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A New Procedure for Highly Stereoselective and Regioselective Synthesis of 2-Ethynyl-3-hydroxytetrahydropyran Derivatives Based on Alkyne-$Co_2(CO)_6$ Complex

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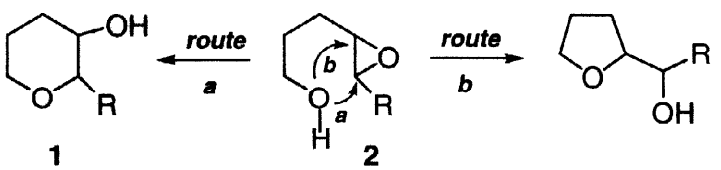
Abstract: Treatment of *trans*-epoxides **3** with $Co_2(CO)_8$ gave the corresponding cobalt complexes, which were subsequently exposed to a catalytic amount of $BF_3{\cdot}OEt_2$ at -78°C to provide exclusively *cis*-2-ethynyl-3-hydroxytetrahydropyran derivatives *via* endo mode cyclization pathway. *cis*-Congeners, *cis*-**3** afforded the corresponding *trans* tetrahydropyran derivatives exclusively. This novel cyclization has been found to proceed with retention of configuration at the propynyl stereogenic center. Requirement for stereoselectivity in cyclization was discussed. © 1997 Elsevier Science Ltd. All rights reserved.

Tetrahydropyran ring systems[1] have been frequently found to be the major component of many biologically important natural products.[2] One of the most straightforward process to build up the substituted tetrahydropyran skeletons like 3-hydroxy-2-substituted-tetrahydropyran derivative **1** would be ring opening of an epoxide by a terminal hydroxy group of 4,5-epoxy-5-substituted-pentan-1-ol **2** *via* endo mode ring closure (route *a*). According to Baldwin rules,[3] however, endo mode ring closure (route *a*) is generally regarded as an unfavorable pathway and competing exo mode ring closure (route *b*) is often preferred over route *a*. In order to override this disadvantage, several intriguing methods[4] (*e.g.* activation of epoxides by an adjacent vinyl moiety[4a,b,g] or by palladium catalyst[4c]) have so far been devised.



Scheme 1

Alkyne-$Co_2(CO)_6$ complexes, derived from propynyl ethers and dicobaltoctacarbonyl, have been well known to liberate easily, on treatment with Lewis acid, the corresponding propynyl cation species, which were subsequently captured by various nucleophiles (Nicholas reaction).[5] In the course of our program[6] directed toward the development of highly stereoselective carbon-carbon bond formation reactions mediated by alkyne-$Co_2(CO)_6$ complexes and their application to total syntheses of bioactive compounds, we paid much attention to the propynyl cation stabilizing ability of alkyne-$Co_2(CO)_6$ complex for regioselective endo mode ring

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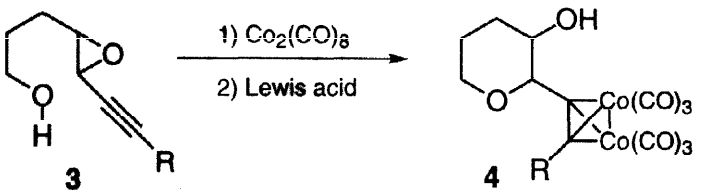
closure. We envisioned that the alkyne-$Co_2(CO)_6$ complex derived from alkyne-epoxide **3** possessing a terminal hydroxy group would, on exposure to acidic condition, generate the propynyl cation regioselectively. The cation stabilized by the cobalt complex moiety might be immediately captured in an endo mode fashion by a terminal primary alcohol resulting in exclusive formation of tetrahydropyran skeleton **4** (Scheme 2). This paper deals with the details[7] of a novel method for highly stereocontrolled synthesis of 2-ethynyl-3-hydroxytetrahydropyran derivatives through endo mode type ring closure of epoxy-alcohol derivatives as a crucial step.



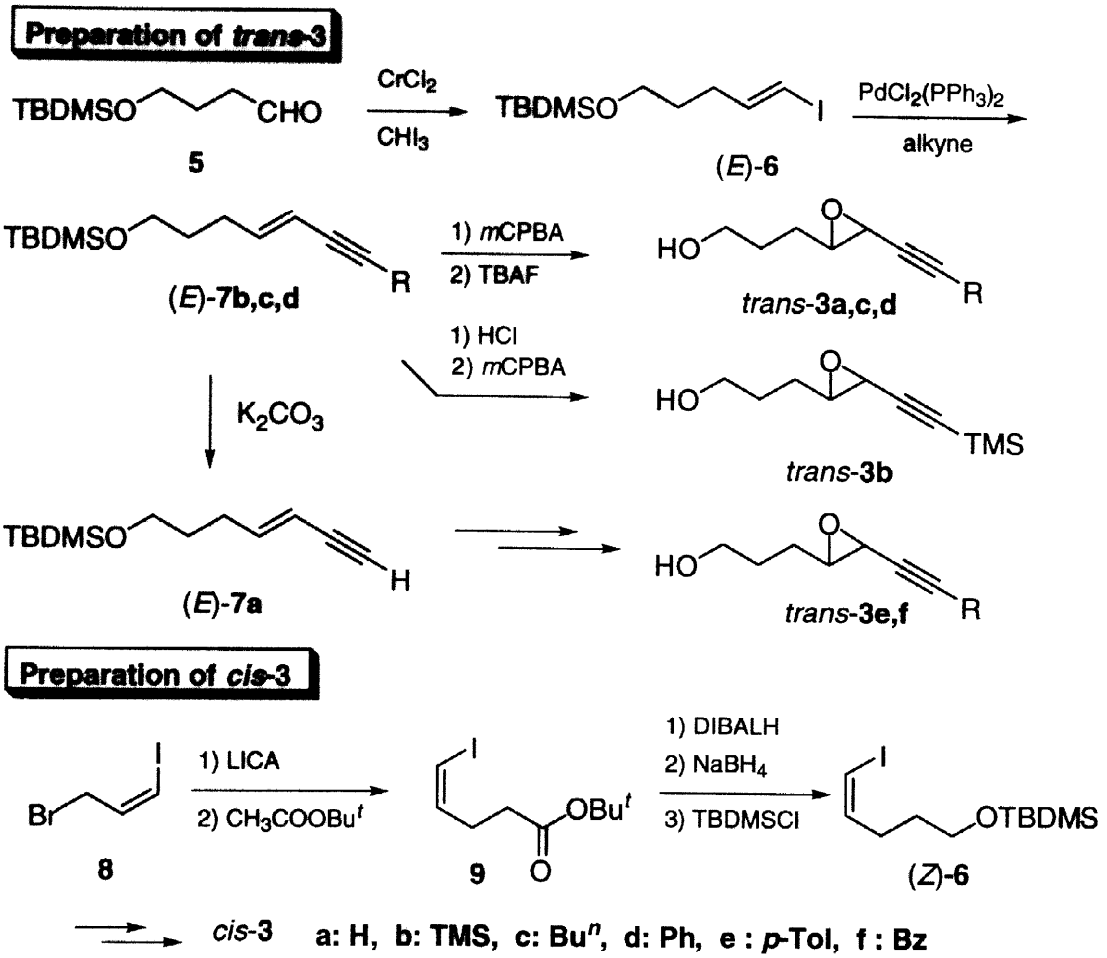
Scheme 2

Syntheses of *trans*- and *cis*-4,5-Epoxy-7-substituted-hept-6-yn-1-ols

The starting *trans*-alkyne-epoxides **3** were prepared as follows (Scheme 3). The aldehyde **5**[8] was treated with chromium (II) chloride ($CrCl_2$)[9] and iodoform in 1,4-dioxane/THF solution to give the iodo-olefin **6** *E*-selectively (*E* : *Z* = 89 : 11). Palladium catalyzed coupling reaction of (*E*)-**6** with trimethylsilylacetylene, phenylacetylene, and *n*-butylacetylene afforded (*E*)-**7b,c,d** in high yield. Enynes (*E*)-**7b,c,d** were subsequently exposed to oxidation condition with *m*CPBA and desilylation to produce *trans*-**3a,c,d** in 34 to 43% yield. Enyne (*E*)-**7b** was hydrolyzed with 1% HCl in EtOH to furnish the primary alcohol in 85% yield, which was converted into *trans*-**3b** in 42% yield under the standard epoxidation condition. In syntheses of *trans*-**3e,f**, the terminal TMS group of (*E*)-**7b** was first removed to produce (*E*)-**7a**. Palladium coupling of (*E*)-**7a** with *p*-iodotoluene was followed by oxidation and deprotection as described above to afford *trans*-**3e**, while *trans*-**3f** was prepared through (*E*)-**7f**. Treatment of (*E*)-**7a** with *n*-BuLi and benzoyl chloride to give (*E*)-**7f** which was converted into *trans*-**3f** under the standard condition. On the other hand, *cis*-alkyne-epoxides **3** were obtained from the known (*Z*)-iodo-olefin **8**.[10] Lithium enolate of *tert*-butyl acetate reacted with **8** to give **9** in 86% yield. Reduction of the ester moiety of **9** provided the corresponding alcohol, which was then protected with *tert*-butyldimethylsilyl (TBDMS) group to furnish (*Z*)-**6** in 84% yield. Palladium coupling of (*Z*)-**6** with alkynes gave (*Z*)-**7**. Transformation of (*Z*)-**7** to *cis*-**3** was undertaken by applying the method shown for conversion of (*E*)-**7** into *trans*-**3** (see Experimental Section).

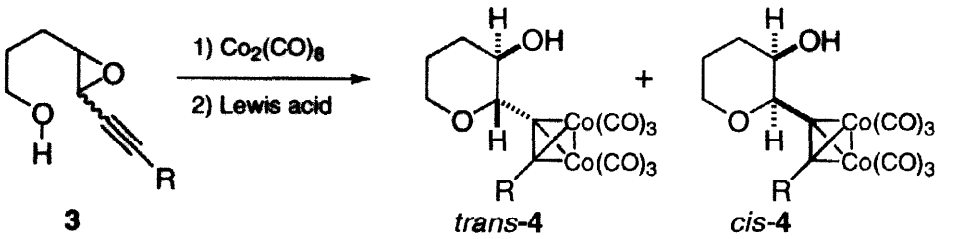
Ring Closure of Epoxides 3

At the outset, *trans*-**3b** was first taken to search for what level of regioselectivity as well as stereoselectivity might be attained in cyclization reaction of cobalt-complexed **3** in the presence of Lewis acid. Thus, treatment of *trans*-**3b** with dicobaltoctacarbonyl in methylene chloride at room temperature to give the corresponding cobalt-complexed *trans*-**3b**, which was subsequently treated with a catalytic amount of $TiCl_4$ (0.1 equiv.) at -78°C to afford tetrahydropyran derivative **4b** (*trans* : *cis* = 26 : 74) in 22% yield. Cyclization proceeded in an endo mode rather than in an exo mode manner (Scheme 1), although chemical yield was fairly



Scheme 3

low. No tetrahydrofuran derivatives due to exo mode type ring closure was detected in the reaction mixture. Significant improvement on chemical yield and stereoselectivity could hardly be made, when Lewis acid was changed from $TiCl_4$ to $SnCl_4$, Et_2AlCl, and $EtAlCl_2$, [$SnCl_4$ (58%; *trans* : *cis* = 34 : 66); Et_2AlCl (9%; *trans* : *cis* = 50 : 50); $EtAlCl_2$ (20%; *trans* : *cis* = 43 : 57)]. We assumed those low yields would be mainly attributed to chloride anion liberated from Lewis acid employed as the reaction proceeded. Attack of chloride anion to an epoxy ring would result in undesired side reactions. Finally, $BF_3{\cdot}OEt_2$ was found to be a suitable Lewis acid for this kind of ring closure reaction. On exposure of cobalt-complexed *trans*-**3b** to a catalytic amount of $BF_3{\cdot}OEt_2$ (0.1 equiv.) at -78°C, ring closure occurred cleanly to give **4b** in 86% yield. Interestingly retention of configuration at the propynyl position of cyclized product was observed (*trans* : *cis* = 9 : 91: Table 1, entry 2). It should be mentioned that same regioselectivity and stereoselectivity were achieved when trifluoroacetic acid (0.1 equiv.) was used instead of $BF_3{\cdot}OEt_2$ (86%, *trans* : *cis* = 9 : 91). Stoichiometric amount of $BF_3{\cdot}OEt_2$ also worked well, but stereoselectivity was somewhat lower (84%, *trans* : *cis* = 35 : 65). Thus, we could find out the suitable reaction condition for regiocontrol and high stereoselectivity (retention of configuration).



3 *trans*-4 *cis*-4

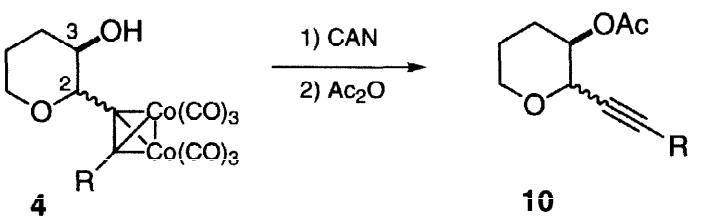
a: H, b: TMS, c: Bu^n, d: Ph, e : *p*-Tol; f : Bz

Table 1. Ring Closure of Cobalt-Complexed 3

entry	substrate	R	product 4 (*trans* : *cis*)[a]	yield (%)[b]
1	*trans*-**3a**	H	**4a** (*trans* : *cis* = 4 : 96)	65
2	*trans*-**3b**	TMS	**4b** (*trans* : *cis* = 9 : 91)	86
3	*trans*-**3c**	Bu^n	**4c** (*trans* : *cis* = 3 : 97)	97
4	*trans*-**3d**	C_6H_5	**4d** (*trans* : *cis* = 1 : 99)	96
5	*trans*-**3e**	*p*-CH_3-C_6H_4	**4e** (*trans* : *cis* = 2 : 98)	98
6	*trans*-**3f**	C_6H_5CO	**4f** (*trans* : *cis* = 2 : 98)	90
7	*cis*-**3a**	H	**4a** (*trans* : *cis* = 99 : 1)	92
8	*cis*-**3b**	TMS	**4b** (*trans* : *cis* = 100: 0)	88
9	*cis*-**3c**	Bu^n	**4c** (*trans* : *cis* = 99 : 1)	92
10	*cis*-**3d**	C_6H_5	**4d** (*trans* : *cis* = 99 : 1)	93
11	*cis*-**3e**	*p*-CH_3-C_6H_4	**4e** (*trans* : *cis* = 97 : 3)	95
12	*cis*-**3f**	C_6H_5CO	**4f** (*trans* : *cis* = 97 : 3)	89

[a] Ratio was determined on the basis of isolated amount of each isomer.
[b] The specific yields are isolated yields of each isomer.

Similar treatment of *cis*-**3b** gave *trans*-**4b** exclusively in 88% yield as expected (Table 1, entry 8). Further examples of successful endo mode cyclization of **3** *via* the corresponding cobalt complexes are listed in Table 1. Several intriguing features observed in the reaction of **3** to **4** deserve comment . (1) Exclusive formation of endo mode products (tetrahydropyran derivatives) was observed regardless of geometry of the starting epoxides **3**. (2) Ring formation took place with retention of configuration at the propynyl position resulting in a highly stereoselective construction of *trans*-2-ethynyl-3-hydroxytetrahydropyran skeleton from *cis*-epoxides and *cis*-congeners from *trans*-epoxides. (3) Irrespective of the electronic property of the terminal substituent on the triple bond, ring closure always proceeded in an endo mode fashion exclusively and exo mode products (tetrahydrofuran derivatives) were never found in more than trace quantities.



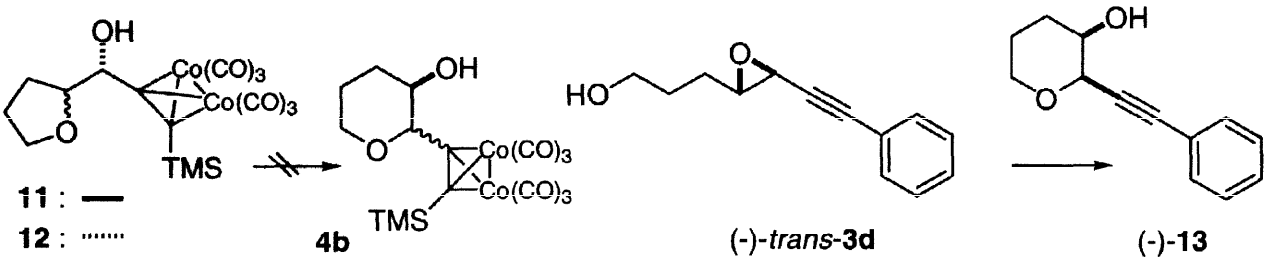
4 **10**

Scheme 4

Regeneration of the triple bond of **4** was realized by the conventional means with cerium (IV) ammonium nitrate (CAN)[11] in methanol to give demetallated compounds, which were subsequently acetylated affording **10** (Scheme 4). Stereochemistry of endo mode products **4** was easily confirmed by their spectral evidence (see Experimental Section). For example, ^{1}H NMR spectrum of *trans*-**4b** showed a larger coupling constant (8.8Hz) between H_2 and H_3 due to axial-axial coupling, while smaller one (broad singlet attributed to axial-equatorial coupling) was recognized in ^{1}H NMR spectrum of *cis*-**4b**. Transformation of **4** into **10** brought about diagnostic down filed shift of H_3 (for instance, 1.51 ppm in the case of *trans*-**4b** and 1.05 ppm in the case of *cis*-**4b**) strongly indicating that cyclized products **4** have tetrahydropyran skeleton, but not the corresponding tetrahydrofuran system (*e.g.* Scheme 1).

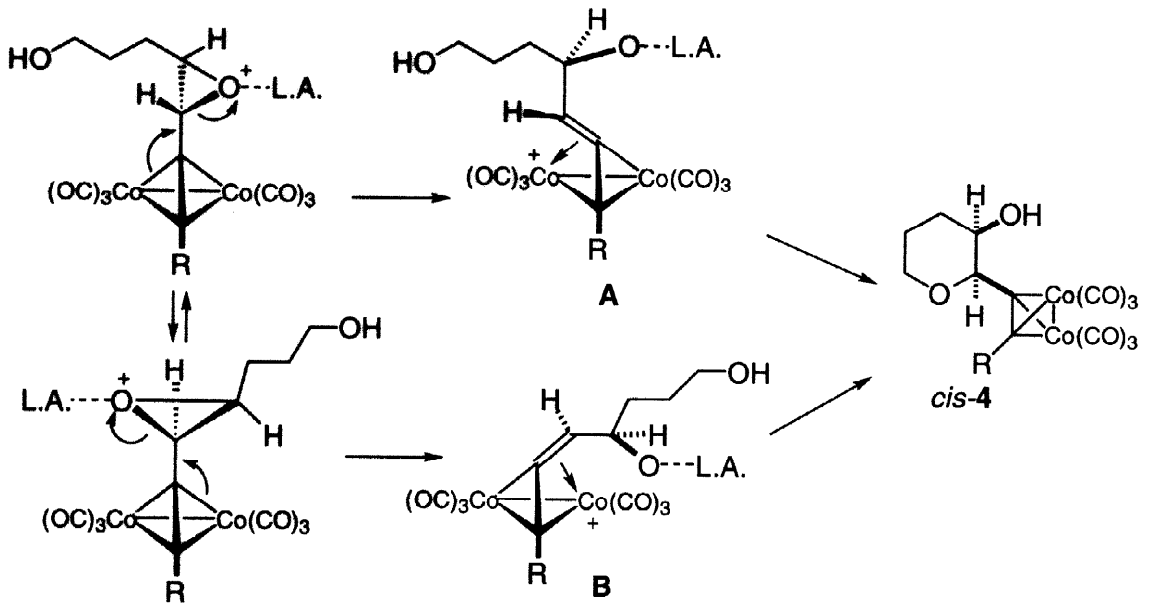
Consideration of Regioselectivity and Stereoselectivity

Exclusive formation of tetrahydropyran derivatives **4** (endo mode product) could be rationalized in terms of intermediacy of propynyl cation species resulted from neighboring group participation of alkyne-cobalt complex moiety.[5] Two possible isomerization processes during cyclization reaction, namely (i) epimerization of *trans*-**4** to *cis*-**4** and *vice versa*, and (ii) ring transformation of cobalt-complexed tetrahydrofuran derivatives to *trans*-**4** and/or *cis*-**4**, could be completely ruled out by the following several experiments (Scheme 5). When *trans*-**4b** and *cis*-**4b** were independently exposed to a catalytic amount of BF_3·OEt_2 in methylene chloride at -78°C, no reaction took place and the starting *trans*-**4b** and *cis*-**4b**, respectively, were recovered intact. On the other hand, independent treatment of cobalt-complexed tetrahydrofuran derivatives, **11** and **12**[12] with BF_3·OEt_2 under the standard condition described above provided recovery of the starting tetrahydrofuran derivatives intact again. These isomerization experiments obviously suggested that endo mode products **4** must be kinetically controlled ones.



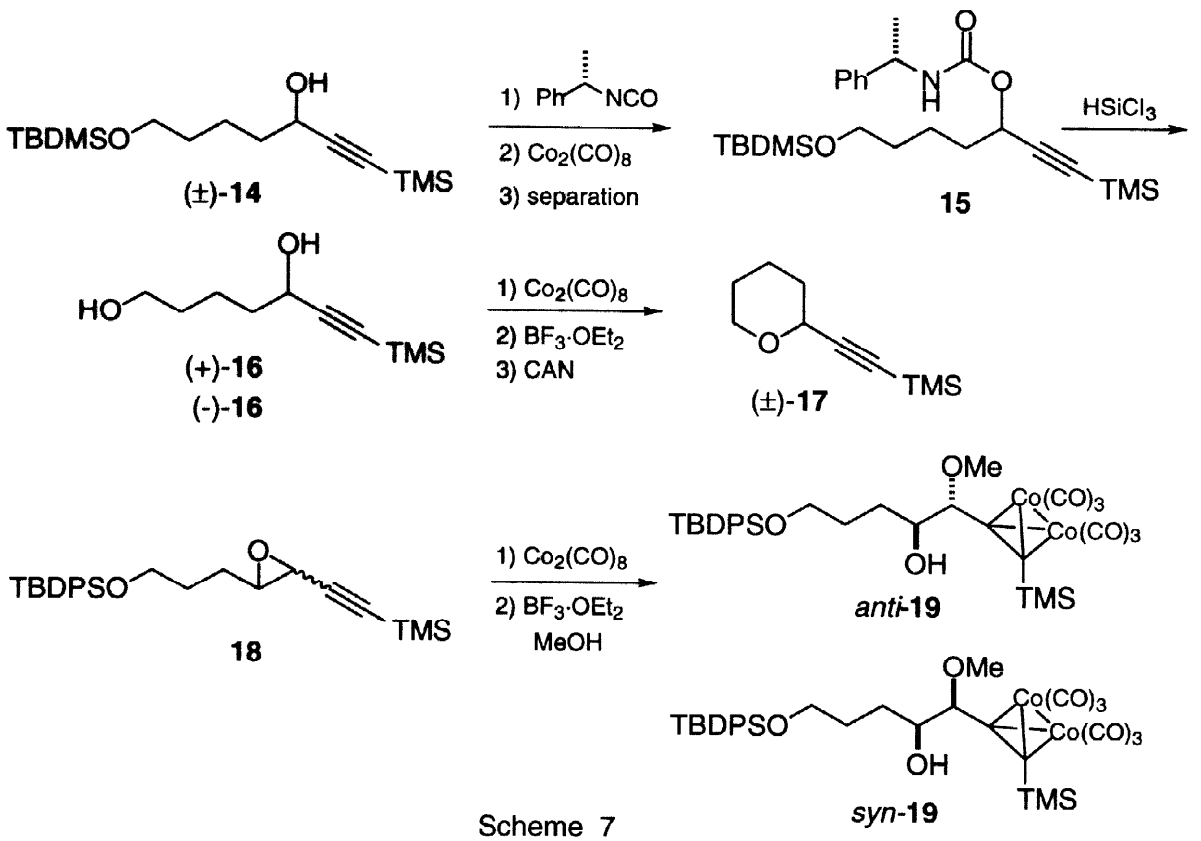
Scheme 5

Unexpectedly high stereoselectivity (retention of configuration at the propynyl position) was observed in the cyclization reaction of **3**. In addition, optically active *trans*-epoxide, (-)-*trans*-**3d** (90% e.e.)[13,14], prepared from (*E*)-**7d** by Sharpless procedure,[15] furnished the cyclized product (-)-**13** (86% e.e.)[14,16] in 89% yield upon successive treatment with $Co_2(CO)_8$, BF_3·OEt_2, and CAN (Scheme 5). These observation might be tentatively interpreted by a stepwise mechanism. Scheme 6 depicts the plausible pathway[17] for transformation of *trans*-**3** into *cis*-**4**. The first step would involve carbon-oxygen bond cleavage of epoxide moiety of cobalt-complexed *trans*-**3** by anchimeric assistance of cobalt atom from its back side in the way of antiperiplanar leading to inversion at the propynyl stereogenic center. In the second step, the cationic intermediates **A**, **B** thus formed in the first step would be immediately captured by an internal nucleophile (terminal hydroxy group) with



Scheme 6

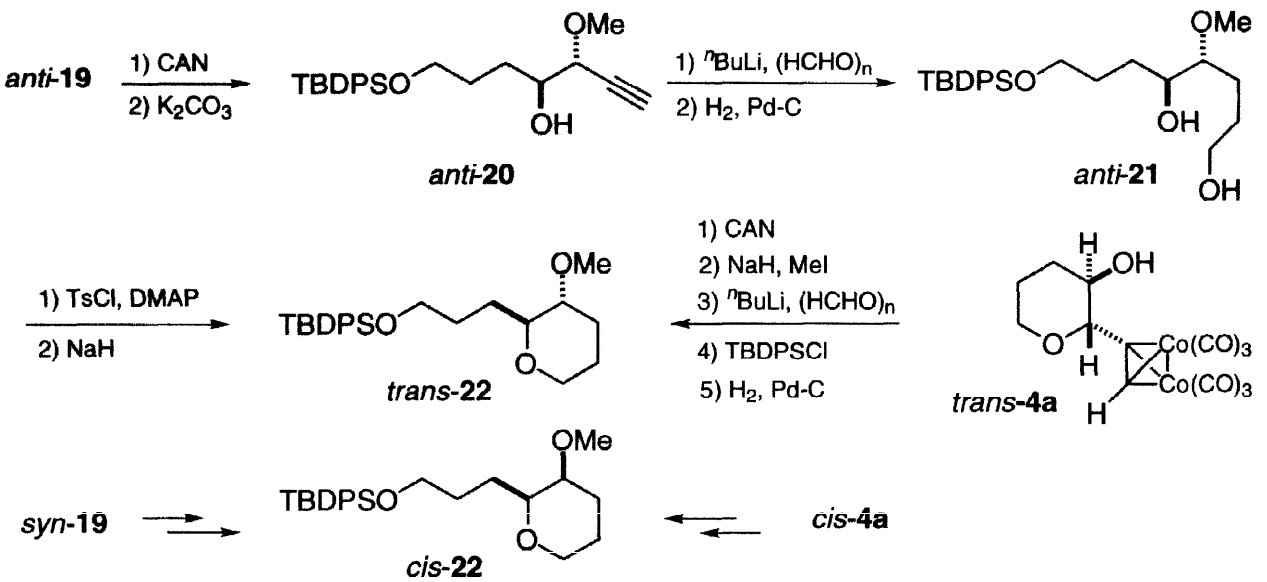
inversion of configuration again from the same face on which the cleaved carbon-oxygen bond originally oriented resulting in exclusive formation of *cis*-**4**. Double inversion process, therefore, would end up retention of configuration at the propynyl position of **4**. According to the above consideration on stereoselectivity



Scheme 7

(retention of configuration), an epoxide functionality at the propynyl position seemed not to be mandatory to attain high stereoselectivity. In order to confirm that, **14** was optically resolved by the method reported previously[18] (Scheme 7). A mixture of (±)-**14** and (*S*)-1-phenylethyl isocyanate was heated in the presence of *N,N*-dimethyl-2-aminoethanol to provide the corresponding carbamates **15**. Because of difficulty of direct separation, carbamates **15** were converted to the cobalt-complexed ones, which were easily isolated by column chromatography and subsequently treated with CAN to give two chiral carbamates **15**. Chiral auxiliaries of **15** were then removed by $HSiCl_3$[19] in benzene to afford (+)- and (-)-**16**. The diol (+)-**16** was converted to the corresponding cobalt-complexed **16**, which was treated with $BF_3{\cdot}OEt_2$ (1.0 equiv.) at -78°C to 0°C (due to somewhat lower reactivity of **16** compared to that of **3**) to afford, after decomplexation, the racemic tetrahydropyran derivative **17**.[20] The similar result was obtained when (-)-**16** was exposed to the same conditions to furnish racemic **17**. Complete racemization[17,20] during cyclization of optically active **16** indicated that an epoxide functionality as a leaving group might be necessary for high stereoselectivity (retention of configuration).

Another question arisen from the above speculation on stereoselectivity was whether intramolecular version would be essential for retention of configuration. Thus intermolecular capture of the propynyl cation stabilized by cobalt complex moiety was made (Scheme 7). *trans*-Epoxide **18**, after cobalt complexation, was treated with a stoichiometric amount of $BF_3{\cdot}OEt_2$ in the presence of methanol as an external nucleophile in methylene chloride at -78°C to provide **19** in 62% yield in an *anti*-selective manner (*anti* : *syn* = 71 : 29). Interestingly enough, similar *anti*-selectivity (66%, *anti* : *syn* = 80 : 20) was observed in the case of *cis*-**18**. Similar non-selective ring opening of 1,2-epoxy-1-ethynylcyclohexane with methanol was reported by Nicholas.[21] Stereochemical outcome of **19** was unambiguously established by chemical transformation (Scheme 8). Decomplexation of *anti*-**19** was followed by treatment with potassium carbonate to afford *anti*-**20** in 73% yield. Carbon elongation reaction of *anti*-**20** was realized by consecutive hydroxymethylation and hydrogenation producing *anti*-**21** in 88% yield, ring closure of which was undertaken by activation of the primary alcohol and base treatment to furnish *trans*-**22**. This compound was identical with the one derived from



Scheme 8

trans-**4a** *via* demetallation, methylation, hydroxymethylation, silylation, and hydrogenation. The minor product, *syn*-**19** was shown to have the same stereochemistry as that of *cis*-**4a** by similar chemical transformation.

Similar ratio between *anti*-**19** and *syn*-**19** was recorded from different starting epoxides (*trans*- and *cis*-**18**). No stereoselectivity (retention of configuration) was recognized in the case of intermolecular version. Acid treatment of cobalt-complexed **18** would produce the corresponding propynyl cations according to the way as shown in Scheme 6. In the case of **3** a terminal hydroxy group would instantly and intramolecularly attack the propynyl cations before their epimerization at the propynyl center occurs. In other words, intramolecular capture of cation would be much faster than epimerization process. Intermolecular capture of the propynyl cation by methanol in the case of **18**, however, would not be as fast as that of intramolecular one. The plausible propynyl cation species (intermediates **A** and **B** in Scheme 6) would isomerize[17] in part to other possible cation species prior to attacking of external nucleophile (methanol) to **A** and/or **B**. Thus, ratio of *anti*-**19** and *syn*-**19** would reflect the stability of these possible epimerized propynyl cation species. It might be supported by the fact that *anti*-**19** and *syn*-**19** are both stable under reaction condition. No isomerization was detected when *anti*-**19** and *syn*-**19** was independently exposed to $BF_3{\cdot}OEt_2$ and methanol. Results so far obtained tend to support the idea that there seem to be two requirements for attainment of this high stereoselectivity (retention of configuration) observed in cyclization of epoxides **3**. The first point is that reaction should be intramolecular and the second one is an epoxide functionality as a leaving group should be essential, although a full mechanistic understanding would be premature.

Conclusion

We have developed a novel method for preparation of 2-ethynyl-3-hydroxytetrahydropyran derivatives from 4,5-epoxyhept-6-yn-1-ol derivatives by taking advantage of the inherent property of alkyne-cobalt complex, which enabled us to control regioselectivity (endo mode ring closure) as well as stereoselectivity (retention of configuration at the propynyl position). Further studies on the detail of mechanism and application to synthesis of bioactive compounds are now in progress.

Experimental Section

Melting points were determined on a Yanagimoto micro melting apparatus and are uncorrected. Infrared spectra were measured with a Shimazu IR-460 spectrometer in $CHCl_3$, mass spectra with a Hitachi M-80 mass spectrometer, optical rotations with Horiba SEPA-300 high sensitive polarimeter, ^1H NMR spectra with JEOL JNM-EX270 and JNM-GSX500 spectrometers for samples in $CDCl_3$, using either tetramethylsilane as an internal standard for compounds that have no silyl group or $CHCl_3$ (7.26 ppm) for compounds possessing the silyl group, and ^{13}C NMR spectra with JEOL JNM-EX270 and JNM-GSX500 spectrometers in $CDCl_3$ with $CDCl_3$ (77.00 ppm) as an internal reference. CH_2Cl_2 was freshly distilled from P_2O_5, and THF from sodium diphenylketyl prior to use. Silica gel (Silica gel 60, 230-400 mesh, Merck) was used for chromatography. Organic extracts were dried over anhydrous Na_2SO_4. All reactions were carried out under nitrogen atmosphere.

(*E*)-1-Iodo-5-*tert*-butyldimethylsilyloxy-pent-1-ene [(*E*)-6]. To a suspension of $CrCl_2$ (3.86 g, 31.4 mmol) in 1,4-dioxane (60 ml) and THF (10 ml) was added a solution of **5** (820 mg, 4.05 mmol) and iodoform (3.34 g, 8.48 mmol) in 1,4-dioxane (10 ml) at 0°C. After being stirred at rt for 10 h, the reaction mixture was diluted with Et_2O (30 ml), washed with water and brine, dreid, and concentrated to dryness.

Chromatography of the residue with hexane-CH_2Cl_2 (5 : 1) gave **6** (859 mg, 65%, *E* : *Z* = 89 : 11) as a pale yellow oil. Selected data for (*E*)-**6**: MS *m/z* (%) 311 (M^+-Me, 2), 269 (100), 75 (55); IR 1610 (C=C) cm^{-1}; ^1H NMR δ 6.52 (1H, dt, *J* = 14.0, 6.8 Hz, olefinic H), 6.00 (1H, dt, *J* = 14.0, 1.4 Hz, olefinic H), 3.60 (2H, t, *J* = 6.8 Hz, CH_2O), 2.13 (2H, qd, *J* = 6.8, 1.4 Hz, allylic H), 1.60 (2H, quint, *J* = 6.8 Hz, CH_2), 0.89 (9H, s, ^{t}Bu), 0.04 (6H, s, Me); ^{13}C NMR δ 146.15, 74.63, 61.94, 32.44, 31.34, 25.91, 18.28, and -5.34. Anal. Calcd for $C_{11}H_{23}IOSi$: C, 40.49; H, 7.10. Found: C, 40.70; H, 7.10.

(*E*)-7-*tert*-Butyldimethylsilyloxy-1-trimethylsilyl-3-hepten-1-yne [(*E*)-7b]. To a solution of **6** (533 mg, 1.63 mmol, *E* : *Z* = 89 : 11) and (trimethylsilyl)acetylene (191 mg, 1.95 mmol) in THF (10 ml) was successively added $Pd(PPh_3)_2Cl_2$ (57.0 mg, 0.081 mmol), CuI (31.0 mg, 0.16 mmol), and diisopropylamine (10 ml) at rt. After being stirred at the same temperatrue for 30 min, the reaction mixture was filtered and the filtrate was concentrated to dryness. Chromatography of the residue with hexane-CH_2Cl_2 (10 : 1) gave **7b** (460 mg, 95%, *E* : *Z* = 88 : 12) as a pale yellow oil. Selected data for (*E*)-**7b**: MS *m/z* (%) 296 (M^+, 0.2), 239 (94), 147 (100), 133 (86), 73 (86); IR 2120 (C≡C), 1630 (C=C) cm^{-1}; ^1H NMR δ 6.22 (1H, dt, *J* = 16.0, 6.9 Hz, olefinic H), 5.50 (1H, dt, *J* = 16.0, 1.4 Hz, olefinic H), 3.60 (2H, t, *J* = 6.9 Hz, CH_2O), 2.17 (2H, qd, *J* = 6.9, 1.4 Hz, allylic H), 1.59 (2H, quint, *J* = 6.9 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.18 (9H, s, TMS), 0.04 (6H, s, Me); ^{13}C NMR δ 145.71, 109.87, 104.08, 92.60, 62.23, 31.70, 29.45, 25.91, 18.28, -0.03, -5.34. Anal Calcd for $C_{16}H_{32}OSi_2$: C, 64.80; H, 10.87. Found: C, 64.75; H, 10.85.

(*E*)-7-*tert*-Butyldimethylsilyloxy-3-hepten-1-yne [(*E*)-7a]. A mixture of K_2CO_3 (0.80 g) and **7b** (206 mg, 0.70 mmol, *E* : *Z* = 88 : 12) in MeOH (5 ml) was stirred at rt for 1 h. The reaction mixture was diluted with Et_2O (10 ml), washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-CH_2Cl_2 (10 : 1) gave **7a** (146 mg, 94%, *E* : *Z* = 88 : 12) as a colorless oil. Selected data for (*E*)-**7a**: IR 3320 (C≡C-H), 2075 (C≡C), 1615 (C=C) cm^{-1}; ^1H NMR δ 6.28 (1H, dt, *J* = 16.0, 6.9 Hz, olefinic H), 5.47 (1H, dt, *J* = 16.0, 1.4 Hz, olefinic H), 3.61 (2H, t, *J* = 6.9 Hz, CH_2O), 2.78 (1H, d, *J* = 1.4 Hz, C≡C-H), 2.18 (2H, qd, *J* = 6.9, 1.4 Hz, allylic H), 1.61 (2H, quint, *J* = 6.9 Hz, CH_2), 0.89 (9H, s, ^{t}Bu), 0.04 (6H, Me); ^{13}C NMR δ 146.33, 108.75, 82.48, 75.65, 62.16, 31.57, 29.36, 25.91, 18.28, -5.34. Anal Calcd for $C_{13}H_{24}OSi$: C, 69.58; H, 10.77. Found: C, 69.31; H, 10.80.

(*E*)-1-*tert*-Butyldimethylsilyloxy-4-undecen-6-yne [(*E*)-7c]. According to the procedure described for preparation of (*E*)-**7b**, **7c** (57.9 mg, 96%, *E* : *Z* = 89 : 11) was obtained from **6** (70.0 mg, 0.22 mmol, *E* : *Z* = 89 : 11) and 1-hexyne (22.0 mg, 0.26 mmol) as a pale yellow oil. Selected data for (*E*)-**7c**: MS *m/z* (%) 280 (M^+, 0.2), 223 (47), 91 (77), 75 (100); IR 2200 (C≡C), 1630 (C=C) cm^{-1}; ^1H NMR δ 6.04 (1H, dt, *J* = 16.0, 6.9 Hz, olefinic H), 5.46 (1H, dt, *J* = 16.0, 1.8 Hz, olefinic H), 3.60 (2H, t, *J* = 6.9 Hz, CH_2O), 2.28 (2H, td, *J* = 6.9, 1.8 Hz, propynyl H), 2.13 (2H, qd, *J* = 6.9, 1.8 Hz, allylic H), 1.59 (2H, quint, *J* = 6.9 Hz, CH_2), 1.49 (2H, *J* = 6.9 Hz, CH_2), 1.41 (2H, sex, *J* = 6.9 Hz, CH_2), 0.91 (3H, t, *J* = 6.9 Hz, Me), 0.88 (9H, s, ^{t}Bu), 0.04 (6H, s, Me); ^{13}C NMR δ 142.59, 110.19, 88.75, 79.08, 62.28, 31.93, 30.91, 29.27, 25.91, 21.96, 19.01, 18.28, 13.57, -5.34. Anal Calcd for $C_{17}H_{32}OSi$: C, 72.79; H, 11.49. Found: C, 73.01; H, 11.34.

(*E*)-7-*tert*-Butyldimethylsilyloxy-1-phenyl-3-hepten-1-yne [(*E*)-7d]. Accordin to the procedure described for preparation of (*E*)-**7b**, **7d** (96.1 mg, 97%, *E* : *Z* = 89 : 11) was obtained from **6** (108 mg, 0.33 mmol, *E* : *Z* = 89 : 11) and phentlacetylene (42.0 mg, 0.41 mmol) as a pale yellow oil. Selected data for (*E*)-**7d**: MS *m/z* (%) 300 (M^+, 0.2), 243 (79), 167 (94), 75 (100); IR 2190 (C≡C), 1600 (C=C) cm^{-1}; ^1H NMR δ 7.45-7.26 (5H, m, aromatic H), 6.27 (1H, dt, *J* = 16.0, 6.9 Hz, olefinic H), 5.72 (1H, dt, *J* = 16.0, 1.4 Hz, olefinic H), 3.65 (2H, t, *J* = 6.9 Hz, CH_2O), 2.25 (2H, qd, *J* = 6.9, 1.4 Hz, allylic H), 1.66 (2H,

quint, J = 6.9 Hz, CH_2), 0.92 (9H, s, ^{t}Bu), 0.07 (6H, s, Me); ^{13}C NMR δ 144.56, 131.41, 128.23, 127.85, 123.63, 109.83, 88.27, 87.96, 62.25, 31.84, 29.58, 25.93, 18.30, -5.30. Anal Calcd for $C_{19}H_{28}OSi$: C, 75.94; H, 9.39. Found: C, 75.74; H, 9.24.

(*E*)-7-*tert*-Butyldimethylsilyloxy-1-*p*-tolyl-3-hepten-1-yne [(*E*)-7e]. To a solution of **7a** (140 mg, 0.62 mmol, *E* : *Z* = 88 : 12) and *p*-iodotoluene (290 mg, 1.33 mmol) in THF (5 ml) was successively added $Pd(PPh_3)_2Cl_2$ (20.0 mg, 0.03 mmol), CuI (10.0 mg, 0.05 mmol), and diisopropylamine (1.0 ml) at rt. After being stirred for 30 min at the same temperatrue, the reaction mixture was filtered and the filtrate was concentrated to dryness. Chromatography of the residue with hexane-CH_2Cl_2 (10 : 1) gave **7e** (163 mg, 83%, *E* : *Z* = 88 : 12) as a pale yellow oil. Selected data for (*E*)-**7e**: MS *m/z* (%) 314 (18), 257 (100), 183 (93), 75 (63); IR 2175 (C≡C), 1605 (C=C) cm^{-1}; ^{1}H NMR δ 7.31 (2H, d, J = 7.8 Hz, aromatic H), 7.10 (2H, d, J = 7.8 Hz, aromatic H), 6.23 (1H, dt, J = 16.0, 6.9 Hz, olefinic H), 5.70 (1H, dt, J = 16.0, 1.4 Hz, olefinic H), 3.64 (2H, t, J = 6.9 Hz, CH_2O), 2.34 (3H, s, Me), 2.23 (2H, qd, J = 6.9, 1.4 Hz, allylic H), 1.64 (2H, quint, J = 6.9 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.06 (6H, s, Me); ^{13}C NMR δ 144.12, 137.90, 131.29, 129.00, 120.54, 109.96, 88.11, 87.57, 62.27, 31.88, 29.56, 25.93, 21.42, 18.30, -5.30. Anal Calcd for $C_{20}H_{30}OSi$: C, 76.38; H, 9.61. Found: C, 76.36; H, 9.59.

(*E*)-1-Benzoyl-7-*tert*-butyldimethylsilyloxy-3-hepten-1-yne [(*E*)-7f]. To a solution of **7a** (400 mg, 1.78 mmol, *E* : *Z* = 88 : 12) in THF (20 ml) was added dropwise *n*-BuLi (1.4 M hexane solution, 1.65 ml, 2.31 mmol) at -78°C. After being stirred for 2 h, a solution of benzoyl chloride (0.41 ml, 3.56 mmol) in THF (5 ml) was added to the reaction mixture and stirring was continued for 1.5 h at the same temperature. The reaction mixture was gradually warmed to rt, quenched by addition of water, and extracted with Et_2O. The extracts were washed with water and brine, dried, and concentrated to dtyness. Chromatography of the residue with hexane-CH_2Cl_2 (10 : 1) gave **7f** (547 mg, 94%, *E* : *Z* = 88 : 12) as a yellow oil. Selected data for (*E*)-**7f**: MS *m/z* (%) 328 (M^+, 0.2), 271 (92), 105 (100); IR 2180 (C≡C), 1635 (CO), 1605 (C=C) cm^{-1}; ^{1}H NMR δ 8.14 (2H, dd, J = 7.3, 1.4 Hz, aromatic H), 7.60 (1H, tt, J = 7.3, 1.4 Hz, aromatic H), 7.48 (2H, t, J = 7.3 Hz, aromatic H), 6.65 (1H, dt, J = 16.0, 6.9 Hz, olefinic H), 5.76 (1H, dt, J = 16.0, 1.4 Hz, olefinic H), 3.65 (2H, t, J = 6.9 Hz, CH_2O), 2.32 (2H, qd, J = 6.9, 1.4 Hz, allylic H), 1.68 (2H, quint, J = 6.9 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.06 (6H, s, Me); ^{13}C NMR δ 178.08, 152.43, 136.96, 133.87, 129.49, 128.50, 107.96, 92.65, 86.11, 62.05, 31.32, 30.10, 25.91, 18.30, -5.34. Anal Calcd for $C_{20}H_{28}O_2Si$: C, 73.12; H, 8.59. Found: C, 73.06; H, 8.73.

***tert*-Butyl (*Z*)-5-Iodo-4-pentenoate (9).** To a solution of *tert*-butyl acetate (3.40 ml, 20.9 mmol) in THF (10 ml) was added lithium isopropylcyclohexylamide (0.5 M THF solution, 38.0 ml, 19.0 mmol) at -78°C and the reaction mixture was stirred for 1h at the same temperature. A solution of (*Z*)-3-bromo-1-iodopropene (4.70 g, 19.0 mmol) in HMPA (10 ml) was added to the reaction mixture and stirring was continued for 30 min. The reaction mixture was quenched by addition of sat. NH_4Cl solution at -78°C, then gradually warmed to rt. The reaction mixture was diluted with water, extracted with Et_2O, which was washed with water several times, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (30 : 1) gave **9** (4.60 g, 86%) as a colorless oil; MS *m/z* (%) 282 (M^+, 2), 225 (9), 209 (48); IR 1720 (CO), 1610 (C=C) cm^{-1}; ^{1}H NMR δ 6.28-6.18 (2H, m, olefinic H), 2.39 (2H, td, J = 6.6, 5.3 Hz, allylic H), 2.35 (2H, t, J = 6.6 Hz, CH_2), 1.45 (9H, s, ^{t}Bu). Anal Calcd for $C_9H_{15}IO_2$: C, 38.32; H, 5.36. Found: C, 38.72; H, 5.48.

(*Z*)-1-Iodo-5-*tert*-butyldimethylsilyloxy-pent-1-ene [(*Z*)-6]. To a solution of **9** (2.10 g, 7.45 mmol) in CH_2Cl_2 (36 ml) was added DIBAL-H (1.0 M hexane solution, 16.4 ml, 16.4 mmol) at -78°C.

After being stirred for 15 min, the reaction mixture was quenched by addition of water and the resulting precipitates were filtered off. The filtrate was dried and concentrated to dryness. To a solution of the crude aldehyde in MeOH (5.0 ml) was added $NaBH_4$ untile the starting material was disappeared (monitored by TLC). MeOH was evaporated off and the residue was taken up in CH_2Cl_2, which was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue hexane-AcOEt (2 : 1) afforded (*Z*)-1-iodo-5-hydroxy-pent-1-ene [1.29 g, 85%; ^{1}H NMR δ 6.26-6.17 (2H, m, olefinic H), 3.68 (2H, t, *J* = 6.6 Hz, CH_2O), 2.25 (2H, q, *J* = 6.6 Hz, CH_2), 1.71 (2H, quint, *J* = 6.6 Hz, CH_2), 1.58 (s, OH). Anal Calcd for C_5H_9IO: C, 28.32; H, 4.28. Found: C, 28.14; H, 4.31.]. A mixture of the alcohol derivative (1.29 g, 6.08 mmol) and TBDMSCl (1.01 g, 6.70 mmol), and imidazole (0.91 g, 13.4 mmol) in DMF (2.0 ml) was stirred at rt for 1 h, diluted with water, and extracted with Et_2O. The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (40 : 1) gave (*Z*)-**6** (1.97 g, 99%) as a colorless oil; MS *m/z* (%) 326 (M^+, 2), 269 (20), 75 (55); IR 1610 (C=C) cm^{-1}; ^{1}H NMR δ 6.22-6.17 (2H, m, olefinic H), 3.64 (2H, t, *J* = 6.3 Hz, CH_2O), 2.20 (2H, td, *J* = 6.3, 5.4 Hz, allylic H), 1.65 (2H, quint, *J* = 6.3 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.06 (6H, s, Me); ^{13}C NMR δ 140.96, 82.45, 62.40, 31.37, 31.10, 25.95, 18.30, -5.29. Anal. Calcd for $C_{11}H_{23}IOSi$: C, 40.49; H, 7.10. Found: C, 40.46; H, 7.15.

(*Z*)-7-*tert*-Butyldimethylsilyloxy-1-trimethylsilyl-3-hepten-1-yne [(*Z*)-7b]. According to the procedure described for preparation of (*E*)-**7b**, (*Z*)-**7b** (971 mg, 100%) was obtained from (*Z*)-**6** (1.07 g, 3.28 mmol) and trimethylsilylacetylene (354 mg, 3.60 mmol) as a colorless oil; MS *m/z* (%) 296 (M^+, 1.5), 239 (100), 133 (97), 73 (84); IR 2120 (C≡C), 1610 (C=C) cm^{-1}; ^{1}H NMR δ 5.96 (1H, dt, *J* = 10.8, 7.3 Hz, olefinic H), 5.49 (1H, dt, *J* = 10.8, 1.5 Hz, olefinic H), 3.64 (2H, t, *J* = 6.8 Hz, CH_2O), 2.37 (2H, qd, *J* = 7.3, 1.5 Hz, allylic H), 1.64 (2H, quint, *J* = 6.8 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.19 (9H, s, TMS), 0.06 (6H, s, Me); ^{13}C NMR δ 145.00, 109.38, 101.96, 98.80, 62.77, 31.90, 26.96, 25.99, 18.35, 0.00, -5.30. High resolution mass calcd for $C_{16}H_{32}OSi_2$ 296.1980, found 296.1991.

(*Z*)-7-*tert*-Butyldimethylsilyloxy-3-hepten-1-yne [(*Z*)-7a]. According to the procedure described for preparation of (*E*)-**7a**, (*Z*)-**7a** (271 mg, 90%) was obtained from (*Z*)-**7b** (396 mg, 1.34 mmol) and K_2CO_3 (185 mg) as a pale yellow oil; MS *m/z* (%) 223 (M^+-1, 0.8), 167 (8.3), 75 (100); IR 3320 (C≡C-H), 2080 (C≡C), 1615 (C=C) cm^{-1}; ^{1}H NMR δ 6.02 (1H, dtd, *J* = 10.9, 7.3, 0.7 Hz, olefinic H), 5.45 (1H, dtd, *J* = 10.9, 2.3, 1.3 Hz, olefinic H), 3.64 (2H, t, *J* = 6.6 Hz, CH_2O), 3.07 (1H, dd, *J* = 2.3, 0.7 Hz, C≡C-H), 2.39 (2H, qd, *J* = 7.3, 1.3 Hz, allylic H), 1.64 (2H, quint, *J* = 6.6 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.05 (6H, Me); ^{13}C NMR δ 145.62, 108.28, 81.44, 80.40, 62.57, 31.92, 26.81, 25.95, 18.31, -5.32. Anal Calcd for $C_{13}H_{24}OSi$: C, 69.58; H, 10.77. Found: C, 69.70; H, 10.87.

(*Z*)-1-*tert*-Butyldimethylsilyl)oxy-4-undecen-6-yne [(*Z*)-7c]. According to the procedure described for preparation of (*E*)-**7b**, (*Z*)-**7c** (348 mg, 97%) was obtained from (*Z*)-**6** (452 mg, 1.39 mmol) and 1-hexyne (125 mg, 1.53 mmol) as a pale yellow oil; MS *m/z* (%) 280 (M^+, 5.5), 265 (11), 223 (60), 165 (8.0), 147 (41), 91 (80), 75 (100); IR 2200 (C≡C), 1615 (C=C) cm^{-1}; ^{1}H NMR δ 5.82 (1H, dt, *J* = 10.6, 7.3 Hz, olefinic H), 5.43 (1H, dt, *J* = 10.6, 1.3 Hz, olefinic H), 3.63 (2H, t, *J* = 6.6 Hz, CH_2O), 2.38-2.30 (4H, m, CH_2), 1.62 (2H, quint, *J* = 6.6 Hz, CH_2), 1.55-1.39 (4H, m, CH_2), 0.90 (3H, t, *J* = 6.9 Hz, Me), 0.90 (9H, s, ^{t}Bu), 0.05 (6H, s, Me); ^{13}C NMR δ 141.89, 109.69, 94.70, 77.20, 62.79, 32.11, 30.98, 26.56, 25.95, 21.98, 19.21, 18.33, 13.61, -5.32. Anal Calcd for $C_{17}H_{32}OSi$: C, 72.79; H, 11.49. Found: C, 72.59; H, 11.72.

(*Z*)-7-*tert*-Butyldimethylsilyl)oxy-1-phenyl-3-hepten-1-yne [(*Z*)-7d]. According to the procedure described for preparation of (*E*)-**7b**, (*Z*)-**7d** (367 mg, 98%) was obtained from (*Z*)-**6** (405 mg, 1.24

mmol) and phenylacetylene (140 mg, 1.37 mmol) as a pale yellow oil; MS *m/z* (%) 300 (M^+, 1.2), 243 (13), 225 (8.4), 141 (76), 89 (33), 73 (100); IR 2180 (C≡C), 1600 (C=C) cm^{-1}; ^1H NMR δ 7.48-7.39 (2H, m, aromatic H), 7.36-7.27 (3H, m, aromatic H), 6.00 (1H, dt, *J* = 10.9, 7.3 Hz, olefinic H), 5.69 (1H, d, *J* = 10.9 Hz, olefinic H), 3.67 (2H, t, *J* = 6.6 Hz, CH_2O), 2.46 (2H, q, *J* = 7.3 Hz, allylic H), 1.69 (2H, quint, *J* = 6.6 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.06 (6H, s, Me); ^{13}C NMR δ 143.70, 131.39, 128.23, 127.96, 123.65, 109.27, 93.69, 86.29, 62.72, 32.06, 26.99, 25.95, 18.33, -5.30. Anal Calcd for $C_{19}H_{28}OSi$: C, 75.94; H, 9.39. Found: C, 75.79; H, 9.40.

(Z)-7-*tert*-Butyldimethylsilyloxy-1-*p*-tolyl-3-hepten-1-yne [(Z)-7e]. According to the procedure described for preparation of (*E*)-**7e**, (*Z*)-**7e** (657 mg, 90%) was obtained from (*Z*)-**7a** (521 mg, 2.33 mmol) and *p*-iodotoluene (558 mg, 2.56 mmol) as a pale yellow oil; MS *m/z* (%) 314 (M^+, 4.3), 299 (1.2), 257 (79), 183 (100), 75 (91); IR 2160 (C≡C), 1605 (C=C) cm^{-1}; ^1H NMR δ 7.33 (2H, d, *J* = 8.3 Hz, aromatic H), 7.12 (2H, *J* = 8.3 Hz, aromatic H), 5.97 (1H, dt, *J* = 10.7, 7.3 Hz, olefinic H), 5.68 (1H, dt, *J* = 10.7, 1.5 Hz, olefinic H), 3.68 (2H, t, *J* = 6.4 Hz, CH_2O), 2.46 (2H, qd, *J* = 7.3, 1.5 Hz, allylic H), 2.35 (3H, s, Me), 1.69 (2H, quint, *J* = 6.4 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.07 (6H, s, Me); ^{13}C NMR δ 143.24, 138.04, 131.27, 129.00, 120.58, 109.39, 93.87, 85.64, 62.74, 32.08, 26.94, 25.95, 21.45, 18.33, -5.29. Anal Calcd for $C_{20}H_{30}OSi$: C, 76.38; H, 9.61. Found: C, 76.39; H, 9.60.

(Z)-1-Benzoyl-7-*tert*-butyldimethylsilyloxy-3-hepten-1-yne [(Z)-7f]. According to the procedure described for preparation of (*E*)-**7f**, (*Z*)-**7f** (733 mg, 96%) was obtained from (*Z*)-**7a** (521 mg, 2.33 mmol) and benzyl chloride (0.32 ml, 2.79 mmol) as a pale yellow oil; MS *m/z* (%) 328 (M^+, 1.8), 313 (4.6), 271 (100), 241 (3.2), 129 (7.3), 105 (99); IR 2160 (C≡C), 1640 (CO), 1600 (C=C) cm^{-1}; ^1H NMR δ 8.15 (2H, d, *J* = 7.3 Hz, aromatic H), 7.61 (1H, t, *J* = 7.3 Hz, aromatic H), 7.48 (2H, t, *J* = 7.3 Hz, aromatic H), 6.36 (1H, dt, *J* = 10.9, 7.6 Hz, olefinic H), 5.74 (1H, dt, *J* = 10.9, 1.3 Hz, olefinic H), 3.67 (2H, t, *J* = 6.3 Hz, CH_2O), 2.54 (2H, qd, *J* = 7.6, 1.3 Hz, allylic H), 1.71 (2H, quint, *J* = 6.3 Hz, CH_2), 0.88 (9H, s, ^{t}Bu), 0.04 (6H, s, Me); ^{13}C NMR δ 177.95, 151.02, 136.96, 133.91, 129.49, 128.54, 107.37, 91.34, 90.08, 62.45, 31.81, 27.91, 25.90, 18.28, -5.34. Anal Calcd for $C_{20}H_{28}O_2Si$: C, 73.12; H, 8.59. Found: C, 72.92; H, 8.70.

(3R*,4R*)-3,4-Epoxy-7-hydroxy-1-heptyne (*trans*-3a). To a suspension of (*E*)-**7a** (1.10 g, 3.70 mmol) and Na_2HPO_4 (6.50 g, 45.8 mmol) in CH_2Cl_2 (40 ml) was added *m*CPBA (80% purity, 2.40 g, 11.1 mmol). After being sitrred at rt for 18 h, the reaction mixture was filtered and the filtrate was washed with sat. Na_2SO_3 solution and brine, dried, and concnetrated to dryness. The residue was taken up in THF (20 ml) to which TBAF (1.0 M THF solution; 4.50 ml, 4.50 mmol) was added at rt. The reaction mixture was stirred for 1 h, diluted with Et_2O, washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (3 :1) gave *trans*-**3a** (156 mg, 34%) as a pale yellow oil; IR 3600 (OH), 3300 (C≡C-H), 2130 (C≡C) cm^{-1}; ^1H NMR δ 3.71 (2H, q, *J* = 4.3 Hz, CH_2O), 3.18-3.13 (2H, m, C_2H_2O), 2.32 (1H, d, *J* = 1.7 Hz, C≡C-H), 1.86-1.52 (4H, m, CH_2), 1.48 (1H, t, *J* = 4.3 Hz, OH); ^{13}C NMR δ 80.25, 71.92, 62.10, 60.06, 44.98, 28.57, 28.16. Anal Calcd for $C_7H_{10}O_2$: C, 66.65; H, 7.99. Found: C, 66.45; H, 7.98.

(3R*,4S*)-3,4-Epoxy-7-hydroxy-1-heptyne (*cis*-3a). According to the procedure described for preparation of *trans*-**3a**, *cis*-**3a** (93.0 mg, 61%) was obtained from (*Z*)-**7a** (357 mg, 1.20 mmol) as a colorless oil; MS *m/z* (%) 126 (M^+, 7.5), 115 (49), 105 (26), 91 52), 71 (75); IR 3450 (OH), 3310(C≡C-H), 2100 (C≡C) cm^{-1}; ^1H NMR δ 3.71 (2H, broad s, CH_2O), 3.43 (1H, dd, *J* = 3.9, 2.0 Hz, C_3-H), 3.07 (1H, td, *J* = 5.4, 3.9 Hz, C_4-H), 2.37 (1H, d, *J* = 2.0 Hz, C≡C-H), 1.87-1.71 (5H, m, CH_2, OH); ^{13}C NMR δ

78.73, 73.80, 62.16, 57.56, 44.87, 28.88, 25.81. Anal Calcd for $C_7H_{10}O_2$: C, 66.65; H, 7.99. Found: C, 66.25; H, 8.01.

(3R*,4R*)-3,4-Epoxy-7-hydroxy-1-trimethysilylhept-1-yne (*trans*-3b). Enyne (*E*)-**7b** (108 mg, 0.36 mmol) was dissolved in 1% HCl solution of EtOH (3.0 ml). The reaction mixture was stirred at rt for 1 h, diluted with Et_2O, which was washed with water and brine, dried, and concentrated to dryness. The residue was passed through a short pad of silica gel with hexane-AcOEt (3 : 1) to afford the corresponding alcohol (56.8 mg, 85%). To a suspension of the alcohol (56.8 g, 0.32 mmol) and Na_2HPO_4 (520 mg, 3.66 mmol) in CH_2Cl_2 (5.0 ml) was added *m*CPBA (80% purity, 2.40 mg, 1.11 mmol). After being sitrred at rt for 18 h, the reaction mixture was filtered and the filtrate was washed with sat. Na_2SO_3 solution and brine, dried, and concnetrated to dryness. Chromatography of the residue with hexane-AcOEt (3 :1) gave *trans*-**3b** (26.0 mg, 42%) as a pale yellow oil; MS *m/z* (%) 197 (M^+-1, 0.9), 183 (4.0), 128 (100), 125 (27); IR 3620, 3450 (OH), 2190 (C≡C) cm^{-1}; ^1H NMR δ 3.68 (2H, t, *J* = 6.4 Hz, CH_2O), 3.14-3.12 (2H, m, C_2H_2O), 1.82-1.49 (5H, m, CH_2, OH), 0.16 (9H, s, TMS); ^{13}C NMR δ 101.58, 89.37, 61.89, 60.45, 45.53, 28.53, 28.12, -0.41. Anal Calcd for $C_{10}H_{18}O_2Si$: C, 60.56; H, 9.14. Found: C, 60.79; H, 8.95.

(3R*,4S*)-3,4-Epoxy-7-hydroxy-1-trimethysilylhept-1-yne (*cis*-3b). According to the procedure described for preparation of *trans*-**3b**, *cis*-**3b** (379 mg, 38%) was obtained from (*Z*)-**7c** (1.51 g, 5.09 mmol) as a colorless oil; MS *m/z* (%) 198 (M^+, 5.3), 181 (11), 139 (100), 125 (3.9); IR 3600, 3450 (OH), 2150 (C≡C) cm^{-1}; ^1H NMR δ 3.70 (2H, t, *J* = 5.9 Hz, CH_2O), 3.43 (1H, d, *J* = 4.4 Hz, C_3-H), 3.05 (1H, q, *J* = 4.4 Hz, C_4-H), 1.71-1.83 (5H, m, CH_2, OH), 0.16 (9H, s, TMS); ^{13}C NMR δ 100.26, 91.47, 62.12, 57.93, 45.40, 28.89, 25.71, -0.36. High resolution mass calcd for $C_{10}H_{18}O_2Si$ 198.1067, found 198.1076.

(4R*,5R*)-4,5-Epoxy-1-hydroxy-6-undecyne (*trans*-3c). According to the procedure described for preparation of *trans*-**3a**, *trans*-**3c** (203mg, 43%) was obtained from (*E*)-**7c** (769 mg, 2.74 mmol) as a pale yellow oil; MS *m/z* (%) 182 (M^+, 0.1), 79 (61), 71 (100); IR 3600, 3440 (OH), 2225 (C≡C) cm^{-1}; ^1H NMR δ 3.70 (2H, t, *J* = 6.4 Hz, CH_2O), 3.13 (1H, q, *J* = 1.8 Hz, C_5-H), 3.07 (1H, ddd, *J* = 6.4, 4.1, 1.8 Hz, C_4-H), 2.20 (2H, td, *J* = 7.3 Hz, 1.8 Hz, C_8-H), 1.82-1.71 (3H, m, CH_2), 1.64 (1H, s, OH), 1.57-1.36 (5H, m, CH_2), 0.90 (3H, t, *J* = 7.3 Hz, Me); ^{13}C NMR δ 84.92, 76.48, 62.09, 60.31, 45.90, 30.37, 28.65, 28.23, 21.85, 18.35, 13.50. Anal Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.18; H, 9.93.

(4R*,5S*)-4,5-Epoxy-1-hydroxy-6-undecyne (*cis*-3c). According to the procedure described for preparation of *trans*-**3a**, *cis*-**3c** (602 mg, 61%) was obtained from (*Z*)-**7c** (1.50 g, 5.35 mmol) as a colorless oil; MS *m/z* (%) 182 (M^+, 3.8), 139 (47), 123 (2.6), 79 (19), 71 (69); IR 3630, 3450 (OH), 2220 (C≡C) cm^{-1}; ^1H NMR δ 3.71 (2H, broad s, CH_2O), 3.45 (1H, dt, *J* = 3.9, 2.0 Hz, C_5-H), 3.04 (1H, td, *J* = 5.9, 3.9 Hz, C_4-H), 2.23 (2H, td, *J* = 6.8 Hz, 2.0 Hz, C_8-H), 2.00 (1H, s, OH), 1.82-1.76 (4H, m, CH_2), 1.50 (2H, quint, *J* = 7.3 Hz, CH_2), 1.41 (2H, sex, *J* = 7.3 Hz, CH_2), 0.91 (3H, t, *J* = 7.3 Hz, Me); ^{13}C NMR δ 86.80, 74.78, 62.16, 57.70, 45.67, 30.40, 28.95, 25.75, 21.80, 18.35, 13.45. Anal Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.38; H, 9.95.

(3R*,4R*)-3,4-Epoxy-7-hydroxy-1-phenylhept-1-yne (*trans*-3d). According to the procedure described for preparation of *trans*-**3a**, *trans*-**3d** (233 mg, 42%) was obtained from (*E*)-**7d** (838 mg, 27.9 mmol) as a pale yellow oil; MS *m/z* (%) 202 (M^+, 1.0), 114 (100), 71 (84); IR 3600, 3450 (OH), 2225 (C≡C) cm^{-1}; ^1H NMR δ 7.44 (2H, dd, *J* = 7.8, 1.5 Hz, aromatic H), 7.35-7.29 (3H, m, aromatic H), 3.73 (2H, t, *J* = 5.9 Hz, CH_2O), 3.37 (1H, d, *J* = 2.4 Hz, C_3-H), 3.25 (1H, ddd, *J* = 6.9, 4.4, 2.4 Hz, C_4-H), 1.85 (1H, m, CH_2), 1.79-1.74 (2H, m, CH_2), 1.62 (1H, m, CH_2), 1.52 (1H, s, OH); ^{13}C NMR δ 131.79,

128.70, 128.25, 121.89, 85.54, 83.60, 62.00, 60.63, 45.88, 28.59, 28.23. Anal Calcd for $C_{13}H_{14}O_2$: C, 77.20; H, 6.97. Found: C, 77.13; H, 7.00.

(3R*,4S*)-3,4-Epoxy-7-hydroxy-1-phenylhept-1-yne (*cis*-3d). According to the procedure described for preparation of *trans*-**3a**, *cis*-**3d** (63.0 mg, 61%) was obtained from (*Z*)-**7d** (153 mg, 0.15 mmol) as a pale yellow oil; MS *m/z* (%) 202 (M^+, 29), 143 (2.4), 71 (54); IR 3420 (OH), 2210 (C≡C) cm^{-1}; ^1H NMR δ 7.47-7.28 (5H, m, aromatic H), 3.74 (2H, t, *J* = 5.9 Hz, CH_2O), 3.67 (1H, d, *J* = 3.9 Hz, C_3-H), 3.17 (1H, td, *J* = 5.9, 3.9 Hz, C_4-H), 1.93-1.79 (4H, m, CH_2), 1.75 (1H, s, OH); ^{13}C NMR δ 131.86, 128.79, 128.31, 121.94, 85.46, 83.98, 62.25, 58.25, 45.74, 29.02, 26.04. Anal Calcd for $C_{13}H_{14}O_2$: C, 77.20; H, 6.97. Found: C, 76.90; H, 6.98.

(3R*,4R*)-3,4-Epoxy-7-hydroxy-1-*p*-tolylhept-1-yne (*trans*-3e). According to the procedure described for preparation of *trans*-**3a**, *trans*-**3e** (53.3 mg, 52%) was obtained from (*E*)-**7e** (220 mg, 1.02 mmol) as a pale yellow oil; MS *m/z* (%) 216 (M^+, 26), 145 (95), 128 (100), 71 (56); IR 3600, 3450 (OH), 2225 (C≡C) cm^{-1}; ^1H NMR δ 7.32 (2H, d, *J* = 8.3 Hz, aromatic H), 7.10 (2H, d, *J* = 8.3 Hz, aromatic H), 3.71 (2H, t, *J* = 6.4 Hz, CH_2O), 3.35 (1H, d, *J* = 2.3 Hz, C_3-H), 3.23 (1H, ddd, *J* = 6.4, 4.1, 2.3 Hz, C_4-H), 2.34 (3H, s, Me), 1.86-1.73 (4H, m, CH_2, OH), 1.61 (1H, m, CH_2); ^{13}C NMR δ 138.93, 131.76, 129.04, 118.87, 84.87, 83.83, 62.11, 60.64, 46.01, 28.66, 28.29, 21.45. Anal Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.45. Found: C, 77.37; H, 7.44.

(3R*,4S*)-3,4-Epoxy-7-hydroxy-1-*p*-tolylhept-1-yne (*cis*-3e). According to the procedure described for preparation of *trans*-**3a**, *cis*-**3e** (46.0mg, 61%) was obtained from (*Z*)-**7e** (121 mg, 0.39 mmol) as a pale yellow oil; MS *m/z* (%) 216 (M^+, 24), 157 (9.0), 145 (26), 128 (100); IR 3630, 3450 (OH), 2230 (C≡C) cm^{-1}; ^1H NMR δ 7.34 (2H, d, *J* = 7.9 Hz, aromatic H), 7.12 (2H, d, *J* = 7.9 Hz, aromatic H), 3.75 (2H, t, *J* = 5.9 Hz, CH_2O), 3.67 (1H, d, *J* = 4.0 Hz, C_3-H), 3.17 (1H, td, *J* = 5.9, 4.0 Hz, C_4-H), 2.35 (3H, s, Me), 1.94-1.76 (4H, m, CH_2), 1.62 (1H, broad s, OH); ^{13}C NMR δ 139.05, 131.79, 129.08, 118.85, 85.68, 83.25, 62.30, 58.26, 45.86, 29.04, 26.02, 21.48. Anal Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.45. Found: C, 77.54; H, 7.49.

(3R*,4R*)-1-Benzoyl-3,4-Epoxy-7-hydroxyhept-1-yne (*trans*-3f). According to the procedure described for preparation of *trans*-**3a**, *trans*-**3f** (73.0 mg, 26%) was obtained from (*E*)-**7f** (401 mg, 1.20 mmol) as a pale yellow oil; MS *m/z* (%) 230 (M^+, 0.3), 160 (91), 71 (100); IR 3575, 3400 (OH), 2210 (C≡C), 1650 (CO) cm^{-1}; ^1H NMR δ 8.11 (2H, d, *J* = 7.3 Hz, aromatic H), 7.63 (1H, t, *J* = 7.3 Hz, aromatic H), 7.49 (2H, d, *J* = 7.3 Hz, aromatic H), 3.73 (2H, t, *J* = 6.4 Hz, CH_2O), 3.41 (1H, d, *J* = 1.8 Hz, C_3-H), 3.35 (1H, ddd, *J* = 6.0, 4.6, 1.8 Hz, C_4-H), 1.90-1.73 (4H, m, CH_2, OH), 1.68 (1H, m, CH_2); ^{13}C NMR δ 177.12, 136.18, 134.44, 129.62, 128.64, 90.13, 80.68, 61.94, 60.74, 44.67, 28.48, 28.26. Anal Calcd for $C_{14}H_{14}O_3$: C, 73.03; H, 6.13. Found: C, 72.81; H, 6.12.

(3R*,4S*)-1-Benzoyl-3,4-Epoxy-7-hydroxyhept-1-yne (*cis*-3f). According to the procedure described for preparation of *trans*-**3a**, *cis*-**3f** (42.0 mg, 27%) was obtained from (*Z*)-**7f** (313 mg, 0.96 mmol) as a pale yellow oil; MS *m/z* (%) 230 (M^+, 2.6), 160 (70), 71 (100); IR 3630, 3450 (OH), 2200 (C≡C), 1645 (CO) cm^{-1}; ^1H NMR δ 8.11 (2H, dd, *J* = 7.3, 1.5 Hz, aromatic H), 7.63 (1H, tt, *J* = 7.3, 1.5 Hz, aromatic H), 7.49 (2H, t, *J* = 7.3 Hz, aromatic H), 3.74 (2H, td, *J* = 6.3, 2.0 Hz, CH_2O), 3.70 (1H, d, *J* = 3.9 Hz, C_3-H), 3.29 (1H, td, *J* = 6.3, 3.9 Hz, C_4-H), 2.07 (broad s, OH), 1.94-1.87 (2H, m, CH_2), 1.85-1.80 (2H, m, CH_2); ^{13}C NMR δ 177.08, 136.14, 134.49, 129.55, 128.66, 88.83, 82.30, 61.98, 58.71, 44.64, 28.83, 26.40. Anal Calcd for $C_{14}H_{14}O_3$: C, 73.03; H, 6.13. Found: C, 72.69; H, 6.14.

General Procedure for Ring Closure of Epoxides 3. To a solution of **3** (1.0 mmol) in CH_2Cl_2 (30 ml) was added $Co_2(CO)_8$ (1.1 mmol) at rt. After being stirred for 30~60 min (consumption of the starting material was monitored by TLC), the reaction mixture was cooled down to -78°C and held at the same temperature for 30 min. A solution of $BF_3{\cdot}OEt_2$ in CH_2Cl_2 (0.1 M solution; 0.1 mmol) was added to the reaction mixture, which was further stirred at -78°C for 10 min. The reaction mixture was quenched by addition of water and gradually warmed to rt. The CH_2Cl_2 layer was separated, washed with brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-Et_2O (3 : 1) to give **4**. Chemical yields and ratio between *trans* and *cis* isomers are summarized in Table 1.

Hexacarbonyl-μ-[η⁴-(2R*,3R*)-2-ethynyl-3-hydroxytetrahydropyran]dicobalt(Co-Co) (*trans*-4a) : a reddish brown oil; MS *m/z* (%) 384 (M^+-CO, 34), 356 (85), 328 (85), 300 (100), 272 (81); IR 2100, 2050, 2030 (CO) cm^{-1}; ^1H NMR δ 6.08 (1H, s, C≡C-H), 4.09 (1H, d, *J* = 8.6 Hz, C_2-H), 4.01 (1H, broad d, *J* = 11.9 Hz, C_6-H), 3.51 (1H, m, C_6-H), 3.29 (1H, m, C_3-H), 2.18 (1H, m, CH_2), 1.82-1.69 (2H, m, CH_2), 1.65 (1H, d, *J* = 4.6 Hz, OH), 1.55 (1H, m, CH_2); ^{13}C NMR δ 199.70, 93.72, 82.34, 72.02, 71.80, 67.67, 32.55, 25.30. Anal Calcd for $C_{13}H_{10}Co_2O_8$: C, 37.89; H, 2.46. Found: C, 37.93; H, 2.45.

Hexacarbonyl-μ-[η⁴-(2R*,3S*)-2-ethynyl-3-hydroxytetrahydropyran]dicobalt(Co-Co) (*cis*-4a) : a reddish brown oil; MS *m/z* (%) 384 (M^+-CO, 14), 356 (62), 328 (64), 300 (100), 272 (84), 244 (62); IR 2100, 2050, 2020 (CO) cm^{-1}; ^1H NMR δ 6.13 (1H, s, C≡C-H), 4.51 (1H, broad s, C_2-H), 4.07 (1H, m, C_6-H), 3.80 (1H, m, C_3-H), 3.63 (1H, m, C_6-H), 2.10 (1H, d, *J* = 8.9 Hz, OH), 2.03-1.85 (2H, m, CH_2), 1.80 (1H, m, CH_2), 1.46 (1H, m, CH_2); ^{13}C NMR δ 199.53, 91.00, 81.49, 72.96, 69.26, 68.12, 30.82, 20.04. Anal Calcd for $C_{13}H_{10}Co_2O_8$: C, 37.89; H, 2.46. Found: C, 38.28; H, 2.55.

Hexacarbonyl-μ-[η⁴-(2R*,3R*)-3-hydroxy-2-(2-trimethylsilyl)ethynyltetrahydropyran]dicobalt(Co-Co) (*trans*-4b) : a reddish brown oil; MS *m/z* (%) 428 (M^+-2CO, 14), 400 (17), 372 (23), 344 (31), 316 (11), 75 (100); IR 2100, 2060, 2040 (CO) cm^{-1}; ^1H NMR δ 4.08 (1H, d, *J* = 8.8 Hz, C_2-H), 4.01 (1H, ddd, *J* = 11.7, 8.8, 4.4 Hz, C_6-H), 3.49 (1H, dt, *J* = 11.7, 3.4 Hz C_6-H), 3.31 (1H, m, C_3-H), 2.18 (1H, m, CH_2), 1.78-1.73 (2H, m, CH_2), 1.58 (1H, m, CH_2), 1.52 (1H, d, *J* = 4.4 Hz, OH), 0.31 (9H, s, TMS); ^{13}C NMR δ 200.45, 109.18, 82.41, 78.62, 72.34, 67.77, 33.00, 25.52, 0.71. Anal Calcd for $C_{16}H_{18}Co_2O_8Si$: C, 39.68; H, 3.75. Found: C, 39.87; H, 3.73.

Hexacarbonyl-μ-[η⁴-(2R*,3S*)-3-hydroxy-2-(2-trimethylsilyl)ethynyltetrahydropyran]dicobalt(Co-Co) (*cis*-4b) : reddish brown neeldes, mp 57-58°C (MeOH); MS *m/z* (%) 428 (M^+-2CO, 10), 400 (15), 372 (21), 344 (27), 316 (16), 75 (100); IR 2120, 2080, 2050 (CO) cm^{-1}; ^1H NMR δ 4.49 (1H, broad s, C_2-H), 4.09 (1H, m, C_6-H), 3.84 (1H, m, C_3-H), 3.63 (1H, m, C_6-H), 2.07 (1H, d, *J* = 9.2 Hz, OH), 2.03-1.93 (2H, m, CH_2), 1.78 (1H, m, CH_2), 1.47 (1H, m, CH_2), 0.31 (9H, s, TMS); ^{13}C NMR δ 200.18, 106.45, 82.19, 79.10, 69.36, 68.36, 31.04, 20.02, 0.76. Anal Calcd for $C_{16}H_{18}Co_2O_8Si$: C, 39.68; H, 3.75. Found: C, 39.77; H, 3.70.

Hexacarbonyl-μ-[η⁴-(2R*,3R*)-2-(1-hexynyl)-3-hydroxytetrahydropyran]dicobalt(Co-Co) (*trans*-4c) : a reddish brown oil; MS *m/z* (%) 440 (M^+-CO, 11), 412 (49), 356 (100), 328 (65); IR 2110, 2070, 2050 (CO) cm^{-1}; ^1H NMR δ 4.08 (1H, d, *J* = 8.3 Hz, C_2-H), 4.00 (1H, broad d, *J* = 11.7 Hz, C_6-H), 3.48 (1H, dt, *J* = 11.7, 3.4 Hz, C_6-H), 3.36 (1H, m, C_3-H), 2.84 (2H, t, *J* = 7.8 Hz, propynyl H), 2.18-2.16 (1H, m, CH_2), 1.81-1.41 (8H, m, CH_2, OH), 0.97 (3H, t, *J* = 7.3 Hz, Me); ^{13}C NMR δ 200.25, 100.09, 96.41, 82.01, 73.07, 67.73, 33.80, 33.46, 33.43, 25.57, 22.70, 13.87. Anal Calcd for $C_{17}H_{18}Co_2O_8$: C, 43.61; H, 3.87. Found: C, 43.73; H, 4.00.

Hexacarbonyl-μ-[η⁴-(2R*,3S*)-2-(1-hexynyl)-3-hydroxytetrahydropyran]dicobalt(Co-Co) (*cis*-4c) : a reddish brown oil; MS *m/z* (%) 440 (M^+-CO, 1.0), 412 (19), 384 (21), 356 (41), 328 (26); IR 2100, 2050, 2020 (CO) cm^{-1}; ^1H NMR δ 4.47 (1H, broad s, C_2-H), 4.08 (1H, m, C_6-H), 3.86 (1H, m, C_3-H), 3.63 (1H, m, C_6-H), 2.84 (2H, t, *J* = 6.9 Hz, propynyl H), 2.12 (1H, d, *J* = 9.9 Hz, OH), 2.07-1.72 (4H, m, CH_2), 1.67-1.41 (4H, m, CH_2), 0.97 (3H, t, *J* = 6.9 Hz, Me); ^{13}C NMR δ 200.02, 100.52, 92.98, 77.49, 69.31, 68.56, 33.87, 33.30, 30.98, 22.66, 20.07, 13.89 . Anal Calcd for $C_{17}H_{18}Co_2O_8$: C, 43.61; H, 3.87. Found: C, 43.53; H, 4.07.

Hexacarbonyl-μ-[η⁴-(2R*,3R*)-3-hydroxy-2-(2-phenylethynyl)tetrahydropyran]-dicobalt(Co-Co) (*trans*-4d) : a reddish brown oil; MS *m/z* (%) 488 (M^+, 0.2), 432 (26), 348 (65), 131 (69); IR 2100, 2060, 2040 (CO) cm^{-1}; ^1H NMR δ 7.67-7.59 (2H, m, aromatic H), 7.38-7.24 (3H, m, armoatic H), 4.36 (1H, d, *J* = 8.6 Hz, C_2-H), 4.07 (1H, m, C_6-H), 3.56 (1H, m, C_6-H), 3.46 (1H, m, C_3-H), 2.19 (1H, m, CH_2), 1.87-1.54 (3H, m, CH_2), 1.56 (1H, d, *J* = 4.3 Hz, OH); ^{13}C NMR δ 199.50, 137.84, 129.83, 128.73, 127.76, 96.19, 90.73, 81.87, 73.14, 67.91, 32.92, 25.59. Anal Calcd for $C_{19}H_{14}Co_2O_8$: C, 46.75; H, 2.89. Found: C, 46.77; H, 2.97.

Hexacarbonyl-μ-[η⁴-(2R*,3S*)-3-hydroxy-2-(2-phenylethynyl)tetrahydropyran]-dicobalt(Co-Co) (*cis*-4d) : a reddish brown oil; MS *m/z* (%) 460 (M^+-CO, 1.0), 432 (29), 404 (23), 376 (30), 348 (71), 131 (100); IR 2100, 2060, 2040 (CO) cm^{-1}; ^1H NMR δ 7.61 (2H, d, *J* = 6.9 Hz, aromatic H), 7.47-7.26 (3H, m, armoatic H), 4.67 (1H, broad s, C_2-H), 4.18 (1H, m, C_6-H), 3.97 (1H, broad d, *J* = 7.8 Hz, C_3-H), 3.73 (1H, m, C_6-H), 2.10-2.06 (3H, m, CH_2, OH), 1.84 (1H, m, CH_2), 1.50 (1H, m, CH_2); ^{13}C NMR δ 199.28, 138.02, 129.70, 128.81, 127.67, 92.96, 91.86, 81.58, 69.40, 68.41, 31.02, 20.04. Anal Calcd for $C_{19}H_{14}Co_2O_8$: C, 46.75; H, 2.89. Found: C, 46.75; H, 3.17.

Hexacarbonyl-μ-[η⁴-(2R*,3R*)-3-hydroxy-2-(2-*p*-tolylethynyl)tetrahydropyran]-dicobalt(Co-Co) (*trans*-4e) : a reddish brown oil; MS *m/z* (%) 502 (M^+, 0.1), 474 (0.2), 279 (11), 149 (58), 71 (26); IR 2100, 2060, 2030 (CO) cm^{-1}; ^1H NMR δ 7.52 (2H, d, *J* = 7.9 Hz, aromatic H), 7.14 (2H, d, *J* = 7.9 Hz, armoatic H), 4.36 (1H, d, *J* = 8.6 Hz, C_2-H), 4.07 (1H, m, C_6-H), 3.55 (1H, m, C_6-H), 3.45 (1H, m, C_3-H), 2.34 (3H, s, Me), 2.19 (1H, m, CH_2), 1.86-1.50 (3H, m, CH_2), 1.58 (1H, d, *J* = 4.0 Hz, OH); ^{13}C NMR δ 199.62, 137.95, 134.61, 129.74, 129.52, 96.12, 90.98, 81.92, 73.21, 67.89, 32.83, 25.59, 21.37. Anal Calcd for $C_{20}H_{16}Co_2O_8$: C, 47.83; H, 3.21. Found: C, 47.64; H, 3.48.

Hexacarbonyl-μ-[η⁴-(2R*,3S*)-3-hydroxy-2-(2-*p*-tolylethynyl)tetrahydropyran]-dicobalt(Co-Co) (*cis*-4e) : a reddish brown oil; MS *m/z* (%) 502 (M^+, 0.1), 474 (2.0), 446 (8.0), 362 (24), 71 (19); IR 2100, 2080, 2050 (CO) cm^{-1}; ^1H NMR δ 7.51 (2H, d, *J* = 8.3 Hz, aromatic H), 7.15 (2H, d, *J* = 8.3 Hz, armoatic H), 4.67 (1H, broad s, C_2-H), 4.18 (1H, broad dd, *J* = 11.5, 4.6 Hz, C_6-H), 3.96 (1H, m, C_3-H), 3.72 (1H, broad dt, *J* = 11.5, 2.3 Hz, C_6-H), 2.35 (3H, s, Me), 2.09 (1H, d, *J* = 8.7 Hz, OH), 2.09-2.01 (2H, m, CH_2), 1.82 (1H, m, CH_2), 1.50 (1H, m, CH_2); ^{13}C NMR δ 199.37, 137.83, 134.83, 129.65, 129.58, 92.87, 92.17, 81.62, 69.40, 68.43, 31.02, 20.06. Anal Calcd for $C_{20}H_{16}Co_2O_8$: C, 47.83; H, 3.21. Found: C, 48.02; H, 3.40.

Hexacarbonyl-μ-[η⁴-(2R*,3R*)-2-(2-benzoylethynyl)-3-hydroxytetrahydropyran]-dicobalt(Co-Co) (*trans*-4f) : a reddish brown oil; MS *m/z* (%) 460 (M^+-2CO, 5.9), 432 (14), 376 (21), 279 (35), 149 (100); IR 2100, 2060, 2040 (CO), 1625 (CO) cm^{-1}; ^1H NMR δ 8.11 (2H, d, *J* = 7.3 Hz, aromatic H), 7.59 (1H, t, *J* = 7.3 Hz, armoatic H), 7.45 (2H, t, *J* = 7.3 Hz, aromatic H), 4.74 (1H, s, OH), 4.22 (1H, d, *J* = 8.3 Hz, C_2-H), 4.05 (1H, broad d, *J* = 11.2 Hz C_6-H), 3.56 (1H, dt,, *J* = 11.2, 3.9 Hz, C_6-

H), 3.42 (1H, m, C_3-H), 2.25 (1H, m, CH_2), 1.84-1.72 (2H, m, CH_2), 1.52 (1H, m, CH_2); ^{13}C NMR δ 198.16, 196.72, 137.86, 133.42, 128.71, 128.39, 100.98, 82.62, 78.68, 71.91, 67.93, 32.44, 25.46. Anal Calcd for $C_{20}H_{14}Co_2O_9$: C, 46.54; H, 2.73. Found: C, 46.55; H, 2.86.

Hexacarbonyl-μ-[η⁴-(2R*,3S*)-2-(2-*p*-tolylethynyl)-3-hydroxytetrahydropyran]-dicobalt(Co-Co) (*cis*-4f) : a reddish brown oil; MS *m/z* (%) 432 (M^+-3CO, 62), 404 (75), 376 (100), 105 (95); IR 2100, 2060, 2040, 1625 (CO) cm^{-1}; ^1H NMR δ 8.16 (2H, d, *J* = 7.3 Hz, aromatic H), 7.57 (1H, t, *J* = 7.3 Hz, armoatic H), 7.46 (2H, t, *J* = 7.3 Hz, aromatic H), 4.64 (1H, broad s, C_2-H), 4.18 (1H, m, C_6-H), 3.96 (1H, broad d, *J* = 8.3 Hz, C_3-H), 3.71 (1H, broad t, *J* = 11.5 Hz, C_6-H), 2.74 (1H, d, *J* = 8.3 Hz, OH), 2.17-2.05 (2H, m, CH_2), 1.83 (1H, m, CH_2), 1.50 (1H, m, CH_2); ^{13}C NMR δ 198.22, 194.59, 137.39, 133.10, 128.81, 128.32, 94.93, 83.86, 81.08, 69.45, 67.91, 30.98, 19.97. Anal Calcd for $C_{20}H_{14}Co_2O_9$: C, 46.54; H, 2.73. Found: C, 46.38; H, 2.90.

(2R*,3S*)-3-Acetoxy-2-ethynyltetrahydropyran (*trans*-10a). To a solution of *trans*-**4a** (36.0 mg, 0.087 mmol) in MeOH (3.0 ml) was added CAN (240 mg, 0.44 mmol) at 0°C. After being stirred for 30 min, the reaction mixture was concentrated, diluted with water, and extracted with AcOEt. The extract was washed with brine, dried, and concnetrated to dryness. The resiude was dissolved in CH_2Cl_2 (1.0 ml), to which DMAP (16.0 mg, 0.13 mmol) and Ac_2O (13.0 mg, 0.13 mmol) was added. The reaction mixture was stirred at rt for 1 h, washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (5 : 1) afforded *trans*-**10a** (14.0 mg, 95%) as a colorless oil; MS *m/z* (%) 167 (M^+-H, 66), 149 (100), 113 (19), 71 (17); IR 3310 (C≡C-H), 2120 (C≡C), 1730 (CO) cm^{-1}; ^1H NMR δ 4.83 (1H, dt, *J* = 5.4, 3.9 Hz, C_3-H), 4.35 (1H, dd, *J* = 5.4, 2.0 Hz, C_2-H), 3.99 (1H, ddd, *J* = 11.7, 8.3, 3.4 Hz, C_6-H), 3.60 (1H, ddd, *J* = 11.7, 5.9, 3.4 Hz, C_6-H), 2.52 (1H, d, *J* = 2.0 Hz, C≡C-H), 2.16 (1H, m, CH_2), 2.10 (3H, s, Ac), 1.86 (1H, m, CH_2), 1.67 (1H, m, CH_2), 1.58 (1H, m, CH_2); ^{13}C NMR δ 170.11, 79.40, 75.37, 70.29, 68.26, 64.64, 25.83, 22.14, 21.08. Anal Calcd for $C_9H_{12}O_3$: C, 64.27; H, 7.19. Found: C, 64.50; H, 7.40.

(2R*,3R*)-3-Acetoxy-2-ethynyltetrahydropyran (*cis*-10a). According to the procedure described for preparation of *trans*-**10a**, *cis*-**10a** (10.0 mg, 98%) was obtained from *cis*-**4a** (25.0 mg, 0.06 mmol) as a colorless oil; MS *m/z* (%) 168 (M^+, 4.0), 167 (41), 149 (100), 71 (20); IR 3300 (C≡C-H), 2100 (C≡C), 1730 (CO) cm^{-1}; ^1H NMR δ 4.90 (1H, dt, *J* = 8.3, 4.1 Hz, C_3-H), 4.64 (1H, m, C_2-H), 3.93 (1H, ddd, *J* = 11.5, 8.7, 3.2 Hz, C_6-H), 3.62 (1H, dt, *J* = 11.5, 4.1 Hz, C_6-H), 2.49 (1H, d, *J* = 2.3 Hz, C≡C-H), 2.11 (3H, s, Ac), 1.95 (1H, m, CH_2), 1.88-1.76 (2H, m, CH_2), 1.64 (1H, m, CH_2); ^{13}C NMR δ 170.31, 78.78, 75.63, 68.75, 67.37, 63.95, 25.57, 22.95, 21.06. Anal Calcd for $C_9H_{12}O_3$: C, 64.27; H, 7.19. Found: C, 64.31; H, 7.29.

(2R*,3S*)-3-Acetoxy-2-(2-trimethylsilyl)ethynyltetrahydropyran (*trans*-10b). According to the procedure described for preparation of *trans*-**10a**, *trans*-**10b** (30.0 mg, 93%) was obtained from *trans*-**4b** (65.0 mg, 0.13 mmol) as a colorless oil; MS *m/z* (%) 240 (M^+, 1.0), 181 (5.0), 170 (36), 71 (100); IR 2175 (C≡C), 1730 (CO) cm^{-1}; ^1H NMR δ 4.82 (1H, ddd, *J* = 10.1, 5.5, 5.0 Hz, C_3-H), 4.30 (1H, d, *J* = 5.0 Hz, C_2-H), 3.98 (1H, ddd, *J* = 11.0, 7.8, 3.2 Hz, C_6-H), 3.56 (1H, ddd, *J* = 11.0, 6.4, 3.7 Hz, C_6-H), 2.14 (1H, m, CH_2), 2.09 (3H, s, Ac), 1.84 (1H, m, CH_2), 1.67-1.53 (2H, m, CH_2), 0.17 (9H, s, TMS); ^{13}C NMR δ 170.10, 100.76, 92.54, 70.44, 69.00, 64.67, 25.99, 22.30, 21.08, -0.30. Anal Calcd for $C_{12}H_{20}O_3Si$: C, 59.96; H, 8.38. Found: C, 59.83; H, 8.51.

(2R*,3R*)-3-Acetoxy-2-(2-trimethylsilyl)ethynyltetrahydropyran (*cis*-10b). According to the procedure described for preparation of *trans*-**10a**, *cis*-**10b** (23.0 mg, 93%) was obtained from *trans*-**4b** (50.0 mg, 0.10 mmol) as a colorless oil; MS *m/z* (%) 240 (M^+, 1.0), 181 (13), 170 (37), 71 (100); IR 2180 (C≡C), 1740 (CO) cm^{-1}; ^1H NMR δ 4.89 (1H, dt, *J* = 6.8, 3.4 Hz, C_3-H), 4.50 (1H, d, *J* = 3.4 Hz, C_2-H), 3.93 (1H, ddd, *J* = 11.2, 7.3, 3.4 Hz, C_6-H), 3.55 (1H, ddd, *J* = 11.2, 6.8, 3.4 Hz, C_6-H), 2.08 (3H, s, Ac), 1.93 (1H, m, CH_2), 1.83-1.75 (2H, m, CH_2), 1.53 (1H, m, CH_2), 0.15 (9H, s, TMS); ^{13}C NMR δ 170.19, 100.36, 92.36, 68.68, 68.29, 64.78, 25.95, 22.27, 20.95, -0.30. Anal Calcd for $C_{12}H_{20}O_3Si$: C, 59.96; H, 8.38. Found: C, 59.91; H, 8.58.

(2R*,3S*)-3-Acetoxy-2-(1-hexynyl)tetrahydropyran (*trans*-10c). According to the procedure described for preparation of *trans*-**10a**, *trans*-**10c** (12.0 mg, 96%) was obtained from *trans*-**4c** (26.0 mg, 0.06 mmol) as a colorless oil; MS *m/z* (%) 223 (M^+-H, 1.6), 167 (52), 149 (82), 71 (100); IR 2250 (C≡C), 1730 (CO) cm^{-1}; ^1H NMR δ 4.79 (1H, ddd, *J* = 6.4, 5.4, 3.9 Hz, C_3-H), 4.30 (1H, dt, *J* = 5.4, 2.0 Hz, C_2-H), 3.98 (1H, ddd, *J* = 11.2, 7.8, 3.4 Hz, C_6-H), 3.57 (1H, ddd, *J* = 11.2, 6.4, 3.4 Hz, C_6-H), 2.23 (1H, td, *J* = 6.8, 2.0 Hz, propynyl H), 2.14 (1H, m, CH_2), 2.10 (3H, s, Ac), 1.83 (1H, m, CH_2), 1.64 (1H, m, CH_2), 1.56 (1H, m, CH_2), 1.50 (2H, quint, *J* = 7.3 Hz, CH_2), 1.41 (2H, sex, *J* = 7.3 Hz, CH_2), 0.91 (3H, t, *J* = 7.3 Hz, Me); ^{13}C NMR δ 170.15, 88.14, 75.62, 70.86, 68.79, 64.46, 30.48, 25.97, 22.37, 21.82, 21.12, 18.30, 13.50. Anal Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99. Found: C, 69.55; H, 8.99.

(2R*,3R*)-3-Acetoxy-2-(1-hexynyl)ethynyltetrahydropyran (*cis*-10c). According to the procedure described for preparation of *trans*-**10a**, *cis*-**10c** (29.0 mg, 96%) was obtained from *trans*-**4c** (63.0 mg, 0.13 mmol) as a colorless oil; MS *m/z* (%) 224 (M^+, 0.3), 109 (59), 71 (100); IR 2230 (C≡C), 1735 (CO) cm^{-1}; ^1H NMR δ 4.89 (1H, dt, *J* = 6.8, 3.4 Hz, C_3-H), 4.54 (1H, m, C_2-H), 3.94 (1H, ddd, *J* = 11.2, 7.3, 3.4 Hz, C_6-H), 3.57 (1H, ddd, *J* = 11.2, 6.8, 3.4 Hz, C_6-H), 2.24 (1H, td, *J* = 6.8, 2.0 Hz, propynyl H), 2.10 (3H, s, Ac), 1.94 (1H, m, CH_2), 1.83-1.77 (2H, m, CH_2), 1.57 (1H, m, CH_2), 1.51 (2H, quint, *J* = 6.8 Hz, CH_2), 1.42 (2H, sex, *J* = 6.8 Hz, CH_2), 0.90 (3H, t, *J* = 6.8 Hz, Me); ^{13}C NMR δ 170.33, 88.16, 75.06, 69.18, 68.03, 64.39, 30.55, 25.91, 22.59, 21.78, 21.06, 18.31, 13.50. Anal Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99. Found: C, 69.54; H, 9.11.

(2R*,3S*)-3-Acetoxy-2-(2-phenyl)ethynyltetrahydropyran (*trans*-10d). According to the procedure described for preparation of *trans*-**10a**,*trans*-**10d** (30.0 mg, 100%) was obtained from *trans*-**4d** (60.0 mg, 0.12 mmol) as a colorless oil; MS *m/z* (%) 244 (M^+, 0.2), 184 (100), 129 (20), 71 (64); IR 2250 (C≡C), 1730 (CO) cm^{-1}; ^1H NMR δ 7.47-7.42 (2H, m, aromatic H), 7.35-7.28 (3H, m, aromatic H), 4.94 (1H, ddd, *J* = 8.8, 5.4, 3.4 Hz, C_3-H), 4.57 (1H, d, *J* = 5.4 Hz, C_2-H), 4.06 (1H, ddd, *J* = 11.7, 8.3, 3.4 Hz, C_6-H), 3.65 (1H, ddd, *J* = 11.7, 5.9, 3.4 Hz, C_6-H), 2.21 (1H, ddd, *J* = 17.6, 8.3, 3.9 Hz, CH_2), 2.12 (3H, s, Ac), 1.91 (1H, m, CH_2), 1.71 (1H, m, CH_2), 1.61 (1H, m, CH_2); ^{13}C NMR δ 170.17, 131.75, 128.60, 128.25, 122.19, 87.27, 84.57, 70.51, 69.02, 64.69, 26.00, 22.27, 21.13. Anal Calcd for $C_{15}H_{16}O_3$: C, 73.75; H, 6.60. Found: C, 73.73; H, 6.67.

(2R*,3R*)-3-Acetoxy-2-(2-phenyl)ethynyltetrahydropyran (*cis*-10d). According to the procedure described for preparation of *trans*-**10a**, *cis*-**10d** (23.0 mg, 94%) was obtained from *cis*-**4d** (49.0 mg, 0.10 mmol) as a colorless oil; MS *m/z* (%) 244 (M^+, 5.0), 129 (100), 71 (85); IR 2235 (C≡C), 1735 (CO) cm^{-1}; ^1H NMR δ 7.47-7.45 (2H, m, aromatic H), 7.35-7.29 (3H, m, aromatic H), 5.00 (1H, dt, *J* = 7.3, 3.7 Hz, C_3-H), 4.81 (1H, d, *J* = 3.7 Hz, C_2-H), 4.01 (1H, ddd, *J* = 11.5, 8.3, 3.2 Hz, C_6-H), 3.66 (1H, ddd, *J* = 11.5, 6.0, 4.6Hz, C_6-H), 2.12 (3H, s, Ac), 2.01 (1H, m, CH_2), 1.91-1.81 (2H, m, CH_2), 1.65

(1H, m, CH_2); ^{13}C NMR δ 170.39, 131.81, 128.54, 128.25, 122.37, 87.40, 84.19, 69.11, 68.29, 64.46, 25.95, 22.79, 21.12. Anal Calcd for $C_{15}H_{16}O_3$: C, 73.75; H, 6.60. Found: C, 73.79; H, 6.71.

(2R*,3S*)-3-Acetoxy-2-(2-*p*-tolyl)ethynyltetrahydropyran (*trans*-10e). According to the procedure described for preparation of *trans*-**10a**,*trans*-**10e** (35.0 mg, 93%) was obtained from *trans*-**4e** (73.0 mg, 0.15 mmol) as a colorless oil; MS *m/z* (%) 258 (M^+, 0.4), 199 (100), 143 (66), 71 (100); IR 2250 (C≡C), 1730 (CO) cm^{-1}; ^1H NMR δ 7.33 (2H, d, *J* = 8.3 Hz, aromatic H), 7.12 (2H, d, *J* = 8.3 Hz, aromatic H), 4.93 (1H, ddd, *J* = 8.8, 4.9, 3.9 Hz, C_3-H), 4.56 (1H, d, *J* = 4.9 Hz, C_2-H), 4.06 (1H, ddd, *J* = 11.7, 8.3, 3.4 Hz, C_6-H), 3.65 (1H, ddd, *J* = 11.7, 6.3, 3.9 Hz, C_6-H), 2.35 (3H, s, Ac), 2.21 (1H, ddd, *J* = 17.6, 8.3, 3.9 Hz, CH_2), 2.12 (3H, s, Me), 1.89 (1H, m, CH_2), 1.72 (1H, m, CH_2), 1.61 (1H, m, CH_2); ^{13}C NMR δ 170.26, 138.80, 131.68, 129.02, 119.12, 87.49, 83.83, 70.60, 69.06, 64.64, 25.98, 22.27, 21.46, 21.18. Anal Calcd for $C_{16}H_{18}O_3$: C, 74.40; H, 7.02. Found: C, 74.02; H, 7.18.

(2R*,3R*)-3-Acetoxy-2-(2-*p*-tolyl)ethynyltetrahydropyran (*cis*-10e). According to the procedure described for preparation of *trans*-**10a**, *cis*-**10e** (35.0 mg, 93%) was obtained from *trans*-**4e** (77.0 mg, 0.15 mmol) as a colorless oil; MS *m/z* (%) 258 (M^+, 2.0), 199 (29), 198 (100), 71 (90); IR 2245 (C≡C), 1730 (CO) cm^{-1}; ^1H NMR δ 7.34 (2H, d, *J* = 8.3 Hz, aromatic H), 7.11 (2H, d, *J* = 8.3 Hz, aromatic H), 4.99 (1H, dt, *J* = 7.3, 3.7 Hz, C_3-H), 4.79 (1H, d, *J* = 3.7 Hz, C_2-H), 4.01 (1H, ddd, *J* = 11.5, 8.3, 3.2 Hz, C_6-H), 3.64 (1H, ddd, *J* = 11.5, 6.0, 4.6 Hz, C_6-H), 2.34 (3H, s, Ac), 2.12 (3H, s, Me), 2.01 (1H, m, CH_2), 1.89-1.80 (2H, m, CH_2), 1.64 (1H, m, CH_2); ^{13}C NMR δ 170.42, 138.70, 131.70, 129.00, 119.30, 87.56, 83.46, 69.17, 68.34, 64.47, 25.97, 22.77, 21.45, 21.12. Anal Calcd for $C_{16}H_{18}O_3$: C, 74.40; H, 7.02. Found: C, 74.14; H, 7.03.

(2R*,3S*)-3-Acetoxy-2-(2-benzoyl)ethynyltetrahydropyran (*trans*-10f). According to the procedure described for preparation of *trans*-**10a**,*trans*-**10f** (36.5 mg, 98%) was obtained from *trans*-**4f** (71.0 mg, 0.12 mmol) as a colorless oil; MS *m/z* (%) 272 (M^+, 4.9), 230 (74), 160 (61), 71 (100); IR 2230 (C≡C), 1735, 1645 (CO) cm^{-1}; ^1H NMR δ 8.13 (2H, dd, *J* = 7.3, 1.5 Hz, aromatic H), 7.63 (1H, tt, *J* = 7.3, 1.5 Hz, aromatic H), 7.50 (2H, t, *J* = 7.3 Hz, aromatic H), 4.96 (1H, ddd, *J* = 6.3, 5.4, 3.9 Hz, C_3-H), 4.65 (1H, d, *J* = 5.4 Hz, C_2-H), 4.04 (1H, ddd, *J* = 11.7, 8.3, 3.4 Hz, C_6-H), 3.70 (1H, ddd, *J* = 11.7, 5.9, 3.4 Hz, C_6-H), 2.20 (1H, m, CH_2), 2.14 (3H, s, Ac), 1.92 (1H, m, CH_2), 1.76 (1H, m, CH_2), 1.64 (1H, m, CH_2); ^{13}C NMR δ 177.11, 170.09, 136.33, 134.37, 129.59, 128.66, 88.83, 84.43, 69.75, 68.50, 65.30, 26.20, 22.01, 21.08. Anal Calcd for $C_{16}H_{16}O_4$: C, 70.58; H, 5.92. Found: C, 70.23; H, 6.22.

(2R*,3R*)-3-Acetoxy-2-(2-benzoyl)ethynyltetrahydropyran (*cis*-10f). According to the procedure described for preparation of *trans*-**10a**, *cis*-**10f** (44.0 mg, 94%) was obtained from *cis*-**4f** (89.0 mg, 0.12 mmol) as a colorless oil; MS *m/z* (%) 272 (M^+, 3.0), 230 (53), 160 (52), 71 (100); IR 2230 (C≡C), 1740, 1645 (CO) cm^{-1}; ^1H NMR δ 8.17 (2H, dd, *J* = 7.8, 1.8 Hz, aromatic H), 7.64 (1H, tt, *J* = 7.8, 1.8 Hz, aromatic H), 7.50 (2H, t, *J* = 7.8 Hz, aromatic H), 5.00 (1H, m, C_3-H), 4.98 (1H, d, *J* = 0.9 Hz, C_2-H), 3.95 (1H, ddd, *J* = 11.9, 9.6, 3.2 Hz, C_6-H), 3.75 (1H, dt, *J* = 11.9, 4.1 Hz, C_6-H), 2.14 (3H, s, Ac), 2.01-1.95 (2H, m, CH_2), 1.83 (1H, m, CH_2), 1.73 (1H, m, CH_2); ^{13}C NMR δ 177.16, 170.12, 136.51, 134.34, 129.58, 128.63, 85.95, 84.98, 68.79, 67.53, 64.15, 25.77, 23.27, 21.01. Anal Calcd for $C_{16}H_{16}O_4$: C, 70.58; H, 5.92. Found: C, 70.21; H, 6.25.

Synthesis of (-)-*trans*-3d. To a suspension of AD-mix-α (3.20 g) and methanesulfonamide (206 mg, 2.17 mmol) in ^tBuOH (13 ml) and H_2O (13 ml) was added (*E*)-**7d** (651 mg, 2.17 mmol) at rt. The reaction mixtture was stirred at rt for 26 h and quenched by addition of Na_2SO_3 (2.40 g, 19.0 mmol). After being stirred for an additional hour, the reaction mixture was extracted with AcOEt, which was washed with water and brine,

dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (3 : 1) afforded (-)-diol [686 mg, 95% as a colorless oil; $[\alpha]_D^{18}$ -13.8° (*c* 0.53, $CHCl_3$); MS *m/z* (%) 316 (M^+-18, 2.0), 301 (2.0), 259 (65), 203 (31), 131 (23), 115 (27), 75 (100); IR 3590, 3360 (OH), 2230 (C≡C) cm^{-1}; ^1H NMR δ 7.45-7.42 (2H, m, aromatic H), 7.33-7.27 (3H, m, aromatic H), 4.41 (1H, dd, *J* = 6.8, 4.4 Hz, propynyl H), 3.74 (1H, broad s, OH), 3.73-3.66 (3H, m, CH_2, OH), 2.95 (1H, d, *J* = 4.4 Hz, OH), 1.96 (1H, dtd, *J* = 14.2, 6.8, 2.9 Hz, CH_2), 1.75 (2H, quint, *J* = 6.8 Hz, CH_2), 1.61 (1H, ddt, *J* = 14.2, 8.8, 6.8 Hz, CH_2), 0.90 (9H, s, ^{t}Bu), 0.77 (3H, s, Me), 0.75 (3H, s, Me); ^{13}C NMR δ 131.74, 128.47, 128.21, 122.38, 87.38, 86.05, 74.74, 66.84, 63.45, 30.29, 28.89, 25.87, 18.26, -5.42, -5.44. Anal Calcd for $C_{19}H_{30}O_3Si$: C, 68.22; H, 9.04. Found: C, 68.03; H, 9.20.]. Treatment of (-)-diol with (*S*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetyl (MTPA) chloride provided the bis-MTPA ester, whose ^1H NMR spectrum indicated its enantiomeric excess to be 90%. To a solution of (-)-diol (234 mg, 0.70 mmol) and trimethyl orthoacetate (0.14 ml, 1.10 mmol) in CH_2Cl_2 (1.0 ml) was added PPTS (17.0 mg, 0.07 mmol) at rt. After being stired for 10 min, the mixture was concentrated to dryness and the residual oil was taken up in CH_2Cl_2 (1.4 ml) to which TMSCl (0.12 ml, 0.95 mmol) was added at 0°C. The reaction mixture was stirred at rt for 24 h, diluted with water, and extracted with CH_2Cl_2. The extract was washed with water and brine, dried, and concentrated to dryness. The residue was dissolved in MeOH (4.0 ml) to which K_2CO_3 (154 mg, 0.90 mmol) was added. After being stirred at rt for 2 h, MeOH was evaporated off and the residue was diluted with sat. NH_4Cl solution, extracted with CH_2Cl_2. The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (10 : 1) afforded the corresponding epoxide (130 mg, 59%). To a solution of the epoxide (130 mg, 0.41 mmol) in THF (3.5 ml) was added TBAF (1.0 M THF solution, 0.54 ml, 0.54 mmol) at rt. The reaction mixture was allowed to stand for 1 h, diluted with water, and ectracted with AcOEt, which was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (2 : 1) gave (-)-*trans*-**3d** (80 mg, 96%) as a colorless oil; $[\alpha]_D^{17}$ -15.9° (*c* 0.49, $CHCl_3$). Anal Calcd for $C_{13}H_{14}O_2$: C, 77.20; H, 6.97. Found: C, 76.97; H, 6.90.

Transformation of (-)-*trnas*-3d into (-)-13. According to the general procedure for ring closure of epoxides, (-)-*trans*-**3d** (39.0 mg, 0.19 mmol) was successively treated with $Co_2(CO)_8$ (79.0 mg, 0.23 mmol) and $BF_3{\cdot}OEt_2$ (0.02 mmol) to give optically active *cis*-**4d** (89.0 mg, 95%). CAN (405 mg, 0.74 mmol) was added to a solution of optically active *cis*-**4d** (89.0 mg, 0.18 mmol) in MeOH (3.0 ml) at 0°C. The reaction mixture was stirred at rt for 30 min, and MeOH was evaporated off. The residue was taken up in AcOEt which was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (3 : 1) afforded (-)-**13** (35.0 mg, 94%) as a colorless oil; $[\alpha]_D^{31}$ -58.9° (*c* 0.31, $CHCl_3$); MS *m/z* (%) 202 (M^+, 19), 173 (10), 146 (12), 131 (92), 114 (53), 102 (42); IR 3600, 3450 (OH), 2220 (C≡C) cm^{-1}; ^1H NMR δ 7.50-7.46 (2H, m, aromatic H), 7.36-7.30 (3H, m, aromatic H), 4.73 (1H, d, *J* = 3.9 Hz, C_2-H), 3.95 (1H, ddd, *J* = 11.2, 8.8, 2.9 Hz, C_6-H), 3.83 (1H, m, C_3-H), 3.63 (1H, ddd, *J* = 11.2, 5.9, 3.9 Hz, C_6-H), 2.03 (1H, d, *J* = 7.8 Hz, OH), 1.90-1.81 (3H, m, CH_2), 1.57 (1H, m, CH_2); ^{13}C NMR δ 131.87, 128.71, 128.29, 122.04, 88.43, 84.32, 71.16, 67.33, 64.60, 29.03, 22.60. Anal Calcd for $C_{13}H_{14}O_2$: C, 77.20; H, 6.97. Found: C, 77.04; H, 7.02. Enantiomeric excess was determined to be 86% by ^1H NMR spectrum of its MTPA ester.

7-*tert*-Butyldimethylsilyloxy-3-hydroxy-1-trimethylsilylhept-1-yne (14). To a solution of trimethylsilylacetylene (1.20 ml, 8.49 mmol) in THF (50 ml) was added dropwise *n*-BuLi (1.65 M hexane solution; 5.20 ml, 8.58 mmol) at -78°C and the reaction mixture was stirred at the same temperature for 1 h. A

solution of 5-*tert*-butyldimethylsilyloxypentanal[22] (1.80 g, 8.32 mmol) in THF (5.0 ml) was added to the reaction mixture. After being stirred for 10 min, the reaction mixture was quenched by addition of water and extracted with AcOEt. The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (10 : 1) afforded **14** (2.46 g, 96%) as a colorless oil; MS *m/z* (%) 314 (M^+, 0.2), 297 (0.3), 131 (10), 73 (100); IR 3630, 3400 (OH), 2150 (C≡C) cm^{-1}; ^1H NMR δ 4.36 (1H, q, *J* = 6.4 Hz, propynyl H), 3.63 (1H, t, *J* = 6.4 Hz, C_7-H), 1.83 (1H, d, *J* = 5.9 Hz, OH), 1.77-1.66 (2H, m, CH_2), 1.60-1.46 (4H, m, CH_2), 0.89 (9H, s, ^{t}Bu), 0.17 (9H, s, TMS), 0.05 (6H, s, Me); ^{13}C NMR δ 106.79, 89.33, 63.02, 62.86, 37.47, 32.37, 25.97, 21.57, 18.35, -0.12, -5.28. Anal Calcd for $C_{16}H_{34}O_2Si_2$: C, 61.08; H, 10.89. Found: C, 59.95; H, 11.06.

Synthesis of Carbamates 15. A mixture of **14** (1.81 g, 5.75 mmol), (*S*)-1-phenylethyl isocyanate (1.86 g, 12.6 mmol), and *N,N*-dimethylaminoethanol (0.30 ml, 2.99 mmol) was heated at 80°C for 8 h. The mixture was passed through a short pad of silica gel with hexane-AcOEt (5 : 1) to leave the residue, which was taken up in CH_2Cl_2 (30 ml). $Co_2(CO)_8$ (2.47 g, 7.22 mmol) was added to the CH_2Cl_2 solution and the reaction mixture was stirred for 1 h. The solvent was evaporated off to give the residual oil which was chromatographed with hexane-AcOEt (20 : 1) to afford less polar compound (**I**) (1.89 g, 44%) and polar compound (**II**) (1.71 g, 40%). Compound **I** was a reddish brown oil; MS *m/z* (%) 579 (M^+-6CO, 0.5), 239 (23), 147 (100), 133 (54), 106 (39); IR 3450 (NH), 2040, 2010, 1990 (CO), 1720 (CO) cm^{-1}; ^1H NMR δ 7.37-7.24 (5H, m, aromatic H), 5.99 (1H, dd, *J* = 9.3, 3.4 Hz, propynyl H), 4.93 (1H, d, *J* = 6.3 Hz, NH), 4.88 (1H, quint, *J* = 6.3 Hz, benzylic H), 3.59-3.55 (2H, m, CH_2), 1.84-1.69 (2H, m, CH_2), 1.62-1.40 (4H, m, CH_2), 1.47 (3H, d, *J* = 6.3 Hz, Me), 0.88 (9H, s, ^{t}Bu), 0.32 (9H, s, TMS), 0.03 (6H, s, Me); ^{13}C NMR δ 199.93, 154.91, 143.49, 128.66, 127.33, 125.91, 111.14, 78.00, 74.36, 62.68, 50.64, 38.38, 32.38, 25.97, 22.43, 22.25, 18.35, 0.85, -5.34. Anal Calcd for $C_{31}H_{43}Co_2NO_9Si_2$: C, 49.80; H, 5.80; N, 1.87. Found: C, 49.82; H, 5.90; N, 1.86. Compound **II** was a reddish brown oil; MS *m/z* (%) 579 (M^+-6CO, 0.6), 356 (2.0), 239 (23), 147 (100), 133 (51), 106 (19); IR 3450 (NH), 2150, 2050, 1990 (CO), 1720 (CO) cm^{-1}; ^1H NMR δ 7.34-7.21 (5H, m, aromatic H), 5.98 (1H, dd, *J* = 8.8, 2.9 Hz, propynyl H), 4.93 (1H, d, *J* = 6.3 Hz, NH), 4.87 (1H, quint, *J* = 6.3 Hz, benzylic H), 3.64-3.62 (2H, m, CH_2), 1.87-1.71 (2H, m, CH_2), 1.66-1.45 (4H, m, CH_2), 1.51 (3H, d, *J* = 6.3 Hz, Me), 0.90 (9H, s, ^{t}Bu), 0.26 (9H, s, TMS), 0.06 (6H, s, Me); ^{13}C NMR δ 200.37, 154.90, 143.03, 128.50, 127.30, 126.10, 110.87, 78.15, 74.36, 62.71, 50.70, 38.46, 32.42, 25.98, 22.47, 22.17, 18.37, 0.78, -5.29. Anal Calcd for $C_{31}H_{43}Co_2NO_9Si_2$: C, 49.80; H, 5.80; N, 1.87. Found: C, 49.78; H, 5.83; N, 1.83. To a solution of compound **I** (1.89 g, 2.53 mmol) and Et_3N (1.80 ml, 13.1 mmol) in MeOH (25 ml) was added CAN (5.54 g, 10.1 mmol) at 0°C. The reaction mixture was allowed to stand for 30 min, then concentrated, diluted with water, and extracted with AcOEt . The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (5 : 1) gave carbamatem **15-I** (1.03 g, 88%) as a colorless oil; $[\alpha]_D^{31}$ -40.0° (*c* 2.39, $CHCl_3$); MS *m/z* (%) 461 (M^+, 0.2), 404 (4.0), 239 (5.0), 222 (16), 147 (90), 132 (79), 73 (100); IR 3450 (NH), 2150 (C≡C), 1720 (CO) cm^{-1}; ^1H NMR δ 7.37-7.23 (5H, m, aromatic H), 5.34 (1H, t, *J* = 6.8 Hz, propynyl H), 5.00 (1H, broad d, *J* = 6.8 Hz, NH), 4.84 (1H, quint, *J* = 6.8 Hz, benzylic H), 3.59 (2H, t, *J* = 6.4 Hz, CH_2), 1.78-1.68 (2H, m, CH_2), 1.57-1.41 (4H, m, CH_2), 1.49 (3H, d, *J* = 6.8 Hz, Me), 0.88 (9H, s, ^{t}Bu), 0.17 (9H, s, TMS), 0.04 (6H, s, Me); ^{13}C NMR δ 154.50, 143.43, 128.62, 127.31, 125.89, 103.20, 90.14, 65.01, 62.90, 50.79, 35.00, 32.30, 25.94, 22.49, 21.40, 18.30, -0.18, -5.31. Anal Calcd for $C_{25}H_{43}NO_3Si_2$: C, 65.02; H, 9.39; N, 3.03. Found: C, 64.74; H, 9.57; N, 2.99. Similar treatment of compound **II** (1.71 g, 2.29 mmol) with CAN (5.02 g,

9.16 mmol) gave **15B-II** (950 mg, 90%) as a colorless oil; $[\alpha]_D^{29}$ -10.5° (*c* 2.07, $CHCl_3$); MS *m/z* (%) 461 (M^+, 0.2), 404 (3.0), 239 (6.0), 222 (16), 147 (94), 132 (89), 73 (100); IR 3450 (NH), 2160 (C≡C), 1720 (CO) cm^{-1}; ^1H NMR δ 7.36-7.22 (5H, m, aromatic H), 5.32 (1H, t, *J* = 6.4 Hz, propynyl H), 4.97 (1H, d, *J* = 6.4 Hz, NH), 4.84 (1H, quint, *J* = 6.4 Hz, benzylic H), 3.62 (2H, t, *J* = 6.4 Hz, CH_2), 1.81-1.69 (2H, m, CH_2), 1.60-1.41 (4H, m, CH_2), 1.48 (3H, d, *J* = 6.8 Hz, Me), 0.89 (9H, s, ^{t}Bu), 0.15 (9H, s, TMS), 0.05 (6H, s, Me); ^{13}C NMR δ 154.52, 143.30, 128.60, 127.32, 125.94, 103.14, 90.15, 65.06, 62.91, 50.69, 34.99, 32.32, 25.97, 22.34, 21.40, 18.32, -0.20, -5.29. Anal Calcd for $C_{25}H_{43}NO_3Si_2$: C, 65.02; H, 9.39; N, 3.03. Found: C, 64.80; H, 9.55; N, 2.95.

Synthesis of (+)- and (-)-3,7-Dihydroxy-1-trimethylsilylhep-1-yne (16). To a solution of compound **15-I** (1.03 g, 2.23 mmol) and Et_3N (1.40 ml, 10.0 mmol) in benzene (23 ml) was added trichlorosilane (0.90 ml, 8.92 mmol) at rt. After being stirred for 10 min, the reaction mixture was quenched by addition of water, extracted with AcOEt . The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (1 : 1) gave (-)-**16** (330 mg, 72%) as a colorless oil; $[\alpha]_D^{30}$ -10.8° (*c* 1.53, $CHCl_3$); MS *m/z* (%) 200 (M^+, 0.8), 167 (31), 155 (12), 127 (100), 111 (41), 99 (100), 73 (76); IR 3630, 3370 (OH), 2160 (C≡C) cm^{-1}; ^1H NMR δ 4.36 (1H, q, *J* = 6.3 Hz, propynyl H), 3.65 (2H, t, *J* = 6.4 Hz, C_7-H), 2.39 (1H, broad d, *J* = 3.4 Hz, OH), 1.83 (1H, broad s, OH), 1.74-1.69 (2H, m, CH_2), 1.62-1.57 (2H, m, CH_2), 1.56-1.50 (2H, m, CH_2), 0.16 (9H, s, TMS); ^{13}C NMR δ 106.77, 89.33, 62.58, 62.56, 37.22, 32.09, 21.31, -0.15. Anal Calcd for $C_{10}H_{20}O_2Si$: C, 59.95; H, 10.06. Found: C, 59.81; H, 9.89. Similar treatment of compound **15-II** (951 mg, 2.06 mmol) with trichlorosilane (0.84 ml, 8.32 mmol) gave (+)-**16** (285 mg, 69%) as a colorless oil; $[\alpha]_D^{30}$ +10.2° (*c* 1.59, $CHCl_3$). Anal Calcd for $C_{10}H_{20}O_2Si$: C, 59.95; H, 10.06. Found: C, 60.02; H, 9.91.

Cyclization of (-)- and (+)-16. $Co_2(CO)_8$ (49.0 mg, 0.14 mmol) was added to a solution of (-)-**16** (24.0 mg, 0.12 mmol) in CH_2Cl_2 (4.0 ml) at 0°C. After being stirred for 30 min, tjhe reaction mixture was cooled down to -78°C and held at the same temperature for 30 min. A solution of $BF_3{\cdot}OEt_2$ in CH_2Cl_2 (0.1 M solution; 0.12 ml, 0.12 mmol) was added to the reaction mixture, which was gradually warmed up to 0°C over a period of 10 min. The reaction mixture was quenched by addition of water and extracted with CH_2Cl_2, which was washed with brine, dried, and concentrated to dryness. The residue was dissolved in MeOH (3.0 ml), to which CAN (230 mg, 0.42 mmol) was added at 0°C. After being stirred for 30 min, MeOH was evaporated off and the residue was taken up in Et_2O, which was washed with water and brine, dried, and concnetrated to dryness. Chromatography of the residue with hexane-Et_2O (10 : 1) affforded (±)-2-(2-trimethylsilyletynyl)tetrahydropyran (**17**) (16.4 mg, 75%) as a colorless oil; MS *m/z* (%) 182 (M^+, 1.0), 167 (15), 73 (13), 58 (100); IR 2160 (C≡C) cm^{-1}; ^1H NMR δ 4.44 (1H, dd, *J* = 8.3, 3.4 Hz, C_2-H), 3.97 (1H, dt, *J* = 11.2, 4.9 Hz, C_6-H), 3.49 (1H, ddd, *J* = 11.2, 8.3, 3.4 Hz, C_6-H), 1.87-1.78 (2H, m, CH_2), 1.66 (1H, m, CH_2), 1.62-1.46 (3H, m, CH_2), 0.16 (9H, s, TMS); ^{13}C NMR δ 104.51, 89.61, 67.40, 66.58, 32.08, 25.55, 21.76, -0.14. High resolution mass calcd for $C_{10}H_{18}OSi$ 182.1126, found 182.1143. Similar treatment of (+)-**16** (23.0 mg, 0.12 mmol) gave (±)-**17** (15.4 mg, 74%). A solution (±)-**17** (112 mg, 0.61 mmol) and K_2CO_3 (42.0 mg, 0.30 mmol) in MeOH (6.0 ml) was stirred at rt for 1 h and then MeOH was evaporated off. The residue was taken up in Et_2O, washed with water, dried, and concentrated to dryness. To a solutionof $NaIO_4$ (1.31 g, 6.12 mmol) in H_2O (3.0 ml) was added a solution of the residue in CCl_4 (3.0 ml) at rt. $RuO_2{\cdot}xH_2O$ (4.0 mg) was added to the reaction mixture and the mixture was vigorously stirred for 8 h. The precipitates were filtered off and the filtrate was diluted with CH_2Cl_2, washed with water and brine, dried, and

concentrated to dryness. The residue was dissolved in CH_2Cl_2 (6.0 ml) to which Et_3N (0.1 ml, 0.72 mmol), HOBt (174 mg, 1.29 mmol), (*S*)-(-)-α-methylbenzylamine (0.10 ml, 0.76 mmol), DCC (139 mg, 0.67 mmol) were successively added. After being stirred at rt for 9 h, the precipitates were filtered off and the filtrate was washed with water and brine, drided, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (3 : 1) gave **23** (112 mg, 78%) as a mixture of two diastereoisomers. Amide **23** : colorless csystals, mp 94-95°C (hexane-CH_2Cl_2); MS *m/z* (%) 233 (M^+, 24), 218 (3.0), 205 (43), 149 (13), 120 (18), 105 (52), 85 (100); IR 3440 (NH), 1665 (CO) cm^{-1}; ^1H NMR δ 7.36-7.23 (5H, m, aromatic H), 6.80 (1H, d, *J* = 6.8 Hz, NH), 5.13 (1H, quint, *J* = 6.8 Hz, benzylic H), 4.02 (1H, m, C_6-H), 3.79 (0.5H, dd, *J* = 11.7, 2.4 Hz, C_2-H), 3.74 (0.5H, dd, *J* = 11.7, 2.4 Hz, C_2-H), 3.46 (1H, dt, *J* = 11.2, 3.4 Hz, C_6-H), 2.12 (1H, m, CH_2), 1.88 (1H, m, CH_2), 1.63-1.29 (4H, m, CH_2), 1.50 (3H, d, *J* = 6.8 Hz, Me); ^{13}C NMR δ 170.98, 170.93, 143.23, 143.13, 128.56, 128.53, 127.19, 127.15, 126.13, 126.00, 77.32, 77.26, 68.25, 68.21, 47.86, 47.82, 29.15, 29.09, 25.58, 25.52, 23.13, 23.11, 21.93, 21.83. Anal Calcd for $C_{14}H_{19}NO_2$: C, 72.07; H, 8.21; N, 6.00. Found: C, 71.99; H, 8.05; N, 5.94.

(3R*,4R*)-7-*tert*-Butyldiphenylsilyloxy-3,4-epoxy-1-trimethysilylhept-1-yne (*trans*-18). To a solution of *trans*-**3b** (826 mg, 4.16 mmol) and imidazole (680 mg, 9.99 mmol) in DMF (2.1 ml) was added TBDPSCl (1.30 ml, 5.00 mmol) at rt. The reaction mixture was stirred for 2 h, diluted with Et_2O, washed with water several times and then brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-benzen (2 : 1) gave *trans*-**18** (1.75 g, 96%) as a colorless oil; MS *m/z* (%) 436 (M^+, 0.3), 379 (75), 363 (20), 293 (27), 271 (37), 199 (98), 135 (89), 73 (100); IR 2150 (C≡C) cm^{-1}; ^1H NMR δ 7.71-7.63 (4H, m, aromatic H), 7.45-7.34 (6H, m, aromatic H), 3.72-3.68 (2H, m, CH_2O), 3.13-3.08 (2H, m, C_2H_2O), 1.79-1.56 (4H, m, CH_2), 1.05 (9H, s, ^{t}Bu), 0.18 (9H, s, TMS); ^{13}C NMR δ 135.53, 133.78, 129.61, 127.66, 101.96, 89.18, 63.15, 60.54, 45.54, 28.50, 28.32, 26.85, 19.19, -0.30. Anal Calcd for $C_{26}H_{36}O_2Si_2$: C, 71.50; H, 8.31. Found: C, 71.27; H, 8.49.

(3R*,4S*)-7-*tert*-Butyldiphenylsilyloxy-3,4-epoxy-1-trimethysilylhept-1-yne (*cis*-18). According to the procedure described for preparation of *trans*-**18**, *cis*-**18** (246 mg, 96%) was obtained from *cis*-**3b** (120 mg, 0.61 mmol) and TBDMSCl (0.18 ml, 0.69 mmol) as a colorless oil; MS *m/z* (%) 436 (M^+, 0.2), 379 (100), 363 (25), 293 (33), 271 (42), 199 (98), 135 (72), 73 (70); IR 2150 (C≡C) cm^{-1}; ^1H NMR δ 7.69-7.66 (4H, m, aromatic H), 7.45-7.35 (6H, m, aromatic H), 3.73 (2H, t, *J* = 5.9 Hz, CH_2O), 3.40 (1H, d, *J* = 3.9 Hz, C_3-H), 3.04 (1H, td, J = 5.9, 3.9 Hz, C_4-H), 1.88-1.72 (4H, m, CH_2), 1.05 (9H, s, ^{t}Bu), 0.16 (9H, s, TMS); ^{13}C NMR δ 135.54, 133.84, 129.56, 127.62, 100.32, 91.12, 63.47, 58.08, 45.34, 28.84, 26.85, 26.11, 19.19, -0.30. Anal Calcd for $C_{26}H_{36}O_2Si_2$: C, 71.50; H, 8.31. Found: C, 71.23; H, 8.52.

Ring Opening of Epoxide 18 with Methanol. $Co_2(CO)_8$ (56.0 mg, 0.16 mmol) was added to a solution of *trans*-**18** (55.0 mg, 0.13 mmol) in CH_2Cl_2 (0.12 ml) at rt. After being stirred for 15 min, MeOH (6.2 M CH_2Cl_2 solution, 0.03 ml, 0.19 mmol) was added to the reaction mxiture, which was then cooled down to -78°C. BF_3·OEt_2 (0.02 ml, 0.16 mmol) was added to the reaction mixture and the mixture was stirred for 30 min at the same temperature, quenched by addition of water. The reaction mixture was extracted with CH_2Cl_2, washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-benzene (1 : 1) gave *anti*-**19** (42 mg, 44%) and *syn*-**19** (17 mg, 18%). Hexacarbonyl-μ-[η^4-(3R*,4R*)-7-*tert*-butyldiphenylsilyloxy-4-hydroxy-3-methoxy-1-trimethysilylhept-1-yne]dicobalt (Co-Co) (*anti*-**19**) was a reddish brown oil; MS *m/z* (%) 670 (M^+-3CO, 0.4), 642 (0.6), 614 (0.6), 586 (9.0), 411 (4.0), 363 (29), 271 (40), 199 (100), 183 (30); IR 2080, 2020, 1980 (CO) cm^{-1}; ^1H NMR δ 7.71-7.66 (4H, m, aromatic H), 7.46-

7.37 (6H, m, aromatic H), 4.15 (1H, d, J = 6.4 Hz, C_3-H), 3.75, 3.71 (2H, AB-qt, J = 10.3, 5.9 Hz, C_7-H), 3.64 (1H, m, C_4-H), 3.58 (3H, s, OMe), 2.85 (1H, d, J = 3.4 Hz, OH), 2.05 (1H, m, CH_2), 1.77 (1H, quint, J = 6.8 Hz, CH_2), 1.66 (1H, m, CH_2), 1.06 (9H, s, ^{t}Bu), 0.31 (9H, s, TMS); ^{13}C NMR δ 200.45, 135.57, 133.43, 129.70, 127.70, 108.22, 86.20, 79.86, 75.04, 64.34, 59.81, 30.27, 29.01, 26.83, 19.15, 0.95. Anal Calcd for $C_{33}H_{40}Co_2O_9Si_2$: C, 52.52; H, 5.34. Found: C, 52.74; H, 5.39. Hexacarbonyl-μ-[η^4-(3R*,4S*)-7-*tert*-butyldiphenylsilyloxy-4-hydroxy-3-methoxy-1-trimethysilylhept-1-yne]dicobalt (Co-Co) (*syn*-**19**) was a reddish brown oil; MS *m/z* (%) 670 (M^+-3CO, 0.5), 642 (0.8), 614 (0.6), 586 (12), 411 (4.0), 363 (28), 271 (43), 199 (100), 183 (33); IR 2080, 2020, 1980 (CO) cm^{-1}; ^{1}H NMR δ 7.71-7.65 (4H, m, aromatic H), 7.45-7.35 (6H, m, aromatic H), 4.17 (1H, d, J = 2.9 Hz, C_3-H), 3.73 (2H, t, J = 5.9 Hz, C_7-H), 3.62 (3H, s, OMe), 3.58 (1H, m, C_4-H) 2.45 (1H, d, J = 7.8 Hz, OH), 1.83 (1H, m, CH_2), 1.78-1.62 (3H, m, CH_2), 1.06 (9H, s, ^{t}Bu), 0.31 (9H, s, TMS); ^{13}C NMR δ 200.29, 135.55, 133.84, 129.58, 127.62, 107.76, 85.07, 79.19, 75.92, 63.85, 60.62, 31.81, 29.14, 26.85, 19.19, 0.95. Anal Calcd for $C_{33}H_{40}Co_2O_9Si_2$: C, 52.52; H, 5.34. Found: C, 52.64; H, 5.33.

(3R*,4S*)-7-*tert*-Butyldiphenylsilyloxy-4-hydroxy-3-methoxyhept-1-yne (*anti*-20). CAN (3.40 g, 6.20 mmol) was added to a solution of *anti*-**19** (1.17 g, 1.55 mmol) in MeOH (16 ml) at 0°C. The reaction mixture was allowed to stand for 30 min, concentrated, diluted with AcOEt, washed with water and brine, dried, and concentrated to dryness. The residue was dissolved in MeOH (13 ml), to which K_2CO_3 (90.0 mg, 0.65 mmol) was added. After being stirred for 1 h at rt, MeOH was evaporated off and the residual oil was diluted with AcOEt, washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (10 : 1) gave *anti*-**20** (452 mg, 73%) as a colorless oil; chemical ionization MS *m/z* (%) 397 (M^++1, 100), 327 (3.0), 319 (2.0), 287 (3.0), 261 (13), 241 (6.0), 141 (3.0); IR 3600 (OH), 3320 (C≡C-H), 2100 (C≡C) cm^{-1}; ^{1}H NMR δ 7.69-7.65 (4H, m, aromatic H), 7.45-7.36 (6H, m, aromatic H), 3.94 (1H, dd, J = 3.4, 2.4 Hz, C_3-H), 3.77 (1H,tdd, J = 8.8, 4.9, 3.4 Hz, C_4-H), 3.73-3.68 (2H, m, C_7-H), 3.47 (3H, s, OMe), 2.48 (1H, d, J = 2.4 Hz, C≡C-H), 2.42 (1H, d, J = 4.9 Hz, OH), 1.84-1.72 (2H, m, CH_2), 1.70-1.60 (2H, m, CH_2), 1.05 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.58, 133.83, 129.58, 127.62, 79.45, 75.81, 75.18, 72.74, 63.81, 57.05, 28.88, 28.66, 26.84, 19.19. Anal Calcd for $C_{24}H_{32}O_3Si$: C, 72.68; H, 8.13. Found: C, 72.43; H, 8.16.

(3R*,4R*)-7-*tert*-Butyldiphenylsilyloxy-4-hydroxy-3-methoxyhept-1-yne (*syn*-20). According to the procedure described for preparation of *anti*-**20**, *syn*-**20** (120 mg, 83%) was obtained from *syn*-**19** (272 mg, 0.36 mmol) as a colorless oil; chemical ionization MS *m/z* (%) 397 (M^++1, 100), 327 (3.0), 319 (2.0), 287 (3.0), 261 (15), 241 (7.0), 141 (4.0); IR 3600 (OH), 3320 (C≡C-H), 2100 (C≡C) cm^{-1}; ^{1}H NMR δ 7.72-7.67 (4H, m, aromatic H), 7.45-7.37 (6H, m, aromatic H), 3.80 (1H, dd, J = 7.3, 2.0 Hz, C_3-H), 3.74, 3.71 (2H, AB-qt, J = 10.3, 6.4 Hz, C_7-H), 3.70 (1H, m, C_4-H), 3.48 (3H, s, OMe), 2.78 (1H, d, J = 2.9 Hz, OH), 2.49 (1H, d, J = 2.0 Hz, C≡C-H), 1.93 (1H, m, CH_2), 1.81 (1H, m, CH_2), 1.71 (1H, m, CH_2), 1.56 (1H, m, CH_2), 1.07 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.56, 133.88, 129.53, 127.59, 79.90, 75.63, 75.35, 73.13, 63.75, 56.93, 28.81, 28.45, 26.83, 19.18. Anal Calcd for $C_{24}H_{32}O_3Si$: C, 72.68; H, 8.13. Found: C, 72.41; H, 8.15.

(4R*,5S*)-8-*tert*-Butyldiphenylsilyloxy-4-methoxyoctan-1,5-diol (*anti*-21). To a solution of *anti*-**20** (226 mg, 0.57 mmol) in THF (5.0 ml) was added n-BuLi (1.60 M hexane solution; 0.84 ml, 1.34 mmol) at -78°C. After being stirred for 1h, $(CH_2O)_n$ (51 mg) was added to the reaction mixture. The mixture was gradually warmed to rt and stirring was continued for 16 h at rt. The reaction mixture was diluted with water and extracted with AcOEt. The extract was washed with water and brine, dried, and concentrated to

dryness. Chromatography of the residue with hexane-AcOEt (1 : 1) gave the hydroxymethylated *anti*-**20** (236 mg, 97%) [^{1}H NMR δ 7.68-7.65 (4H, m, aromatic H), 7.45-7.36 (6H, m, aromatic H), 4.32 (2H, dd, J = 6.3, 2.0 Hz, CH_2O), 3.97 (1H, dt, J = 3.4, 2.0 Hz, propynyl H), 3.76 (1H, m, CH_2), 3.73-3.68 (2H, m, CH_2), 3.45 (3H, s, OMe), 2.53 (1H, d, J = 4.9 Hz, OH), 1.83-1.70 (3H, m, CH_2, OH), 1.69-1.58 (2H, m, CH_2), 1.05 (9H, s, ^{t}Bu). Anal Calcd for $C_{25}H_{34}O_4Si$: C, 70.38; H, 8.03. Found: C, 70.14; H, 7.94.]. A solution of the hydroxymethylated *anti*-**20** (236 mg, 0.55 mmol) in AcOEt (5.5 ml) was hydrogenated over 10% Pd-C (28 mg) under hydrogen atmosphere at rt for 1h. The catalyst was filtered off and the filtrate was concentrated to dryness. Chromatography of the residue with hexane-AcOEt (1 : 1) afforded *anti*-**21** (217 mg, 91%; 88% from *anti*-**20**) as a colorless oil; chemical ionization MS *m/z* (%) 431 (M^++1, 100), 411 (7.0), 381 (2.0), 327 (5.0), 295 (2.0), 263 (7.0), 243 (6.0), 175 (3.0); IR 3620, 3420 (OH) cm^1; ^{1}H NMR δ 7.69-7.65 (4H, m, aromatic H), 7.45-7.36 (6H, m, aromatic H), 3.78 (1H, td, J = 9.3, 3.9 Hz, C_5-H), 3.72, 3.70 (2H, AB-qt, J = 10.8, 6.3 Hz, C_8-H), 3.65 (2H, t, J = 6.4 Hz, C_1-H), 3.40 (3H, s, OMe), 3.11 (1H, td, J = 6.3, 3.9 Hz, C_4-H), 2.58 (1H, broad s, OH), 2.04 (1H, broad s, OH), 1.81-1.57 (7H, m, CH_2), 1.50 (1H, m, CH_2), 1.06 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.55, 133.70, 129.61, 127.63, 84.22, 71.09, 64.04, 62.92, 57.60, 29.14, 28.85, 26.82, 25.16, 19.16. Anal Calcd for $C_{25}H_{38}O_4Si$: C, 69.72; H, 8.89. Found: C, 69.43; H, 9.04.

(4R*,5R*)-8-*tert*-Butyldiphenylsilyloxy-4-methoxyoctan-1,5-diol (*syn*-21). According to the procedure described for preparation of *anti*-**21**, *syn*-**20** (94.0 mg, 0.24 mmol) was treated with *n*-BuLi and $(CH_2O)n$ to give the hydroxymethylated *syn*-**20** (97%)[^{1}H NMR δ 7.71-7.66 (4H, m, aromatic H), 7.45-7.36 (6H, m, aromatic H), 4.28 (2H, broad d, J = 4.4 Hz, CH_2O), 3.84 (1H, dt, J = 6.8, 1.5 Hz, propynyl H), 3.73, 3.71 (2H, AB-qt, J = 10.3, 6.4 Hz, CH_2), 3.68 (1H, m, CH_2), 3.46 (3H, s, OMe), 2.90 (1H, broad s, OH), 2.16 (1H, s, OH), 1.89 (1H, m, CH_2), 1.80 (1H, m, CH_2), 1.69 (1H, m, CH_2), 1,55 (1H, m, CH_2), 1.06 (9H, s, ^{t}Bu). Anal Calcd for $C_{25}H_{34}O_4Si$: C, 70.38; H, 8.03. Found: C, 70.11; H, 8.11.]. The hydroxymethylated *syn*-**20** was then hrdrogenated to afford *syn*-**21** (98.0 mg, 99%) as a colorless oil; chemical ionization MS *m/z* (%) 431 (M^++1, 100), 411 (7.0), 381 (2.0), 327 (4.0), 295 (2.0), 263 (5.0), 243 (4.0), 175 (2.0); IR 3630, 3410 (OH) cm^1; ^{1}H NMR δ 7.70-7.65 (4H, m, aromatic H), 7.45-7.36 (6H, m, aromatic H), 3.71 (2H, t, J = 5.9 Hz, C_8-H), 3.64 (2H, t, J = 5.9 Hz, C_1-H), 3.59 (1H, m, C_5-H), 3.43 (3H, s, OMe), 3.09 (1H, q, J = 5.9 Hz, C_4-H), 2.66 (1H, broad s, OH), 1.79-1.44 (9H, m, CH_2, OH), 1.06 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.53, 133.79, 129.56, 127.60, 84.03, 72.21, 63.94, 62.86, 58.19, 29.52, 28.84, 28.28, 26.82, 26.14, 19.17. Anal Calcd for $C_{25}H_{38}O_4Si$: C, 69.72; H, 8.89. Found: C, 69.32; H, 8.89.

(2R*,3S*)-2-(3-*tert*-Butyldiphenylsilyloxypropyl)-3-methoxytetrahydropyran (*trans*-22). To a solution of *anti*-**21** (28.0 mg, 0.06 mmol), Et_3N (0.02 ml, 0.14 mmol), and DMAP (2.0 mg, 0.02 mmol) in CH_2Cl_2 (1.5 ml) was added TsCl (15.0 mg, 0.08 mmol) at rt. After being stirred for 3 h, the reaction mixture was diluted with CH_2Cl_2, washed with water and brine, dried, and concentrated to dryness. The residue was dissolved in THF (2.0 ml), to which NaH (60% in oil; 4.0 mg, 0.10 mmol) was added. The reaction mixture was heated under reflux for 20 h, diluted with sat. NH_4Cl solution, extracted with Et_2O. The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (20 : 1) gave *trans*-**22** (21.0 mg, 78%) as a colorless oil; chemical ionization MS *m/z* (%) 413 (M^++1, 100), 355 (20), 335 (9.0), 323 (2.0), 303 (1.0), 157 (7.0); ^{1}H NMR δ 7.70-7.66 (4H, m, aromatic H), 7.43-7.34 (6H, m, aromatic H), 3.86 (1H, ddt, J = 11.7, 4.4, 2.0 Hz, C_6-H), 3.68 (2H, t, J = 6.4 Hz, C_3-H), 3.34 (3H, s, OMe), 3.28 (1H, dt, J = 11.7, 2.4 Hz, C_6-H), 3.04 (1H, dt, J = 8.8, 2.9 Hz, C_3-H), 2.84 (1H, ddd, J = 10.3, 8.8, 4.4 Hz, C_2-H), 2.23 (1H, m, CH_2), 1.93 (1H, m, CH_2), 1.80 (1H, m,

CH_2), 1.71-1.57 (3H, m, CH_2), 1.43 (1H, m, CH_2), 1.27 (1H, m, CH_2), 1.05 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.60, 134.16, 129.42, 127.53, 80.80, 79.25, 67.53, 64.16, 56.50, 28.69, 28.60, 28.52, 26.85, 25.35, 19.20. Anal Calcd for $C_{25}H_{36}O_3Si$: C, 72.77; H, 8.79. Found: C, 72.57; H, 8.89.

(2R*,3R*)-2-(3-*tert*-Butyldiphenylsilyloxypropyl)-3-methoxytetrahydropyran (*cis*-22). According to the procedure described for preparation of *trans*-**22**, *cis*-**22** (21.0 mg, 68%) was obtained from *syn*-**21** (32.0 mg, 0.07 mmol) as a colorless oil; chemical ionization MS *m/z* (%) 413 (M^++1, 100), 355 (27), 335 (12), 323 (2.0), 303 (2.0), 157 (11); ^{1}H NMR δ 7.70-7.66 (4H, m, aromatic H), 7.45-7.35 (6H, m, aromatic H), 3.95 (1H, ddt, *J* = 11.7, 4.9, 2.4 Hz, C_6-H), 3.71, 3.68 (2H, AB-qt, *J* = 10.3, 6.4 Hz, C_3'-H), 3.41 (1H, dt, *J* = 11.7, 2.4 Hz, C_6-H), 3.35 (3H, s, OMe), 3.27 (1H, dt, *J* = 5.4, 1.5 Hz, C_3-H), 3.12 (1H, broad s, C_2-H), 2.12 (1H, m, CH_2), 1.89 (1H, m, CH_2), 1.75-1.57 (4H, m, CH_2), 1.43 (1H, m, CH_2), 1.32 (1H, m, CH_2), 1.05 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.55, 134.05, 129.46, 127.54, 79.18, 75.26, 67.90, 63.95, 56.89, 28.64, 27.70, 26.85, 25.61, 20.76, 19.18. Anal Calcd for $C_{25}H_{36}O_3Si$: C, 72.77; H, 8.79. Found: C, 72.41; H, 8.84.

Synthesis of 22 from 4a. To a solution of *trans*-**4a** (521 mg, 1.26 mmol) in MeOH (13 ml) was added CAN (2.80 g, 5.11 mmol) at 0°C. After being stirred for 30 min, MeOH was evaporated off and the residue was taken up in AcOEt, which was then washed with water and brine, dried, and concentrated to dryness. The residue was passed through a short pad of silica gel with hexane-AcOEt (5 : 1) to afford the decomplexed compound (151 mg, 95%). This compound (151 mg, 1.08 mmol) was dissolved in THF (3.0 ml), to which NaH (60% in oil; 61 mg, 1.52 mmol) was added at 0°C. After being stirred for 1h, MeI (0.40 ml, 6.32 mmol) was added to the reaction mixture and stirring was continued for an additional hour. The reaction mixture was quenched by addition of sat. NH_4Cl solution, extracted with Et_2O. The extract was washed with water and brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-Et_2O (10 : 1) gave (2R*,3S*)-2-ethynyl-3-methoxytetrahydropyran (129 mg, 73%) as a colorless oil; MS *m/z* (%) 140 (M^+, 1.0), 125 (4.0), 110 (12), 95 (7.0), 71 (38), 58 (100); IR 3320 (C≡C-H), 2100 (C≡C) cm^{-1}; ^{1}H NMR δ 4.18 (1H, dd, *J* = 5.9, 2.0 Hz, C_2-H), 3.93 (1H, ddd, *J* = 11.2, 7.3, 3.9 Hz, C_6-H), 3.49 (1H, ddd, *J* = 11.2, 7.3, 3.4 Hz, C_6-H), 3.43 (3H, s, OMe), 3.23 (1H, ddd, *J* = 6.8, 5.9, 3.4 Hz, C_3-H), 2.50 (1H, d, *J* = 2.0 Hz, C≡C-H), 2.12 (1H, m, CH_2), 1.80 (1H, m, CH_2), 1.59-1.47 (2H, m, CH_2); ^{13}C NMR δ 81.08, 77.81, 74.49, 69.05, 65.33, 57.10, 26.28, 22.66. Anal Calcd for $C_8H_{12}O_2$: C, 68.54; H, 8.63. Found: C, 68.28; H, 8.82. According to the procedure described for preparation of *anti*-**21** from *anti*-**20**, the methoxy derivative (129 mg, 0.92 mmol) was successively treated with *n*-BuLi (1.60 M hexane solution; 0.64 ml, 1.02 mmol) and $(CH_2O)n$ (110 mg) to provide, after chromatography with hexane-AcOEt (3 : 1), the hydroxymethylated compound (128 mg, 82%). TBDPSCl (0.22 ml, 0.85 mmol) was added to a solution of the hydroxymethylated compound (128 mg, 0.75 mmol) and imidazole (123 mg, 1.80 mmol) in DMF (0.38 ml). After being stirred at rt for 2 h, the reaction mixture was diluted with Et_2O, washed with water several times and then brine, dried, and concentrated to dryness. Chromatography of the residue with hexane-AcOEt (10 : 1) afforded (2R*,3S*)-2-(3-*tert*-butyldiphenyl-silyloxyprop-1-ynyl)-3-methoxytetrahydropyran (292 mg, 95%) as a colorless oil; MS *m/z* (%) 408 (M^+, 0.3), 351 (51), 319 (41), 241 (33), 199 (100), 153 (78), 105 (20), 91 (29); ^{1}H NMR δ 7.72-7.70 (4H, m, aromatic H), 7.45-7.34 (6H, m, aromatic H), 4.39 (2H, d, *J* = 2.0 Hz, CH_2O), 4.26 (1H, broad d, *J* = 4.9 Hz, C_2-H), 3.87 (1H, ddd, *J* = 11.2, 7.8, 3.4 Hz, C_6-H), 3.50 (1H, ddd, *J* = 11.2, 6.4, 3.4 Hz, C_6-H), 3.41 (3H, s, OMe), 3.15 (1H, ddd, *J* = 6.8, 4.9, 3.4 Hz, C_3-H), 2.00 (1H, ddd, *J* = 12.7, 8.8, 3.9 Hz, CH_2), 1.81 (1H, m, CH_2), 1.58 (1H, m, CH_2), 1.44 (1H, m, CH_2), 1.05 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.50, 133.03, 129.70, 127.62, 85.04, 82.06, 77.64, 68.75, 64.64, 57.04, 52.62, 26.58, 25.80, 22.29,

19.08. Anal Calcd for $C_{25}H_{32}O_3Si$: C, 73.49; H, 7.89. Found: C, 73.36; H, 8.03. A solution of the above TBDPS derivative (292 mg, 0.71 mmol) in AcOEt (7.5 ml) was hydrogenated over 10% Pd-C (30 mg) under hydrogen atmosphere at rt for 1h. The catalyst was filtered off and the filtrate was concentrated to dryness. Chromatography of the residue with hexane-AcOEt (30 : 1) gave *trans*-**22** (283 mg, 96%) , which was identified with the one derived from *anti*-**19** by ^{1}H NMR, ^{13}C NMR, and IR spectra. Similar treatment of *cis*-**4a** (415 mg, 1.01 mmol) gave *cis*-**22** (171 mg, 47% overall yield) through (2R*,3R*)-2-ethynyl-3-methoxytetrahydropyran [MS *m/z* (%) 140 (M^+, 1.0), 125 (4.0), 110 (10), 95 (7.0), 71 (31), 58 (70); IR 3320 (C≡C-H), 2100 (C≡C) cm^{-1}; ^{1}H NMR δ 4.73 (1H, dd, *J* = 3.9, 2.0 Hz, C_2-H), 3.85 (1H, dt, *J* = 11.2, 2.9 Hz, C_6-H), 3.63 (1H, ddd, *J* = 11.2, 3.4, 1.5 Hz, C_6-H), 3.42 (3H, s, OMe), 3.35 (1H, td, *J* = 10.3, 3.9 Hz, C_3-H), 2.52 (1H, d, *J* = 2.0 Hz, C≡C-H), 1.90 (1H, m, CH_2), 1.79 (1H, m, CH_2), 1.73 (1H, m, CH_2), 1.58 (1H, m, CH_2); ^{13}C NMR δ 79.21, 76.20, 76.06, 67.64, 62.84, 56.70, 25.24, 23.89. Anal Calcd for $C_8H_{12}O_2$: C, 68.54; H, 8.63. Found: C, 68.14; H, 8.83.] and (2R*,3R*)-2-(3-*tert*-butyldiphenylsilyloxyprop-1-ynyl)-3-methoxytetrahydropyran [MS *m/z* (%) 408 (M^+, 0.3), 351 (39), 319 (31), 241 (24), 199 (100), 153 (59), 105 (16), 91 (22); ^{1}H NMR δ 7.74-7.72 (4H, m, aromatic H), 7.45-7.37 (6H, m, aromatic H), 4.72 (1H, dt, *J* = 4.4, 1.5 Hz, C_2-H), 4.43 (2H, d, *J* = 1.5 Hz, CH_2O), 3.79 (1H, dt, *J* = 11.2, 2.9 Hz, C_6-H), 3.57 (1H, dt, *J* = 11.2, 4.4 Hz, C_6-H), 3.39 (3H, s, OMe), 3.32 (1H, td, *J* = 5.8, 4.4 Hz, C_3-H), 1.84 (1H, m, CH_2), 1.77-1.66 (2H, m, CH_2), 1.56 (1H, m, CH_2), 1.07 (9H, s, ^{t}Bu), 1.05 (9H, s, ^{t}Bu); ^{13}C NMR δ 135.60, 133.18, 133.16, 129.71, 127.65, 86.45, 80.39, 76.41, 67.90, 62.88, 56.59, 52.80, 26.65, 25.44, 23.91, 19.15. Anal Calcd for $C_{25}H_{32}O_3Si$: C, 73.49; H, 7.89. Found: C, 73.21; H, 7.91.].

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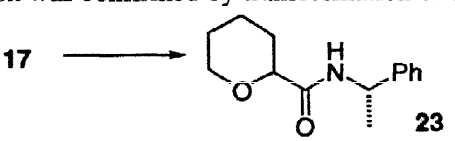

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