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Enantioselective and aerobic oxidative coupling of 2-naphthol derivatives using chiral dinuclear vanadium(V) complex in water

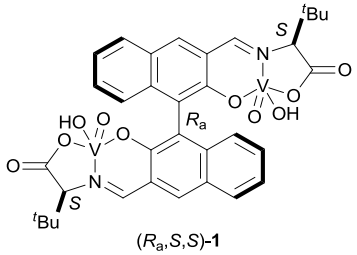
Makoto Sako, Shinobu Takizawa*,Yasushi Yoshida, and Hiroaki Sasai*

The Institute of Scientific and Industrial Research (ISIR), Osaka University, Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Abstract—The enantioselective oxidative coupling of 2-naphthols in water was established using dinuclear vanadium(V/IV) catalysis with O_2 as the sole co-oxidant. In the vanadium-catalyzed reaction, the corresponding coupling products were obtained in good to excellent yields with up to 94% enantiomeric excess. In water, racemization of the coupling product was suppressed even at high temperature (70 °C).

1. Introduction

Water is a much safer reaction solvent compared to toxic and/or flammable organic solvents, making aqueous processes environmentally benign methodologies. To date, a number of efficient, metal-catalyzed reactions and organocatalyzed reactions in water have been reported.[1] The preparation of enantiomerically pure 1,1′-bi-2-naphthol (BINOL) and its derivatives are of great importance due to their wide utility in asymmetric synthesis.[2] Among the synthetic methods used to access enantiomerically pure BINOLs, asymmetric and catalytic oxidative coupling of 2-naphthols is one of the most straightforward processes.[3,4] We previously developed the dinuclear vanadium(V) complex (R_a,*S*,*S*)-**1** (Figure 1), which can catalyze the oxidative coupling of 2-naphthols through a dual activation mechanism.[4m-4p] (R_a,*S*,*S*)-**1** can be easily prepared in a one-pot, single operation reaction from a chiral binaphthyl derivative, amino acids, and vanadium salts in MeOH under an O_2 atmosphere and reflux conditions. The vanadium complex is stable in hydrophilic, polar solvents such as MeOH and EtOH in air. Thus we envisioned that in water, the chiral dinuclear vanadium(V) complex could promote the oxidative coupling of 2-naphthols to give BINOLs in high yields and with high enantioselectivities. To date, several procedures for the oxidative coupling of 2-naphthols in water have been developed using $Ru(OH)_x/Al_2O_3$,[5] biopolymer-supported copper,[6] or ferric hydrogensulfate.[7] These protocols produced BINOL, but only as a racemic form. In 2015, Adão and Pessoa et al. reported the enantioselective oxidative coupling of 2-naphthol using amino acid-derived Cu(II) catalysts in $EtOH/H_2O$ to provide BINOL (up to 33% yield, 44% ee).[8] However, the yield and enantiomeric excess of BINOL remain unsatisfactory. Therefore, the development of an efficient oxidative coupling of 2-naphthols in water with high enantiocontrol has been a challenge. Herein, we report the highly enantioselective oxidative coupling of 2-naphthols in water. Under O_2 in water, the dinuclear vanadium(V) complex (R_a,*S*,*S*)-**1** promotes oxidative coupling of 2-naphthols, to afford the corresponding coupling products in good yields with high enantioselectivities.



(R_a,*S*,*S*)-**1**

Figure 1. Dinuclear vanadium(V) complex (R_a,*S*,*S*)-**1**

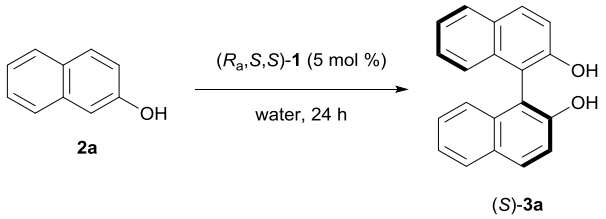
2. Results and discussion

Initially, the optimization of the reaction conditions for the oxidative coupling of 2-naphthol **2a** was performed with (R_a,*S*,*S*)-**1** (5 mol %) in water (Table 1). We previously reported that the oxidative coupling of **2a** in the presence of 5 mol % (R_a,*S*,*S*)-**1** in CH_2Cl_2 under air at 30 °C afforded (*S*)-BINOL **3a** in quantitative yield with 90% ee (entry 9).[4n] In contrast, either no reaction or low conversion was observed in aqueous media, most likely due to the low solubility of 2-naphthol in water (entries 1 and 2). To improve the solubility, a catalytic amount of surfactant, such as anionic surfactant sodium dodecyl sulfate (SDS), cationic surfactant tetrabutylammonium bromide (TBAB), or neutral surfactant polyoxyethylene *p*-*t*-octylphenyl ether (Triton X-100) was added (entries 3–5), although almost no improvement in either the chemical yield or enantioselectivity was observed. However, when the

* Corresponding author. Tel.: +81-6-6879-8466; fax: +81-6-6879-8469; e-mail: taki@sanken.osaka-u.ac.jp

temperature was raised to 50 °C, **3a** was isolated in 91% yield with 80% ee (entry 6). When the temperature was increased to over 90 °C, the product's ee drastically decreased due to decomposition of the complex (entry 7). Without (R_a,*S*,*S*)-**1**, no reaction was observed under the optimized reaction conditions (entry 8). Based on these results, efficient dual activation of 2-naphthol using (R_a,*S*,*S*)-**1** in water requires a temperature of at least 50 °C to promote a single electron transfer from 2-naphthol to the catalyst.[4m-4p]

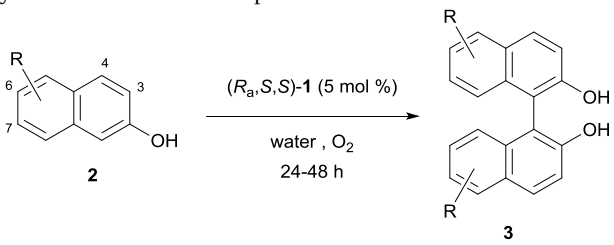
Table 1 Optimization of reaction conditions for the oxidative coupling of 2-naphthol **2a** in water



Entry	Air or O_2	Temp. (°C)	Additive (5 mol %)	% yield[a]	% ee[b]
1	Air	30	None	NR	—
2	O_2	30	None	11	Rac.
3	O_2	30	SDS	9	Rac.
4	O_2	30	TBAB	5	17
5	O_2	30	Triton X-100	26	25
6	O_2	50	None	92 (91)[c]	80
7	O_2	90	None	>99	66
8[d]	O_2	50	None	NR	—
9[e]	Air	30	None	quant	90

[a]^{1}H NMR yield, 1,3,5-trimethoxybenzene was used as an internal standard.
[b]Determined by HPLC.
[c]Yield of isolated product.
[d]Without (R_a,*S*,*S*)-**1**.
[e]Result when the reaction was carried out in CH_2Cl_2.[4n]

Table 2 Oxidative coupling of 2-naphthol derivatives catalyzed by dinuclear vanadium complex in water



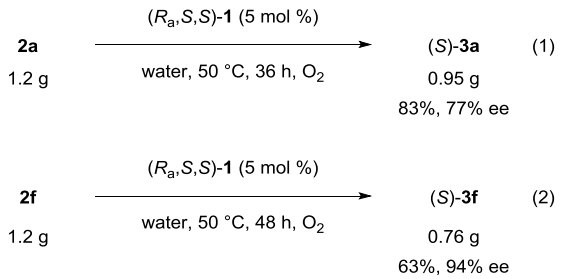
Entry	Substrate, R	Temp. (°C)	Yield (%)[a]	Ee (%)[b]
1	**2a**, H	50	**3a**, 91	80 (*S*)
2	**2b**, 7-OMOM	50	**3b**, 78	83 (*S*)
3	**2c**, 7-OMEM	50	**3c**, 65	63 (*S*)
4	**2d**, 7-OCH_2CHCH_2	50	**3d**, 78	85 (*S*)
5	**2e**, 7-Br	70	**3e**, 85	73 (*S*)
6	**2f**, 7-OMe	50	**3f**, 87	94 (*S*)
7	**2g**, 6-OMe	70	**3g**, 95	63 (*S*)
8	**2h**, 6-Me	70	**3h**, 89	77 (*S*)
9	**2i**, 4-Ph	70	**3i**, 82	85 (*R*)
10	**2j**, 3-OMe	70	**3j**, 69	44 (*S*)

[a]Isolated product yield. [b]Determined by HPLC.

To elucidate the applicability of the oxidative coupling using the vanadium complex in water, various 2-naphthol derivatives were examined (Table 2). 2-Naphthols bearing electron-donating or withdrawing groups such as MOM-O, MEM-O, CH_2=$CHCH_2O$, Br, MeO, Me, or Ph, at the C7, C6, or C4 position underwent the coupling reaction to produce the corresponding BINOL derivatives **3b**–**3i** in good yields with high enantioselectivities (entries 2–9). 3-MeO-2-naphthol **2j** was also converted into coupling product **3j** in good yield with moderate enantioselectivity (entry 10). The reactions of **2e** and **2g-j** had to be carried out at higher temperature (70 °C) and longer reaction time (48 h) due to the low solubility of **2e** and **2g-j** in water.

In an effort to clarify whether racemization of the products occurs, optically active 7,7′-dimethoxy-substituted BINOL **3f** [94% ee (*S*)] or 6,6′-dimethoxy-substituted BINOL **3g** [81% ee (*S*)] was stirred in water at 70 °C under the coupling conditions [100 mol % 2-naphthol **2a** and 5 mol % dinuclear vanadium(V) complex (R_a,*S*,*S*)-**1**]. After 24 h, the dimethoxy-substituted BINOLs were recovered with 93% ee for (*S*)-**3f** and 77% ee for (*S*)-**3g**.[9] Under the optimal reaction conditions in water, the ee of **3f** and **3g** decreased slightly. However, using $ClCH_2CH_2Cl$ as the reaction solvent instead of water resulted in decreasing ee; **3f**: from 94% ee (*S*) to 74% ee (*S*); **3g**: from 81% ee (*S*) to 11% ee (*R*).[10] It should be noted that in water, racemization of BINOLs is significantly suppressed as compared to an organic solvent.[11]

To prove the utility of the present methodology, the oxidative coupling of **2** on a gram scale was examined (Scheme 1). The reaction using 1.2 g of **2a** or **2f** in the presence of 5 mol % (R_a,*S*,*S*)-**1** allowed the formation of (*S*)-**3a** in 83% yield with 77% ee and (*S*)-**3f** in 63% yield with 94% ee, respectively (eqs. 1 and 2).



Scheme 1 Oxidative coupling of 2-naphthols catalyzed by dinuclear vanadium complex in water on a gram scale

3. Conclusion

In conclusion, we have developed the first example of a highly efficient and enantioselective oxidative coupling of 2-naphthols **2** in water catalyzed by a chiral dinuclear vanadium(V) complex. In water, (R_a,*S*,*S*)-**1** maintained high catalytic activity for the coupling reaction to produce BINOLs **3** in high yields with up to 94% ee. In water, almost no racemization of BINOLs was observed at 70 °C. Furthermore, a gram scale synthesis of BINOLs in aqueous

media was achieved with good yields and high enantioselectivities.

4. Experimental

4.1. General

^{1}H- and ^{13}C-NMR and spectra were recorded with JEOL JMN ECS400 FT NMR, JNM ECA600 FT NMR or Bruker AVANCE II (^{1}H-NMR 400, 600 or 700 MHz, ^{13}C-NMR 100, 150 or 175 MHz). ^{1}H-NMR spectra are reported as follows: chemical shift in ppm relative to the chemical shift of TMS at 0 ppm, integration, multiplicities (s = singlet, d = doublet, t = triplet, m = multiplet), and coupling constants (Hz). ^{13}C-NMR spectra are reported in ppm relative to the central line of triplet for $CDCl_3$ at 77 ppm. Optical rotations were measured with JASCO P-1030 polarimeter. HPLC analyses were performed on a JASCO HPLC system (JASCO PU 980 pump and UV-975 UV/Vis detector) using a mixture of hexane and 2-propanol as eluents. Column chromatography on SiO_2 was performed with Kishida Silica Gel (63-200 μm). Commercially available organic and inorganic compounds were used without further purification. (*R*$_a$,*S*,*S*)-**1**, **2b**, **2d**, **2h**, **2i** and **2j** were prepared following the reported procedures.[4o,12] Products **3a**, **3b**, **3d**, **3e**, **3f**, **3g**, **3h**, **3i** and **3j** were identical in all respects with the data reported in the literature.[4n,13] Absolute configurations were assigned by comparison of the specific rotation reported in the literature.[4n,13]

4.2. Preparation of 7-((2-methoxyethoxy)methoxy)-2-naphthol 2c

To a solution of 2,7-dihydroxynaphthalene (961 mg, 6.0 mmol) in CH_2Cl_2 (30 mL) were added ^{i}Pr$_2$NEt (1.15 mL, 6.6 mmol) and MEMCl (0.75 mL, 6.6 mmol) at 0 °C. The mixture was warmed to rt and then stirred for 24 h. After the reaction was completed, water was added to the reaction mixture and the solution was extracted with CH_2Cl_2. The organic layer was washed with brine, dried over Na_2SO_4, and evaporated in vacuo. After the purification via SiO_2 column chromatography (hexane/acetone = 3/1), the desired product was obtained as a yellow oil (675 mg, 45%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.67 (d, *J* = 8.7, 2H), 7.27 (d, *J* = 2.3 Hz, 1H), 7.05 (dd, *J* = 8.7, 2.3 Hz, 1H), 7.04 (d, *J* = 2.3 Hz, 1H), 6.96 (dd, *J* = 8.7, 2.3 Hz, 1H), 5.37 (s, 2H), 5.01 (s, 1H), 3.88-3.86 (m, 2H), 3.60-3.57 (m, 2H), 3.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 155.2 (C), 154.4 (C), 135.6 (C), 129.1 (CH), 129.1 (CH), 124.4 (C), 116.0 (CH), 115.9 (CH), 108.7 (CH), 108.4 (CH), 93.1 (CH_2), 71.3 (CH_2), 67.3 (CH_2), 58.6 (CH_3); HRMS (ESI) calcd for $C_{14}H_{16}NaO_4$, *m*/*z* = 271.0946 [(M + Na)$^+$], found *m*/*z* = 271.0938; IR (KBr): *v* 3360, 3062, 2931, 1635, 1515, 1448, 1200, 1159, 1007, 833 cm^{-1}.

4.3. General procedure for coupling reactions of 2-naphthols 2 using (*R*$_a$,*S*,*S*)-1 in water

A test tube was charged with a water (1 mL) heterogeneous solution of coupling substrate **2** (0.2 mmol) under O_2 (1 atm) atmosphere. Vanadium catalyst (*R*$_a$,*S*,*S*)-**1** (0.01 mmol, 5 mol %) was added to the solution. The reaction mixture was stirred at 50 °C for **2a**, **2b**, **2c**, **2d** and **2f** or 70 °C for **2e**, **2g**, **2h**, **2i** and **2j** until the reaction had reached completion by monitoring with TLC analysis. The reaction mixture was then directly purified by silica gel column chromatography eluting with ethyl acetate/hexane to give the coupling product.

4.4. (*S*)-1,1'-Bi-2-naphthol 3a[4n]

Reaction time: 24 h; Reaction temperature: 50 °C; 91% yield; $[\alpha]_D^{22}$ = –26.9 (*c* 1.0, THF, 80% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.98 (d, *J* = 8.7 Hz, 2H), 7.89 (d, *J* = 7.8 Hz, 2H), 7.43-7.34 (m, 4H), 7.31 (td, *J* = 7.8 Hz, 1.6 Hz, 2H), 7.15 (d, *J* = 8.2 Hz, 2H), 5.04 (s, 2H); The enantiometric excess was determined by HPLC with a Daicel Chiralpak AS-H column (hexane:2-propanol = 7:1, λ = 229 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 9.8 min, t_R (minor enantiomer) = 15.1 min, 80% ee.

4.5. (*S*)-7,7'-Bis(methoxymethoxy)-1,1'-bi-2-naphthol 3b[4n]

Reaction time: 48 h; Reaction temperature: 50 °C; 78% yield; $[\alpha]_D^{13}$ = +127.6 (*c* 1.1, $CHCl_3$, 83% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.7 Hz, 2H), 7.79 (d, *J* = 8.7 Hz, 2H), 7.21 (d, *J* = 8.7 Hz, 2H), 7.14 (dd, *J* = 8.7, 2.3 Hz, 2H), 6.65 (d, *J* = 2.3 Hz, 2H), 5.08 (s, 2H), 4.99 (s, 4H), 3.31 (s, 6H); The enantiometric excess was determined by HPLC with a Daicel Chiralpak AS-H column (hexane:2-propanol = 7:1, λ = 235 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 16.5 min, t_R (minor enantiomer) = 27.9 min, 83% ee.

4.6. (*S*)-7,7'-Bis((2-methoxyethoxy)methoxy)-1,1'-bi-2-naphthol 3c

Reaction time: 48 h; Reaction temperature: 50 °C; 65% yield, yellow oil; $[\alpha]_D^{22}$ = +61.9 (*c* 0.7, $CHCl_3$, 63% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88 (d, *J* = 9.2 Hz, 2H), 7.80 (d, *J* = 8.7 Hz, 2H), 7.26 (s, 2H), 7.23 (d, *J* = 9.2 Hz, 2H), 7.16 (dd, *J* = 8.7, 2.3 Hz, 2H), 6.71 (d, *J* = 2.3 Hz, 2H), 5.15 (s, 2H), 5.10 (s, 4H), 3.70-3.62 (m, 4H), 3.45-3.34 (m, 4H), 3.28 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 156.4 (C), 153.3 (C), 134.6 (C), 131.1 (CH), 130.0 (CH), 125.4 (C), 116.0 (CH), 115.8 (CH), 110.2 (C), 107.9 (CH), 93.4 (CH_2), 71.4 (CH_2), 67.5 (CH_2), 59.0 (CH_3); HRMS (ESI) calcd for $C_{28}H_{30}NaO_8$, *m*/*z* = 517.1838 (M + Na)$^+$], found *m*/*z* = 517.1826; IR (KBr): *v* 3390, 3058, 2931, 1621, 1512, 1203, 1159, 1019, 982, 834 cm^{-1}; The enantiometric excess was determined by HPLC with a Daicel Chiralpak AS-H column (hexane:2-propanol = 4:1, λ = 220 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 22.0 min, t_R (minor enantiomer) = 30.1 min, 63% ee.

4.7. (*S*)-7,7'-Bis(allyloxy)-1,1'-bi-2-naphthol 3d[4n]

Reaction time: 48 h; Reaction temperature: 50 °C; 78% yield; $[\alpha]_D^{22}$ = +177.6 (*c* 1.5, $CHCl_3$, 85% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85 (d, *J* = 8.7 Hz, 2H), 7.77 (d, *J* = 8.7 Hz, 2H), 7.20 (d, *J* = 8.7 Hz, 2H), 7.04 (dd, *J* = 8.7, 2.4

Hz, 2H), 6.47 (d, *J* = 2.4 Hz, 2H), 5.90-5.80 (m, 2H), 5.15-5.09 (m, 4H), 5.06 (s, 2H), 4.32-4.21 (m, 4H); The enantiometric excess was determined by HPLC with a Daicel Chiralpak IA column (hexane:2-propanol = 7:1, λ = 235 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 12.2 min, t_R (minor enantiomer) = 22.7 min, 85% ee.

4.8. (*S*)-7,7'-Dibromo-1,1'-bi-2-naphthol 3e[13a]

Reaction time: 48 h; Reaction temperature: 70 °C; 85% yield; $[\alpha]_D^{21}$ = +129.1 (*c* 1.8, $CHCl_3$, 73% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.94 (d, *J* = 9.2 Hz, 2H), 7.76 (d, *J* = 8.7 Hz, 2H), 7.47 (dd, *J* = 8.7, 1.8 Hz, 2H), 7.38 (d, *J* = 9.2 Hz, 2H), 7.23 (d, *J* = 1.8 Hz, 2H), 5.05 (s, 2H); The enantiometric excess was determined by HPLC with a Daicel Chiralcel OD-H column (hexane:2-propanol = 9:1, λ = 235 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 15.9 min, t_R (minor enantiomer) = 33.4 min, 73% ee.

4.9. (*S*)-7,7'-Dimethoxy-1,1'-bi-2-naphthol 3f[4n]

Reaction time: 48 h; Reaction temperature: 50 °C; 87% yield; $[\alpha]_D^{22}$ = +122.3 (*c* 1.0, $CHCl_3$, 94% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86 (d, *J* = 8.7 Hz, 2H), 7.77 (d, *J* = 8.7 Hz, 2H), 7.21 (d, *J* = 8.7 Hz, 2H), 7.02 (dd, *J* = 8.7, 2.7 Hz, 2H), 6.47 (d, *J* = 2.7 Hz, 2H), 5.04 (s, 2H), 3.56 (s, 6H); The enantiometric excess was determined by HPLC with a Daicel Chiralpak AS-H column (hexane:2-propanol = 9:1, λ = 235 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 18.8 min, t_R (minor enantiomer) = 28.0 min, 94% ee.

4.10. (*S*)-6,6'-Dimethoxy-1,1'-bi-2-naphthol 3g[4n]

Reaction time: 48 h; Reaction temperature: 70 °C; 95% yield; $[\alpha]_D^{20}$ = +25.6 (*c* 1.6, $CHCl_3$, 63% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (dd, *J* = 9.2, 1.8 Hz, 2H), 7.33 (dd, *J* = 9.2, 1.8 Hz, 2H), 7.19 (s, 2H), 7.05 (d, *J* = 9.2 Hz, 2H), 6.97 (dd, *J* = 9.2, 1.8 Hz, 2H), 4.94 (s, 2H), 3.89 (s, 6H); The enantiometric excess was determined by HPLC with a Daicel Chiralpak AS column (hexane:2-propanol = 4:1, λ = 260 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 12.1 min, t_R (minor enantiomer) = 21.8 min, 63% ee.

4.11. (*S*)-6,6'-Dimethyl-1,1'-bi-2-naphthol 3h[4n]

Reaction time: 48 h; Reaction temperature: 70 °C; 89% yield; $[\alpha]_D^{17}$ = +51.9 (*c* 0.7, $CHCl_3$, 77% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88 (d, *J* = 9.2 Hz, 2H), 7.66 (s, 2H), 7.34 (d, *J* = 9.2 Hz, 2H), 7.14 (d, *J* = 8.2 Hz, 2H), 7.05 (d, *J* = 8.2 Hz, 2H), 4.96 (s, 2H), 2.47 (s, 6H); The enantiometric excess was determined by HPLC with a Daicel Chiralpak AS-H column (hexane:2-propanol = 7:1, λ = 229 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 8.2 min, t_R (minor enantiomer) = 12.9 min, 77% ee.

4.12. (*R*)-4,4'-Diphenyl-1,1'-bi-2-naphthol 3i[13b]

Reaction time: 48 h; Reaction temperature: 70 °C; 82% yield; $[\alpha]_D^{22}$ = –22.1 (*c* 1.0, $CHCl_3$, 85% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.97-7.94 (m, 2H), 7.64-7.48 (m, 10H), 7.38 (s, 2H), 7.36-7.31 (m, 6H), 5.16 (s, 2H); The enantiometric excess was determined by HPLC with a Daicel Chiralcel OD-H column (hexane:2-propanol = 4:1, λ = 220 nm, flow rate = 1.0 mL/min); t_R (minor enantiomer) = 8.4 min, t_R (major enantiomer) = 13.3 min, 85% ee.

4.13. (*S*)-3,3'-Dimethoxy-1,1'-bi-2-naphthol 3j[4n]

Reaction time: 48 h; Reaction temperature: 70 °C; 69% yield; $[\alpha]_D^{23}$ = –6.2 (*c* 1.2, $CHCl_3$, 44% ee); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78 (d, *J* = 8.2 Hz, 2H), 7.34-7.29 (m, 4H), 7.18-7.12 (m, 4H), 5.88 (s, 2H), 4.09 (s, 6H); The enantiometric excess was determined by HPLC with a Daicel Chiralpak AS column (hexane:2-propanol = 1:1, λ = 236 nm, flow rate = 1.0 mL/min); t_R (major enantiomer) = 19.2 min, t_R (minor enantiomer) = 46.4 min, 44% ee.

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9. After the reaction in water, (*S*)-**3a** was obtained quantitatively with 82% ee (recovering with **3f**) and 78% ee (recovering with **3g**), respectively.
10. After the reaction in $ClCH_2CH_2Cl$ at 70 ^oC, (*S*)-**3a** was obtained quantitatively with 13% ee (recovering with **3f**) and 23% ee (recovering with **3g**), respectively.
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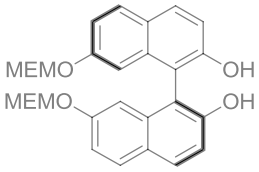

Ee = 63% by HPLC on Daicel Chiralpak AS-H column
$[\alpha]_D^{22}$ = +61.9 (*c* 0.7, $CHCl_3$)
Source of chirality: Enantioselective oxidative coupling
Absolute configuration: (*S*)

$C_{28}H_{30}O_8$
(*S*)-7,7'-Bis((2-methoxyethoxy)methoxy)-1,1'-bi-2-naphthol

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Enantioselective and aerobic oxidative coupling of 2-naphthol derivatives using chiral dinuclear vanadium(V) complex in water

Makoto Sako, Shinobu Takizawa*, Yasushi Yoshida, and Hiroaki Sasai*

The Institute of Scientific and Industrial Research (ISIR), Osaka University, Mihogaoka, Ibaraki, Osaka 567-0047, Japan

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