The absolute configurations of enantiomerically pure bisoxazolines **11b-d** were determined by the absolute configurations of major enantiomers of the *trans* products in the copper-bisoxazoline catalyzed cyclopropanation, based on the results that the ligand **8** with the (*S*)-configuration at the 4-position on the oxazoline ring predominantly provided the (*1S,3S*)-isomer of *trans* chrysanthemate, and that with the (*R*)-configuration provided the (*1R,3R*)-isomer.

1. a) Evans, D. A.; Peterson, G. S.; Johnson, J. S.; Barnes, D.M.; Campos, K. R.; Woerpel, K. A. *J. Org. Chem.* **1998**, 63, 4541
b) Østergaard, N.; Jensen, J. F.; Tanner, D. *Tetrahedron* **2001**, 57, 6083.
2. Corey, E. J.; Ishihara, K. *J. Am. Chem Soc.* **1994**, 113, 728.

II. General Procedure for Preparation of Bisoxazolines 11b, 11c, and 11d:

1. Preparation of diketoimidazolidine derivatives

1-1. 5-(2-Methoxyphenyl)-imidazolidine-2,4-dione (13b):

A solution of KCN (60 g, 921 mmol) in H₂O (500 mL) was added dropwise to a

solution of 2-methoxybenzaldehyde (100g, 734 mmol), and $(\text{NH}_4)_2\text{CO}_3$ (190g, 1.98 mol) in H_2O (320 mL) and EtOH (800 mL) over 30 min at 50 °C. The reaction mixture was warmed to 60 °C and stirred for 5 h at that temperature. Ethanol was removed at atmospheric pressure, and the residue was cooled to 20 °C. The reaction mixture was acidified by 35% aqueous HCl (pH = 1) and cooled to 0 °C to begin to precipitate as the product. The solids were filtered and washed with cold water (200 mL), followed by ether (400 mL) to yield diketoimidazolidine derivative **13b** (110.3 g, 72%) as a pale gray powder which was used in the next step without further purification: ^1H NMR (300MHz, CF_3COOD); δ 7.51-7.46 (m, 1H), 7.35-7.26 (m, 1H), 7.10 –6.99 (m, 2H), 5.53 (s, 1H), 3.90 (s, 3H).

1-2. 5-(1-Naphthyl)-imidazolidine-2,4-dione (13c):

The title compound was prepared by the same procedure as that for **13b**. Yield 95%, a pale gray powder which was used in the next step without further purification; ^1H NMR (300MHz, CF_3COOD) δ 7.98-7.92 (m, 3H), 7.66-7.64 (m, 3H), 7.61-7.56 (m, 2H), 6.22 (s, 1H).

1-3. 5-(2-Naphthyl)-imidazolidine-2,4-dione (13d):

The title compound was prepared by the same procedure as that for **13b**. Yield 84%, a pale gray powder which was used in the next step without further purification; ^1H NMR

(300MHz, CF₃COOD) δ 7.93-7.85 (m, 5H), 7.57-7.49 (m, 3H), 7.26-7.24 (m, 1H), 5.49 (s, 1H).

2. Preparation of Arylglycines 14b-d

2-1. 2-Methoxyphenylglycine (14b):

Diketoimidazolidine derivative **13b** (109 g, 0.530 mol) was added to a solution of KOH (123 g, 2.19 mol) in H₂O (435 mL) in one portion, and the reaction mixture was refluxed for 60 h. After the reaction mixture was cooled to 0 °C, 35% aqueous HCl was slowly added dropwise to the solution to reach pH 7. The precipitate was filtered and washed with cold water (150 mL), followed by ether (150 mL) to yield 2-methoxyphenylglycine **14b** (73.1 g, 55%) as a pale gray powder which was used in the next step without further purification: ¹H NMR (300MHz, CF₃COOD); δ 7.59 (t, *J* = 7.5 Hz, 1H), 7.42 (d, *J* = 7.5 Hz, 1H), 7.16 –7.07 (m, 2H), 5.41 (s, 1H), 3.97 (s, 3H).

2-2. 1-Naphthylglycine (14c):

The title compound was prepared by the same procedure as that for **14b**. Yield 99%, a pale gray powder which was used in the next step without further purification: ¹H NMR (300MHz, CF₃COOD); δ 8.38-7.89 (m, 3H), 7.74-7.48 (m, 4H), 6.27 (s, 1H).

2-3. 2-Naphthylglycine (14d):

The title compound was prepared by the same procedure as that for **14b**. Yield 87%, a pale yellow powder which was used in the next step without further purification: ^1H NMR (300MHz, CF_3COOD); δ 8.02-7.99 (m, 2H), 7.93-7.87 (m, 2H), 7.66-7.59 (m, 2H), 7.52-7.48 (m, 1H), 5.61 (s, 1H).

3. Preparation of Arylglycine methyl ester hydrochlorides 15b-d

3-1. 2-Methoxyphenylglycine methyl ester hydrochloride (15b):

Thionyl chloride (27.4 g, 0.230 mol) was added dropwise to a solution of 2-methoxyphenylglycine (22.3 g, 0.123 mol) in MeOH (anhydrous, 100 mL) over 1 h at 30 °C. After the reaction mixture was stirred at 35 °C for 3 h, the solution was evaporated under reduced pressure to yield a white solid. The resulting solid was triturated with ether (100 mL), followed by filtration and washing with ether. The white powder was dried in vacuo at 50 °C to yield 2-methoxyphenylglycine methyl ester hydrochloride **15b** (21.5 g, 75 %) as a white powder which was used in the next step without further purification: ^1H NMR (300MHz, CD_3OD); δ 7.48-7.36 (m, 2H), 7.13-7.01 (m, 2H), 5.25 (s, 1H), 3.90 (s, 3H), 3.78(s, 3H).

3-2. 1-Naphthylglycine methyl ester hydrochloride (15c):

The title compound was prepared by the same procedure as that for **15b**. Yield 98%, a pale yellow powder which was used in the next step without further purification: ^1H NMR

(300MHz, CD₃OD); δ 8.23 (d, J = 9.0 Hz, 1H), 8.01 (d, J = 9.0 Hz, 2H), 7.69-7.58 (m, 3H), 6.06 (s, 1H), 3.78 (s, 3H).

3-3. 2-Naphthylglycine methyl ester hydrochloride (15d):

The title compound was prepared by the same procedure as that for **15b**. Yield 94%, a white powder which was used in the next step without further purification: ¹H NMR (300MHz, CD₃OD); δ 8.03-7.91 (m, 4H), 7.61-7.52 (m, 3H), 5.40 (s, 1H), 3.82 (s, 3H).

4. Preparation of *N*-trifluoroacetyl arylglycine methyl esters 16b-d

4-1. *N*-Trifluoroacetyl 2-methoxyphenylglycine methyl ester (16b):

This compound was prepared by an adaptation of Corey's method.³ A dry 3-L three-necked round-bottom flask equipped with a mechanical stirrer and a 200-mL addition funnel was charged with methyl ester hydrochloride of 2-methoxyphenylglycine (21.47 g, 92.7 mmol) and 134 mL of CH₂Cl₂ (anhydrous). The solution was stirred while Et₃N (19.69 g, 195 mmol) was added in one portion. The solution was cooled to -50 °C and trifluoroacetic acid anhydride (21.41 g, 102 mmol) was added dropwise to the reaction mixture through the addition funnel over 1 h. The solution was stirred at -50 °C for 1 h and then was allowed to warm to 0 °C. 100 ml of 1.5 % aqueous HCl was added to the solution in one portion, and the aqueous layer was separated by an extraction. The

organic extracts were washed by 100 mL of H₂O, dried over Na₂SO₄, filtered, and concentrated in vacuo to give a pale yellow solid. The solid was dissolved in ethyl acetate, and the resulting solution was purified by column chromatography (SiO₂, AcOEt/hexane = 1/1) to yield 21g of a white solid. The solid was recrystallized from CH₂Cl₂/hexane to yield 17.6g of a white crystalline solid (yield 65%); mp 89.0-89.8 °C; ¹H NMR (300 MHz, CDCl₃) δ 7.51 (d, *J* = 6.0 Hz, 1H), 7.40-7.34 (m, 2H), 7.02-6.92 (m, 2H), 5.69 (d, *J* = 6.0 Hz, 1H), 3.86 (s, 3H), 3.73 (s, 3H); ¹³CNMR (75 MHz, CDCl₃) δ 169.8, 156.9, 156.7, 156.2, 130.8, 130.6, 123.4, 121.3, 117.6, 111.3, 55.6, 53.8, 53.0.

3) Corey, E. J.; Ishihara, K. *J. Am. Chem Soc.* **1994**, *113*, 728.

4-2. *N*-Trifluoroacetyl 1-naphthylglycine methyl ester (16c):

The title compound was prepared by the same procedure as that for **16b**. Yield 67 %, a white crystalline solid: mp 183-184 °C; ¹H NMR (300 MHz, CDCl₃) δ 8.1 (d, *J* = 8.4 Hz, 1H), 7.93-7.89 (m, 2H), 7.64-7.59 (m, 2H), 7.64-7.59 (m, 2H), 7.64-7.59 (m, 2H), 7.56-7.55 (m, 2H), 7.48-7.46 (m, 1H), 6.31 (d, *J* = 8.0Hz, 1H), 3.76 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 170.4, 156.8, 134.1, 130.7, 130.5, 130.2, 129.2, 127.5, 126.4, 126.0, 125.3, 122.5, 113.7, 53.7, 53.3.

4-3. *N*-Trifluoroacetyl 2-naphthylglycine methyl ester (16d):

The title compound was prepared by the same procedure as that for **16b**. Yield 76 %, a

crystalline solid: mp 96.6-97.5 °C; ¹H NMR (300 MHz, CDCl₃) δ 7.88-7.81 (m, 4H), 7.55-7.50 (m, 3H), 7.43 (d, J = 7.5 Hz, 1H), 5.72 (d, J = 6.0Hz, 1H), 3.77 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 170.0, 133.4, 133.2, 131.9, 129.4, 128.1, 127.8, 127.0, 126.9, 126.8, 124.1, 56.7, 53.4.

5. Preparation of 2-amino-2-aryl-1,1-dimethylethanols 17b-d

5-1. 2-Amino-2-(2-methoxyphenyl)-1,1-dimethylethanol (17b):

A solution of *N*-trifluoroacetyl 2-methoxyphenylglycine methyl ester (17.45 g, 59.9 mmol) in THF (anhydrous, 200 mL) was added dropwise to a Grignard solution of methyl magnesium bromide (3 mol/L, 100 mL, 300 mmol) over 30 min at 5 °C. The mixture was allowed to warm to 20 °C, stirred for 2 h at the same temperature, and then added dropwise to 2 % aqueous HCl (300 ml) at 0 °C over 15 min. After toluene (200 mL) was added to the mixture, the aqueous phase was separated and back-extracted with toluene (200 mL). The combined organic extracts were washed with 200 mL of brine, dried over Na₂SO₄, filtered through celite, and concentrated in vacuo to give a pale yellow oil as a crude *N*-trifluoroacetyl-2-amino-2-(2-methoxyphenyl)-1,1-dimethylethanol (18.7 g, quant): ¹H NMR (CDCl₃) δ 7.75 (br, 1H), 7.31-7.18 (m, 2H), 7.01-6.94 (m, 2H), 5.17 (d, J = 9.0 Hz, 1H), 3.89 (s, 3H), 2.30 (brs, 1H), 1.32 (s, 3H), 1.09 (s, 3H). The crude

product (18.7 g, 64.1 mmol) was subsequently added to a solution of KOH (8.88 g, 135 mmol) in 20 mL of H₂O and 200 mL of methanol in one portion. The reaction mixture was stirred at 50 °C for 2 h and then concentrated in vacuo. The pale yellow oil product was dissolved in CHCl₃ (300 mL) and partitioned with water (100 mL). The organic phase was dried over Na₂SO₄, filtered, and concentrated under reduced pressure to give 11.3 g of a pale yellow oil of a crude product **17b** which was used in the next step without further purification (Yield 97%): ¹H NMR (300 MHz, CDCl₃) δ 7.36 (d, J = 9.0 Hz, 1H), 7.27-7.20 (m, 1H), 6.98-6.92 (m, 1H), 6.88 (d, J = 9.0 Hz, 1H), 4.25 (s, 1H), 3.82 (s, 3H), 1.80-2.0 (brs, 3H), 1.22 (s, 3H), 1.05 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 156.8, 131.0, 128.4, 127.9, 120.5, 110.5, 72.6, 57.4, 55.2, 27.2, 25.2.

5-2. 2-Amino-2-(1-naphthyl)-1,1-dimethylethanol (17c):

The title compound was prepared by the same procedure as that for **17b**. Yield 69%, a pale yellow solid which was used in the next step without further purification: ¹H NMR (300 MHz, CDCl₃) δ 8.18 (d, J = 9.0 Hz, 1H), 7.88-7.84 (m, 1H), 7.79-7.71 (m, 2H), 7.54-7.45 (m, 3H), 4.83 (s, 1H), 4.25 (s, 1H), 3.82 (s, 3H), 1.89-1.72 (brs, 3H), 1.29 (s, 3H), 1.07 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 138.8, 133.2, 131.6, 128.5, 127.2, 125.5, 124.9, 124.2, 123.0, 72.5, 56.4, 27.7, 25.1.

¹H NMR (300 MHz, CDCl₃) of

N-trifluoroacetyl-2-amino-2-(1-naphthyl)-1,1-dimethylethanol (a pale yellow oil) as the intermediate of **17c**: δ 8.18 (d, J = 9.0 Hz, 1H), 7.89-7.81 (m, 2H), 7.57-7.43 (m, 4H), 5.83 (d, J = 9.0 Hz, 1H), 1.82 (brs, 1H), 1.47 (s, 3H), 0.98 (s, 3H).

5-3. 2-Amino-2-(2-naphthyl)-1,1-dimethylethanol (17d):

The title compound was prepared by the same procedure as that for **17b**. Yield 97%, a pale yellow solid which was used in the next step without further purification: ^1H NMR (300 MHz, CDCl_3) δ 7.83-7.76 (m, 4H), 7.50-7.44 (m, 3H), 3.97(s, 1H), 2.13 (brs, 3H), 1.26 (s, 3H), 1.09 (s, 3H); ^{13}C NMR (75 MHz, CDCl_3) δ 140.1, 133.1, 132.8, 127.8, 127.6, 126.6, 126.1, 125.7, 72.4, 64.6, 27.7, 25.0.

^1H NMR (300 MHz, CDCl_3) of *N*-trifluoroacetyl-2-amino-2-(2-naphthyl)-1,1-dimethylethanol (a pale yellow solid) as the intermediate of **17d**: δ 7.85-7.82 (m, 3H), 7.76-7.75 (m, 1H), 7.51-7.44 (m, 4H), 4.95 (d, J = 9.0 Hz, 1H), 1.67 (brs, 1H), 1.42 (s, 3H), 1.09 (s, 3H).

6. Optical resolution of 2-amino-2-aryl-1,1-dimethylethanols 17b-d for (*R*)-2-amino-2-aryl-1,1-dimethylethanols [(*R*)-17b-d]

6-1. (*R*)- 2-Amino-2-(2-methoxyphenyl)-1,1-dimethylethanol [(*R*)-17b]:

To a solution of racemic 2-amino-2-(2-methoxyphenyl)-1,1-dimethylethanol (11.3 g, 57.9

mmol) in 150 mL of *i*PrOH was added a solution of (2*R*,3*R*)-tartranilic acid (5.22 g, 23.2 mmol, purchased from TCI) in 200 mL of *i*PrOH at room temperature, and the mixture was then warmed to 80 °C to dissolve the mixture in *i*PrOH completely. After cooling the reaction mixture to room temperature, a precipitate was formed, which was collected by filtration, washed with cold *i*PrOH and dried in vacuo. The resulting white solid was recrystallized from 35 mL of H₂O and 300 mL of *i*PrOH to give a salt (2*R*,3*R*)-tartranilic acid / optically active amino alcohol (***R***)-**17b** as a white crystalline solid. mp 197.5-197.9 °C, Anal. Calcd. for C₂₁H₂₈N₂O₇: C, 59.99; H, 6.71; N, 6.66. Found: C, 59.9; H, 6.6; N, 6.6. To the resulting salt was added 1N NaOH (30 mL), H₂O (120 mL), and CHCl₃ (300 mL). The organic layers were separated, washed with H₂O, dried over Na₂SO₄, filtered through cotton, and concentrated in vacuo to give a white solid, which was recrystallized from CH₂Cl₂/hexane to give 2.71 g (27 % from the racemic amino alcohol) of (*R*)-amino alcohol (***R***)-**17b** as a white crystalline solid : 99.7 %ee (determined by chiral HPLC; Sumichiral OA-8000 (15cm x 4.6mm), hexane/EtOH/CF₃COOH = 85/15/0.1, 0.5 mL/min, 254 nm; [α]_D= -30.6 (c = 0.50, MeOH); mp 50.0-51.0 °C; δ 7.35 (d, J = 9.0 Hz, 1H), 7.33-7.20 (m, 1H), 6.97-6.95 (m, 1H), 6.88 (d, J = 9.0 Hz, 1H), 4.25 (s, 1H), 3.82 (s, 3H), 1.83 (brs, 3H), 1.22 (s, 3H), 1.05 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 156.8, 131.0, 128.4, 127.9, 120.5, 110.5, 72.6, 57.4, 55.1, 27.2, 25.2; Anal. Calcd. for C₁₁H₁₇NO₂: C,

67.66; H, 8.78; N, 7.17. Found: C, 67.5; H, 8.7; N, 7.1.

6-2. (*R*)- 2-Amino-2-(1-naphthyl)-1,1-dimethylethanol [(*R*)-17c]:

To a solution containing racemic 2-amino-2-(1-naphthyl)-1,1-dimethylethanol (27.5 g, 108 mmol) and 410 mL of *i*PrOH was added a solution of *N*-formyl-(*R*)-phenylalanine (8.44 g, 43.7 mmol) and 410 mL of *i*PrOH at room temperature, and the mixture was then warmed to 60 °C to dissolve the mixture in *i*PrOH completely. After cooling the reaction mixture to room temperature, a precipitate was formed, which was collected by filtration, washed with cold *i*PrOH and dried in vacuo. The resulting white solid was recrystallized from 40 mL of H₂O and 750 mL of *i*PrOH to give a salt of *N*-formyl-(*R*)-phenylalanine / optically active amino alcohol (**(*R*)-17c**) as a white crystalline solid. mp 186-188 °C, Anal. Calcd. for C₂₄H₂₈N₂O₄: C, 70.56; H, 6.91; N, 6.86. Found: C, 69.8; H, 7.0; N, 6.7. To the resulting salt was added 1N NaOH (60mL), H₂O (80mL), and CHCl₃ (300mL). The organic layers were separated, washed with H₂O, dried over Na₂SO₄, filtered through cotton, and concentrated in vacuo to give 6.6 g (24% from the racemic amino alcohol) of (*R*)-amino alcohol (**(*R*)-17c**) as a white powder: 99.7 %ee (determined by chiral HPLC; Sumichiral OA-8000 (15cm x 4.6mm), H₂O/MeCN/MeOH=1/0.02/0.01 (containing HClO₄ to be pH = 1.5) 1.0 mL/min, 254 nm; [α]_D²⁰ = -60.4 (c = 0.51, MeOH); mp 86.0-87.0 °C; ¹H NMR (300 MHz, CDCl₃) δ 8.18 (d, J = 9.0 Hz, 1H), 7.87-7.84 (m, 1H), 7.79-7.71 (m, 2H),

7.54-7.46 (m, 3H), 4.83 (s, 1H), 4.25 (s, 1H), 3.82 (s, 3H), 1.89-1.72 (brs, 3H), 1.29 (s, 3H), 1.07 (s, 3H); ^{13}C NMR (75 MHz, CDCl_3) δ 139.2, 133.6, 132.0, 128.9, 127.6, 125.9, 125.3, 125.2, 124.6, 123.4, 72.9, 56.8, 28.1, 25.5; Anal. Calcd. for $\text{C}_{14}\text{H}_{17}\text{NO}$: C, 78.10; H, 7.96; N, 6.51. Found: C, 77.8; H, 7.9; N, 6.4.

6-3. (*R*)- 2-Amino-2-(2-naphthyl)-1,1-dimethylethanol [(*R*)-17d]:

To a solution containing racemic 2-amino-2-(2-naphthyl)-1,1-dimethylethanol (24.0 g, 112 mmol) and 410 mL of *i*PrOH was added a solution of *N*-formyl-(*R*)-phenylalanine (8.29 g, 42.9 mmol) and 410 mL of *i*PrOH at room temperature, and the mixture was then warmed to 40 °C to dissolve the mixture in *i*PrOH completely. After cooling the reaction mixture to room temperature, a precipitate was formed, which was collected by filtration, washed with cold *i*PrOH and dried in vacuo. The resulting white solid was recrystallized from 45 mL of H_2O and 750 mL of *i*PrOH to give a salt of *N*-formyl-(*R*)-phenylalanine / optically active amino alcohol (***R***)-17d as a white crystalline solid. mp 193-195 °C, Anal. Calcd. for $\text{C}_{24}\text{H}_{28}\text{N}_2\text{O}_4$: C, 70.56; H, 6.91; N, 6.86. Found: C, 70.4; H, 6.9; N, 6.8. To the resulting salt was added 1N NaOH (35 mL), H_2O (100 mL), and CHCl_3 (300mL). The organic layers were separated, washed with water, dried over Na_2SO_4 , filtered through cotton, and concentrated in vacuo to give 6.2 g (26% from the racemic amino alcohol) of (*R*)-amino alcohol (***R***)-17d as a white powder: 99.8 %ee (determined by chiral HPLC;

Chiralcel OD-H (25cm x 4.6mm), (0.1% Et₂NH in hexane) / (0.1% Et₂NH in ⁱPrOH) = 80 / 20 0.5 mL/min, 254 nm; [α]_D = -14.1 (c = 0.51, MeOH); mp 77.0-78.0 °C; ¹H NMR (300 MHz, CDCl₃) δ 7.83-7.76 (m, 4H), 7.50-7.44 (m, 3H), 3.97 (s, 1H), 1.81 (brs, 2H), 1.26 (s, 3H), 1.09 (s, 3H); ¹³C NMR (75MHz, CDCl₃) δ 139.7, 132.6, 132.3, 127.4, 127.1, 126.1, 125.6, 125.3, 72.0, 64.2, 27.3, 24.6. Anal. Calcd. for C₁₄H₁₇NO: C, 78.10; H, 7.96; N, 6.51. Found: C, 78.0; H, 8.0; N, 6.4.

7. Preparation of bisamide alcohols (18b-d)

7-1.(*R,R*)-N,N'-Bis[2-hydroxy-2-methyl-1-(2-methoxyphenyl)propyl]-2,2-dimethyl-

1,3-propanediamide (18b):

A solution of amino alcohol (*R*)-**17b** (1.50 g, 7.53 mmol) and Et₃N (1.25 mL, 8.96 mmol) in CH₂Cl₂ (anhydrous, 13 mL) was cooled to -10 °C. 2,2-Dimethylmalonyl chloride (0.65 g, 3.77 mmol, purchased from Aldrich) was then added dropwise over 3 min. The reaction mixture was allowed to warm to 20 °C and stirred for 6h. Subsequently, aqueous HCl (1N, 15 mL) was added in one portion. The organic phase was separated, washed with aqueous NaHCO₃ (5%, 20mL), washed with H₂O (5 mL), dried over Na₂SO₄, and concentrated under reduced pressure to give a white solid **18b** which was used in the next step without further purification (1.85 g, quant). Mp 171.0-171.7 °C; ¹H NMR (300

MHz, CD₃OD) δ 7.22-7.10 (m, 4H), 6.92 (d, J = 9.0 Hz, 2H), 6.82 (t, J = 9.0 Hz, 2H), 5.23 (s, 2H), 4.91 (s, 4H), 3.79 (s, 6H), 1.44 (s, 6H), 1.23 (s, 6H), 1.02 (s, 6H); ¹³C NMR (75MHz, CD₃OD) δ 174.9, 159.0, 130.8, 129.9, 129.0, 121.9, 112.3, 74.0, 57.9, 56.3, 51.3, 28.6, 27.2, 24.5. HRMS-EI (m/z): [MH⁺] calcd. for C₂₇H₃₈N₂O₆, 487.2802; found, 487.2824.

7-2. (*R,R*)-N,N'-Bis[2-hydroxy-2-methyl-1-(1-naphthyl)propyl]-2,2-dimethyl-1,3-propanediamide (18c):

The title compound was prepared by the same procedure as that for **18b**. Yield: quant, a white solid which was used in the next step without further purification. ¹H NMR (300 MHz, CD₃OD) δ 8.29 (d, J = 9.0 Hz, 2H), 7.85 (d, J = 9.0 Hz, 2H), 7.70 (d, J = 9.0 Hz, 2H), 7.52-7.45 (m, 4H), 7.34 (m, 2H), 7.13 (t, J = 9.0 Hz, 2H), 5.77 (s, 2H), 4.85 (s, 4H), 1.46 (s, 6H), 1.36 (s, 6H), 0.90 (s, 6H); ¹³C NMR (75MHz, CD₃OD) δ 175.1, 137.9, 135.4, 134.0, 130.2, 129.1, 127.4, 126.8, 126.7, 125.2, 73.8, 57.1, 51.2, 29.3, 27.9, 24.5. HRMS-EI (m/z): [MH⁺] calcd. for C₃₃H₃₈N₂O₄, 527.2904; found, 527.2926.

7-3. (*R,R*)-N,N'-Bis[2-hydroxy-2-methyl-1-(2-naphthyl)propyl]-2,2-dimethyl-1,3-propanediamide (18d):

The title compound was prepared by the same procedure as that for **18b**. Yield: quant, a

white solid which was used in the next step without further purification. ^1H NMR (300 MHz, CD_3OD) δ 7.70-7.66 (m, 6H), 7.45-7.26 (m, 8H), 4.87 (s, 2H), 4.86 (s, 4H), 1.50 (s, 6H), 1.30 (s, 6H), 1.01 (s, 6H); ^{13}C NMR (75MHz, CD_3OD) δ 175.2, 138.7, 134.8, 134.6, 129.3, 129.0, 128.9, 128.8, 127.6, 127.4, 127.1, 73.2, 63.8, 51.4, 28.9, 28.1, 24.6. HRMS-EI (m/z): $[\text{MH}^+]$ calcd. for $\text{C}_{33}\text{H}_{38}\text{N}_2\text{O}_4$, 527.2904; found, 527.2905.

8. Preparation of bisoxazoline compounds (11b-d)

8-1. 2,2-Bis{2-[(4*R*)-(2-methoxyphenyl)-5,5-dimethyloxazolinyl]}propane (11b):

Bisamide alcohol **18b** (1.74 g, 3.58 mmol) and xylene (anhydrous, 100 mL) were charged into a Schlenk tube, and the reaction mixture was heated to reflux to dissolve the alcohol completely. $\text{Ti}(\text{O}^i\text{Pr})_4$ (106 mg, 0.358 mmol) was then added to the solution in one portion, and the reaction mixture was refluxed for 48h with removal of the water by-product. After the reaction mixture was cooled to 20 $^\circ\text{C}$, the solution was concentrated under reduced pressure. The resulting pale yellow oil was purified by column chromatography (neutral alumina, hexane : AcOEt = 10 : 1 to 2:1) to give a white solid, which appeared pure by ^1H NMR. The solid was recrystallized from CH_2Cl_2 /hexane to give a white powder (1.42 g, 88%). Mp 78.0-79.0 $^\circ\text{C}$; $[\alpha]_{\text{D}} = +16.0$ ($c = 0.12$, CHCl_3); ^1H NMR (300 MHz, CDCl_3) δ 7.28-7.18 (m, 4H), 6.90 (t, $J = 9.0$ Hz, 2H), 6.82 (d, $J = 9.0$ Hz, 2H), 5.26 (s, 2H), 3.81 (s, 6H), 1.68 (s, 6H), 1.59 (s, 6H), 0.85 (s, 6H); ^{13}C NMR

(75MHz, CDCl₃) δ 168.9, 156.7, 128.2, 128.0, 126.0, 120.4, 109.7, 87.4, 71.4, 55.2, 38.8, 28.7, 24.0, 23.2. HRMS-EI (m/z): [MH⁺] calcd. for C₂₇H₃₄N₂O₄, 451.2591; found, 451.2600.

8-2. 2,2-Bis{2-[(4*R*)-(1-naphthyl)-5,5-dimethyloxazoliny]}propane (11c):

The title compound was prepared by the same procedure as that for **11b**. Yield: 83 %, a white crystalline solid; Mp 61.5-63.0 °C; $[\alpha]_D = -187$ (c = 0.10, CHCl₃); ¹H NMR (300 MHz, CDCl₃) δ 7.94 (d, J = 9.0 Hz, 2H), 7.87 (d, J = 9.0Hz, 2H), 7.75 (d, J = 9.0 Hz), 7.55-7.39 (m, 8H), 5.85 (s, 2H), 1.81 (s, 6H), 1.78 (s, 6H), 0.81 (s, 6H); ¹³C NMR (75MHz, CDCl₃) δ 169.8, 135.5, 134.0, 132.1, 129.4, 128.1, 126.5, 125.8, 125.7 123.1, 88.1, 73.6, 39.5, 29.4, 24.4, 23.8. HRMS-EI (m/z): [MH⁺] calcd. for C₃₃H₃₄N₂O₂, 491.2693; found, 491.2712.

8-3. 2,2-Bis{2-[(4*R*)-(2-naphthyl)-5,5-dimethyloxazoliny]}propane (11d):

The title compound was prepared by the same procedure as that for **11b**. Yield: 77 %, a white crystalline solid; Mp 103.2-105.0 °C; $[\alpha]_D = +196$ (c = 0.11, CHCl₃); ¹H NMR (300 MHz, CDCl₃) δ 7.81-7.66 (m, 8H), 7.46-7.34 (m, 6H), 5.05 (s, 2H), 1.76 (s, 6H), 1.66 (s, 6H), 0.90 (s, 6H); ¹³C NMR (75MHz, CDCl₃) δ 169.9, 137.0, 133.6, 133.3, 128.3,

128.2, 128.0, 126.5, 126.4, 126.1, 126.0, 88.1, 78.5, 77.6, 39.5, 29.6, 24.4, 24.2. HRMS-EI (m/z): [MH⁺] calcd. for C₃₃H₃₄N₂O₂, 491.2693; found, 491.2676.

III. General Procedure for Cyclopropanation

CuOTf (toluene)_{0.5} (12.9 mg, 0.05 mmol) and a bisoxazoline ligand (0.055 mmol) were dissolved in 5 mL of EtOAc (anhydrous), and the solution was stirred for 30 min. 2,5-Dimethyl-2,4-hexadiene (3.86 g, 70 mmol) was added to the solution, and the reaction mixture was warmed to 40 °C. A solution of *t*-butyl diazoacetate (1.41 g, 10 mmol) in 5 mL of ethyl acetate (anhydrous) was added dropwise to the solution over a period of 2 h at 40 °C, and then the mixture was further stirred at the same temperature for 0.5 h. The reaction mixture was filtrated through silica gel and then analyzed by GC (DB-1, 30 m x 0.25 mm ID, 0.25 mm film, column temp. 100 °C - 10 min to 250 °C) using the internal method with n-decane as a standard for determining the yield and *trans/cis* ratio. After concentration of the reaction mixture under reduced pressure, the residue containing 1.13 g of *t*-butyl chrysanthemate (5 mmol) was dissolved in 10 mL of toluene. Trifluoroacetic acid (57 mg, 0.5 mmol) was then added to the solution, and the solution was refluxed for 3 h to afford chrysanthemic acid, which was analyzed by GC (DB-210, 30 m x 0.25 mm ID, 0.25 mm film, column temp. 115 °C) after transformation into the *l*-menthyl

chrysanthemate with SOCl_2 , pyridine, and *L*-menthol. The absolute configurations of the products were determined by comparison of the GC elution order of the enantiomers with authentic samples.