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Enantioselective Construction of Highly Functionalized Bicyclo[4.3.0] System through Diels-Alder Cycloaddition

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Abstract: The Diels-Alder reaction of chiral 2-alkylsulfinyl-1-nitroalkene **4** with Danishefsky's diene afforded adducts **9a** and **10a** in good chemical yield with a high enantiomeric excess, while diastereomeric nitroalkene **5** gave **9b** and **10b**, enantiomeric to **9a** and **10a**, respectively. The synthesis of the chiral dienophiles and mechanism of the chiral induction in the cycloaddition are discussed.

Introduction.

Recently, asymmetric induction utilizing optically active tricoordinate sulfur compounds has been developed and was successfully applied to the effective organic transformations, including alkylation,[2] [2,3]sigmatropic rearrangement,[3] conjugate addition[4] as well as cycloaddition reaction.[5] In connection with cycloaddition, the Diels-Alder reaction is one of the most efficient weapons in synthetic organic reactions. since its remarkable stereo- and regioselectivity and *endo* selectivity render possible control of the relative stereochemistries of up to four asymmetric centers of the cyclohexene ring in a single operation. Consequently, a combination of Diels-Alder reaction with asymmetric induction is a most powerful and attractive method for the C-C bond formation in predictable and controllable manner.

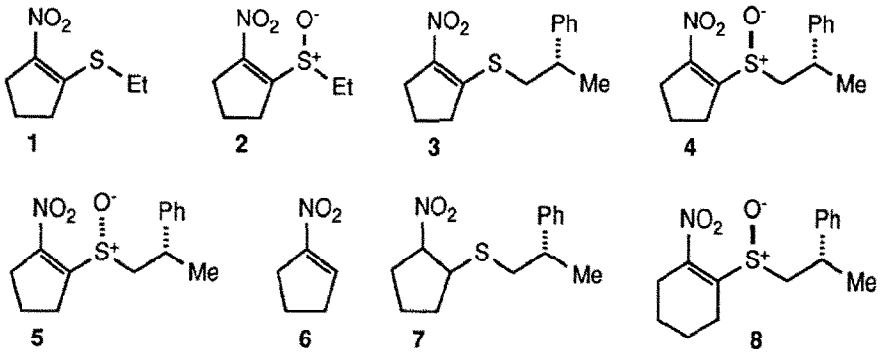
Among the tricoordinate sulfur compounds, the chiral sulfinylalkene is a promising candidate for a dienophile in asymmetric Diels-Alder reactions due to both the inherent electron-withdrawing nature and the location of the sulfinyl group in close proximity to the reaction center. However, drastic conditions or introduction of an additional activating group are often required for the progress of the cycloadditions, since simple sulfinylalkenes are unexpectedly inert towards dienes.[6] Although diastereoselective Diels-Alder reactions,[7] including their applications to natural product synthesis,[8] have been studied extensively, no report has appeared on their enantioselective version in which the chiral auxiliary is eliminated under the reaction conditions or during the work-up procedure.

As an activating group, we selected a nitro group at the β-position of the sulfinylalkenes. The nitro group is not only suitable for activating the dienophiles[9] is a versatile moiety for functional group

transformations.[10] Asymmetric reactions employing a chiral auxiliary have often faced difficulties in removing the auxiliary from the product in the later step. Recently, we reported a chiral induction based on the addition-elimination process with optically active 2-alkylsulfinyl-1-nitroalkene.[11] A methodology utilizing a chiral auxiliary as a leaving group[12] can be applicable to Diels-Alder reaction with chiral sulfinyl groups. By choosing the specific diene, the sulfinyl group can work not only as an activating and directing group but also as a good leaving group. Thus, the chiral sulfinyl group might be spontaneously extruded from the cycloadduct to provide one enantiomer directly. In this paper we report our full account[13] of investigations into the enantioselective Diels-Alder reaction of chiral 2-alkylsulfinyl-1-nitroalkenes with Danishefsky's diene.

Results and Discussion

Two independent routes were examined for the synthesis of the optically active dienophiles, 2-alkylsulfinyl-1-nitroalkenes **4** and **5**. Thus, 2-ethylthio-1-nitrocyclopentene (**1**), which was derived from 2-nitrocyclo-pentanone according to the published procedure,[14] was oxidized with OXONE to yield a racemic sulfoxide **2** in good yield. The sulfoxide **2** was then subjected to the sulfur-sulfur exchange reaction with optically active (*S*)-2-phenylpropanethiol, which is easily obtainable from (*S*)-2-phenylpropionic acid, resulting in the chiral sulfide **3** in satisfactory yield. Treatment of the chiral sulfide **3** with OXONE afforded easily separable mixture of two diastereomers **4** and **5** in a 3:1 ratio quantitatively. Separation of these diastereomers was effected by silica gel column chromatography to furnish the pure crystalline compounds of **4** and **5** after recrystallization.

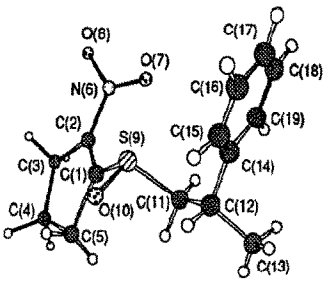


Alternatively, the chiral sulfide **3** was also prepared from 1-nitrocyclopentene (**6**).[15] Conjugate addition of (*S*)-2-phenylpropanethiol to **6** afforded the adduct **7**. Treatment of **7** with N-chlorosuccinimide (NCS) provided **3**. In spite of the fewer synthetic steps involved in this latter approach, the overall yield was poorer than that of the former route. The absolute configuration of the chiral sulfur in **4** was unambiguously determined to be *S* by an X-ray analysis, whose perspective view is shown in Figure 1. Thus, the chiral sulfur in **5** has *R*-configuration.

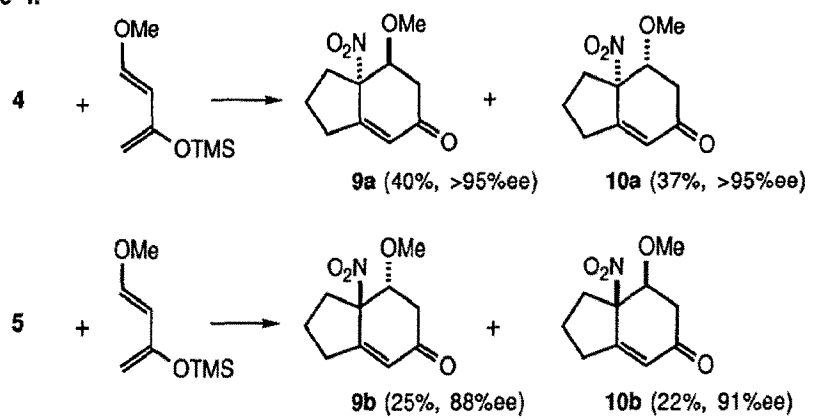
The [4+2]cycloaddition of a chiral 2-sulfinyl-1-nitroalkene **4** with Danishefsky's diene proceeded smoothly under mild conditions to give enones **9a** and **10a** in good chemical yield after an acidic work-up, with an elimination of the chiral auxiliary occurring expectedly in the cycloadducts. In this reaction, high enantioselectivities were observed for both *exo*- and *endo*-adducts **9a** and **10a**, though the *endo*/*exo* selectivity was poor. Enantiomeric excesses (ee) ware determined by ^{1}H NMR using Eu(hfc)$_3$ as a chiral shift reagent.

After several fruitless efforts, the absolute stereochemistries of the adducts **9a** and **10a** were determined by an X-ray analysis of the derivatized compound (*vide infra*). Similarly, Diels-Alder reaction of **5** having an opposite configuration at the sulfur with the same diene afforded *exo*- and *endo*-adducts **9b** and **10b** in an approximately 1:1 ratio with slightly lower enantioselectivities than those for **9a** and **10a**, respectively. These results indicate that the stereochemical course of cycloaddition is influenced little by the chiral center at the alkyl side chain but is controlled by that at the sulfur atom.

Figure 1. Crystal structure of **4**, showing the atom-labeling scheme. Note the nearly anti orientation of the S(9)-O(10) bond against the C(1)-C(2) double bond in the cyclopentene ring.



Scheme I.



Contrary to the five-membered dienophiles **4** and **5**, the six-membered analogue, (*SS*,2*S*)-2-(2-phenylpropylsulfinyl)-1-nitrocyclohexene (**8**),[11] was quite inert toward Danishefsky's diene under the same reaction conditions. Considering the fact that Diels-Alder cycloaddition primarily depends upon the steric factor in the ground state conformation, it is likely that the cyclohexene has the higher energy barrier for the transition state than the flatter cyclopentene derivative. Another reason is the degree of compression of the trigonal angle of the alkene in the cyclopentene compared with the effectively constrained double bond of the cyclohexane.

In order to determine the absolute stereochemistries of the cycloadducts **9** and **10**, these compounds were converted to (*S*)-camphanate esters whose X-ray analyses were undertaken. Reduction of **9a** with sodium borohydride gave a separable mixture of allylic alcohols **11** and **13** in 2:1 ratio. The predominant alcohol **11** was esterified with (*S*)-camphanic chloride to yield the ester **12**. On the other hand, the same

reduction of **10a** afforded **14** as a sole product, which was transformed into the ester **15** in a similar manner. The crystalline structures of **12** and **15** are shown in Figures 2 and 3 confirming the absolute stereochemistries of the Diels-Alder products.

Figure 2. Crystal structure of **12**, showing the atom-labeling scheme.

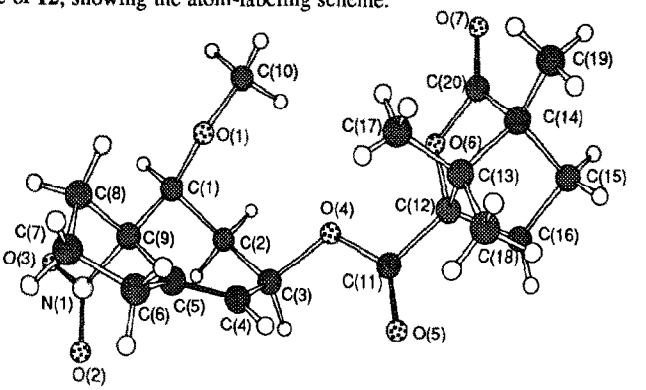
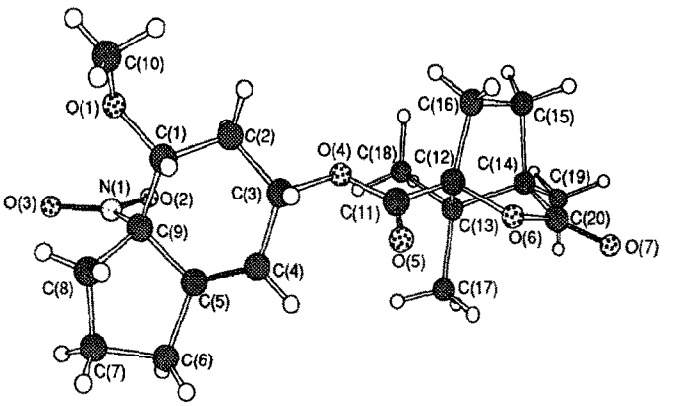
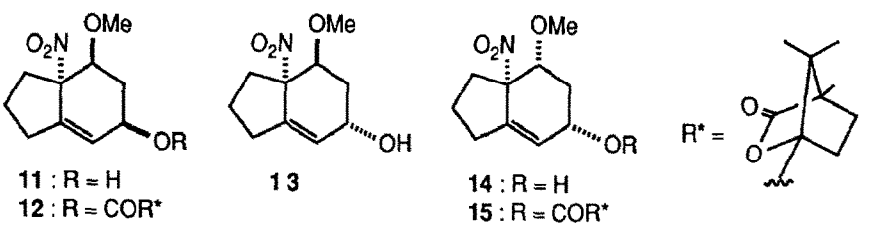


Figure 3. Crystal structure of **15**, showing the atom-labeling scheme.





11 : R = H
12 : R = COR*

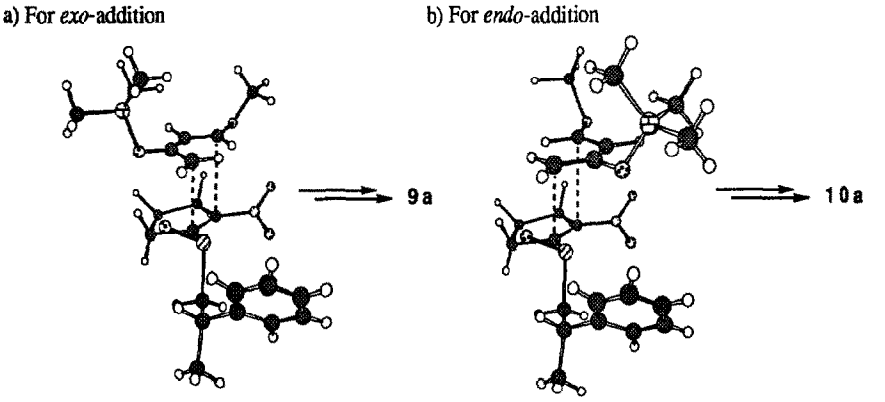
13

14 : R = H
15 : R = COR*

As previously mentioned, the steric factor in the ground state conformation primarily controls the stereochemistry observed in Diels-Alder reaction.[16] Thus, the more energetically favored conformation dictates the diastereofacial differentiation. The high enantioselectivities obtained in our Diels-Alder reactions could be deduced from the consideration on the conformation of the chiral sulfinyl dienophiles. The enantioselectivity should be determined by the difference in steric bulk between the alkyl group and the lone pair electrons on the sulfur. As can be seen from Figure 1, X-ray data on the dienophile **4** indicate an *s-trans*

conformation of the S(9)-O(10) bond to the olefinic bond (dihedral angle: O(10)-S(9)-C(1)-C(2) = 146.4°) probably owing to both electronic and steric repulsion between the nitro and the sulfinyl oxygen. Assuming the same conformation is preserved in solution, the *si*-face of the C(1) in **4** is totally hindered by the presence of the side chain attached to the sulfur. It is clearly seen from the Figure 4, generated through *Chem3D*, that the preferred mode of approach of the diene involves a *re*-attack to the C(1) in both cases of *exo*- and *endo*-addition resulting in the formation of **9a** and **10a**. The absolute stereochemistries of **9a** and **10a** observed in our asymmetric Diels-Alder reaction are well consistent with this transition model, which also accounts for the findings that the stereochemical course of the reaction were not regulated by the chiral center on the side chain but the chirality on the sulfur atom in dienophiles **4** and **5**.

Figure 4. Possible approach of the Danishefsky's diene to the nitroolefin **4**.



Conclusions

The present work clearly shows that asymmetric Diels-Alder reactions which lead to direct formation of one enantiomer are possible by correct choice of the chiral auxiliary attached to the diene. The chiral 2-alkylsulfinyl-1-nitroalkene is now proven to be an active dienophile having a substituent of excellent stereo-directing ability and ability to act as a good leaving group. The stereochemical outcome of the reaction can be well illustrated through a consideration of the transition state model based on the information about the ground state conformation of the dienophile obtained from the single X-ray crystallographic analysis. Despite the poor *exo*/*endo* selectivity, the present study provides an efficient method for the construction of the optically active functionalized cyclohexene derivatives, which present versatile and useful intermediates for the synthesis of biologically interesting compounds. More work is required to understand the mechanistic aspects and improve the *exo*/*endo* selectivity.

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Experimental Section

General. Melting points were measured on a Yanagimoto melting point apparatus and are uncorrected. Infrared spectra (IR) were recorded on a JASCO A-202 spectrophotometer in chloroform. Nuclear magnetic

resonance spectra (NMR) were taken with a Varian Gemini 200 (200 MHz) in $CDCl_3$ with chemical shift being reported as δ ppm from a tetramethylsilane as an internal standard and couplings are expressed in hertz. High resolution mass spectra (HRMS) were obtained with a JEOL JMS-DX300 mass spectrometer. Optical rotations were determined on a Horiba SEPA-200 polarimeter. Column chromatography was carried out with Wako-gel C-200 and Silica gel 60F-254 plates (E. M. Merck) were used for preparative TLC. All organic solutions were dried over anhydrous magnesium sulfate.

2-Ethylsulfinyl-1-nitrocyclopentene (2). To a solution of 2-ethylthio-1-nitrocyclopentene (**1**) (3.1 g, 17.9 mmol) in a mixture of tetrahydrofuran (50 ml), methanol (25 ml) and water (50 ml), was added portionwise OXONE (7.2 g, 11.6 mmol). The mixture was vigorously stirred for 3 h at room temperature. After extractive work-up with dichloromethane and purification by silica gel column chromatography with ethyl acetate, the sulfinyl compound **2** (3.4 g, 99%) was obtained as yellow oil: IR 3020, 1520, 1340 cm^{-1}; ^1H NMR δ 1.46 (t, J = 7.3, 3H), 2.13 - 2.24 (m, 2H), 3.09 (q, J = 7.3, 2H), 2.96 - 3.20 (m, 4H); ^{13}C NMR δ 7.46, 20.01, 31.24, 32.40, 47.51, 149.13, 161.95; HRMS *m/z* 189.0465. $C_7H_{11}NO_3S$ requires 189.0460.

(2*S*)-1-(2-Phenylpropylthio)-2-nitrocyclopentene (3). a) Triethylamine (2.7 ml, 19.6 mmol) was added dropwise to a solution of **2** (3.4 g, 17.8 mmol) and (*S*)-2-phenylpropanethiol (2.7 g , 17.8 mmol) in dry methylene chloride (50 ml) at -78°. The resulting mixture was further stirred at the same temperature for 50 min. The reaction mixture was poured into dil. HCl and extracted with methylene chloride. The extracts were washed with brine and dried. The solvent was removed under reduced pressure to give the crystalline residue which was recrystallized from ether to yield **3** (4.2 g, 89%) as yellow needles: mp 77.0 - 77.5°C; $[\alpha]_D^{22}$ -121.3 (*c* 1.00, $CHCl_3$); IR 2980, 1570, 1470, 1335, 1310 cm^{-1}; ^1H NMR δ 1.43 (d, J = 6.8, 3H), 2.03 (m, 2H), 2.84 (m, 2H), 2.93 (m, 2H), 3.03 (m, 2H), 3.14 (m, 1H), 7.21 - 7.35 (m, 5H); ^{13}C NMR δ 20.49, 20.98, 31.23, 36.02, 40.01, 40.45, 127.23, 127.40, 129.13, 142.00, 144.65, 158.17; Anal. Calcd for $C_{14}H_{17}NO_2S$: C, 63.86; H, 6.51; N, 5.32. Found: C, 63.83; H, 6.44; N, 5.22.

b) Triethylamine (2.2 ml, 15.5 mmol) was added dropwise to a stirred solution of 1-nitrocyclopentene (**6**, 1.6 g, 14.1 mmol) and (*S*)-2-phenylpropanethiol (2.2 g, 14.1 mmol) in dry methylene chloride (20 ml) at 0° and the mixture was stirred at the same temperature for 20 min and then poured into 1N HCl. Extraction with methylene chloride and concentration under reduced pressure gave the oily residue. Purification of the residue by silica gel column chromatography with hexane-ethyl acetate (9:1) yielded a mixture of four distereomers (**7**, 2.2 g, 58%), which was used directly for the next oxidation without further purification. Thus, a solution of the above mixture of the sulfides **7** (2.2 g, 8.5 mmol) in methylene chloride (50 ml) was treated with N-chlorosuccinimide (1.1 g, 8.5 mmol) with stirring at 0° for 2 h. The resulting mixture was poured into water and extracted with methylene chloride. The extract was washed with brine, dried and evaporated under reduced pressure to leave a yellow residual oil. Purification of the residue by silica gel column chromatography with hexane-methylene chloride (2:1) afforded **3** (1.2 g, 52%).

(*SS*,2*S*)-1-(2-Phenylpropylsulfinyl)-2-nitrocyclopentene (4)[17] and (*SR*,2*S*)-1-(2-phenylpropylsulfinyl)-2-nitrocyclopentene (5). To a solution of **3** (3.1 g, 11.8 mmol) in a mixture of tetrahydrofuran (50 ml), methanol (25 ml), and water (50 ml) was added OXONE (4.7 g, 7.7 mmol). The mixture was vigorously stirred at room temperature for 3 h. After extractive work-up with methylene chloride the residue was purified by silica gel column chromatography with ethyl acetate-hexane (1:1). From the more polar fractions, the sulfinyl compound **4** (2.6 g, 77%) was obtained and recrystallized from methylene

chloride-hexane. From the less polar fractions, the minor sulfinyl compound **5** (0.8 g, 23%) was yielded, which was recrystallized from ether.

4: $[\alpha]_D^{20}$ -72.9 (*c* 1.68, $CHCl_3$); mp 137.5-138°C (needles); IR 3020, 1510, 1340 cm^{-1}; ^1H NMR δ 1.46 (d, J = 7.3, 3H), 2.05 - 2.25 (m, 2H), 2.90 - 3.00 (m, 2H), 3.05 -3.15 (m, 2H), 3.18 - 3.32 (m, 2H), 3.45 - 3.50 (m, 1H), 7.27 - 7.41 (m, 5H); ^{13}C NMR δ 20.08, 22.76, 30.60, 32.49, 35.44, 61.20, 127.84, 127.88, 129.36, 143.09, 148.71, 162.78; Anal. Calcd for $C_{14}H_{17}NO_3S$: C, 60.20, H, 6.14, N, 5.02. Found: C, 60.11, H, 6.01, N, 4.76; crystal data: space group $P2_12_12_1$ with a = 13.468(3), b = 15.063(2), c = 6.920(1) Å and Dc = 1.322 g cm^{-3} for Z = 4.

5: $[\alpha]_D^{20}$ +388.3 (*c* 0.84, $CHCl_3$); mp 119 - 120°C (needles); IR 3020, 1510, 1350 cm^{-1}; ^1H NMR δ 1.57 (d, J = 6.8, 3H), 1.88 - 1.99 (m, 1H), 2.00 - 2.20 (m, 1H), 2.74 - 2.93 (m, 2H), 3.00- 3.19 (m, 3H), 3.34 (m, 1H), 3.46 - 3.57 (m, 1H), 7.20 - 7.36 (m, 5H); ^{13}C NMR δ 19.85, 20.46, 30.79, 32.24, 33.84, 60.97, 127.37, 127.46, 129.23, 144.65, 148.60, 162.59; Anal. Calcd for $C_{14}H_{17}NO_3S$: C, 60.20, H, 6.14, N, 5.02. Found: C, 60.02, H, 6.15, N, 5.03.

(1*S*,2*S*)-Bicyclo[4.3.0]-1-nitro-2-methoxy-5-nonene-4-one (9a) and (1*S*,2*R*)-bicyclo[4.3.0]-1-nitro-2-methoxy-5-nonene-4-one (10a). Danishefsky's diene (580 µl, 3.00 mmol) was added to a solution of **4** (210 mg, 0.75 mmol) in dry methylene chloride (5 ml) under nitrogen atmosphere, and the solution was allowed to stand for 39 h at an ambient temperature. The mixture was poured into in 5% HCl and the resulting mixture was stirred for 5 min at 0°. After extraction with methylene chloride, the extracts were washed with brine, dried and evaporated to leave a residue which was subjected to silica gel column chromatography with hexane-ethyl acetate (4:1) to give **9a** (65 mg, 40%) and **10a** (58 mg, 37%) as an oil.

9a : $[\alpha]_D^{22}$ +87.1 (*c* 1.00, $CHCl_3$); IR 1675, 1540, 1095 cm^{-1}; ^1H NMR δ 1.71 - 2.07 (m, 2H), 2.32 - 2.98 (m, 6H), 3.44 (s, 3H), 4.39 (t, J = 2.7, 1H), 6.16 (brs, 1H); ^{13}C NMR δ 21.55, 30.97, 34.33, 37.65, 58.33, 78.13, 97.01, 127.14, 158.83, 195.04; Anal. calcd for $C_{10}H_{13}NO_4$: C, 56.87, H, 6.20, N, 6.63. Found: C 56.85, H, 6.24 N, 6.36.

10a: $[\alpha]_D^{22}$ + 302.5 (*c* 1.62, $CHCl_3$); IR 1670, 1555, 1115 cm^{-1}; ^1H NMR δ 1.72 - 2.08 (m, 3H), 2.51 - 2.74 (m, 2H), 2.64 (dd, J = 11.4,17.5, 1H), 2.86 (dd, J = 5.9, 17.5, 1H), 3.36 (m, 1H), 3.48 (s, 3H), 3.82 (dd, J = 5.9, 11.4, 1H), 6.24 (brs, 1H); ^{13}C NMR δ 21.46, 29.64, 36.25, 38.47, 58.22, 80.31, 97.27, 129.58, 160.12, 196.99; Anal. Calcd. for $C_{10}H_{13}NO_4$: C, 56.87, H, 6.20, N, 6.63. Found: C, 56.63, H, 6.14, N, 6.43.

(1*R*,2*R*)-Bicyclo[4.3.0]-1-nitro-2-methoxy-5-nonene-4-one (9b) and (1*R*,2*S*)-bicyclo-[4.3.0]-1-nitro-2-methoxy-5-nonene-4-one (10b). A mixture of Danishefsky's diene (120 µl, 612 µmol), **5** (43mg, 153 µmol) and dry methylene chloride (3 ml) was allowed to stand at an ambient temperature under nitrogen atmosphere for 30 h. The reaction mixture was worked up and the resulting residue was purified in the same way as above to yield **9b** (8 mg, 25%) and **10b** (7 mg, 22%) as colorless oil. Spectroscopic data of **9b** and **10b** were completely identical with those of **9a** and **10a**, respectively. **9b:** $[\alpha]_D^{20}$ -79.0 (*c* 0.48, $CHCl_3$); **10b:** $[\alpha]_D^{20}$ -288.1 (*c* 0.21, $CHCl_3$).

(1*S*,2*S*,4*R*)-Bicyclo[4.3.0]-1-nitro-2-methoxy-5-nonene-4-ol (11) and (1*S*,2*S*,4*S*)-bicyclo[4.3.0]-1-nitro-2-methoxy-5-nonene-4-ol (13). A solution of **9a** (33 mg, 156 µmol) in methanol (3 ml) was treated with sodium borohydride (5.9 mg, 156 µmol) under stirring at an ambient temperature for 1 h. The reaction mixture was poured into water and extracted with methylene chloride. The

extracts were washed with brine and dried. Evaporation of the extract under reduced pressure gave the residue which was subjected to preparative TLC (methylene chloride) to give **11** (21 mg, 63%) and **13** (11 mg, 34%) as a colorless oil, respectively. **11:** $[\alpha]_D^{22}$ +192.1 (*c* 1.00, $CHCl_3$); IR 1540, 1110, 1085 cm^{-1}; ^1H NMR δ 1.55-1.95 (m, 3H), 2.28 - 2.77 (m, 6H, one exchangable with D_2O), 3.52 (s, 3H), 4.13 (brs, 1H), 4.23 (dd, J = 1.9, 3.7, 1H), 6.05 (d, J = 2.0, 1H); Anal. Calcd for $C_{10}H_{15}NO_4$: C, 56.33, H, 7.09, N, 6.57. Found: C, 56.28, H, 7.19, N, 6.49.

13: $[\alpha]_D^{22}$ +113.2 (*c* 0.57, $CHCl_3$); IR 1540, 1105, 1095 cm^{-1}; ^1H NMR δ 1.38 (ddd, J = 1.6, 9.2, 14.2, 1H), 1.60 - 1.91 (m, 2H), 2.25 - 2.74 (m, 5H), 3.47 (s, 3H), 4.20 (dd, J = 1.8, 3.8, 1H), 4.35 (brs, 1H), 5.91 (brs, 1H); HRMS *m/z* 167.1055. $C_{10}H_{15}NO_4$-NO_2 requires 167.1072; Anal. Calcd for $C_{10}H_{15}NO_4$: C, 56.33, H, 7.09, N, 6.57. Found: C, 55.92, H, 7.20, N, 6.40.

(1*S*,2*R*,4*S*)-Bicyclo-[4.3.0]-1-nitro-2-methoxy-5-nonene-4-ol (14). A mixture of **10a** (32 mg, 152 μmol), methanol (3 ml) and sodium borohydride (5.7 mg, 152 μmol) was stirred at 0° for 10 min and worked up in the same way as above. The extracts were washed with brine and dried. The solvent was removed under reduced pressure, and the resulting residue was subjected to purification by preparative TLC with hexane-ethyl acetate (1:1) to give **14** (30 mg, 92%) as a colorless oil. $[\alpha]_D^{22}$ +98.5 (*c* 1.13, $CHCl_3$); IR 1545, 1115, 1085 cm^{-1}; ^1H NMR δ 1.60 - 1.95 (m, 4H), 2.14 - 2.57 (m, 4H, one of them is exchangable with D_2O), 3.20 (m, 1H), 3.38 (dd, J = 4.0, 12.5, 1H), 3.48 (s, 3H), 4.40 (brs, 1H), 5.92 (d, J = 2.2, 1H); HRMS *m/z* 167.1064 $C_{10}H_{15}NO_4$-NO_2 requires 167.1072; Anal. Calcd for $C_{10}H_{15}NO_4$: C, 56.33, H, 7.09, N, 6.57. Found: C, 56.18, H, 7.23, N, 6.20.

Camphanate 12.[17] Triethylamine (21 μl, 146 μmol) and 4-*N*,*N*-dimethylaminopyridine (2.4 mg, 20 μmol) were successively added to a stirred mixture of **11** (21 mg, 98 μmol), (*S*)-camphanic chloride (25 mg, 117 μmol) and methylene chloride (2 ml) at 0° and the resulting mixture was stirred at the same temperature for a further 10 min. The reaction mixture was poured into 1N HCl at 0° and extracted with methylene chloride. The extract was washed with brine and dried . The solvent was removed under reduced pressure, and the residue was subjected to preparative TLC with hexane-ethyl acetate (1:1). The crude crystalline compond was recrystallized from methylene chloride to give the pure **12** (26 mg, 67%) as colorless prisms. mp 114-115°C ; $[\alpha]_D^{22}$ +151.9 (*c* 1.01, $CHCl_3$); IR 1790, 1725, 1540, 1275, 1110, 1095 cm^{-1}; ^1H NMR δ 0.96 (s, 3H), 1.06 (s, 3H), 1.11 (s, 3H), 1.56 - 2.10 (m, 7H), 2.26 - 2.77 (m, 5H), 3.43 (s, 3H), 4.17 (t, J = 2.6, 1H), 5.42 (brs, 1H), 5.94 (brs, 1H); HRMS *m/z* 347.1874. $C_{20}H_{27}NO_7$-NO_2 requires 347.1859; Anal. Calcd. for $C_{20}H_{27}NO_7$: C, 61.06, H, 6.92, N, 3.56. Found: C, 60.74, H, 6.94, N, 3.64; crystal data: space group C_2 with a = 22.897(5), b = 10.133(2), c = 8.970(1) Å and Dc = 1.307g cm^{-3} for Z = 4.

Camphanate 15.[17] In a similar way to the above procedure, the campanate **10** (43 mg, 78%) was obtained as colorless crystals from **14** (30 mg, 140 μmol). mp 190°C (decomp); $[\alpha]_D^{22}$ +72.7 (*c* 0.55, $CHCl_3$); IR 1790, 1745, 1545, 1270, 1110, 1060 cm^{-1}; ^1H NMR δ 0.99 (s, 3H), 1.08 (s, 3H), 1.13 (s, 3H), 1.60 - 2.20 (m, 7H), 2.30 -2.60 (m, 4H), 3.23 (m, 1H), 3.45 (dd, J = 4.0, 12.7, 1H), 3.56 (s, 3H), 5.61 (m, 1H), 5.87 (d, J = 2.2, 1H); Anal. Calcd for $C_{20}H_{27}NO_7$: C, 61.06, H, 6.92, N, 3.56. Found: C, 61.00, H, 6.87, N, 3.55; crystal data: space group $P2_12_12_1$ with a = 21.718(2), b = 12.216(1), c = 7.619(1) Å and Dc = 1.293g cm^{-3} for Z = 4.

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