Formal Total Synthesis of (−)-Dendrobine Using Zirconium-Promoted Reductive Cyclization

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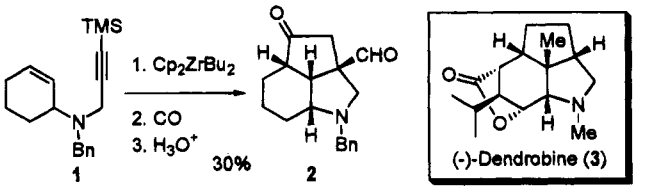
The alkaloid (−)-dendrobine was synthesized from (+)-calvone by a short sequence using zirconium-promoted reductive cyclization. The absolute configuration of a synthetic intermediate was determined by an improved version of Mosher's method.

Zirconium-promoted reductive coupling[1,2] is a useful process because new carbon–carbon bonds are formed from dienes, diynes, and enynes, and cyclic compounds are obtained in a regio- and stereocontrolled one-pot reaction. We previously reported a new synthesis of heterocycles using this procedure.[3] From enyne **1**, we were able to obtain tricyclic ketone **2** in a one-pot reaction. These results prompted us to synthesize the alkaloid dendrobine (**3**),[4,5] because the framework and the stereochemistry of **2** are the same as those of **3**. Dendrobine was first isolated from *Dendrobium nobile* LINDL by Inubushi.[4] Total syntheses of dendrobine have been achieved by several groups.[5] Optically active dendrobine was synthesized by Trost,[5d] but no details were reported. Our retrosynthetic analysis is shown in Scheme 2. An intermediate (**4**) in Kende's dendrobine synthesis[5a] would be prepared from tricyclic ketone **5**, which should be obtainable from diene **6** by means of zirconium-promoted reductive cyclization. Thus, we chose commercially available (−)-carvone (**7**) as the starting material.

Scheme 1



We questioned whether a compound having a substituent on the double bond would yield the desired product in the reductive cyclization. Professor Negishi[2c] reported that zirconium-promoted reductive coupling of enyne **8a** afforded cyclized product **9**, but enyne **8b** with a substituent on the double bond afforded product **10**, resulting from intermolecular coupling of the alkyne. However, Negishi also reported that compounds **11a** and **11b**, having nitrogen in the molecule, provided cyclized products **13a** and **13b** in good yields. These results stimulated us to synthesize optically active dendrobine by means of zirconium-promoted reductive cyclization.

Synthesis of the Optically Pure Diene

In the first attempt to prepare optically pure cyclohexenylamine **6a**, cyclohexenyl bromide **15** was prepared from (−)-carvone. (−)-Carveol (**14**), which was obtained

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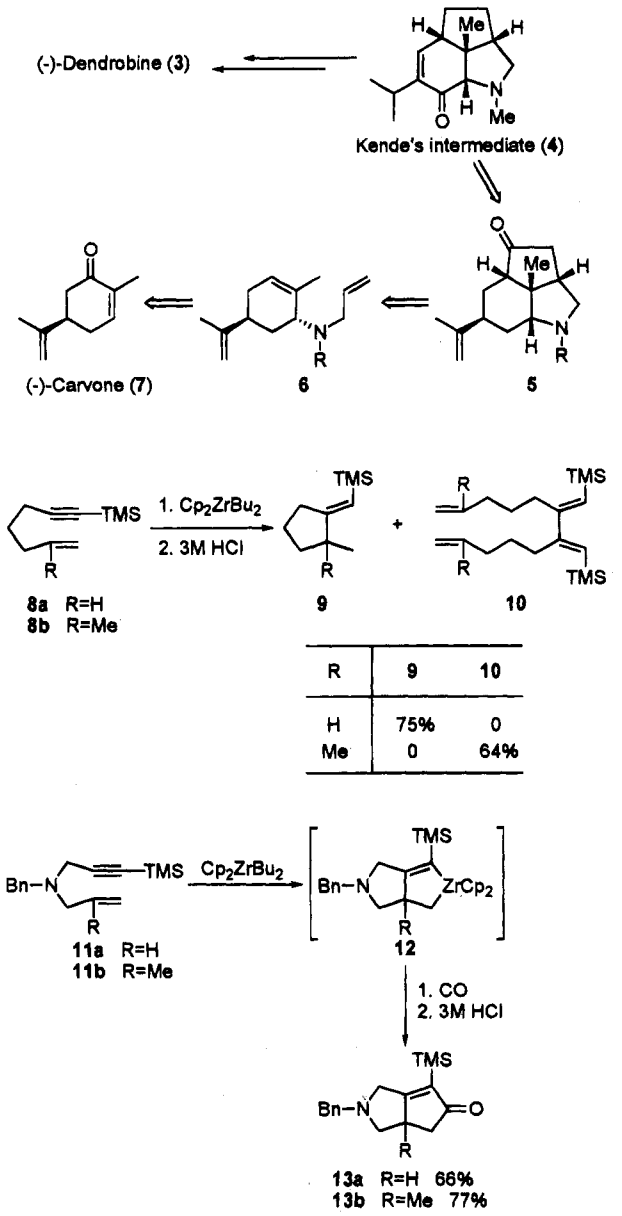
Scheme 2



by the reduction of (−)-carvone (**7**) with $NaBH_4$ in the presence of $CeCl_3 \cdot 7H_2O$,[6] was treated with CBr_4 and PPh_3 in CH_2Cl_2 (Scheme 3). Unstable crude product **15** was then treated with benzylamine to give compound **16** in 48% yield. The first step of this process, bromination of the alcohol, proceeds *through* an S_N2 reaction, and the second step, amination of the bromide, proceeds *through* a *syn*-S_N2' reaction.[7] Thus, (−)-carveol (**14**) should afford *trans*-cyclohexenylamine **16**. However, a significant amount of *cis* product **17** was obtained (9% yield). Since the formation of the allyl cation intermediate was possible in each process, the enantiomeric purity of cyclohexenylamine **16** had to be determined. Thus, *racemic* amine **16** was prepared by amination of a (π-allyl)-palladium complex. In general, formation of a (π-allyl)-palladium complex proceeds through an S_N2 reaction, and a soft nucleophile attacks from the back side of the metal. Since the nucleophile attacks both allylic positions of (π-allyl)palladium complex **19**, product **16** would be obtained in *racemic* form. (−)-Carveol (**14**) was treated with DEAD and PPh_3 in the presence of benzoic acid (the Mitsunobu reaction[8]) to produce *trans* cyclohexenyl benzoate **18** in 93% yield. Benzoate **18** reacted with benzylamine in the presence of $Pd(PPh_3)_4$ in DMSO to afford *trans* benzylamine *rac*-**16**. In order to confirm the enantiomeric purity of benzylamine **16**, *rac*-**16** was treated with benzoyl chloride in the presence of pyridine. The HPLC chromatogram of *rac*-**20** obtained on a chiral stationary phase column (CHIRALPAK AD, hexane/i-PrOH = 9/1) is shown in Figure 1. Product **16** obtained from cyclohexenyl bromide **15** was also converted to benzamide **20** in a similar manner, and the enantiomeric purity was determined by HPLC to be only 15% ee.

In order to improve the enantiomeric purity of benzylamine **16**, we prepared amine **16** using Mitsunobu reaction conditions.[8] (+)-Carveol, which was obtained from (+)-carvone in a manner similar to that used for the (−) enantiomer, was treated with *N*-tosylbenzylamide in the presence of PPh_3 and DEAD (Scheme 4). Deprotection of the tosyl group of **21** with sodium naphthalenide gave desired benzylamine **16** in 77% yield. Benzylamine **16** was converted to benzamide **20** in 90% yield. The enantiomeric purity of **20** was determined by the same procedure to be 90% ee (Figure 2). Benzylamine **16** was treated with allyl bromide in the presence of K_2CO_3 to afford desired diene **6a** in good yield.

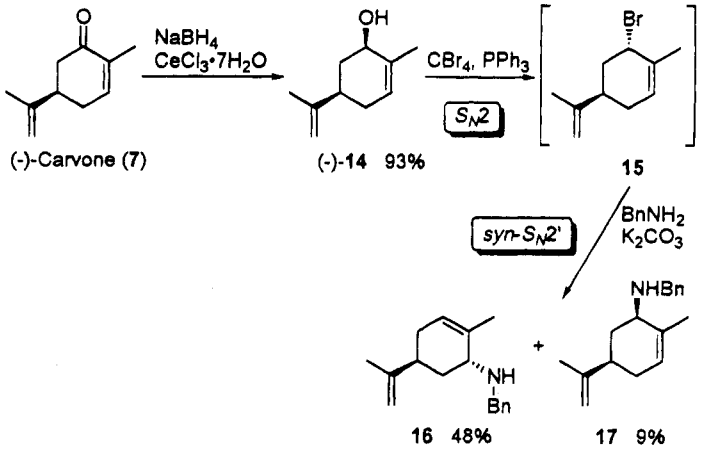
Cyclization Reaction of the Diene Using Zirconocene

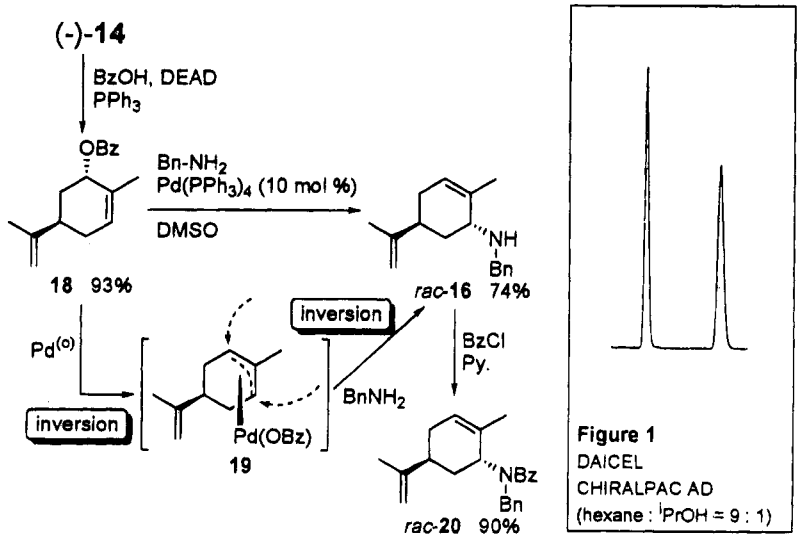
Subsequently, zirconium-promoted diene cyclization was carried out. *N*-Benzylallylamine **6a** was treated with zirconocene, and subsequent treatment with 10% HCl gave unsaturated cyclized product **23** in 58% yield along with deallylation product **16**. The results of NOE experiments indicated that the ring junction is *cis* and that the methyl group on the five-membered ring is *trans* to the ring junction methyl group. This meant that the stereochemistry of the zirconacycle was the same as that of dendrobine. The results indicated that zirconacycle **22** was formed in spite of the presence of a methyl group on the double bond. However, if β-hydride elimination occurred from zirconacycle **22** before acid treatment, the desired tricyclic compound **5a** could not be obtained from zirconacycle **22**. A THF solution of diene **6a** was treated with zirconocene at −78 °C under argon and then stirred at room temperature for 3 h. The argon in the reaction vessel was replaced with carbon monoxide, and the solution was stirred at room temperature for 17.5 h. We were very pleased to find that desired tricyclic compound **5a** was obtained in 47% yield along with **23** and deallylation product **16**. Therefore, unsaturated compound **23** would be obtained by the acid treatment of zirconacyle **22** as shown in Scheme 5.

The structure of tricyclic ketone **5a** was confirmed by X-ray analysis. Debenzylation of compound **5a** with 10% palladium on charcoal in MeOH under hydrogen and subsequent treatment with *p*-nitrobenzoyl chloride in the presence of pyridine in CH_2Cl_2 gave *p*-nitrobenzamide **24** as a colorless crystalline product. The X-ray structure is shown in Figure 3. Evidently, all ring junctions of tricyclic ketone **24** are *cis*.[9]

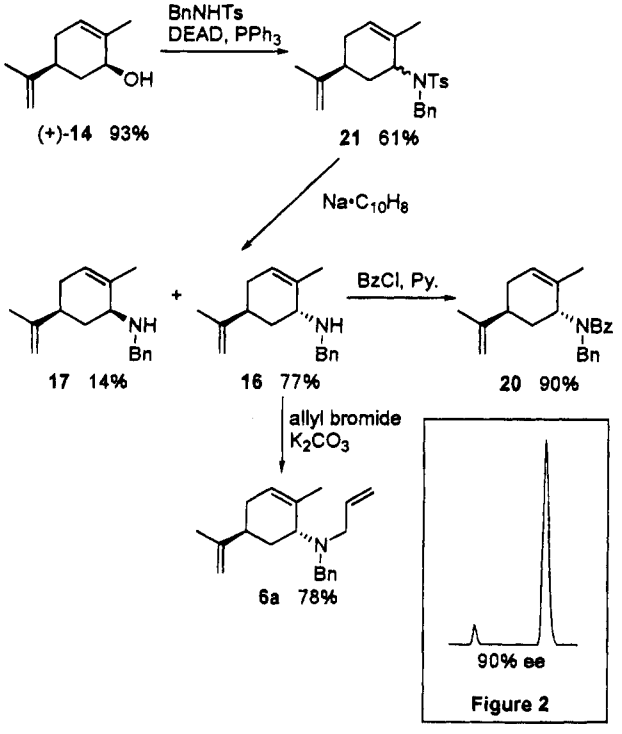
(6) Gemal, A. L.; Luche, J. L. *J. Am. Chem. Soc.* **1981**, *103*, 5454.
(7) Magid, R. M. *Tetrahedron* **1980**, *36*, 1901.
(8) Mitsunobu, O. *Synthesis* **1981**, 1. Henry, J. R.; Marcin, L. R.; McIntosh, M. C.; Scola, P. M.; Davis Harris, G., Jr.; Weinreb, S. M. *Tetrahedron Lett.* **1989**, *30*, 5709.
(9) The author has deposited atomic coordinates for this structure with the Cambridge Crystallographics Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

Scheme 3





Scheme 4



In order to prepare *N*-methyl tricyclic ketone **5b**, *N*-methyl-*N*-cyclohexenylallylamine **6b**, prepared from carvone (**7**), was treated with zirconocene and then with carbon monoxide. However, desired tricyclic ketone **5b** was obtained in low yield (14%), and deallylation product **25** was the main product (52%). Deallylation probably occurred *via* (π-allyl)zirconium complex **26**, as shown in Scheme 6.[10] Thus, the benzyl group was chosen as the N-protecting group for the synthesis of **4**.

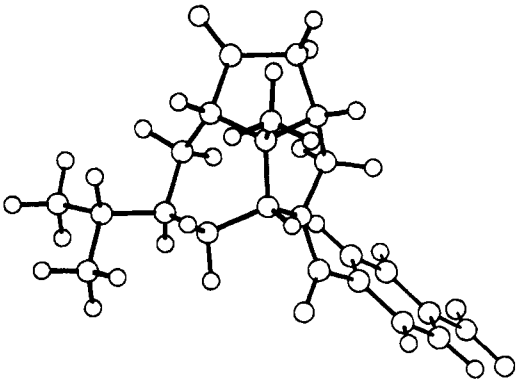
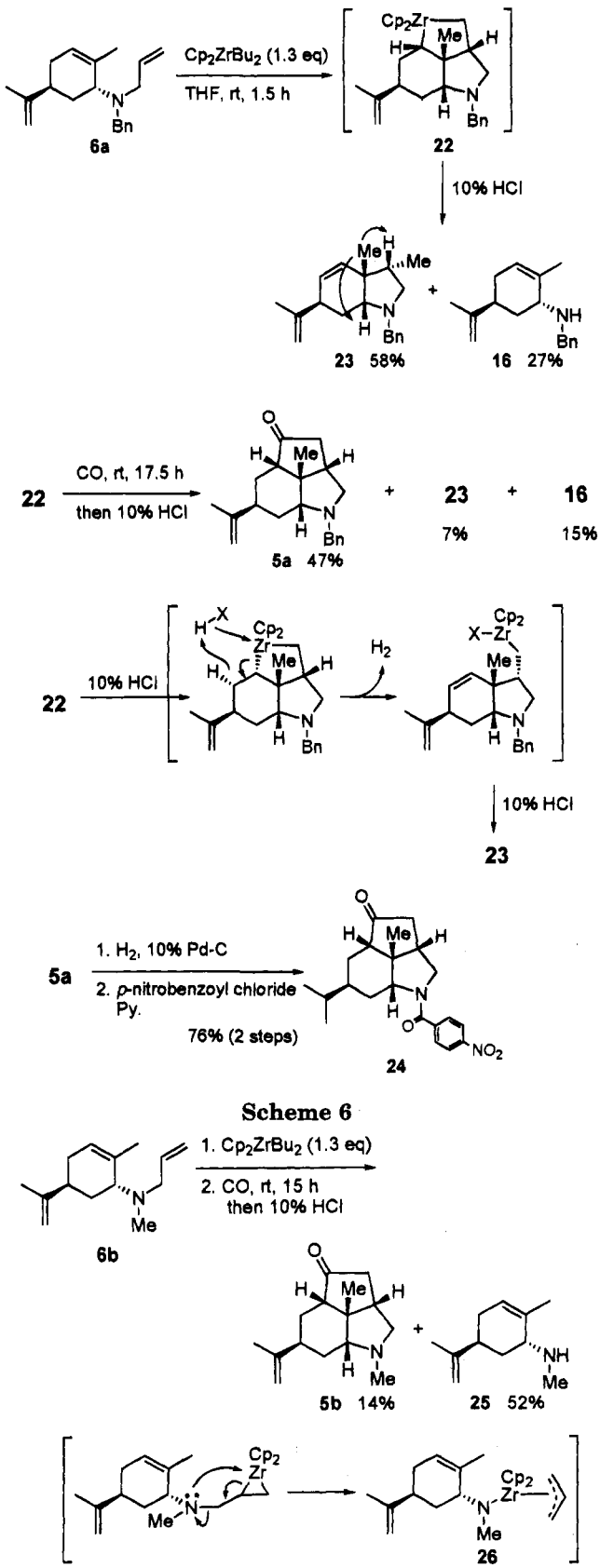


Figure 3. X-ray crystal structure of **24**.

(10) Ito, H.; Taguchi, T.; Hanzawa, Y. *Tetrahedron Lett.* **1992**, *33*, 1295. Ito, H.; Nakamura, T.; Taguchi, T.; Hanzawa, Y. *Tetrahedron Lett.* **1992**, *33*, 3769. Ito, H.; Taguchi, T.; Hanzawa, Y. *Tetrahedron Lett.* **1992**, *33*, 4469. Ito, H.; Taguchi, T.; Hanzawa, Y. *Tetrahedron Lett.* **1992**, *33*, 7873. Ito, H.; Taguchi, T.; Hanzawa, Y. *J. Org. Chem.* **1993**, *58*, 774. Ito, H.; Motoki, Y.; Taguchi, T.; Hanzawa, Y. *J. Am. Chem. Soc.* **1993**, *115*, 8835.

Scheme 5

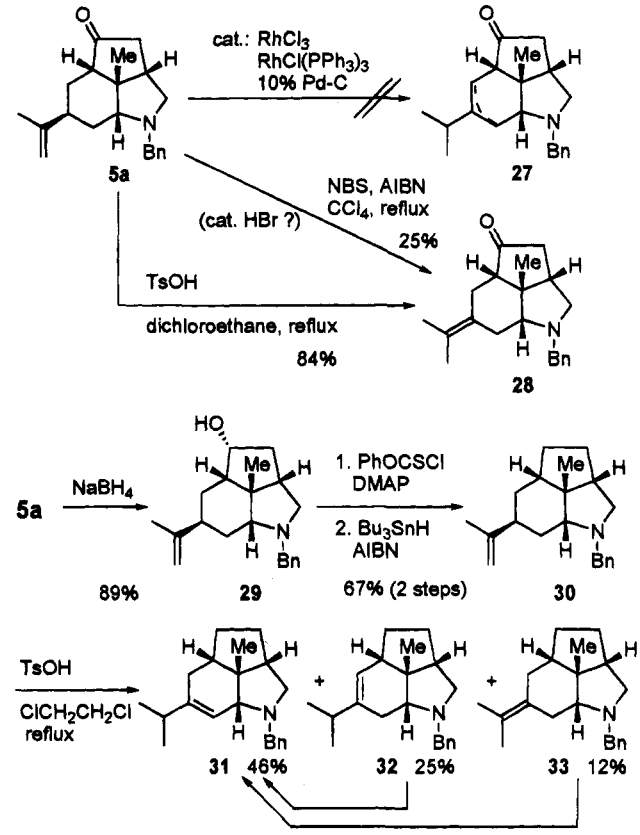


Scheme 6

Formal Total Synthesis of (−)-Dendrobine

In order to isomerize the double bond of tricyclic ketone **5a**, compound **5a** was treated with various transition-metal complexes, such as $RhCl_3$, $RhCl(PPh_3)_3$, and 10%Pd on charcoal (Scheme 7). However, these trials were fruitless. When a CCl_4 solution of compound **5a** was heated with NBS in the presence of AIBN, *exo*-alkylidene

Scheme 7

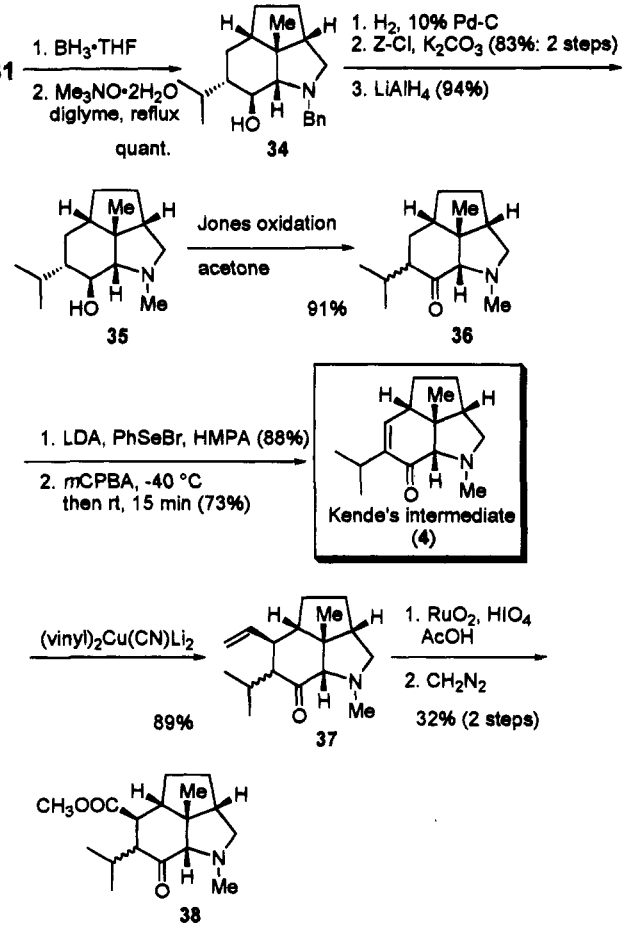


product **28** was obtained in 25% yield. Presumably, terminal olefin was isomerized by the HBr generated under the reaction conditions because the oxidation state of product **28** is the same as that of starting material **5a**. Thus, the isomerization of tricyclic ketone **5a** was studied. Compound **5a** was treated with TsOH in dichloroethane, and upon heating, desired product **28** was obtained in 84% yield. Next, we attempted to remove the carbonyl group on the five-membered ring of **5a**. Reduction of ketone **5a** with $NaBH_4$ was followed by treatment with phenyl chlorothionoformate and then Bu_3SnH in the presence of AIBN to give deoxygenated product **30**.[11] A solution of compound **30** and TsOH in dichloroethane was refluxed for 2 days to give isomerized products **31**, **32**, and **33** in 46%, 25%, and 12% yields, respectively. Presumably, the thermodynamically most stable isomer was **31** because isomers **31**, **32**, and **33** were in a state of equilibrium in the presence of acid. Compounds **32** and **33** gave a mixture of **31**, **32**, and **33** in the same ratio when heated with TsOH in dichloroethane.

Finally, we examined the conversion of compound **31** into Kende's intermediate, **4** (Scheme 8). Hydroboration of compound **31** followed by treatment with trimethylamine *N*-oxide provided alcohol **34** in quantitative yield. The benzyl group was cleaved with 10% Pd on charcoal, and the resulting product was treated with carbobenzyloxy chloride in the presence of K_2CO_3. $LiAlH_4$ reduction of the carbamate afforded *N*-methyl derivative **35**, which was oxidized with Jones' reagent to give ketone **36** as a mixture of epimers. Compound **36** was treated with LDA and PhSeBr; subsequent MCPBA oxidation gave compound **4**, Kende's intermediate.[5a] The structure of compound **4** was confirmed by spectroscopic data, but

(11) Robins, M. J.; Wilson, J. S.; Hansske, F. *J. Am. Chem. Soc.* **1983**, *105*, 4059.

Scheme 8

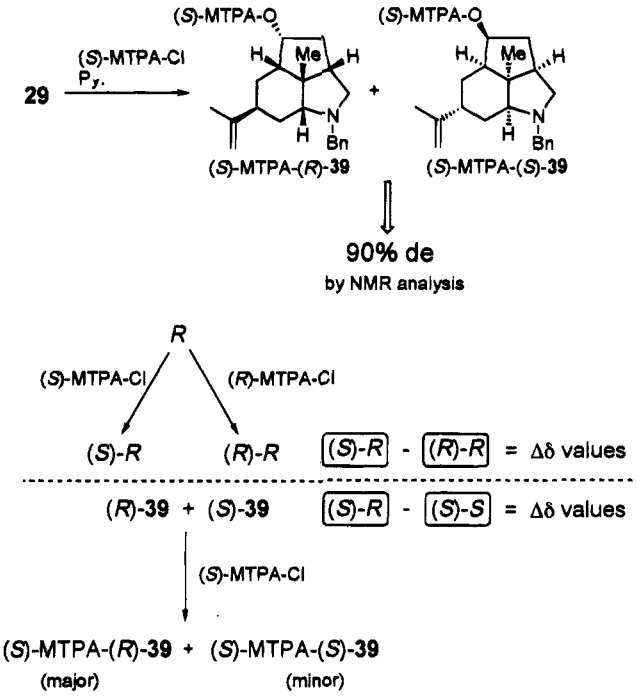


the NMR spectrum of product **4** differed partially from that reported by Kende. Thus, compound **4** was converted to compounds **37** and **38** by means of the Kende synthetic route. Fortunately, the spectral data and the melting point of compound **37** and the spectral data of compound **38** were fully identical with those reported by Kende.[5a] Thus the formal total synthesis of dendrobine was realized by a short sequence of steps.

Conformation of the Enantiomeric Purity and the Absolute Configuration of the Synthetic Dendrobine

Since there has been no report of the total synthesis of optically active dendrobine,[12] the absolute configuration and the enantiomeric purity of a synthetic intermediate of dendrobine were determined. For this purpose, the improved version of Moscher's method developed by Kusumi[13] was applied (Scheme 9). Thus, alcohol **29** was treated with (*S*)-MTPA-Cl in the presence of pyridine in CH_2Cl_2 to give two diastereomers, (*S*)-MTPA-(*R*)-**39** and (*S*)-MTPA-(*S*)-**39**. When the absolute configuration of the optically pure natural product is determined by the improved Moscher's method, (*S*)-MTPA-(*R*) and (*R*)-MTPA-(*R*) esters [or (*S*)-MTPA-(*S*) and (*R*)-MTPA-(*S*) esters)] are prepared, and their $\Delta\delta$ values are calculated. Since (*S*)-MTPA-(*S*)-**39** was an enantiomer of (*R*)-MTPA-(*R*)-**39**, the NMR spectrum of (*S*)-MTPA-(*S*)-**39** was the same as that of (*R*)-MTPA-(*R*)-**39**. Thus, the absolute configuration of one diastereomer derived from the *racemic* compound can be determined by use of the improved Moscher's method.

Scheme 9



From the NMR spectrum of the mixture of diastereomers (*S*)-MTPA-(*R*)-**39** and (*S*)-MTPA-(*S*)-**39**, the diastereomeric purity of **39** was determined to be 90%. The two diastereomers were separated by thin layer chromatography on silica gel. From a NOESY experiment on the major product (*S*)-MTPA-(*R*)-**39**, the configuration of the hydroxy group of **29** was determined to be *trans* to the angular methyl group (α-configuration). On the basis of H, H COSY, NOESY, HSQC, and HMBC spectra, the chemical shifts of each isomer were determined, and the values of $\Delta\delta = |\delta_{major}| - |\delta_{minor}|$ were calculated and are shown in Figure 4. All assigned protons with positive and negative $\Delta\delta$ values are actually found on the right and left sides of the MTPA plane, respectively, and the results indicate that the improved Moscher method can be used for the determination of the absolute configuration of the major enantiomer of tricyclic ketone **5a**. On the basis of these results, we decided that the enantiomeric excess of the tricyclic ketone was 90% and that the absolute configuration of the secondary alcohol of **29** is *R*, as shown in Figure 4.[14]

This is the first example of the use of the improved version of Mosher's method for determining the absolute configuration of one isomer of the synthetic *racemic* compound. The improved version of Mosher's method was effective not only for determining the diastereomeric purity of the synthesized product but also for determining the absolute configuration of the major (or minor) diastereomer.

Thus, we succeeded in the formal total synthesis of (−)-dendrobine (**3**) using zirconium-promoted reductive cyclization.

Experimental Section

All manipulations were performed under an argon atmosphere. Solvents were distilled under an argon atmosphere

(12) Recently, Professor Trost reported the total synthesis of (−)-dendrobine,[5d] but the spectral data were not described.

(13) Ohtani, I.; Kusumi, T.; Kashman, Y.; Kakisawa, H. *J. Am. Chem. Soc.* **1991**, *113*, 4092. Kusumi, T.; Fukushima, F.; Ohtani, I.; Kakisawa, H. *Tetrahedron Lett.* **1991**, *32*, 2939. Hamada, T.; Kusumi, T.; Ishitsuka, M.; Kakisawa, H. *Chem. Lett.* **1992**, 33.

(14) Mori, M.; Saitoh, F.; Uesaka, N.; Shibasaki, M. *Chem. Lett.* **1993**, 213.

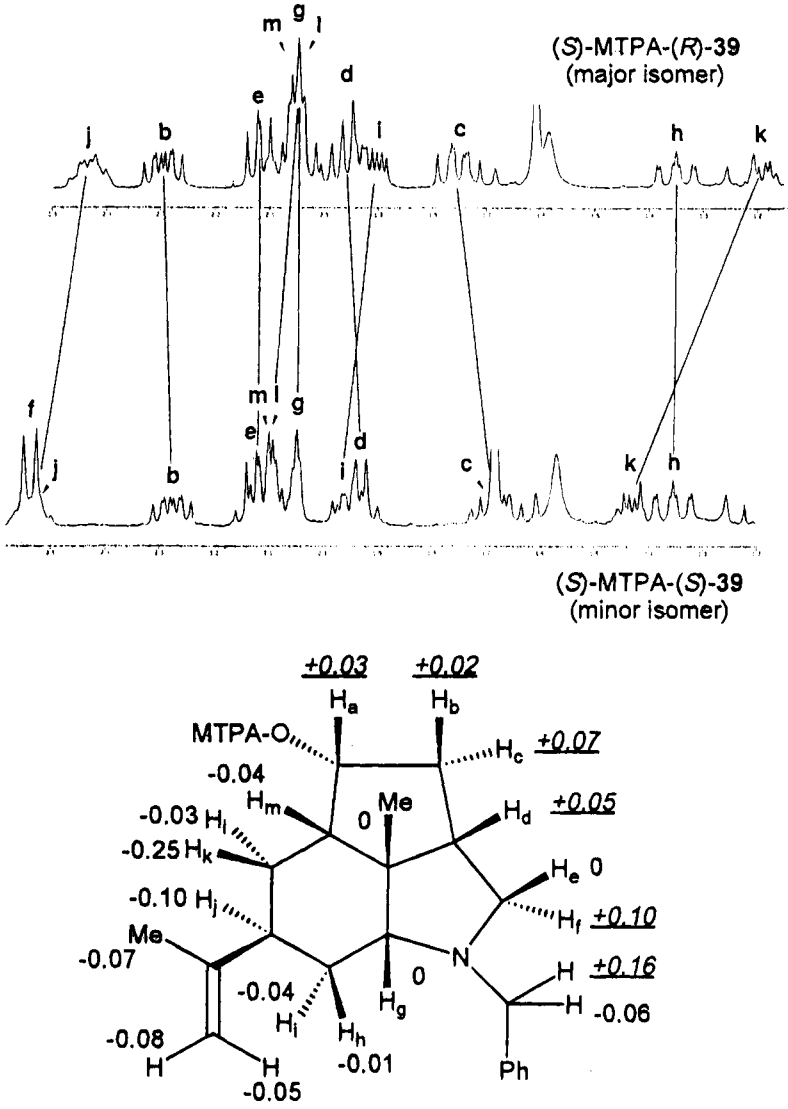


Figure 4. $\Delta\delta$ values obtained from the MTPA esters **39**.

from sodium benzophenone (THF, ether, diglyme) or CaH_2 (CH_2Cl_2, dichloroethane, diisopropylamine, HMPA). All other reagents and solvents were purified when necessary using standard procedures. Column chromatography was performed on silica gel 60 (70–230 mesh, 60 Å) and flash chromatography was performed on silica gel 60 (230–400 mesh, 60 Å) using the indicated solvent. Melting points are uncorrected.

(1*R*,5*S*)-1-(Benzylamino)-5-isopropenyl-2-methyl-2-cyclohexene (16) and (1*S*,5*S*)-1-(Benzylamino)-5-isopropenyl-2-methyl-2-cyclohexene (17) (*via* Allyl Bromide). To a stirred solution of (−)-carveol (42.6 g, 0.28 mol), prepared from (−)-carvone,[6] in CH_2Cl_2 (560 mL) containing CBr_4 (186.0 g, 0.56 mol) at 0 °C was added PPh_3 (147.0 g, 0.56 mol), and the solution was stirred at rt for 20 min. After removal of the solvent, Ph_3PO was removed by short column chromatography (AcOEt–hexane, 1:10). The resultant crude allyl bromide was dissolved in acetonitrile (560 mL) containing K_2CO_3 (77.0 g, 0.56 mol), and benzylamine (92.0 mL, 0.84 mol) was added at 0 °C. After the mixture was stirred at rt for 21 h, H_2O (10 mL) was added. The resultant mixture was extracted with AcOEt, and the organic layer was washed with brine and dried over Na_2SO_4. After removal of the solvent, the residue was purified by column chromatography (AcOEt–hexane, 1:10) to afford 32.6 g (48%) of **16** and 6.08 g (9%) of **17** as colorless oils: **16**: IR (neat) ν 3331, 1676, 1644, 1604 cm^{-1}; ^1H NMR (100 MHz, $CDCl_3$) δ 1.12–1.54 (m, 2 H), 1.76 (br s, 6 H), 1.88–2.52 (m, 3 H), 2.90–3.08 (m, 1 H), 3.72 (d, J = 13.5 Hz, 1 H), 3.96 (d, J = 13.5 Hz, 1 H), 4.74 (br s, 2 H), 5.38–5.58 (m, 1 H), 7.12–7.48 (m, 5 H); MS (EI, m/z) 241 (M^+), 240, 226, 200, 173, 158, 150, 149 (100), 91; HRMS (EI, m/z) for $C_{17}H_{23}N$, calcd 241.1830, found 241.1804. Anal. Calcd for $C_{17}H_{23}N$: C, 84.59; H, 9.60; N, 5.80. Found: C, 84.52; H, 9.69; N, 5.65. $[\alpha]^{20}_D$ + 86.6° (c 0.920, $CHCl_3$) (90% ee). **17**: IR (neat) ν 3333, 1644, 1605 cm^{-1}; ^1H NMR (100 MHz, $CDCl_3$) δ 1.16–2.42 (m, 8 H), 1.74 (s, 3 H), 1.76 (s, 3 H), 3.14–3.44 (m, 1 H), 3.70 (d, J = 12.7 Hz, 1 H), 3.86 (d, J = 12.7 Hz, 1 H), 4.72 (br s, 2 H), 5.38–5.62 (m, 1 H), 7.08–7.64 (m, 5 H); MS (EI, m/z) 241 (M^+, 3), 240 (11), 226 (13), 173 (10), 158 (6), 149 (100), 91 (69); HRMS (EI, m/z) for $C_{17}H_{23}N$, calcd 241.1831, found 241.1804.

(1*R*,5*R*)-1-Benzoyl-5-isopropenyl-2-methyl-2-cyclohexene (18). To a stirred solution of (−)-carveol (**14**) (500.0 mg, 3.28 mmol) in THF (33 mL) containing PPh_3 (1.72 g, 6.56 mmol) and benzoic acid (801.0 mg, 6.56 mmol) at 0 °C was added DEAD (1.10 mL, 6.57 mmol), and the solution was stirred at rt for 3 h. After removal of the solvent, the residue was purified by column chromatography (AcOEt–hexane, 1:10, 1:5) to afford 79.1 mg (92%) of **18** as a colorless oil: IR (neat) ν 1717 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.67–1.83 (m, 1 H), 1.71 (s, 3 H), 1.74 (s, 3 H), 1.84–2.01 (m, 1 H), 2.05–2.16 (m, 1 H), 2.19–2.33 (m, 1 H), 2.35–2.50 (m, 1 H), 4.69–4.78 (m, 2 H), 5.48–5.55 (m, 1 H), 5.76–5.84 (m, 1 H), 7.39–7.62 (m, 3 H), 8.04–8.14 (m, 2 H); MS (EI, m/z) 256 (M^+, 1), 213 (6), 135 (4), 134 (13), 119 (27), 105 (100), 77 (48); HRMS (EI, m/z) for $C_{17}H_{20}O_2$, calcd 256.1463, found 256.1437. Anal. Calcd for $C_{17}H_{20}O_2$: C, 79.65; H, 7.86. Found: C, 79.71; H, 7.96.

(3*R*,5*S*)-3-(*N*-Benzyl-*N*-benzoylamino)-5-isopropenyl-2-methylcyclohexene (20). To a stirred solution of **16** (4.0 mg, 0.017 mmol) and pyridine (0.03 mL, 0.34 mmol) in CH_2Cl_2 (0.5 mL) at 0 °C was added benzoyl chloride (0.02 mL, 0.17 mmol). After the mixture was stirred at rt for 35 h, H_2O (1.0 mL) was added at 0 °C, and the resultant mixture was extracted with

AcOEt. The organic layer was dried over anhydrous Na_2SO_4. After removal of the solvent, the residue was purified by column chromatography (AcOEt−hexane, 1:10) to afford 5.3 mg (90%) of **20** as a colorless oil: IR (neat) ν 1638 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.19−1.37 (m, 1 H), 1.28 (s, 3 H), 1.51 (s, 3 H), 1.53−2.04 (m, 4 H), 3.95 (d, J = 15.8 Hz, 1 H), 4.20−4.29 (m, 2 H), 4.45−4.58 (m, 1 H), 5.30 (d, J = 15.8 Hz, 1 H), 5.67−5.76 (m, 1 H), 7.13−7.45 (m, 10 H); MS (EI, m/z) 345 (M^+, 2), 254 (40), 212 (10), 105 (100), 91 (22), 77 (27); HRMS (EI, m/z) for $C_{24}H_{27}NO$, calcd 345.2093, found 345.2094. Anal. Calcd for $C_{24}H_{27}NO$: C, 83.44; H, 7.80; N, 4.05. Found: C, 83.49; H, 7.97; N, 3.88. $[\alpha]^{20}_D$ = +60.4° (c 0.880, $CHCl_3$) (90% ee).

(3R,5S)-3-(*N*-Benzyl-*N*-tosylamino)-5-isopropenyl-2-methylcyclohexene (21). To a stirred solution of (+)-carveol (47.0 mg, 0.315 mmol), benzyltosylamine (248.0 mg, 0.949 mmol), and PPh_3 (250.0 mg, 0.953 mmol) in THF (4.5 mL) at 0 °C was added diethyl azodicarboxylate (0.12 mL, 0.79 mmol). After the mixture was stirred at rt for 6 h, H_2O (1.0 mL) was added, and the resultant mixture was extracted with AcOEt. The organic layer was washed with 10% NaOH and brine and dried over Na_2SO_4. After removal of the solvent, the residue was purified by column chromatography (AcOEt−hexane, 1:15) to afford 76.2 mg (61%, as a mixture of diastereomer) of **21** as a white crystal: IR (Nujol) ν 1647, 1596, 1332, 1153 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.09 (s, 3 H), 1.41 (s, 3 H), 1.49−2.06 (m, 5 H), 2.42 (s, 3 H), 3.95 (d, J = 16.6 Hz, 1 H), 4.17−4.25 (m, 1 H), 4.28 (br s, 1 H), 4.53−4.58 (m, 1 H), 4.74 (d, J = 16.6 Hz, 1 H), 5.60−5.72 (m, 1 H), 7.18−7.41 (m, 5 H), 7.28 (d, J = 8.3 Hz, 2 H), 7.73 (d, J = 8.3 Hz, 2 H); MS (EI, m/z) 395 (M^+, 1), 352 (1), 331 (3), 288 (6), 240 (25), 148 (15), 107 (11), 91 (100), 77; HRMS (EI, m/z) for $C_{24}H_{29}NO_2S$, calcd 395.1919, found 395.1943. Anal. Calcd for $C_{24}H_{29}NO_2S$: C, 72.88; H, 7.39; N, 3.54; S, 8.10. Found: C, 72.71; H, 7.48; N, 3.67; S, 8.09.

(1R,5S)-1-(Benzylamino)-5-isopropenyl-2-methyl-2-cyclohexene (16) and (1S,5S)-1-(Benzylamino)-5-isopropenyl-2-methyl-2-cyclohexene (17) (from 21). To a stirred solution of **21** (15.0 mg, 0.038 mmol) in THF (0.5 mL) at −78 °C was added sodium naphthalenide (0.121 M solution in THF, 0.95 mL, 0.115 mmol). After the mixture was stirred at −78 °C for 20 min, H_2O (1.0 mL) was added at −78 °C, and the resultant mixture was warmed to rt and diluted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:15) to afford 7.1 mg (77%) of **16** and 1.3 mg (14%) of **17**.

(3R,5S)-3-(*N*-Allyl-*N*-benzylamino)-5-isopropenyl-2-methylcyclohexene (6a). To a stirred suspension of **16** (134.9 mg, 0.56 mmol) and K_2CO_3 (154.3 mg, 1.10 mmol) in acetonitrile (6.0 mL) at 0 °C was added allyl bromide (0.08 mL, 0.84 mmol). After the mixture stirred at rt for 2 days, H_2O (1.0 mL) was added, and the resultant mixture was diluted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:30) to afford 122.7 mg (78%) of **6a** as a colorless oil: IR (neat) ν 1644, 1603 cm^{-1}; ^1H NMR (100 MHz, $CDCl_3$) δ 1.32 (ddd, J = 6.4, 11.5, 14.0 Hz, 1 H), 1.56−2.48 (m, 4 H), 1.74 (br s, 6 H), 2.94 (dd, J = 8.2, 14.0 Hz, 1 H), 3.08−3.52 (m, 2 H), 3.42 (d, J = 13.9 Hz, 1 H), 3.94 (d, J = 13.9 Hz, 1 H), 4.72 (br s, 2 H), 4.88−5.34 (m, 2 H), 5.50−6.06 (m, 2 H), 7.06−7.48 (m, 5 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.40, 140.91, 137.98, 134.82, 128.51, 128.11, 126.57, 125.4, 116.2, 108.8, 55.6, 53.9, 53.0, 38.2, 30.4, 26.6, 21.4, 21.0; MS (EI, m/z) 281 (M^+, 3), 280 (31), 240 (2), 146 (25), 91 (100); HRMS (EI, m/z) for $C_{20}H_{27}N$, calcd 281.2178, found 281.2161. Anal. Calcd for $C_{20}H_{27}N$: C, 85.35; H, 9.67; N, 4.98. Found: C, 85.23; H, 9.75; N, 4.89. $[\alpha]^{20}_D$ = −33.4° (c 1.410, $CHCl_3$) (90% ee).

(1S,3aR,6R,7aR)-1-Benzyl-6-isopropenyl-3,3a-dimethyl-2,3,3a,6,7,7a-hexahydroindole (23). To a stirred suspension of Cp_2ZrCl_2 (67.5 mg, 0.23 mmol) in THF (0.5 mL) at −78 °C was added dropwise BuLi (1.62 M solution in hexane, 0.28 mL, 0.45 mmol), and the solution was stirred at −78 °C for 1 h. Compound **6a** (49.9 mg, 0.18 mmol) in THF (1.0 mL) was added to the −78 °C solution, which was allowed to warm to rt and stirred at rt for 1.5 h. The solution was cooled to 0 °C, and 10% HCl (1.0 mL) was added. The resultant mixture was stirred at rt for 1 h and basified with K_2CO_3. The aqueous layer was extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:5, 2:1, 1:0) to afford 28.9 mg (58%) of **23** and 11.6 mg (27%) of **16** as colorless oils: IR (neat) ν 1644 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.88 (d, J = 6.9 Hz, 3 H), 1.05 (s, 3 H), 1.45 (ddd, J = 2.1, 11.1, 13.2 Hz, 1 H), 1.71 (s, 3 H), 1.81 (ddd, J = 3.0, 7.7, 13.2 Hz, 1 H), 1.76−1.95 (m, 1 H), 2.48 (dd, J = 1.0, 9.8 Hz, 1 H), 2.56 (dd, J = 1.5, 9.8 Hz, 1 H), 2.62 (br dd, J = 2.1, 3.0 Hz, 1 H), 3.05−3.15 (m, 1 H), 3.42 (d, J = 13.6 Hz, 1 H), 3.96 (d, J = 13.6 Hz, 1 H), 4.74 (s, 1 H), 4.75 (s, 1 H), 5.42 (br dd, J = 3.0, 10.3 Hz, 1 H), 5.61 (br d, J = 10.3 Hz, 1 H), 7.18−7.41 (m, 5 H); MS (EI, m/z) 281 (M^+, 19), 280 (8), 266 (15), 200 (18), 190 (8), 146 (29), 119 (7), 105 (2), 91 (100); HRMS (EI, m/z) for $C_{20}H_{27}N$, calcd 281.2144, found 281.2143. Anal. Calcd for $C_{20}H_{27}N$: C, 85.35; H, 9.67; N, 4.98. Found: C, 85.15; H, 9.91; N, 4.94.

(1S,4R,6S,8S,11S)-3-Benzyl-6-isopropenyl-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-9-one (5a). To a stirred suspension of Cp_2ZrCl_2 (2.13 g, 7.28 mmol) in THF (30 mL) at −78 °C was added dropwise BuLi (1.80 M solution in hexane, 7.8 mL, 14 mmol), and the solution was stirred at −78 °C for 1 h. To the −78 °C solution was added **6a** (1.58 g, 5.60 mmol) in THF (14 mL), and the solution was allowed to warm to rt. After the solution was stirred at rt for 1.5 h, the argon atmosphere was exchanged for carbon monoxide, and the solution was stirred at rt for 15 h. After the solution was cooled to 0 °C, 10% HCl (10 mL) was added, and the solution was stirred at rt for 6 h. The resultant mixture was basified with K_2CO_3, and the aqueous layer was extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:10) to afford 814.5 mg (47%) of **5a** as colorless crystals: mp 51.5−52.0 °C (recrystallized from hexane, at −78 °C); IR (KBr) ν 1740 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.32 (ddd, J = 7.0, 13.2, 25.7 Hz, 1 H), 1.37 (s, 3 H), 1.38 (ddd, J = 3.8, 12.6, 13.4 Hz, 1 H), 1.69 (s, 3 H), 1.92 (dd, J = 2.1, 17.3 Hz, 1 H), 1.98 (ddd, J = 2.6, 5.1, 13.4 Hz, 1 H), 2.08−2.26 (m, 5 H), 2.29 (ddd, J = 2.5, 5.6, 13.2 Hz, 1 H), 2.58 (d, J = 8.8 Hz, 1 H), 2.70 (ddd, J = 2.7, 10.9, 17.3 Hz, 1 H), 2.90 (d, J = 13.2 Hz, 1 H), 3.93 (d, J = 13.2 Hz, 1 H), 4.67−4.71 (m, 2 H), 7.17−7.31 (m, 5 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 215. 3, 150.0, 139.3, 128.3, 128.2, 126.7, 108.3, 70.6, 62.3, 56.4, 53.5, 46.4, 45.4, 40.6, 33.5, 29.3, 26.6, 26.5, 21.2; MS (EI, m/z) 309 (M^+, 19), 294 (5), 281 (4), 266 (6), 240 (13), 218 (17), 91 (100); HRMS (EI, m/z) for $C_{21}H_{27}NO$, calcd 309.2093, found 309.2068. Anal. Calcd for $C_{21}H_{27}NO$: C, 81.51; H, 8.79; N, 4.53. Found: C, 81.49; H, 8.89; N, 4.63. $[\alpha]^{20}_D$ = +8.3° (c 0.980, $CHCl_3$) (90% ee).

(1S,4R,6S,8S,11S)-6-Isopropyl-11-methyl-3-(*p*-nitrobenzoyl)-3-azatricyclo[6.2.1.0^{4,11}]undecan-9-one (24). A suspension of **5a** (52.6 mg, 0.17 mmol) and 10% Pd on charcoal (50.0 mg) in MeOH (1.5 mL) was stirred at rt for 3 h under an atmosphere of hydrogen. After the catalyst was filtered off, the solvent was removed. To the residue in CH_2Cl_2 (1.5 mL) containing pyridine (0.03 mL, 0.34 mmol) at 0 °C was added *p*-nitrobenzoyl chloride (48.0 mg, 0.26 mmol). After the mixture was stirred at rt for 1.5 h, H_2O (1.0 mL) was added at 0 °C, and the aqueous layer was extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:1) to afford 47.3 mg (76%) of **24** as a colorless crystal: mp 146.0−148.5 °C (recrystallized from AcOEt); IR (KBr) ν 1730, 1524, 1349, 1180 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.76 (d, J = 6.5 Hz, 3 H), 0.82 (d, J = 6.6 Hz, 3 H), 1.21−1.79 (m, 8 H), 2.02−2.21 (m, 2 H), 2.21 (dd, J = 3.2, 17.8 Hz, 1 H), 2.52−2.67 (m, 1 H), 2.70 (ddd, J = 1.1, 9.5, 17.8 Hz, 1 H), 3.23 (dd, J = 6.7, 12.2 Hz, 1 H), 3.79−4.10 (m, 2 H), 7.62 (d, J = 8.7 Hz, 2 H), 8.28 (d, J = 8.7 Hz, 2 H); MS (EI, m/z) 370 (M^+, 21), 355 (3), 340 (16), 271 (10), 220 (5), 150 (57), 120 (100); HRMS (EI, m/z) for $C_{21}H_{26}N_2O_4$, calcd 370.1893, found 370.1870. Anal. Calcd for $C_{21}H_{26}N_2O_4$: C, 68.46; H, 6.57; N, 7.60. Found: C, 68.16; H, 6.95; N, 7.51.

(3R,5S)-3-(*N*-Allyl-*N*-methylamino)-5-isopropenyl-2-methylcyclohexene (6b). (i) (3R,5S)-3-(*N*-Allylamino)-5-

isopropenyl-2-methylcyclohexene (*Trans* Isomer) and (3*R*,5*S*)-3-(*N*-Allylamino)-5-isopropenyl-2-methylcyclohexene (*Cis* Isomer). To a stirred solution of **15** (prepared from (−)-carveol (1.99 g, 13.0 mmol), CBr_4 (8.62 g, 26.0 mmol), and PPh_3 (6.83 g, 26.0 mmol)) in acetonitrile (2.6 mL) containing K_2CO_3 (3.60 g, 26.0 mmol) was at 0 °C added allylamine (3.0 mL, 39.0 mmol), and the solution was stirred at rt for 18 h. H_2O (1.0 mL) was added at 0 °C, and the aqueous layer was extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:8) to afford 1.31 g (53%) of the *trans* isomer and 644.8 mg (26%) of the *cis* isomer as colorless oils. ***Trans* isomer**: IR (neat) ν 3347, 1644 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.95 (br s, 1 H), 1.39 (ddd, J = 5.5, 12.7, 12.7 Hz, 1 H), 1.56−1.99 (m, 2 H), 1.75 (s, 3 H), 1.77 (s, 3 H), 2.02−2.20 (m, 1 H), 2.20−2.36 (m, 1 H), 2.92−3.06 (m, 1 H), 3.22 (dddd, J = 1.0, 1.0, 1.1, 10.1 Hz, 1 H), 3.38 (dddd, J = 1.1, 1.6, 5.7, 14.0 Hz, 1 H), 4.73 (br s, 2 H), 5.08 (dddd, J = 1.0, 1.0, 1.1, 10.1 Hz, 1 H), 5.20 (dddd, J = 1.0, 1.0, 1.6, 17.1 Hz, 1 H), 5.43−5.54 (m, 1 H), 5.92 (dddd, J = 5.7, 6.2, 10.1, 17.1 Hz, 1 H); MS (EI, *m/z*) 191 (M^+), 190, 176, 150, 108, 41 (bp); HRMS (EI, *m/z*) for $C_{13}H_{21}N$, calcd 191.1674, found 191.1657. ***Cis* isomer**: IR (neat) ν 3343, 1644 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.35 (ddd, J = 10.5, 12.1, 12.1 Hz, 1 H), 1.36−1.59 (br s, 1 H), 1.72 (s, 3 H), 1.74 (s, 3 H), 1.82−2.28 (m, 4 H), 3.16−3.35 (m, 1 H), 3.21 (dddd, J = 1.0, 1.0, 6.0, 13.8 Hz, 1 H), 3.29 (dddd, J = 1.1, 1.6, 5.6, 13.8 Hz, 1 H), 4.72 (br s, 2 H), 5.08 (dddd, J = 1.0, 1.0, 1.1, 10.2 Hz, 1 H), 5.20 (dddd, J = 1.0, 1.0, 1.6, 12.1 Hz, 1 H), 5.50−5.60 (m, 1 H), 595 (dddd, J = 5.6, 6.0, 10.2, 12.1 Hz, 1 H); MS (EI, *m/z*) 191 (M^+), 176, 150, 108, 91 (bp), 44; HRMS (EI, *m/z*) for $C_{13}H_{21}N$, calcd 191.1674, found 191.1703.

(ii) 6b. To a stirred suspension of the *trans* isomer (101.0 mg, 0.53 mmol) and K_2CO_3 (217.3 mg, 1.59 mmol) in acetonitrile (1.0 mL) at 0 °C was added iodomethane (66 μL, 1.06 mmol). After the mixture was stirred at rt for 19 h, H_2O (1.0 mL) was added. The aqueous layer was extracted with AcOEt, and the organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:20, 1:10) to afford 56.6 mg (52%) of **6b** as a colorless oil: IR (neat) ν 1643 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.33 (ddd, J = 6.6, 11.7, 13.8 Hz, 1 H), 1.73 (br s, 3 H), 1.74 (br s, 3 H), 1.76−2.31 (m, 4 H), 2.24 (s, 3 H), 2.93 (dd, J = 7.3, 13.6 Hz, 1 H), 3.05−3.19 (m, 1 H), 3.23 (dd, J = 5.2, 13.6 Hz, 1 H), 4.69 (br s, 1 H), 4.72 (br s, 1 H), 5.07 (br d, J = 10.0 Hz, 1 H), 5.17 (br d, J = 17.2 Hz, 1 H), 5.59−5.69 (m, 1 H), 5.80 (dddd, J = 5.2, 7.3, 10.0, 17.2 Hz, 1 H); MS (EI, *m/z*) 205 (M^+, 16), 190 (6), 164 (4), 150 (15), 134 (48), 122 (67), 108 (52), 96 (76), 72 (bp); HRMS (EI, *m/z*) for $C_{14}H_{23}N$, calcd 205.1830, found 205.1832.

(1*S*,4*R*,6*S*,8*S*,11*S*)-6-Isopropenyl-3,11-dimethyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-9-one (5b) and (1*R*,5*S*)-5-Isopropenyl-2-methyl-1-(methylamino)-2-cyclohexene (25). To a stirred suspension of Cp_2ZrCl_2 (167.2 mg, 0.57 mmol) in THF (1.0 mL) at −78 °C was added dropwise BuLi (1.70 M solution in hexane, 0.56 mL, 1.10 mmol), and the solution was stirred at −78 °C for 1 h. To the −78 °C solution was added **6b** (91.0 mg, 0.44 mmol) in THF (2.0 mL), and the solution was allowed to warm to rt. After the mixture was stirred at rt for 1.5 h, the argon atmosphere was exchanged for carbon monoxide, and the solution was stirred at rt for 15 h. The solution was cooled to 0 °C, and 10% HCl (10 mL) was added. After the mixture stirred at rt for 2 h, the resultant mixture was basified with K_2CO_3. Then AcOEt was added. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:20, MeOH−AcOEt, 1:5) to afford 14.5 mg (14%) of **5b** and 37.5 mg (52%) of **25** as colorless oils: **5b**: IR (neat) ν 1742, 1644 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.19−1.41 (m, 3 H), 1.34 (s, 3 H), 1.71−1.89 (m, 3 H), 1.74 (s, 3 H), 1.93−2.29 (m, 5 H), 2.09 (s, 3 H), 2.33 (dd, J = 6.1, 9.2 Hz, 1 H), 2.69 (d, J = 9.2 Hz, 1 H), 2.76 (ddd, J = 2.5, 10.6, 17.6 Hz, 1 H), 4.62−4.74 (m, 2 H); MS (EI, *m/z*) 233 (M^+, 43), 218 (2), 205 (10), 192 (3), 177 (3), 164 (19), 149 (6), 134 (74), 119 (43), 108 (28), 96 (51), 72 (100); HRMS (EI, *m/z*) for $C_{15}H_{23}NO$, calcd 233.1780, found 233.1789. **25**: IR (neat) ν 3374, 1645 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.42 (ddd, J = 10.7, 12.2, 12.2 Hz, 1 H), 1.71−1.79 (m, 3 H), 1.74 (s, 3 H), 1.82−2.32 (m, 4 H), 2.43 (s, 3 H), 2.91−3.32 (m, 1 H), 3.32−3.51 (m, 1 H), 4.73 (br s, 2 H), 5.59−5.68 (m, 1 H); MS (EI, *m/z*) 165 (M^+, 14), 150 (35), 134 (11), 97 (100), 82 (97), 71 (86); HRMS (EI, *m/z*) for $C_{11}H_{19}N$, calcd 165.1518, found 165.1498.

(1*S*,4*R*,8*S*,11*S*)-3-Benzyl-6-isopropylidene-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-9-one (28). A solution of **5a** (438.7 mg, 1.42 mmol) and TsOH (414.0 mg, 2.18 mmol) in dichloroethane (15.0 mL) was refluxed for 4 h. The solution was basified with K_2CO_3 at 0 °C, and AcOEt was added. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. After removal of the solvent, the residue was purified by column chromatography (AcOEt−hexane, 1:40, 1:10) to afford 367.5 mg (84%) of **28** as colorless crystals: mp 67.5−68.5 °C (recrystallized from hexane, at −78 °C); IR (KBr) ν 1728 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.32 (s, 3 H), 1.59 (s, 3 H), 1.77 (s, 3 H), 2.01 (dd, J = 3.9, 18.3 Hz, 1 H), 2.02−2.24 (m, 5 H), 2.30 (dd, J = 5.9, 9.1 Hz, 1 H), 2.43 (dd, J = 6.0, 15.9 Hz, 1 H), 2.56 (d, J = 9.1 Hz, 1 H), 2.61 (ddd, J = 2.1, 10.3, 18.3 Hz, 1 H), 3.00 (d, J = 13.9 Hz, 1 H), 3.02 (d, J = 13.2 Hz, 1 H), 4.03 (d, J = 13.2 Hz, 1 H), 7.16−7.31 (m, 5 H); MS (EI, *m/z*) 309 (M^+, 27), 281 (10), 266 (3), 218 (3), 148 (68), 134 (52), 119 (66), 91 (100); HRMS (EI, *m/z*) for $C_{21}H_{27}NO$, calcd 309.2093, found 309.2093. Anal. Calcd for $C_{21}H_{27}NO$: C, 81.51; H, 8.79; N, 4.53. Found: C, 81.44; H, 8.87; N, 4.47.

(1*S*,4*R*,6*S*,8*S*,9*R*,11*S*)-3-Benzyl-6-isopropenyl-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-9-ol (29). To a stirred solution of **5a** (415.7 mg, 1.34 mmol) in ethanol (12 mL) at 0 °C was added $NaBH_4$ (153.5 mg, 4.06 mmol). After the mixture was stirred at rt for 3 h, saturated NH_4Cl (1.0 mL) and AcOEt were added. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:5) to afford 379.2 mg (91%) of **29** as a colorless crystal: mp 47.5−48.5 °C; IR (KBr) ν 3164, 1640 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.23 (s, 3 H), 1.36−1.59 (m, 3 H), 1.73 (s, 3 H), 1.82−2.17 (m, 6 H), 2.25 (dd, J = 8.2, 9.5 Hz, 1 H), 2.63−2.82 (m, 1 H), 2.68 (d, J = 9.5 Hz, 1 H), 3.03 (d, J = 12.6 Hz, 1 H), 3.83−3.95 (m, 1 H), 4.04 (d, J = 12.6 Hz, 1 H), 4.69−4.75 (m, 2 H), 6.65 (br d, J = 6.0 Hz, 1 H), 7.19−7.37 (m, 5 H); MS (EI, *m/z*) 311 (M^+, 43), 296 (4), 294 (2), 255 (6), 228 (6), 220, 172 (21), 91 (100); HRMS (EI, *m/z*) for $C_{21}H_{29}NO$, calcd 311.2249, found 311.2237. Anal. Calcd for $C_{21}H_{29}NO$: C, 80.98; H, 9.38; N, 4.50. Found: C, 81.08; H, 9.38; N, 4.52. $[\alpha]^{20}_D$ = −40.7° (*c* 1.040, $CHCl_3$) (90% ee).

(1*S*,4*R*,6*S*,8*S*,11*R*)-3-Benzyl-6-isopropenyl-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]undecane (30). To a stirred solution of **29** (9.1 mg, 0.029 mmol) and DMAP (10.2 mg, 0.087 mmol) in CH_2Cl_2 (1 mL) at 0 °C was added phenoxythiocarbonyl chloride (6.0 μL, 0.044 mmol). After the mixture was stirred at rt for 2 h, the solvent was removed, and the resultant residue was purified by column chromatography (AcOEt−hexane, 1:10) to afford the thiocarbonate. A solution of the thiocarbonate in toluene (1.0 mL) containing Bu_3SnH (16.0 mL, 0.058 mmol) and azobis(isobutyronitrile) (1.0 mg, 0.0058 mmol) was heated at 75 °C with stirring for 1.5 h. After the mixture was cooled to rt, the solvent was removed, and the resultant residue was purified by column chromatography (1:40) to afford 5.7 mg (67%, 2 steps) of **30** as a colorless oil: IR (neat) ν 1644, 1603, 1495 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.18 (s, 3 H), 1.22−1.82 (m, 10 H), 1.70 (s, 3 H), 1.89−2.20 (m, 4 H), 2.25 (ddd, J = 1.2, 9.2, 9.2 Hz, 1 H), 2.48−2.63 (m, 1 H), 2.63 (d, J = 9.2 Hz, 1 H), 2.74 (d, J = 13.2 Hz, 1 H), 3.97 (d, J = 13.2 Hz, 1 H), 4.69 (br s, 2 H), 7.12−7.34 (m, 5 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.3, 140.6, 128.4, 128.2, 126.4, 108.0, 71.7, 63.4, 58.3, 48.6, 48.5, 47.2, 34.3, 33.1, 33.0, 31.6, 30.4, 26.4, 21.2; MS (EI, *m/z*) 295 (M^+, 33), 238 (11), 204 (19), 184 (11), 172 (30), 91 (100); HRMS (EI, *m/z*) for $C_{21}H_{29}N$, calcd 295.2300, found 295.2290. Anal. Calcd for its picrate $C_{27}H_{32}N_4O_7$: C, 61.82; H, 6.15; N, 10.68. Found: C, 61.67; H, 6.25; N, 10.52.

(1*S*,4*R*,8*S*,11*R*)-3-Benzyl-6-isopropyl-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]undec-5-ene (31), (1*S*,4*R*,8*S*,11*R*)-3-Benzyl-6-isopropyl-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]-undec-6-ene (32), and (1*S*,4*R*,8*S*,11*R*)-3-Benzyl-6-isopropylidene-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]-undecane (33). A stirred solution of **30** (27.2 mg, 0.092 mmol)

and *p*-TsOH (35.0 mg, 0.184 mmol) in dichloroethane (2.5 mL) was refluxed for 54 h. The solution was basified with K_2CO_3 at 0 °C, and AcOEt was added. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by flash column chromatography (AcOEt−hexane, 1:300, 1:200, 1:100) to afford 12.6 mg (46%) of **31** as colorless crystals, 6.9 mg (25%) of **32** as a colorless oil, and 3.3 mg (12%) of **33** as a colorless oil: **31**: mp 39.5−40.0 °C; IR (KBr) ν 1671 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.99 (d, J = 7.0 Hz, 3 H), 1.00 (d, J = 7.0 Hz, 3 H), 1.06 (s, 3 H), 1.33−1.44 (m, 1 H), 1.44−1.55 (m, 1 H), 1.64−1.88 (m, 4 H), 1.93−2.03 (m, 1 H), 2.08 (d, J = 4.5 Hz, 1 H), 2.20 (dd, J = 6.0, 8.8 Hz, 1 H), 2.16−2.31 (m, 2 H), 2.61 (d, J = 8.8 Hz, 1 H), 3.10 (d, J = 13.4 Hz, 1 H), 3.99 (d, J = 13.4 Hz, 1 H), 5.46−5.52 (m, 1 H), 7.15−7.32 (m, 5 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.4, 140.6, 128.5, 127.9, 126.4, 116.2, 69.2, 60.0, 58.4, 50.0, 49.5, 45.9, 35.3, 33.1, 32.2, 27.5, 27.1, 21.3, 21.00; MS (EI, *m/z*) 295 (M^+, 17), 280 (20), 252 (45), 167 (21), 91 (100); HRMS (EI, *m/z*) for $C_{21}H_{29}N$, calcd 295.2300, found 295.2282. Anal. Calcd for its picrate $C_{27}H_{32}N_4O_7$: C, 61.82; H, 6.15; N, 10.68. Found: C, 61.66; H, 6.21; N, 10.66. Mp of picrate 123.0−125.0 °C. **32**: IR (neat) ν 1605 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.99 (d, J = 7.0 Hz, 3 H), 1.01 (d, J = 6.9 Hz, 3 H), 1.11 (s, 3 H), 1.36−1.46 (m, 1 H), 1.46−1.80 (m, 5 H), 1.89−2.06 (m, 2 H), 2.06−2.24 (m, 4 H), 2.16 (dd, J = 3.3, 9.3 Hz, 1 H), 2.28 (dd, J = 2.1, 4.2 Hz, 1 H), 2.45 (dd, J = 1.5, 9.3 Hz, 1 H), 2.85 (d, J = 13.2 Hz, 1 H), 3.99 (d, J = 13.2 Hz, 1 H), 5.38 (br dd, J = 2.5, 2.5 Hz, 1 H), 7.12−7.32 (m, 5 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 140.7, 137.9, 128.4, 128.0, 126.4, 121.2, 69.5, 60.8, 58.2, 49.1, 48.8, 47.3, 35.2, 34.7, 32.8, 26.8, 25.1, 21.6, 21.2; MS (EI, *m/z*) 295 (M^+, 40), 280 (20), 252 (10), 91 (100); HRMS (EI, *m/z*) for $C_{21}H_{29}N$, calcd 295.2300, found 295.2298. Anal. Calcd for the picrate $C_{27}H_{32}N_4O_7$: C, 61.82; H, 6.15; N, 10.68. Found: C, 61.79; H, 6.21; N, 10.58. **33**: mp 27.5−28.0 °C; IR (KBr) ν 1604 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.14 (s, 3 H), 1.30−1.45 (m, 1 H), 1.48−1.87 (m, 3 H), 1.62 (s, 3 H), 1.67 (s, 3 H), 1.89−2.00 (m, 1 H), 2.00−2.18 (m, 4 H), 2.08 (dd, J = 7.2, 9.1 Hz, 1 H), 2.47−2.60 (m, 1 H), 2.53 (d, J = 9.1 Hz, 1 H), 2.66−2.78 (m, 1 H), 2.79 (d, J = 13.2 Hz, 1 H), 4.00 (d, J = 13.2 Hz, 1 H), 7.16−7.37 (m, 5 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 140.7, 128.4, 128.0, 126.9, 126.4, 122.7, 71.7, 61.0, 57.8, 50.3, 47.4, 33.8, 32.7, 30.1, 27.3, 27.0, 20.1, 20.0; MS (EI, *m/z*) 295 (M^+, 54), 280 (9), 212 (14), 204 (29), 122 (40), 91 (bp); HRMS (EI, *m/z*) for $C_{21}H_{29}N$, calcd 295.2300, found 295.2278. Anal. Calcd for its picrate $C_{27}H_{32}N_4O_7$: C, 61.82; H, 6.15; N, 10.68. Found: C, 61.49; H, 6.19; N, 10.52. Mp of picrate 175.5−176.0 °C.

(1*S*,4*S*,5*S*,6*S*,8*S*,11*R*)-3-Benzyl-6-isopropyl-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-5-ol (34). To a stirred solution of **31** (13.2 mg, 0.04 mmol) in diglyme (0.5 mL) at 0 °C was added dropwise BH_3·THF (1.10 M solution in THF, 0.41 mL, 0.40 mmol). After the mixture was stirred at 0 °C for 40 min, $Me_3NO·2H_2O$ (134.0 mg, 1.20 mmol) was added at 0 °C in one portion, and the solution was refluxed with stirring for 30 min. H_2O (1.0 mL) was added, and the resultant mixture was extracted with AcOEt. The organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:10) to afford 14.6 mg (quantitative) of **34** as a colorless oil: IR (neat) ν 3375 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.79 (d, J = 6.8 Hz, 3 H), 0.91 (d, J = 6.9 Hz, 3 H), 1.15 (s, 3 H), 1.08−1.95 (m, 11 H), 2.06 (dd, J = 7.9, 9.2 Hz, 1 H), 2.13 (d, J = 1.7 Hz, 1 H), 2.46 (dd, J = 1.6, 9.2 Hz, 1 H), 2.99 (d, J = 13.3 Hz, 1 H), 3.73 (dd, J = 1.7, 7.9 Hz, 1 H), 4.13 (d, J = 13.3 Hz, 1 H), 7.05−7.35 (m, 5 H); MS (EI, *m/z*) 313 (M^+, 10), 296 (15), 270 (44), 222 (10), 215 (7), 172 (33), 120 (8), 91 (100); HRMS (EI, *m/z*) for $C_{21}H_{31}NO$, calcd 313.2406, found 313.2386. Anal. Calcd for its picrate $C_{27}H_{34}N_4O_8$: C, 59.77; H, 6.32; N, 10.33. Found: C, 59.60; H, 6.29; N, 10.34.

(1*S*,4*S*,5*S*,6*S*,8*S*,11*R*)-3-(Benzyloxycarbonyl)-6-isopropyl-11-methyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-5-ol (Benzyl Carbamate Compound). A suspension of **34** (97.3 mg, 0.31 mmol) and 10% Pd on charcoal (95.3 mg) in AcOH (3.0 mL) was stirred at rt for 4 h under hydrogen. After the catalyst was filtered off, the solvent was removed. After the residue was dissolved in CH_2Cl_2 (3.0 mL) containing K_2CO_3 (855.3 mg, 6.2 mmol) and cooled to 0 °C, benzyl chloroformate (0.47 mL, 3.1 mmol) was added. After the mixture was stirred at rt for 12 h, H_2O (1.0 mL) at 0 °C, and the resultant mixture was extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:10) to afford 92.3 mg (83%) of the benzyl carbamate compound as a colorless crystal: mp 91.5−92.5 °C (recrystallized from hexane, at −78 °C); IR (KBr) ν 3439, 1678 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.77 (d, J = 7.2 Hz, 3 H), 0.92 (d, J = 7.2 Hz, 3 H), 1.25 (s, 3 H), 1.13−2.02 (m, 11 H), 3.03 (dd, J = 7.3, 11.2 Hz, 1 H), 3.40−3.51 (m, 1 H), 3.67 (d, J = 6.3 Hz, 1 H), 3.89 (dd, J = 9.4, 11.2 Hz, 1 H), 5.15 (s, 2 H), 7.25−7.42 (m, 5 H); MS (EI, *m/z*) 357 (M^+, 9), 266 (9), 222 (94), 204 (5), 91 (100); HRMS (EI, *m/z*) for $C_{22}H_{31}NO_3$, calcd 357.2304, found 357.2325. Anal. Calcd for $C_{22}H_{31}NO_3$: C, 73.92; H, 8.74; N, 3.92. Found: C, 73.77; H, 8.90; N, 3.80.

(1*S*,4*S*,5*S*,6*S*,8*S*,11*R*)-6-Isopropyl-3,11-dimethyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-5-ol (35). To a stirred solution of benzyl carbamate (40.9 mg, 0.11 mmol) in ether (1.0 mL) at 0 °C was added lithium aluminum hydride (42.5 mg, 1.1 mmol). After the mixture was stirred at 0 °C for 1 h, $Na_2SO_4·10H_2O$ was added at 0 °C, and the suspension was stirred at rt for 5 h. After the undissolved material was filtered off, the solvent was removed, and the resultant residue was purified by column chromatography (MeOH−AcOEt, 1:10) to afford 24.0 mg (92%) of **35** as a colorless crystal: mp 46.0−47.0 °C (recrystallized from hexane at −78 °C); IR (KBr) ν 3345 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.84 (d, J = 7.0 Hz, 3 H), 0.97 (d, J = 7.0 Hz, 3 H), 1.13−2.02 (m, 12 H), 1.20 (s, 3 H), 2.23 (dd, J = 7.2, 9.3 Hz, 1 H), 2.32 (s, 3 H), 2.69 (dd, J = 1.1, 9.3 Hz, 1 H), 3.63−3.71 (m, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 81.3, 70.6, 61.1, 51.9, 51.4, 47.5, 47.4, 41.9, 34.1, 31.9, 31.1, 28.9, 25.3, 20.9, 17.5; MS (EI, *m/z*) 237 (M^+, 18), 222 (15), 220 (34), 194 (100), 176 (16), 167 (26); HRMS (EI, *m/z*) for $C_{15}H_{27}NO$, calcd 237.2092, found 237.2073. Anal. Calcd for its picrate $C_{21}H_{30}N_4O_8$: C, 54.07; H, 6.48; N, 12.01. Found: C, 53.89; H, 6.62; N, 11.92. Mp of picrate 160.5−161.5 °C.

(1*S*,4*S*,8*S*,11*R*)-6-Isopropyl-3,11-dimethyl-3-azatricyclo-[6.2.1.0^{4,11}]undecan-5-one (36). To a stirred solution of **35** (24.0 mg, 0.10 mmol) in acetone (1.0 mL) at 0 °C was added Jones reagent (8 N, 0.13 mL). After the solution was stirred at rt for 6.5 h, ^{i}PrOH (1.0 mL) was added at 0 °C. The solution was basified with K_2CO_3 and extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:30) to afford 21.4 mg (91%, as a mixture of diastereomers) of **36** as a colorless oil: IR (neat) ν 1705 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.83 (d, J = 7.2 Hz, 6/3 H), 0.87 (d, J = 6.8 Hz, 3/3 H), 0.91 (d, J = 6.8 Hz, 3/3 H), 0.94 (d, J = 7.1 Hz, 6/3 H), 1.08 (s, 6/3 H), 1.15 (s, 3/3 H), 2.02 (s, 3/3 H), 2.14 (s, 6/3 H), 1.44−2.52 (m, 35/3 H), 2.74−2.99 (m, 4/3 H); MS (EI, *m/z*) 235 (M^+, 3), 220 (1), 207 (73), 192 (46), 164 (48), 122 (17), 109 (89), 96 (bp); HRMS (EI, *m/z*) for $C_{15}H_{25}NO$, calcd 235.1937, found 235.1920.

(1*S*,4*S*,6*R*,8*S*,11*R*)-6-Isopropyl-3,11-dimethyl-6-(phenylseleno)-3-azatricyclo[6.2.1.0^{4,11}]undecan-5-one (α-Phenylseleno Ketone Compound). To a stirred solution of diisopropylamine (0.42 mL, 2.99 mmol) in THF (2.0 mL) at −78 °C was added BuLi (1.61 M solution in hexane, 1.70 mL, 2.72 mmol). After the mixture was stirred at −78 °C for 30 min, HMPA (2.0 mL) was added at −78 °C. A solution of **36** (319.7 mg, 1.36 mmol) in THF (1.5 mL) was added to the solution at −78 °C. After the mixture was stirred at 0 °C for 30 min, PhSeBr (705.0 mg, 2.99 mmol) in THF (2.5 mL) was added at 0 °C, and the solution was stirred at rt for 1.5 h. H_2O (1.0 mL) was added at 0 °C, and the resultant mixture was extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:20) to afford 466.2 mg (88%) of the α-phenylseleno ketone compound as a colorless oil: IR (neat) ν 1684 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 0.75 (d, J = 7.0 Hz, 3 H), 1.19 (d, J = 7.0 Hz, 3 H), 1.38 (s, 3 H), 1.46−1.65 (m, 3 H), 1.72 (dd, J = 4.9, 13.3 Hz, 1 H), 1.79−2.18 (m, 4 H), 2.13 (s, 3 H), 2.21 (s, 1 H), 2.26 (dd, J = 6.6, 8.9 Hz, 1 H), 2.33 (dd, J = 13.3, 13.3 Hz, 1 H), 2.79 (d, J = 8.9 Hz, 1 H), 7.22−7.56 (m, 5 H).

(1*S*,4*S*,8*S*,11*R*)-6-Isopropyl-3,11-dimethyl-3-azatricyclo-

[6.2.1.0^{4,11}]undec-6-en-5-one (4). To a stirred solution of the α-phenylseleno ketone compound (524.3 mg, 1.34 mmol) in THF (14 mL) at −40 °C was added MCPBA (80%, 348.9 mg, 1.62 mmol) in one portion. After the mixture was stirred at −40 °C for 1 h and at rt for an additional 30 min, the solution was basified with saturated $NaHCO_3$ and extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. After removal of the solvent, the residue was purified by column chromatography (AcOEt−benzene, 1:30) to afford 228.7 mg (73%) of **4** as a colorless oil: IR (neat) ν 1669 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.00 (d, J = 6.6 Hz, 3 H), 1.04 (d, J = 7.0 Hz, 3 H), 1.17 (s, 3 H), 1.62−2.02 (m, 4 H), 2.14 (s, 3 H), 2.05−2.22 (m, 1 H), 2.27 (s, 1 H), 2.22−2.38 (m, 1 H), 2.47 (dd, J = 8.6, 9.7 Hz, 1 H), 2.75 (dd, J = 0.9, 9.7 Hz, 1 H), 2.80−2.93 (m, 1 H), 6.46 (d, J = 4.8 Hz, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.3, 142.0, 141.1, 80.0, 64.7, 53.5, 50.3, 48.3, 41.4, 34.2, 33.9, 26.7, 26.4, 22.0, 21.4; MS (EI, m/z) 233 (M$^+$, 26), 205 (32), 190 (24), 162 (27), 108 (44), 96 (100); HRMS (EI, m/z) for $C_{15}H_{23}NO$, calcd 233.1780, found 233.1799.

(1*S*,4*S*,7*S*,8*S*,11*R*)-6-Isopropyl-3,11-dimethyl-7-vinyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-5-one (37). To a stirred suspension of CuCN (62.9 mg, 0.7 mmol) in Et_2O (1.5 mL) at −78 °C was added vinyllithium (1.05 M solution in Et_2O, 1.35 mL, 1.42 mmol). After the mixture was stirred at 0 °C for 5 min, it was cooled to −78 °C, and a solution of **4** (81.7 mg, 0.35 mmol) in Et_2O (3.0 mL) was added. The resultant solution was stirred at −50 °C for 1 h. To the solution was added saturated NH_4Cl (1.0 mL) at −50 °C, and the resultant mixture was allowed to warm to rt. The aqueous layer was extracted with AcOEt, and the organic layer was washed with brine and dried over Na_2SO_4. After removal of the solvent, the residue was purified by column chromatography (AcOEt−hexane, 1:30) to afford 81.3 mg (89%) of **37** as colorless crystals: mp 31.0−32.0 °C (recrystallized from hexane, at −78 °C); IR (KBr) ν 1699 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.90 (d, J = 7.0 Hz, 3 H), 1.09 (s, 3 H), 1.11 (d, J = 7.0 Hz, 3 H), 1.30−1.40 (m, 1 H), 1.44−2.20 (m, 8 H), 2.09 (s, 1 H), 2.25 (dd, J = 7.2, 9.0 Hz, 1 H), 2.83 (d, J = 9.0 Hz, 1 H), 3.07 (ddd, J = 9.9, 11.0, 11.6 Hz, 1 H), 5.01 (dd, J = 2.2, 16.6 Hz, 1 H), 5.07 (dd, J = 2.2, 9.9 Hz, 1 H), 5.34 (ddd, J = 9.9, 9.9, 16.6 Hz, 1 H); MS (EI, m/z) 261 (M$^+$, 23), 233 (18), 218 (6), 190 (77), 109 (26), 108 (26), 96 (100).

(1*S*,4*R*,7*S*,8*S*,11*R*)-6-Isorpopyl-7-(methoxycarbonyl)-3,-11-dimethyl-3-azatricyclo[6.2.1.0^{4,11}]undecan-5-one (38). To a stirred solution of **37** (5.3 mg, 0.02 mmol) in 60% AcOH (0.5 mL) at rt was added dropwise a solution of RuO_2 (1.0 mg) containing periodic acid (45 mg, 0.2 mmol) in 60% AcOH (1.0 mL). After the mixture was stirred at rt for 10 min, the catalyst was filtered off, and the solvent was removed. The residue in MeOH (2.0 mL) at 0 °C was treated with CH_2N_2. The resultant mixture was extracted with AcOEt. The solution was washed with H_2O and brine, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography (AcOEt−hexane, 1:10) to afford 1.9 mg (32%) of **38** as a colorless oil: IR (neat) ν 1736, 1705 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.91 (d, J = 7.0 Hz, 3 H), 1.02 (d, J = 7.0 Hz, 3 H), 1.10 (s, 3 H), 1.50−1.90 (m, 5 H), 1.97−2.19 (m, 1 H), 2.14 (s, 3 H), 2.15 (s, 1 H), 2.23−2.34 (m, 2 H), 2.83 (d, J = 9.0 Hz, 1 H), 3.52 (dd, J = 11.1, 11.1 Hz, 1 H), 3.67 (d, J = 11.1 Hz, 1 H), 3.70 (s, 3 H); MS (EI, m/z) 293 (M$^+$, 2), 265 (44), 250 (15), 222 (85), 206 (38), 137 (48), 109 (100).

(*S*)-MTPA-(*R*)-39 and (*S*)-MTPA-(*S*)-39. To a 0 °C stirred solution of **29** (24.8 mg, 0.08 mmol) in CH_2Cl_2 (1.0 mL) containing pyridine (0.13 mL, 1.60 mmol) was added (*S*)-(−)-MTPA-Cl (0.15 mL, 0.80 mmol). After the solution was stirred at rt for 1.5 h, H_2O (1.0 mL) was added, and the resultant mixture was extracted with AcOEt. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. After removal of the solvent, the residue was purified by column chromatography (AcOEt−hexane, 1:5) to afford 41.5 mg (quantitative, as a mixture of diastereomers) of the MTPA ester as a colorless oil. The mixture was further purified by TLC (AcOEt−hexane, 1:50). **(*S*)-MTPA-(*R*)-39** (major diastereomer): IR (neat) ν 1744, 1644 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.12 (s, 3 H), 1.19 (m, 1 H), 1.35 (ddd, J = 2.2, 11.7, 14.5 Hz, 1 H), 1.61 (s, 3 H), 1.75 (ddd, J = 8.8, 10.3, 12.4 Hz, 1 H), 1.92 (ddd, J = 3.6, 7.1, 14.5 Hz, 1 H), 1.97 (ddd, J = 7.7, 8.6, 8.8 Hz, 1 H), 2.05 (m, 1 H), 2.05 (m, 1 H), 2.06 (m, 1 H), 2.12 (dd, J = 7.7, 9.5 Hz, 1 H), 2.30 (ddd, J = 6.9, 8.6, 12.4 Hz, 1 H), 2.43 (m, 1 H), 2.64 (d, J = 9.5 Hz, 1 H), 3.00 (d, J = 13.5 Hz, 1 H), 3.54 (s, 3 H), 3.96 (d, J = 13.5 Hz, 1 H), 4.58 (s, 1 H), 4.61 (s, 1 H), 5.36 (ddd, J = 6.9, 6.9, 10.3 Hz, 1 H), 7.20−7.60 (m, 10 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.4, 150.6, 139.6, 132.6, 130.0, 128.6, 128.4, 128.2, 127.2, 126.7, 124.9, 122.0, 108.1, 97.0, 69.7, 59.1, 57.7, 55.4, 49.0, 44.4, 36.8, 34.1, 27.7, 26.2, 22.8, 21.0; MS (EI, m/z) 527 (M$^+$, 16), 512 (1), 436 (2), 338 (1), 310 (3), 294 (22), 212 (10), 189 (19), 172 (13), 91 (bp), 77; HRMS (EI, m/z) for $C_{31}H_{36}NF_3O_3$, calcd 527.2648, found 527.2695. **(*S*)-MTPA-(*S*)-39** (minor diastereomer): IR (neat) ν 1740, 1644 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.12 (s, 3 H), 1.36 (ddd, J = 2.4, 11.8, 13.0 Hz, 1 H), 1.44 (m, 1 H), 1.68 (br s, 3 H), 1.68 (m, 1 H), 1.92 (m, 1 H), 1.96 (m, 1 H), 2.05 (dd, J = 2.4, 3.7 Hz, 1 H), 2.08 (m, 1 H), 2.10 (m, 1 H), 2.12 (dd, J = 7.2, 9.5 Hz, 1 H), 2.28 (ddd, J = 6.5, 8.5, 12.4 Hz, 1 H), 2.53 (m, 1 H), 2.54 (d, J = 9.5 Hz, 1 H), 3.06 (d, J = 14.0 Hz, 1 H), 3.53 (s, 3 H), 3.80 (d, J = 14.0 Hz, 1 H), 4.66 (s, 2 H), 5.33 (ddd, J = 6.5, 9.8, 12.8 Hz, 1 H), 7.02−7.60 (m, 10 H); MS (EI, m/z) 527 (M$^+$, 57), 512 (2), 470 (5), 436 (5), 338 (2), 310 (5), 294 (21), 254 (9), 189 (11), 172 (15), 91 (100), 77 (6); HRMS (EI, m/z) for $C_{31}H_{36}NF_3O_3$, calcd 527.2648, found 527.2646.

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Supplementary Material Available: Copies of ^{1}H NMR spectra of **17**, *cis*- or *trans*-**6b**, **25**, **36**, the α-phenylseleno ketone compound, **4**, **37**, **38**, (*S*)-MTPA-(*R*)-**39**, and (*S*)-MTPA-(*S*)-**39** (11 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from ACS; see any current masthead page for ordering information.