Comparative Studies on the Synthesis of an *anti,syn* Stereotriad with Chiral Allenylstannane and Allenylindium Reagents

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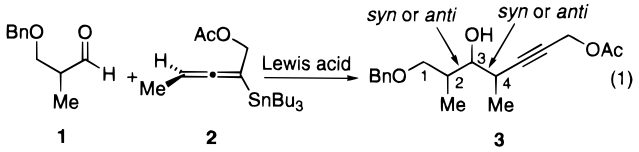
Addition of the chloroallenylstannane derived from the Bu_3Sn allene (*S*)-**2** and $SnCl_4$ to nonracemic α-methyl-*β*-oxygenated aldehyde **1a** afforded mixtures of *anti,syn* and *anti,anti* adducts **3a** and **3b**. When $InCl_3$ was employed in the transmetalation of allenylstannane (*S*)-**2**, a mixture of adducts **3a** and *ent*-**3b** was produced. Experiments with the *β*-ODPS aldehydes **1b** and **5** showed that $InBr_3$ and InI_3 yield a transient InX_n species from allenylstannane (*S*)-**2** with mainly retention of configuration. In contrast, transmetalation of (*S*)-**2** with $SnCl_4$ or $BuSnCl_3$ affords an intermediate allenyl species of inverted configuration. The (*S*)-**2**/$BuSnCl_3$ reagent showed high enantio- and diastereoselectivity in addition to aldehydes **1a**, **1b**, and **5**. The (*S*)-**2**/$InBr_3$ or InI_3 reagent, while somewhat less selective, afforded enantiomeric or diastereomeric adducts.

In a previous report we described a synthetic route to the four nonracemic stereotriads **3**[1] and their enantiomers through Lewis acid promoted additions of (*R*)- or (*S*)-allenylstannane **2**[2] to the (*R*) or (*S*)-*β*-oxygenated α-methylpropanal **1** (eq 1).[3] By varying the Lewis acid

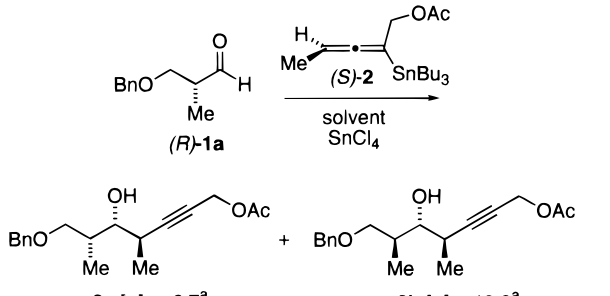


and the stannane chirality, we were able to prepare each of the four with excellent enantio- and diastereoselectivity. The 2,3-*syn* 3,4-*anti* isomer was the most difficult to obtain as the reaction conditions ($SnCl_4$, CH_2Cl_2) caused partial epimerization of the aldehyde **1** and subsequent formation of the *anti,anti* diastereomer by a favored chelation-controlled addition. A change of solvent from CH_2Cl_2 to hexanes appeared to solve the problem (Table 1, entries 1 and 2).

In connection with a projected total synthesis, we recently had occasion to repeat this reaction. However, despite numerous trials, we were unable to reproduce our earlier results with $SnCl_4$ (Table 1, entries 3−5). Our best effort employed a 1:1 mixture of toluene and hexanes as solvent and gave an 84:16 mixture of **3a** and **3b** in 48% yield after prolonged reaction times.

As a possible alternative approach to **3a**, we carried out the reaction with $InCl_3$ in place of $SnCl_4$.[4] We expected an *anti* S_E2' transmetalation and subsequent 1,3-isomerization to take place followed by addition of the resulting allenylindium species to aldehyde (*R*)-**1a**. In fact, this scenario was realized, but the product of the

Table 1. Addition of Allenylstannane (*S*)-2 to Aldehyde (*R*)-1a



entry	solvent	*T* °C	yield, %	**3a:3b**
1	CH_2Cl_2	−78	90	33:67[a]
2	hexane	−40	91	93:7[a]
3	CH_2Cl_2	−78	65	69:31[b]
4	hexane	−40	31	85:15[b]
5	*c*	−40	48	84:16[b]

[a] Reference 3. The rotation of **3a** is that of an 88:12 mixture of **3a** and **3b** obtained from stannane (*S*)-**2** of 89% ee and that of **3b** is from a 97:3 mixture derived from the same stannane. [b] This work. [c] 1:1 hexane−toluene.

reaction was a 29:71 mixture of *anti,syn* (**3a**) and *anti, anti* (*ent*-**3b**) adducts, favoring the latter (eq 2). Although we were unable to separate this mixture for positive identification of the components, the ^1H NMR spectrum clearly showed the characteristic peaks for these two isomers. Moreover, the optical rotation of the mixture, $[\alpha]_D$ +3.6, suggested that the *anti,anti* adduct was *ent*-**3b** and not **3b**. The rotations of enantioenriched **3a** and **3b** measured in our previous study were +6.7 and −10.0, respectively.[3,5] Therefore, a 29:71 mixture of the two should exhibit a negative rotation.

This finding suggested that the allenylindium intermediate derived from stannane (*S*)-**2** was formed largely with retention of configuration. This conclusion was surprising to us, as the related chlorostannane species, derived analogously from the allenylstannane precursor (*S*)-**2** and $SnCl_4$, was formed with inversion of configuration. This was also found to be the case in the reaction

⊗ Abstract published in *Advance ACS Abstracts,* August 1, 1997.

(1) Hoffmann, R. W. *Angew. Chem., Int. Ed. Engl.* **1987**, *26*, 489. Roush, W. R. *J. Org. Chem.* **1991**, *56*, 4151 and references therein.

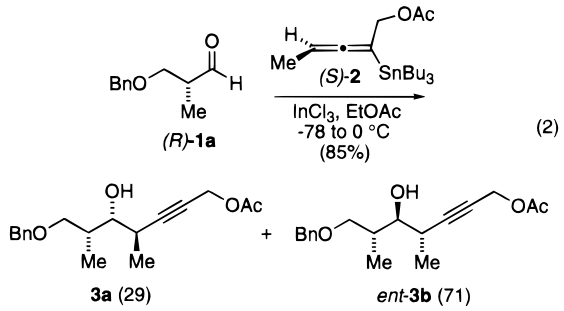
(2) Allenylstannane **2** was prepared from (*R*)-3-butyn-2-ol (DSM Fine Chemicals Inc., Saddle Brook, NJ) of ∼97% ee by our previously reported procedure[3] (Bu_3SnLi/CuBr displacement of the mesylate). For details, see the Supporting Information.

(3) Marshall, J. A.; Perkins, J. F.; Wolf, M. A. *J. Org. Chem.* **1995**, *60*, 5556.

(4) Marshall, J. A.; Hinkle, K. W. *J. Org. Chem.* **1995**, *60*, 1920.

(5) This value was erroneously reported as −6.7 in ref 3.

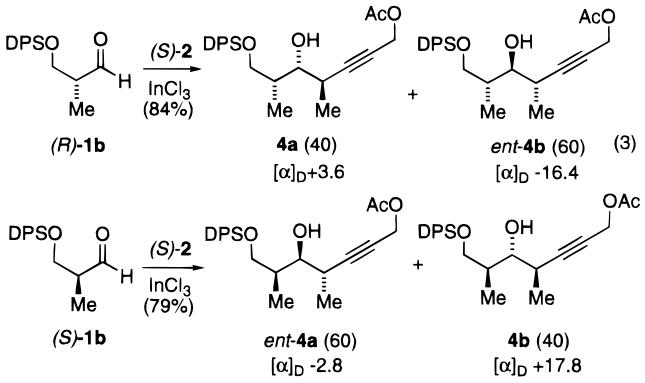
S0022-3263(97)00650-6 CCC: $14.00



of oxygenated allylic stannanes with $InCl_3$ to give allylic chloroindium intermediates by an *anti* S_E2' process.[4]

In order to place this conclusion on firmer ground, we studied additions of the allenylindium species derived from stannane (*S*)-**2**, to the β-ODPS aldehydes (*R*)-**1b** and (*S*)-**1b**.[6] The reasons for this change were 2-fold. First, we hoped that replacement of Bn by DPS would lessen the tendency for favored chelation-controlled additions, which lead to the *anti,anti* adduct **3b**.[3] Of equal importance, the products of the ODPS aldehyde addition, **4a** and **4b**, were separable by column chromatography. These reactions were conducted with aldehyde **1b** of >95% ee[3] and stannane (*S*)-**2** of ~97% ee.[2]

The additions were performed in EtOAc starting at −78 °C and gradually warming to rt. From aldehyde (*R*)-**1b** and stannane (*S*)-**2** we obtained a 40:60 mixture of the *anti,syn* adduct **4a**, $[\alpha]_D$ +3.6, and the *anti,anti* adduct *ent*-**4b**, $[\alpha]_D$ −16.4. Aldehyde (*S*)-**1b** was similarly converted to a 60:40 mixture of adducts *ent*-**4a**, $[\alpha]_D$ −2.8, and **4b**, $[\alpha]_D$ +17.8 (eq 3). The relative stereochemistry was initially assigned by comparison of the ^1H NMR spectra with those of the benzyl ethers **3a** and **3b**. Specifically, the two CH_3 doublets of the latter were more widely separated than those of the former. Confirmation of relative and absolute configuration was made through conversion of adducts **4a** and **4b** to the known benzyl ethers **3a** and **3b**.[3]

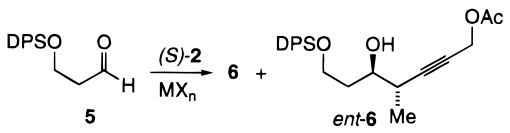


To further probe the unexpected course of the transmetalation reaction, we conducted additional experiments on allenylstannane (*S*)-**2** and the achiral aldehyde **5** as summarized in Table 2. Transmetalation with $SnCl_4$ and subsequent addition of aldehyde **5** led to the adduct **6** of 90% ee,[7] albeit in only 28% yield. The analogous experiment with $InCl_3$ afforded the enantiomeric *anti* adduct but with negligible ee (Table 2, entry 2).

(6) Roush, W. R.; Palkowitz, A. D.; Palmer M. A. J. *J. Org. Chem.* **1987**, *52*, 316.

(7) Trost, B. M.; Belletire, J. L.; Godleski, S.; McDougal, P. G.; Balkovec, J. M.; Baldwin, J. J.; Christy, M. E.; Ponticello, G. S.; Varga, S. L.; Springer, J. D. *J. Org. Chem.* **1986**, *51*, 2370.

Table 2. Additions of Allenylmetal Reagents Derived from Allenylstannane (*S*)-2 to Aldehyde 5



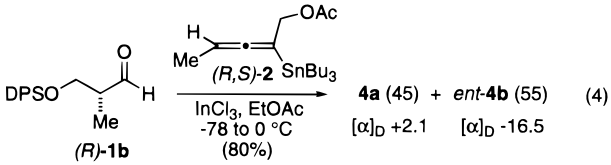
entry	MX_n	*T*, °C	*t*, h	yield, %	$[\alpha]_D$ (ee, %)
1	$SnCl_4$	−78	1	28	+10.1 (90)
2	$InCl_3$	−78 to rt[a]	12	84	−0.5 (4)
3	$InBr_3$	−78 to rt[a]	10	83	−4.7 (40)
4	$InBr_3$	rt[a]	0.5	71	−6.8 (60)
5	$InCl_3$	rt[b]	0.5	75	−2.2 (20)
6	$InBr_3$	rt[b]	0.25	60	−8.5 (75)
7	InI_3	rt[b]	0.5	60	−9.5 (80)

[a] 0.04 M in (*S*)-**2** and **5**. [b] 0.5 M in (*S*)-**2** and **5**.

With $InBr_3$ as the transmetalating reagent, we obtained alcohol *ent*-**6** of *ca.* 40% ee under conditions that afforded essentially racemic product with $InCl_3$. The ee of the adduct was increased to *ca.* 60% when the reaction was conducted at rt. Further improvement, to 75% ee, was realized by increasing the concentration of the reactants. Transmetalation with InI_3 under these conditions afforded alcohol **6** of 80% ee. Apparently factors that increase the rate of the addition also increase the ee of the adduct. In the foregoing experiments the stannane and aldehyde were added to a solution of InX_3. When the stannane and $InBr_3$ were stirred for 1 h before the aldehyde was added, the alcohol adduct was racemic.

Several points emerge from these studies. In the experiments that afforded adduct of measureable ee (Table 2, entries 1 and 3−7) the reagent derived from $SnCl_4$ gave **6** and those from InX_3 led mainly to *ent*-**6**. We have previously shown that the former reagent is formed with inversion of the allene configuration. Assuming the subsequent reactions of both intermediates with aldehyde **5** proceed *via* cyclic transition states, the InX_3 transmetalation must occur with retention of allene configuration. Our experience with the intermediate stannane derived from **2** and $SnCl_4$ indicates that the reaction with aldehydes is significanttly faster than racemization of the stannane. The corresponding indium reagent, on the other hand, must racemize at rates comparable to those of the additions.

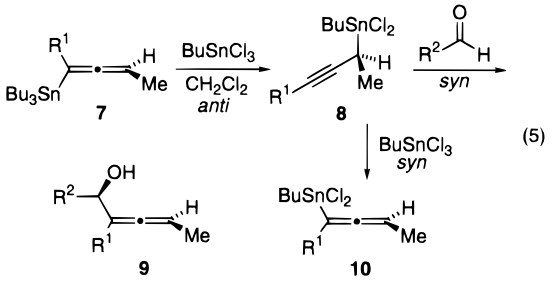
We carried out one additional experiment to confirm the suspected racemization of the allenylindium intermediates. Thus, the indium reagent derived from racemic allenylstannane (*R,S*)-**2** and $InCl_3$ afforded a 45:55 mixture of adducts **4a** and *ent*-**4b** from aldehyde (*R*)-**1b**, (eq 4), not unlike the 40:60 mixture of **4a** and *ent*-**4b** obtained from (*S*)-**2** and (*R*)-**1b**, depicted in eq 3.



That slightly different ratios of the two adducts are obtained from each of the enantiomeric aldehydes suggests that the rate of racemization is not significantly faster than the rate of addition. The differences in the rotations of products in this experiment and those of eq 3 presumably reflects varying degrees of aldehyde epimerization.[3]

Finally, it is worth noting that the rate of allenyl InX_n racemization relative to addition is decreased through the use of $InBr_3$, and more so InI_3, in reactions involving aldehyde **5** and stannane (*S*)-**2** (Table 2, entries 6 and 7). A similar trend was not found in the additions of these intermediates to aldehyde (*R*)-**1b**. The ratios of *anti* adducts *ent*-**4b**:**4a** were 70:30 from experiments with $InCl_3$, $InBr_3$, and InI_3. However, aldehyde (*S*)-**1b** gave a 91:9 mixture favoring the *anti,syn* adduct *ent*-**4a** in 78% yield with the allenylstananne (*S*)-**2** and $InBr_3$ reagent. This combination therefore represents the matched pairing, a result in accord with a presumed transmetalation−isomerization with retention and subsequent *syn*-addition through a cyclic transition state.[3]

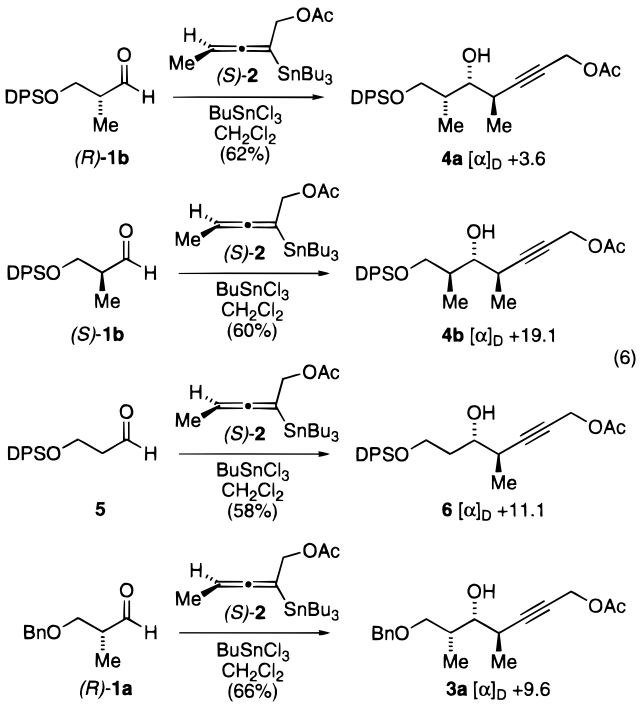
We have previously shown that $BuSnCl_3$ adds to allenylstannanes such as **7** at −40 °C to afford transient propargylic stannanes **8** with inversion of configuration.[8] These propargylstannanes react with aldehydes to yield allenylcarbinols **9** (eq 5). On standing, propargylic stannanes **8** isomerize to the allenic species **10**.



(5)

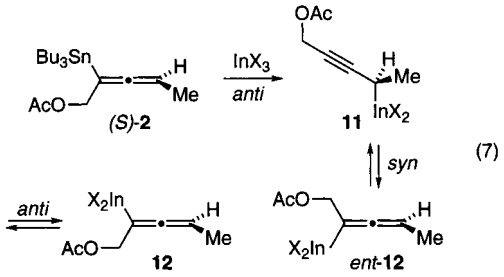
As these intermediates are configurationally stable, we decided to examine additions of the allenyl species **10** (R^1 = CH_2OAc), derived from stannane (*S*)-**2**, to aldehydes (*R*)- and (*S*)-**1b**. The reaction was conducted in CH_2Cl_2 at −78 °C with gradual warming to rt, following an induction period to permit the exchange to occur. In each case, a single adduct was obtained, *anti,syn* (**4a**) from (*R*)-**1b** and *anti,anti* (**4b**) from (*S*)-**1b** (eq 6). Similarly, stannane (*S*)-**2** gave only adduct **3a** with aldehyde (*R*)-**1a** under these conditions. Addition to the achiral aldehyde **5** afforded the *anti* adduct **6**, $[\alpha]_D$ +11.1, of *ca.* 98% ee. The identity of these adducts was confirmed by their ^1H NMR spectra and optical rotations.

We are unable to account for the apparent nonreproducibility of our earlier result with stannane (*S*)-**2**/$SnCl_4$ and aldehyde (*R*)-**1a**. However, the use of $BuSnCl_3$ or $InBr_3/InI_3$ in transmetalations of (*S*)-**2** solves the problem. The differing configurational stability of allenyltin *vs* allylindium intermediates is intriguing. We have shown that the transmetalation of allenylstannanes with $BuSnCl_3$ proceeds by sequential *anti,syn* S_E2' processes (eq 5). Based on the known *anti* pathway for transmetalation of α-oxygenated allylic stannanes with $InCl_3$,[4] it could be surmized that allenyl transmetalations with InX_3 proceed mainly by *anti,anti* and, to a lesser degree, *anti,syn* processes (eq 7).[9] Thus, the initial exchange would afford mainly an intermediate with retained stereochemistry, which would subsequently lead to increasing amounts of



(6)

the inverted isomer as the exchange process between allenyl and propargyl continues. Evidently the exchange process is slowest or the addition is fastest with the InI_3-derived reagent.



(7)

Finally it should be noted that the complimentarity of the $BuSnCl_3$ and $InBr_3/InI_3$ exchange process allows access to enantiomeric or diastereomeric adducts from a single pair of reactants. Thus aldehyde (*S*)-**1b** and stannane (*S*)-**2** afford the *anti,syn* adduct *ent*-**4a** as the major product (91:9) with $InBr_3$ whereas this same pairing leads to the *anti,anti* adduct **4b** when $BuSnCl_3$ is employed in the transmetalation step. Likewise aldehyde **5** and stannane (*S*)-**2** afford the *anti* adduct **6** of 98% with $BuSnCl_3$ and *ent*-**6** of 80% ee with InI_3.

Experimental Section

(2*R*,3*R*,4*R*)-(+)-1-(Benzyloxy)-2,4-dimethyl-7-acetoxy-5-heptyn-3-ol (3a). A. Standard Procedure with Tin(IV) Chloride in CH_2Cl_2. To a solution of stannane (*S*)-**2** (67.4 mg, 0.149 mmol) in CH_2Cl_2 (0.5 mL) at −78 °C was added tin(IV) chloride (0.16 mL, 0.149 mmol), and the mixture was allowed to reach 0 °C. After 40 min, the mixture was recooled to −78 °C and aldehyde (*R*)-**1a** (24.2 mg, 0.136 mmol) in CH_2Cl_2 (0.2 mL) was added. After 22 h, the reaction was quenched with 10% HCl (1 mL) and the solution was extracted with ether. The combined organic layers were washed with brine and dried over anhydrous $MgSO_4$, and triethylamine (0.5 mL) was added. The resulting white slurry was stirred at 0

(8) Marshall, J. A.; Yu, R. H.; Perkins, J. F. *J. Org. Chem.* **1995**, *60*, 5550.

(9) The structures for the indium species **11**, **12**, and *ent*-**12** of eq 7 are depicted as $RInX_2$ for clarity. The actual structures may involve bridged dimers as is found for other organoindium halides. *Cf. Dictionary of Organometallic Compounds*; Chapman and Hall: London, 1995; Vol. 2, pp 1980, 1982, 1984, 1990.

°C for 15 min and then filtered through a pad of Celite with ether. The filtrate was concentrated to give the crude alcohol contaminated with tin byproducts. The residue was chromatographed twice on silica gel (eluting first with 25% ethyl ether in hexanes, and a second time with 25% ethyl acetate in hexanes) to give 27.0 mg (65%) of the known alcohols **3a**/**3b** as an inseparable 69:31 mixture of diastereomers:[3] ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (m, 5H), 4.67 (m, 2H), 4.52 (m, 2H), 3.69−3.28 (m, 3H), 2.69 (m, 1H), 2.07 (s, 3H), 1.97 (m, 1H), 1.28 (d, J = 6.96 Hz, 3H), 1.18 (d, J = 6.96 Hz, 3H), 0.97 (d, J = 9.69 Hz, 3H), 0.91 (d, J = 6.96 Hz, 3H).

B. Hexanes as Solvent. The standard procedure was followed with stannane (*S*)-**2** (72.6 mg, 0.175 mmol), tin(IV) chloride (0.18 mL, 0.175 mmol), and aldehyde (*R*)-**1a** (28.0 mg, 0.159 mmol) in hexanes (2 mL) at −40 °C for 48 h to give 15.1 mg (31%) of alcohols **3a**/**3b** as an 85:15 mixture.

C. Hexanes/Toluene as Solvent. The standard procedure was followed with stannane (*S*)-**2** (72.9 mg, 0.176 mmol), tin(IV) chloride (0.18 mL, 0.176 mmol), and aldehyde (*R*)-**1a** (28.0 mg, 0.160 mmol) in hexanes:toluene (2 mL, 1:1) at −40 °C for 17 h to give 23.3 mg (48%) of alcohols **3a**/**3b** as an 84:16 mixture.

D. Transmetalation with Butyltin Trichloride. The standard procedure was followed with $BuSnCl_3$ (0.028 mL, 0.166 mmol), aldehyde (*R*)-**1a** (25.0 mg, 0.144 mmol), and stannane (*S*)-**2** (65.9 mg, 0.156 mmol) in CH_2Cl_2 (2 mL) for 22 h to give 29.0 mg (66%) of alcohol **3a** as a yellow oil: $[\alpha]_D$ +9.6 (*c* 1.01 $CHCl_3$).

(2*R*,3*S*,4*S*)-(+)-1-(Benzyloxy)-2,4-dimethyl-7-acetoxy-5-heptyn-3-ol (*ent*-3b). Standard Procedure with Indium(III) Chloride. A suspension of indium(III) chloride (76.0 mg, 0.342 mmol) in ethyl acetate (8.6 mL) was sonicated for 15 min. The solution was cooled to −78 °C, aldehyde (*R*)-**1a** (61.0 mg, 0.342 mmol) and stannane (*S*)-**2a** (213 mg, 0.513 mmol) were added, and the mixture was allowed to warm to rt. After 20 h, the reaction was quenched with 10% HCl solution (2 mL) and the solution was extracted with ether. The combined organic layers were washed with brine and dried over anhydrous $MgSO_4$, and triethylamine (1.0 mL) was added. The resulting white slurry was stirred at 0 °C for 15 min and then filtered through a pad of Celite with ether. The filtrate was concentrated to give the crude alcohol contaminated with tin byproducts. The residue was chromatographed twice on silica gel (first with 35% ethyl ether in hexanes, and a second time with 40% ethyl acetate in hexanes) to give 88.4 mg (85%) of the known alcohols **3a**/*ent*-**3b**[3] as a 29:71 inseparable mixture of diastereomers: $[\alpha]_D$ +3.6 (*c* 1.15 $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (m, 5H), 4.67 (m, 2H), 3.70−3.43 (m, 2H), 3.35 (dd, J = 3.3, 8.06 Hz, 1H), 2.71 (m, 1H), 2.07 (s, 3H), 1.27 (d, J = 6.96 Hz, 3H), 1.18 (d, J = 6.96 Hz, 3H), 0.97 (d, J = 6.96 Hz, 3H), 0.91 (d, J = 6.96 Hz, 3H).

(2*R*,3*S*,4*S*)-(−)-1-[(*tert*-Butyldiphenylsilyl)oxy]-2,4-dimethyl-7-acetoxy-5-heptyn-3-ol (*ent*-4b). A. From Allenic Stannane (*S*)-2 and Indium(III) Chloride. The standard procedure was followed with indium(III) chloride (43.0 mg, 0.193 mmol), aldehyde (*R*)-**1b** (63.0 mg, 0.193 mmol), and stannane (*S*)-**2** (0.120 g, 0.289 mmol) in ethyl acetate (5 mL) for 12.5 h to give 73.9 mg (84%) of the alcohols **4a**/*ent*-**4b** as a 40:60 mixture after chromatography on silica gel (first with 25% ethyl ether in hexanes, and then with 25% ethyl acetate in hexanes).

Alcohol 4a: $[\alpha]_D$ +3.6 (*c* 2.76 $CHCl_3$); IR (neat) 3503, 2245, 1749; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.66 (m, 4H), 7.40 (m, 6H), 4.67 (d, J = 1.83 Hz, 2H), 3.80−3.57 (m, 3H), 2.70 (m, 1H), 2.07 (s, 3H), 1.82 (m, 1H), 1.17 (d, J = 6.96 Hz, 3H), 1.06 (s, 9H), 0.95 (d, J = 6.60 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.8, 136.2, 136.1, 130.2, 128.2, 89.5, 76.9, 76.1, 67.9, 53.3, 38.6, 31.4, 27.4, 21.3, 19.8, 18.1, 11.1. Anal. Calcd for $C_{27}H_{36}O_4Si$: C, 71.64; H, 8.02. Found: C, 71.47; H, 8.11.

Alcohol *ent*-4b: $[\alpha]_D$ −16.4 (*c* 3.80 $CHCl_3$); IR (neat) 3487, 2237, 1749; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.68 (m, 4H), 7.41 (m, 6H), 4.69 (d, J = 1.83 Hz, 2H), 3.72 (m, 2H), 3.43 (m, 2H), 2.74 (m, 1H), 2.08 (s, 3H), 2.01 (m, 1H), 1.30 (d, J = 7.33 Hz, 3H), 1.06 (s, 9H), 0.83 (d, J = 6.97 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.8, 136.1, 133.5, 130.4, 128.3, 88.4, 78.7, 76.7, 69.0, 53.4, 39.5, 31.0, 27.3, 21.3, 19.6, 18.2, 14.1. Anal. Calcd for $C_{27}H_{36}O_4Si$: C, 71.64; H, 8.02. Found: C, 71.58; H, 8.08.

B. Indium(III) Bromide. The standard procedure was followed with aldehyde (*R*)-**1b** (81.0 mg, 0.247 mmol), stannane (*S*)-**2** (0.117 g, 0.371 mmol), and indium(III) bromide (88.0 mg, 0.247 mmol) in ethyl acetate (6.2 mL) at rt for 30 min to give 88.6 mg (79%) of the alcohols **4a**/*ent*-**4b** as a 30:70 mixture.

C. Indium(III) Iodide. The standard procedure was followed with aldehyde (*R*)-**1b** (74.0 mg, 0.226 mmol), stannane (*S*)-**2** (0.140 g, 0.339 mmol), and indium(III) iodide (112 mg, 0.226 mmol) in ethyl acetate (5.6 mL) at rt for 30 min to give 72.1 mg (70%) of the alcohols **4a**/*ent*-**4b** as a 30:70 mixture.

D. From Racemic Stannane (*R,S*)-2. The standard procedure was followed with indium(III) chloride (83.0 mg, 0.377 mmol), aldehyde (*R*)-**1b** (0.123 mg, 0.377 mmol), and stannane (*R,S*)-**2** (0.235g, 0.566 mmol) in ethyl acetate (9.4 mL) for 10 h to give 0.136 g (80%) of the alcohols **4a**/*ent*-**4b** as a 45:55 mixture.

(2*S*,3*S*,4*S*)-(−)-1-[(*tert*-Butyldiphenylsilyl)oxy]-2,4-dimethyl-7-acetoxy-5-heptyn-3-ol (*ent*-4a). A. Indium(III) Chloride. The standard procedure was followed with indium(III) chloride (39.0 mg, 0.178 mmol), aldehyde (*S*)-**1b** (58.0 mg, 0.178 mmol), and stannane (*S*)-**2** (0.111 g, 0.267 mmol) in ethyl acetate (4.5 mL) for 9 h to give 63.7 mg (79%) of the alcohols *ent*-**4a**/**4b** as a 60:40 mixture.

Alcohol *ent*-4a: $[\alpha]_D$ −2.8 (*c* 3.80 $CHCl_3$). Anal. Calcd for $C_{27}H_{36}O_4Si$: C, 71.64; H, 8.02. Found: C, 71.38; H, 8.07.

Alcohol 4b: $[\alpha]_D$ +17.8 (*c* 2.76 $CHCl_3$). Anal. Calcd for $C_{27}H_{36}O_4Si$: C, 71.64; H, 8.02. Found: C, 71.65; H, 8.09.

B. Indium(III) Bromide. The standard procedure was followed with aldehyde (*S*)-**1b** (117 mg, 0.357 mmol), stannane (*S*)-**2** (0.222 g, 0.535 mmol), and indium(III) bromide (126 mg, 0.357 mmol) in ethyl acetate (0.71 mL) at rt for 30 min to give 127 mg (78%) of the alcohols *ent*-**4a**/**4b** as a 91:9 mixture: *ent*-**4a**: $[\alpha]_D$ −2.4 (*c* 1.30 $CHCl_3$).

(2*R*,3*R*,4*R*)-(+)-1-[(*tert*-Butyldiphenylsilyl)oxy]-2,4-dimethyl-7-acetoxy-5-heptyn-3-ol (4a). Standard Procedure with Butyltin Trichloride. To a solution of allenic stannane (*S*)-**2** (0.133 g, 0.320 mmol) in CH_2Cl_2 (0.7 mL) at −78 °C was added $BuSnCl_3$ (0.056 mL, 0.335 mmol). The dry ice bath was removed, and after 5 h, aldehyde (*R*)-**1b** (95.0 mg, 0.291 mmol) was added in CH_2Cl_2 (0.2 mL). After 18 h, the reaction was quenched with 10% HCl solution (0.5 mL) and the solution was extracted with ether. The combined organic layers were washed with brine and dried over anhydrous $MgSO_4$. Triethylamine (0.5 mL) was added, and the mixture was vigorously stirred at 0 °C for 15 min. The resulting white slurry was filtered through a pad of Celite with ether, and the filtrate was concentrated to give the crude alcohol as a yellow oil. The residue was chromatographed on silica gel (first with 25% ether in hexanes, and then 25% ethyl acetate in hexanes) to give 68.9 mg (62%) of alcohol **4a** as a clear oil. $[\alpha]_D$ +3.6 (*c* 6.27 $CHCl_3$).

(2*S*,3*R*,4*R*)-(+)-1-[(*tert*-Butyldiphenylsilyl)oxy]-2,4-dimethyl-7-acetoxy-5-heptyn-3-ol (4b). The standard procedure was followed with $BuSnCl_3$ (0.11 mL, 0.665 mmol), aldehyde (*R*)-**1b** (0.19 g, 0.578 mmol), and stannane (*S*)-**2** (0.264 g, 0.636 mmol) in CH_2Cl_2 (1.3 mL) for 18.5 h to give 0.158 g (60%) of alcohol **4a** as a yellow oil: $[\alpha]_D$ +19.1 (*c* 1.23 $CHCl_3$).

(3*S*,4*S*)-(+)-1-[(*tert*-Butyldiphenylsilyl)oxy]-4-methyl-7-acetoxy-5-heptyn-3-ol (6). A. Tin(IV) Chloride. The standard procedure was followed with tin(IV) chloride (0.54 mL, 0.542 mmol), aldehyde **5** (0.17 g, 0.542 mmol), and stannane (*S*)-**2** (0.225 g, 0.542 mmol) in CH_2Cl_2 (1.1 mL) for 1 h to give 66.6 mg (28%) of the alcohol **6**: $[\alpha]_D$ +10.1 (*c* 6.00 $CHCl_3$). HPLC analysis of the (*R*)-Mosher ester indicated an ee of 90% for this sample.

B. Butyltin Trichloride. The standard procedure was followed with aldehyde **5** (87.0 mg, 0.278 mmol), stannane (*S*)-**2** (0.127 g, 0.306 mmol), and $BuSnCl_3$ (0.053 mL, 0.320 mmol) in CH_2Cl_2 (0.64 mL) at rt for 18 h to give 70.4 mg (58%) of alcohol **6**: $[\alpha]_D$ = +11.1 (*c* 7.00 $CHCl_3$).

(3*R*,4*R*)-(−)-1-[(*tert*-Butyldiphenylsilyl)oxy]-4-methyl-7-acetoxy-5-heptyn-3-ol (*ent*-6). A. Indium(III) Chloride. The standard procedure was followed with indium(III) chloride

(73.0 mg, 0.324 mmol), aldehyde **5** (0.103 g, 0.329 mmol), and stannane (*S*)-**2** (0.205 g, 0.494 mmol) in ethyl acetate (0.66 mL) for 30 min at rt to give 75.1 mg (75%) of alcohol *ent*-**6**/**6** after chromatography on silica gel (first with 35% ether in hexanes, and then 25% ethyl acetate in hexanes): $[\alpha]_D$ −2.2 (*c* 1.47 $CHCl_3$); IR (neat) 3495, 2269, 1741; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.68 (m, 4H), 7.40 (m, 6H), 4.67 (d, J = 1.86 Hz, 2H), 3.86 (m, 3H), 2.62 (m, 1H), 2.07 (s, 3H), 1.78 (m, 2H), 1.23 (d, J = 7.33 Hz, 3H), 1.05 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.8, 136.1, 133.7, 130.3, 128.3, 88.9, 76.8, 73.7, 63.2, 53.3, 36.7, 33.4, 27.4, 21.3, 19.6, 17.0. Anal. Calcd for $C_{26}H_{34}O_4Si$: C, 71.19; H, 7.81. Found: C, 71.10; H, 7.80.

B. Indium(III) Bromide. The standard procedure was followed with aldehyde **5** (75.5 mg, 0.241 mmol), stannane (*S*)-**2** (0.150 g, 0.362 mmol), and indium(III) bromide (85.4 mg, 0.241 mmol) in ethyl acetate (0.5 mL) at rt for 15 min to give 64.0 mg (60%) of alcohol *ent*-**6**/**6**: $[\alpha]_D$ −8.5 (*c* 6.40 $CHCl_3$).

C. Indium(III) Iodide. The standard procedure was followed with aldehyde **5** (59.0 mg, 0.188 mmol), stannane (*S*)-**2** (0.117 g, 0.282 mmol), and indium(III) bromide (93.0 mg, 0.188 mmol) in ethyl acetate (0.4 mL) at rt for 30 min to give 49.6 mg (60%) of alcohol *ent*-**6**/**6**: $[\alpha]_D$ −9.5 (*c* 4.79 $CHCl_3$).

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Supporting Information Available: Experimental procedures and ^{1}H NMR spectra (23 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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