Stereoselective Radical Carbon−Carbon Bond Forming Reactions of β-Alkoxy Esters: Atom and Group Transfer Allylations under Bidentate Chelation Controlled Conditions

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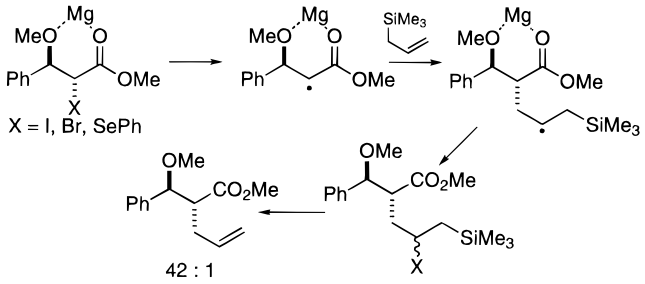
Abstract: The radical allylation of a series of β-alkoxy esters using allyltrimethylsilane in the presence of $MgBr_2 \cdot OEt_2$ is described. Under bidentate chelation-controlled conditions, allyltrimethylsilane rivals allyltributyltin in efficiency and is a superior reagent from ecological and practical perspectives. The reactions work with iodides and bromides as well as phenylselenides. The isolation of γ-phenylseleno intermediates indicates that the reaction proceeds by an atom transfer process. These reactions require initiation with Et_3B and can be inhibited by galvinoxyl, *m*- and *p*-dinitrobenzene indicating that this atom transfer sequence involves the intermediacy of radicals.

Asymmetric induction in free radical reactions is a topic of current interest.[1] Facial selectivity in radical reactions can be influenced by a stereogenic center adjacent to a radical center (1,2-induction)[2−4] and by the use of chiral auxiliaries.[5] A significant development in this field is the observation that complexation with a Lewis acid can be used to enhance levels of stereoselection or to reverse the facial bias of radical reactions.[6−9] Lewis acids have been shown to be compatible with reduction, allylation, and β-addition processes. In this



paper we report results we have obtained in chelation-controlled allylation reactions of α-halo-β-alkoxy esters using allyltrimethylsilane and present evidence for a radical atom transfer mechanism. To our knowledge, this represents the first example of an atom transfer reaction in which facial selectivity is controlled by Lewis acid complexation.[10,11]

Results

A general mechanism for a typical atom transfer reaction is shown in Scheme 1. In order to be successful, the reactivity of

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(4) (a) Guindon, Y.; Yoakim, C.; Lemieux, R.; Boisvert, L.; Delorme, D.; Lavallée, J.-F. *Tetrahedron Lett*. **1990**, *31*, 2845−2848. (b) Guindon, Y.; Lavallée, J.-F.; Boisvert, L.; Chabot, C.; Delorme, D.; Yoakim, C.; Hall, D.; Lemieux, R.; Simoneau, B. *Tetrahedron Lett*. **1991**, *32*, 27−30. (c) Durkin, K.; Liotta, D.; Rancourt, J.; Lavallée, J.-F.; Boisvert, L.; Guindon, Y. *J. Am. Chem. Soc*. **1992**, *114*, 4912−4914. (d) Guindon, Y.; Yoakim, C.; Gorys, V.; Ogilvie, W. W.; Delorme, D.; Renaud, J.; Robinson, G.; Lavallée, J.-F.; Slassi, A.; Jung, G.; Rancourt, J.; Durkin, K.; Liotta, D. *J. Org. Chem.* **1994**, *59*, 1166−1178. (e) Guindon, Y.; Slassi, A.; Rancourt, J.; Bantle, G.; Bencheqroun, M.; Murtagh, L.; Ghiro, E.; Jung, G. *J. Org. Chem.* **1995**, *60*, 288−289.

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(6) Monodentate: (a) Renaud, P.; Moufid, N.; Kuo, L. H.; Curran, D. P. *J. Org. Chem.* **1994**, *59*, 3547−3552. (b) Renaud, P.; Ribezzo, M. *J. Am. Chem. Soc*. **1991**, *113*, 7803−7805. (c) Curran, D. P.; Kuo, L. H. *J. Org. Chem.* **1994**, *59*, 3259−3261. (d) Nishida, M.; Ueyama, E.; Hayashi, H.; Ohtake, Y.; Yamaura, Y.; Yanaginuma, E.; Yonemitsu, O.; Nishida, A.; Kawahara, N. *J. Am. Chem. Soc.* **1994**, *116*, 6455−6456. (e) Renaud, P.; Bourquard, T.; Gerster, M.; Moufid, N. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 1601−1603. (f) Nishida, M.; Hayashi, H.; Yamaura, Y.; Yanaginuma, E.; Yonemitsu, O. *Tetrahedron Lett*. **1995**, *36*, 269−272. (g) Murakata, M.; Tsutsui, H.; Hoshino, O. *J. Chem. Soc., Chem. Commun.* **1995**, 481−482. (h) Urabe, H.; Kobayashi, K.; Sato, F. *J. Chem. Soc., Chem. Commun.* **1995**, 1043−1044. (i) Moufid, N.; Renaud, P.; Hassler, C.; Giese, B.; *Helv. Chim. Acta* **1995**, *78*, 1006−1012.

(7) Bidendate: (a) Guindon, Y.; Lavallée, J. -F.; Llinas-Brunet, M.; Horner, G.; Rancourt, J. *J. Am. Chem. Soc.* **1991**, *113*, 9701−9702. (b) Guindon, Y.; Guérin, B.; Chabot, C.; Mackintosh, N.; Ogilvie, W. W. *Synlett*. **1995**, 449−451. (c) Guindon, Y.; Guérin, B.; Rancourt, J.; Chabot, C.; Mackintosh, N.; Ogilvie, W. W. *Pure Appl. Chem*. **1996**, *68*, 89−96. (d) Toru, T.; Watanabe, Y.; Tsusaka, M.; Ueno, Y. *J. Am. Chem. Soc.* **1993**, *115*, 10464−10465. (e) Rück, K.; Kunz, H. *Synthesis*, **1993**, 1018. (f) Nagano, H.; Kuno, Y. *J. Chem. Soc., Chem. Commun.* **1994**, 987−988. (g) Yamamoto, Y.; Onuki, S; Yumoto, M.; Asao, N. *J. Am. Chem. Soc.* **1994**, *116*, 421−422. (h) Wu, J. H.; Radinov, R.; Porter, N. A.; *J. Am. Chem. Soc.* **1995**, *117*, 11029−11030. (i) Sibi, M. P.; Jasperse, C. P.; Ji, J. *J. Am. Chem. Soc*. **1995**, *117*, 10779−10780. (j) Sibi, M. P.; Ji, J. *Angew. Chem., Int. Ed. Engl*. **1996**, *35*, 190−192. (k) Sibi, M. P.; Ji, J. *J. Am. Chem. Soc.* **1996**, *118*, 3063−3064.

(8) Solvent complexation: (a) Waldner, A.; De Mesmaeker, A.; Hoffmann, P.; Mindt, T.; Winkler, T. *Synlett* **1991**, 101−104. (b) De Mesmaeker, A.; Waldner, A.; Hoffmann, P.; Mindt, T. *Synlett* **1993**, 871−874

(9) Intramolecular hydrogen bonding: (a) Kündig, E. P.; Xu, L.-H.; Romanens, P. *Tetrahedron Lett.* **1995**, *36*, 4047−4050. (b) Curran, D. P.; Abraham, A. C.; Liu, H. *J. Org. Chem*. **1991**, *56*, 4335−4337. See also ref 2b.

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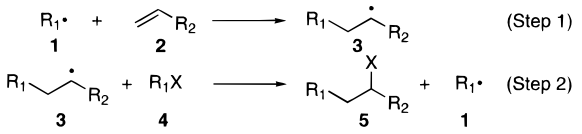
Scheme 1

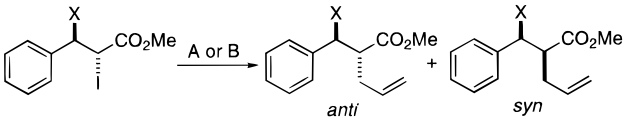


the participating species must be carefully modulated so that chain propagation steps will dominate over standard chain terminations. Conditions are especially favorable when the initial radicals (**1)** have long enough lifetimes to allow radical addition to occur (Step 1) and when the subsequent radicals undergo rapid atom transfer with the donor species **4** (Step 2) resulting in a viable chain reaction.[11] A convenient way of doing this is to use α-iodo esters as the atom donating component. These types of substrates are well suited to atom transfer reactions due to the presence of the ester adjacent to the carbon bearing the radical. This functionality facilitates the chain propagation steps by lowering the SOMO energy of radical **1** thus improving the overlap between the SOMO of the radical and the HOMO of the olefin component. Lowering the SOMO of this radical also encourages atom transfer.[11] Malonate[12] and malononitrile[13] benefit from an additional electron withdrawing group and are especially useful if one wants to promote this type of reaction.

In our earlier studies of chelation controlled radical processes[7a−c] we noticed that hydrogen transfer and allylation reactions involving α-halo esters proceeded more readily than those done in absence of Lewis acid.[14] Presumably complexation between the carbonyl of the ester and the Lewis acid increased the efficiency of these processes by rendering the ester even more electronegative, thus lowering the SOMO energy of these radicals. This hypothesis suggested to us that complexation with a Lewis acid could perhaps be beneficial to the atom transfer reaction. Control of diastereoselectivity through bidentate chelation with Lewis acids in such reactions was as well sought.

Preparation of Materials and Standards. The *β*-alkoxy esters needed for this study were prepared by a variety of routes. Secondary and tertiary *anti* iodides **9**, **12**, **15**, **18**, **21**, **24**, and **27** (Table 2) and secondary bromide **36** (Table 3) were prepared by a halo etherification reaction as described by Vishwakarma and Walia.[15] Phenylselenide **37** was synthesized by using a modification of this method in which silver triflate, a soluble silver salt, was used in place of silver nitrate. S*yn* substrates **38**, **39**, and **40** (Table 3) were prepared from the appropriate *Z* olefin using procedures analogous to those of the corresponding *anti* substrates.[15] Tetrahydropyran **30** and tetrahydrofuran **33** (Table 2) were obtained by an iodocyclization reaction involving the appropriate α, *β*-unsaturated ester.[4d] Silyl ether **6** (Table 1) was readily derived from the previously described secondary alcohol.[16]

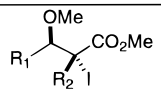
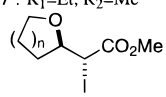
Table 1. Radical Allylation Reactions of Iodoesters with Allyltrimethylsilane under Chelation and Nonchelation Controlled Conditions



entry	substrate	conditions[a]	ratio[b] *anti*:*syn*	yield[c]
1	**6**:X = OTBS	A	1:9.5	82
2	**6**:X = OTBS	B	1:13	39
3	**9**:X = OMe	A	42:1	87
4	**9**:X = OMe	B	1:5	39

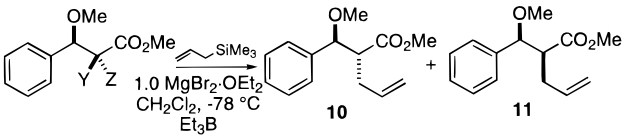
[a] A: 2.0 equiv of $CH_2CHCH_2SiMe_3$, 1.0 equiv of $MgBr_2{\cdot}OEt_2$, 0.2 equiv of Et_3B, CH_2Cl_2, −78 °C. B: 2.0 equiv of $CH_2CHCH_2SiMe_3$, 0.2 equiv of Et_3B, CH_2Cl_2, −78 °C. [b] Determined by NMR using crude reaction mixtures. [c] Isolated combined yield.

Table 2. Radical Allylation of Various Substrates under Chelation Control

Entry	Substrate	Products[a] *anti* *syn*	Ratio[b] *anti* : *syn*	Yield[c]
				
1	**9** : R_1=Ph, R_2=H	**10** **11**	42 : 1	87
2	**12** : R_1=Me, R_2=H	**13** **14**	>100 : 1	87
3	**15** : R_1=c-C_6H_{11}, R_2=H	**16** **17**	>100 : 1	87
4	**18** : R_1=*i*Pr, R_2=H	**19** **20**	>100 : 1	70
5	**21** : R_1=Ph, R_2=Me	**22** **23**	>100 : 1	39[e]
6	**24** : R_1=Me, R_2=Me[d]	**25** **26**	>100 : 1	35[e]
7	**27** : R_1=Et, R_2=Me[d]	**28** **29**	>100 : 1	40[e]
				
8	**30** : n=2	**31** **32**	27 : 1	81
9	**33** : n=1	**34** **35**	1.5 : 1	78

[a] Conditions: 2.0 equiv of $CH_2CHCH_2SiMe_3$, 1.0 equiv of $MgBr_2{\cdot}OEt_2$, 0.2 equiv of Et_3B, CH_2Cl_2, −78 °C. [b] Determined by GC using crude reaction mixtures. [c] Isolated yield of major product. [d] Ethyl ester was used. [e] α-Hydroxy-*β*-alkoxy esters were obtained in *ca*. 40% yield.

Table 3. Effect of the Relative Configuration and α-Substituent of Substrates on Chelation Controlled Radical Allylations



entry	substrate	ratio[a,b] **10**:**11**	yield[c]
1	**9**:Y = H, Z = I	42:1	87
2	**36**:Y = H, Z = Br	>100:1	67
3	**37**:Y = H, Z = SePh	>100:1[d]	75
4	**38**:Y = I, Z = H		0[e]
5	**39**:Y = Br, Z = H	10:1	72
6	**40**:Y = SePh, Z = H	100:1[d]	48
7	**38**:Y = I, Z = H[f]		0[e]

[a] Conditions: 2.0 equiv of $CH_2CHCH_2SiMe_3$, 1.0 equiv of $MgBr_2{\cdot}OEt_2$, 0.2 equiv of Et_3B, CH_2Cl_2, −78 °C. [b] Determined by GC using crude reaction mixtures. [c] Isolated yield of major product. [d] Ratio determined after chromatography (see text). [e] Starting material is consumed, *ca*. 40% α-hydroxy ester obtained. [f] Conditions: 2.0 equiv of $CH_2CHCH_2SiMe_3$, 0.2 equiv of Et_3B, CH_2Cl_2, −78 °C.

The relative configurations of the acyclic allylated products were established by independent synthesis and correlation of NMR spectra. The propensity of the aldol reaction to give *syn* adducts was capitalized upon to obtain adduct **43**[17] which was methylated using MeOTf and Proton-sponge to give *syn* adduct **14** (Scheme 2). This compound, along with the known adducts

(10) For other examples of stereoselective atom transfer reactions see: (a) Curran, D. P.; Geib, S. J.; Kuo, L. H. *Tetrahedron Lett.* **1994**, *35*, 6235−6238. (b) Thoma, G.; Curran, D. P.; Geib, S. V.; Giese, B.; Damm, W.; Wetterich, F. *J. Am. Chem. Soc.* **1993**, *115*, 8585−8591. (c) Curran, D. P.; Thoma, G. *Tetrahedron Lett.* **1991**, *32*, 6307−6310.

(11) For reviews see: (a) Curran, D. P. *Synthesis* **1988**, 489−513. (b) Jasperse, C. P.; Curran, D. P.; Fevig, T. L. *Chem. Rev.* **1991**, *91*, 1237−1286. See also ref 10.

(12) Curran, D. P.; Chang, C.-T. *J. Org. Chem.* **1989**, *54*, 3140−3157.

(13) Curran, D. P.; Seong, C.-M. *J. Am. Chem. Soc*. **1990**, *112*, 9401.

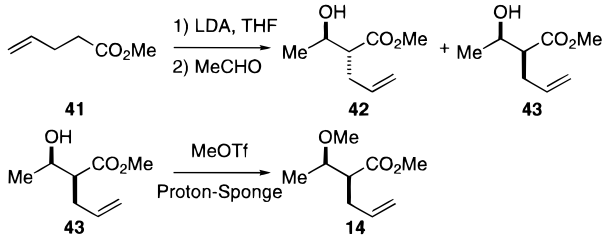
(14) Lewis acid accelerations have been noted in other radical process: (a) Newcomb, M.; Ha, C. *Tetrahedron Lett.* **1991**, *32*, 6493−6496. (b) Urabe, H.; Yamashita, K.; Suzuki, K.; Kobayashi, K.; Sato, F. *J. Org. Chem.* **1995**, *60*, 3576−3577. See also ref 7d.

(15) Vishwakarma, L. C.; Walia, J. S. *J. Indian Chem. Soc.* **1976**, *53*, 156−162

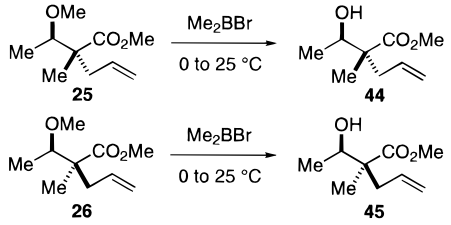
(16) Cambie, R. C.; Chambers, D.; Rutledge, P. S.; Woodgate, P. D. *J. Chem. Soc., Perkin Trans. 1* **1977**, *20*, 2231−2235.

(17) Fráter, G.; Müller, U.; Günther, W. *Tetrahedron* **1984**, *40*, 1269−1277. See also Reference 2b.

Scheme 2



Scheme 3



10[2b] and **11**,[2b] was used as a standard to characterize the allylation products of the corresponding secondary iodides (Table 2). The relative configuration of the quaternary allylated products was determined by treating *anti* adduct **25** (Table 2, entry 6), with Me_2BBr[18] at 0 °C to give β-hydroxy ester **44** whose NMR spectrum was identical to that previously reported[17] (Scheme 3). In a similar manner, *syn* adduct **26** was cleaved to give the known product **45**.[17] The relative configurations of the remaining tertiary and quaternary acyclic products were deduced by correlation of NMR spectra[19] with products **10**,[2b] **11**,[2b] **14**, **22**,[2b] **23**,[2b] **25**, and **26**. In all cases, the difference in chemical shift between the NMR resonances of the methylene protons of the allyl side chain ($\Delta\upsilon$) of the *anti* diastereomers were greater than the values of $\Delta\upsilon$ for the *syn* diastereomers. The chemical shifts of the resonances of these same hydrogens in the *anti* series were also consistently upfield to those resonances of the corresponding *syn* diastereomers.[20]

The relative configurations of cyclic products **31**, **32**, **34**, and **35** (Table 2, entries 8 and 9) were determined by correlation of their NMR spectra with those of silyl ethers **46** and **48**.[7b] These compounds were chosen as references since the relative configurations of the asymmetric centers could be determined easily. As shown in Scheme 4, exposure of *anti* adduct **46** to 5% HF in CH_3CN resulted in the formation of lactone **47**. NOE analysis of this material showed strong interactions between H_a and H_b and between H_a and H_c indicating that these three hydrogens are located on the same face of the bicyclic lactone and hence that the configuration of **46** is *anti*. Hydrolysis of silyl ether **48** gave lactone **49**, in which there is a weak NOE interaction between H_a and H_c. In addition, there was no coupling observed between H_a and H_c in this adduct suggesting a 90° dihedral angle between these two hydrogens. This is only possible if H_a and H_c are *trans* to one another, and hence compound **48** must have a *syn* configuration. The configurations of exocyclic substrates **31**, **32**, **34**, and **35** were deduced by correlation of NMR spectra with those of *anti* and *syn* compounds **46** and **48** (see above).[19]

Allylation Reactions. With the required substrates and stereochemical tools in hand we proceeded to try the atom transfer reactions. Thus silyl derivative **6** was allowed to react with allyltrimethylsilane[21] in the presence of $MgBr_2{\cdot}OEt_2$. This reaction proceeded readily and in good yield (Table 1, entry 1) providing the *syn* product **8** in a 9.5:1 ratio. In the absence of $MgBr_2{\cdot}OEt_2$ however, this same transformation resulted in a poor yield of allyl transfer product (entry 2) in a 13:1 ratio in favor of the *syn* isomer. The next obvious step was to replace the silyl ether by another protecting group (e.g., OMe) that would permit the formation of a bidentate intermediate and to evaluate its effect. As shown in entries 3 and 4, the yield was once again improved by the addition of $MgBr_2{\cdot}OEt_2$; more importantly a reversal in the facial selectivity of the reaction was also observed consistent with bidentate chelation.

Scheme 4

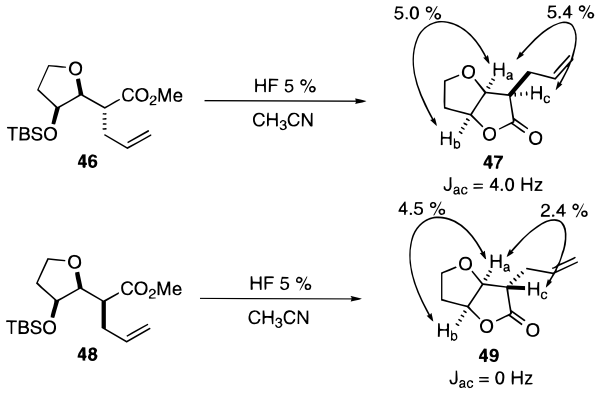


Table 4. Effect of Radical Inhibitors on Chelation Controlled Allylations using Allyltrimethylsilane

entry	substrate	inhibitor	yield[a]
1	**9**:X = I	none	87
2	**9**:X = I	1,3-DNB	7
3	**9**:X = I	1,4-DNB	4
4	**9**:X = I	galvinoxyl	3
5	**36**:X = Br	none	67
6	**36**:X = Br	1,4-DNB	trace
7	**37**:X = SePh	none	75
8	**37**:X = SePh	1,4-DNB	trace

[a] Determined by ^{1}H NMR integration of crude reaction isolates.

Other secondary acyclic iodides underwent allylation with excellent selectivity when treated with allyltrimethylsilane and $MgBr_2{\cdot}OEt_2$, furnishing ratios higher than 100:1 (Table 4, entries 2, 3, and 4).[22] Tertiary acyclic iodides all displayed excellent diastereoselectivities in the present chelation controlled reaction; unfortunately poor yields were observed (entries 5, 6, and 7).[23] In these cases, lower substrate reactivity (reflected by longer reaction times) results in competitive formation of the corresponding α-hydroxy esters. The formation of these types of products is presumably a result of chain termination by

(18) (a) Guindon, Y.; Yoakim, C.; Morton, H. E. *Tetrahedron Lett.* **1983**, *24*, 2969. (b) Guindon, Y.; Therien, M.; Girard, Y.; Yoakim, C. *J. Org. Chem.* **1987**, *52*, 1680. (c) Guindon, Y.; Anderson, P. C. *Encyclopedia of Reagents for Organic Synthesis*; Paquette, L. A. Ed.; Wiley & Sons: New York, 1995; pp 715−718.

(19) Tables of the chemical shift data used to make these correlations can be found in the supplementary material.

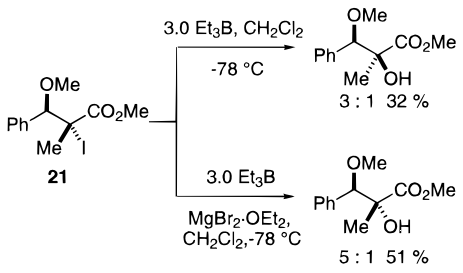
(20) A similar trend has been observed in the case of reduction. See ref 4 and: Gouzoules, F. H.; Whitney, R. A. *J. Org. Chem.* **1986**, *51*, 2024−2030.

(21) This reagent is reported to give allyl adducts through an atom transfer/elimination sequence. (a) Curran, D. P.; Chen, M.-H.; Spletzer, E.; Seong, C. M.; Chang, C.-T. *J. Am. Chem. Soc.* **1989**, *111*, 8872−8878. (b) Hwu, J. R.; Chen, C. N.; Shiao, S.-S. *J. Org. Chem.* **1995**, *60*, 856−862. (c) Hirao, T.; Fujii, T.; Ohshiro, Y. *Tetrahedron Lett.* **1994**, *35*, 8005−8008 and refs cited therein.

(22) Ratios were determined by GC using crude reaction mixtures. These ratios were comparable to those obtained by NMR spectroscopy. In the case of the phenyl and cyclohexyl substituted secondary substrates (**9** and **15**, Table 2, entries 1 and 3), the GC and NMR results were calibrated using product mixtures of varying composition.

(23) A similar drop in reactivity has been previously observed for other tertiary iodides. Curran, D. P.; Kim, D.; Ziegler, C. *Tetrahedron* **1991**, *47*, 6189−6196.

Scheme 5



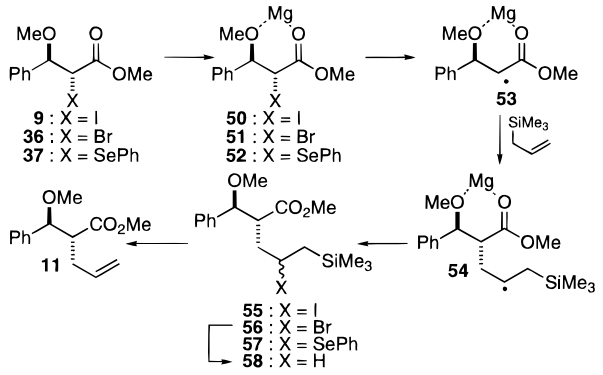
combination with peroxyborate radicals.[24] We have noted that α-iodo-β-alkoxy esters react slowly with Et_3B and oxygen to give the corresponding α-hydroxy esters with relatively low diastereoselectivity as illustrated in Scheme 5.[25,26]

We were interested in probing the effect of bicyclic bidentate complex formation in the present reaction. In the presence of $MgBr_2$·OEt_2, the allylation of tetrahydropyranyl substituted iodo ester **30** gave a ratio of 27:1 in favor of the *anti* product (entry 8). In contrast, almost no selectivity was observed when the corresponding tetrahydrofuranyl derivative **33** was subjected to the same reaction conditions (entry 9). This reactivity pattern was previously observed in the case of the analogous reaction using allyltributyltin.[7b] It is possible that the formation of a bicyclic [3.3.0] intermediate in the reaction of tetrahydrofuranyl derivative **33** is disfavored sterically (see below).

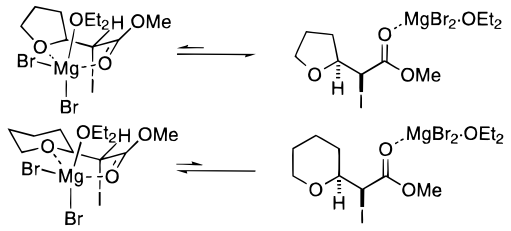
In addition to iodides, bromides and phenylselenides[27] were able to function as substrates in the reaction (Table 3, entries 1−3). As anticipated from previous observations using Bu_3-SnH or allyltributyltin,[7a,b] we were expecting a decrease in diastereoselectivity for the *syn* iodo isomer. We were somewhat surprised to note that while *anti* iodide **9** underwent a facile allylation reaction with allyltrimethylsilane, the corresponding *syn* iodide **38** did not (entries 1 and 4). When *syn* iodide **38** was treated with allyltrimethylsilane in the presence of $MgBr_2$·OEt_2 the starting material was consumed but almost no allylated product was found.[28] A similar unexplained result was also observed in the absence of Lewis acid (entry 7).[29] This effect was only minor in the case of bromides (entries 2 and 5) and absent in the case of phenylselenides (entries 3 and 6).

To prove that an atom transfer mechanism was operative, we examined the reaction of phenylselenide substrate **37** since the initially formed adduct (**57**) should be relatively stable (Scheme 6). This was in fact the case; we noticed the presence of a new product in the NMR spectrum of the crude reaction mixture. Careful chromatography using silica neutralized with Et_3N afforded the intermediate phenylselenide **57** as a 4:1 mixture of isomers, epimeric at the carbon β to silicon.[30] Subjecting this material to flash chromatography affords compound **11** (>100:1 *anti*:*syn*). A similar intermediate (**56**) was detected in the crude reaction mixtures when the corresponding

Scheme 6



Scheme 7



bromide **36** was treated with allyltrimethylsilane and $MgBr_2$·OEt_2 under the same conditions. This compound proved to be too labile to be isolated but could be converted to alkylsilane **58** by reduction with Bu_3SnH. Unfortunately the same experiment could not be done with iodide **9** as the subsequent elimination was extremely rapid.

We have performed several experiments to prove whether the initial atom transfer reaction is radical based. Triethylborane[24,31] was required to initiate the reaction with all of the substrates studied, implying that this process involves a radical chain. The reaction could also be terminated by the presence of inhibitors (Table 4). In all cases when inhibitors were used (entries 2, 3, 4, 6, and 8), the intermediate adducts (**55**, **56**, and **57**) were not observed and virtually all of the starting material was recovered. This was true of iodides, bromides, and phenylselenides. Taken together these are good indications that the stereofacial-determining, carbon−carbon bond forming step of the process is indeed a radical reaction.

Discussion

This work illustrates the first use of bidentate chelation to control facial selectivity in atom and group transfer reactions. This complements the use of Lewis acids in reduction, allylation and β-addition. As illustrated in Table 2 the use of allyltrimethylsilane leads to the overall addition of an allyl group with very high selectivity. One substrate class which does not give high selectivity however are those iodides exocyclic to a tetrahydrofuran ring (Entry 9). As shown in Scheme 7, the formation of a chelate in the tetrahydrofuran system may be impaired by eclipsing interactions between the C−O bond and an Mg−Br bond in the bicyclo [3.3.0] complex. For this reason the acyclic (monodentate or uncomplexed) pathway becomes competitive in the tetrahydrofuran series resulting in low selectivity. In the tetrahydropyran case the bicyclic complex does not suffer the same type of interactions and therefore the equilibrium favors the bidentate chelated complex.

That this process involves a radical based process is indicated by the requirement of initiation and by the observation that radical inhibitors are able to prevent the reaction from occurring.

(24) Brown, H. C.; Midland, M. M.; Kabalka, G. W. *J. Am. Chem. Soc.* **1971**, *93*, 1024−1025.

(25) We are on one hand trying to avoid this reaction pathway and on the other hand trying to optimize it for a different application. Guindon, Y.; Yoakim, C.; Soucy, F. unpublished results.

(26) Details of this reaction including proof of configuration will be published elsewhere.

(27) For examples of group transfer reactions involving selenium see: (a) Beyers, J. H.; Harper, B. C. *Tetrahedron Lett.* **1992**, *23*, 6953−6954. (b) Curran, D. P.; Martin-Esker, A. A.; Ko, S.-B.; Newcomb, M. *J. Org. Chem.* **1993**, *58*, 4691−4695 and refs cited therein. See also ref 10a.

(28) The reaction mixture contained *ca.* 40% of the α-hydroxy-β-alkoxy ester.

(29) We have found in several radical processes that there is often a large difference in reactivity between *syn* and *anti* iodide diastereomers. The fact that two such diastereomers can have such dissimilar behaviors is very intriguing, and we are currently investigating this phenomenon.

(30) The same intermediate was observed when *syn* phenylselenide **40** was used.

(31) Nozaki, K.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 403−409.

The fact that the ratios of products obtained using allyltrimethylsilane with and without Lewis acid are the same as those of the corresponding reactions performed using allyltributyltin[7b] suggests that the stereofacial-determining step (radical addition) is the same for both processes.

The inclusion of $MgBr_2 \cdot OEt_2$ also appears to improve the efficiency of the overall atom transfer process for the present series of substrates. In the absence of Lewis acid, allylation does occur in most cases; however, the reaction suffers from competitive chain terminating processes, particularly hydroxylation.[32] This is reflected in the low yields obtained when allyltrimethylsilane was used in the absence of Lewis acid and in the contrast in overall quality between reactions performed with and without Lewis acid. One notable exception to this is the case of *syn* iodide **38**, whereas the addition of $MgBr_2 \cdot OEt_2$ was not sufficient to avoid this reaction pathway.

The overall results of this study suggests that a Lewis acid may be used to improve the reactivity of substrates that do not give facile atom transfer. We are now pursuing this possibility in order to better define the scope and limitations of this reaction.

Is this improvement in reaction efficiency attributable to a more rapid atom transfer (Step 2, Scheme 1) or to an accelerated addition step (Step 1)? In principle both steps could be implicated. Coordination of the Lewis acid to the ester would make this group more electronegative potentially improving the atom donating ability of these complexes (**50**, **51**, and **52** Scheme 6). The addition step may as well be influenced by rendering the ester group more electronegative. This may decrease the SOMO energy of the intermediate radical (**53**) thus permitting a better overlap with the HOMO of the allylsilane olefin. The fact that tertiary substrates give poor results relative to the secondary series (Table 2) may suggest that it is the addition step which is affected since tertiary iodides should be better atom donors than secondary ones.[11,23] Firm conclusions will have to wait for a better understanding of the hydroxylation reactions and of the influence of Lewis acid on the kinetic characteristics of these processes.

Dissecting these reactions is not a trivial exercise. In principle there could be at least three distinct competing reaction pathways (not considering the hydroxylation pathways): the uncomplexed pathway giving a preference for the *syn* product; the monodentate intermediate which also leads to the *syn* product; and the bidentate pathway leading to the *anti* product. The overall kinetic preference of one pathway with respect to the others will affect the outcome of the reaction. The need for equimolar amounts of $MgBr_2 \cdot OEt_2$ in the reaction mixture suggests that the bidentate pathway may not benefit from a strong kinetic bias. The implications of the nature of the Lewis acid,[33] its solubility and the stability of the complex generated are aspects we are presently considering. In conclusion, we have described herein studies that support the use of Lewis acids in atom transfer processes both for the improvement of the efficiency of this reaction when needed, as well as to control the diastereoselectivity of the reaction when bidentate Lewis acids are used.

Experimental Section[34]

Methyl (2*R,3*R**)-2-Iodo-3-[((1, 1-dimethylethyl)dimethylsilyl)-oxy]-3-phenylpropanoate (6).** To a solution of methyl cinnamate (1.70 g, 10.52 mmol) in water (37 mL) and acetone (18 mL) was successively added *N*-iodosuccinimide (4.73 g, 21.04 mmol) and H_2SO_4 (180 μL). The reaction was stirred at 25 °C until judged to be no more than 50% complete by TLC. The mixture was then extracted with ether, and the combined ether extracts were washed with 10% $Na_2S_2O_3$, water, and brine and dried over $MgSO_4$. Flash chromatography (25% EtOAc in hexanes) afforded the iodohydrin as a white solid (3.02 g). Mp 98−99 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.36 (s, 1H), 3.78 (s, 3H), 4.59 (d, J = 8 Hz, 1H), 5.09 (d, J = 6 Hz, 1H), 7.32−7.39 (m, 5H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 24.37, 53.01, 76.17, 126.88, 128.48, 128.66, 139.31, 171.60; IR ($CHCl_3$) 3672, 3090, 1726, 1350, 1300, 1230, 1004 cm^{-1}; MS (FAB) 307 (MH^+); HRMS calcd for $C_{10}H_{12}IO_3$ (M^+) 306.9831, found 306.9844. To a solution of this alcohol (500 mg, 1.634 mmol) and 2,6-lutidine (380 μL, 3.268 mmol) in CH_2Cl_2 (15 mL) at −78 °C was added slowly *tert*-butyldimethylsilyl trifluoromethanesulfonate (560 μL, 2.451 mmol). After the reaction was judged to be complete by TLC, the mixture was diluted with ether and washed with water, saturated NH_4Cl, and brine. Drying over $MgSO_4$ followed by flash chromatography (5% EtOAc in hexanes) afforded silyl ether **6** as a white solid (690 mg, 98%). Mp 95−97 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.31 (s, 3H), 0.01 (s, 3H), 0.78 (s, 9H), 3.79 (s, 3H), 4.38 (d, J = 10.0 Hz, 1H), 5.05 (d, J = 10 Hz, 1H) 7.34−7.36 (m, 5H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ −4.61, −4.82, 17.83, 25.37, 27.60, 52.66, 77.42, 127.59, 128.03, 128.49, 140.45, 170.73; IR (neat) 2955, 1737, 1436, 1270, 1202, 1170 cm^{-1}; MS (FAB) 421 (MH), 363; HRMS calcd for $C_{16}H_{26}IO_3Si$ (MH^+) 421.0696, found 421.0669; Anal. Calcd for $C_{16}H_{25}IO_3Si$: C, 45.71; H, 6.00. Found: C, 45.30; H, 5.93.

General Procedure for the Preparation of Iodides 9, 12, 15, 18, 21, 24, and 27.[15] To a solution of methyl cinnamate (5.05 g, 31.1 mmol) in methanol (70 mL) was successively added $AgNO_3$ (15.81 g, 62.2 mmol) and iodine (10.6 g, 62.2 mmol). The reaction mixture was stirred at room temperature in the dark for 6 h, then filtered through Celite, and concentrated. The residue was taken up in ether and washed with 10% $Na_2S_2O_3$, water, and brine. The organic layer was dried ($MgSO_4$), filtered, and concentrated to afford a residue which was purified by flash chromatography to afford pure iodide **9**[15] as a white solid (10 g, 78%). Iodides prepared in this manner were stable for several months if kept in a freezer.

Methyl (2*R,3*R**)-2-Iodo-3-methoxy-butanoate (12).** Colorless oil, ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.39 (d, J = 6.1 Hz, 3H), 3.35 (s, 3H), 3.61 (dd, J = 6.1, 8.8 Hz, 1H), 3.75 (s, 3H), 4.23 (d, J = 8.8 Hz, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 17.52, 24.99, 52.55, 57.25, 77.64, 170.35; IR (neat) 2980, 2830, 1740, 1440, 1305, 1220, 1150, 1100 cm^{-1}; MS (CI, CH_4) 259 (MH^+, 100), 244 (15), 227 (79), 199 (18), 175 (19), 131 (48), 101 (48); HRMS calcd for $C_6H_{11}IO_3$ (MH) 257.9753, found 257.9746.

Methyl (2*R,3*R**)-2-Iodo-3-methoxy-3-cyclohexylpropanoate (15).** Colorless oil, ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.09−1.74 (m, 10H), 2.03−2.07 (m, 1H), 3.44 (s, 3H), 3.55 (dd, J = 2.3, 10.2 Hz, 1H), 3.76 (s, 3H), 4.26 (d, J = 10.2 Hz, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 20.94, 24.32, 25.82, 26.09, 26.28, 30.57, 39.82, 52.56, 61.58, 85.49, 171.15; IR (neat) 2940, 2860, 1740, 1440, 1280, 1220, 1170, 1110 cm^{-1}; MS (CI,CH_4) 327 (MH^+,33), 295 (100), 263 (18), 168 (32), 127 (17); HRMS calcd for $C_{11}H_{19}O_3I$ (M^+) 326.0381, found 326.0398; Anal. Calcd for $C_{11}H_{19}IO_3$: C, 40.51; H, 5.87. Found: C, 40.85; H, 6.00.

Methyl (2*R,3*R**)-2-Iodo-3-methoxy-4-methylpentanoate (18).** Colorless oil, ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.84 (d, J = 6.8 Hz,3H), 1.05 (d, J = 7 Hz, 3H), 2.40 (m, 1H), 3.48 (s, 3H), 3.61 (dd, J = 2.4, 10.2 Hz, 1H), 3.78 (s, 3H), 4.22 (d, J = 10.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.96, 20.37, 21.61, 29.88, 52.68, 61.84, 85.78, 171.32; IR (neat) 2960, 1740, 1435, 1367, 1200, 995 cm^{-1}; MS (FAB) 287 (MH, 26), 128 (16), 87 (100); HRMS calcd for $C_8H_{15}IO_3$ (MH) 287.0144, found 287.0120.

(32) This hydroxylation pathway was not observed in the analogous reaction performed using allyltributyltin. See ref 7b.

(33) For a recent example of the effect of the nature of Lewis acid on reaction pathways see ref 7k.

(34) **General Methods:** Melting points were determined on an electrothermal melting point apparatus and are uncorrected. NMR spectra were recorded on a Bruker AC200 or Bruker AMX400 spectrometer and are referenced to TMS as internal standard. IR spectra were recorded on a Perkin-Elmer 781 spectrophotometer. CI and EI mass spectra were recorded on an MF 50 TATC instrument operating at 70 eV. Capillary GC analyses were performed on a Shimadzu GC-9AM instrument using a 0.25 mm × 25 m Chromatopac C-R3A column. Flash chromatography was performed on Merck silica gel 60 (0.040−0.063 mm) using nitrogen pressure. Analytical thin-layer chromatography (TLC) was carried out on precoated (0.25 mm) Merck silica gel F-254 plates. All reactions were conducted under a positive nitrogen atmosphere in oven-dried glassware using standard syringe techniques. Tetrahydrofuran (THF) and ether were distilled from sodium/benzophenone immediately prior to use. Dichloromethane (CH_2Cl_2), $(iPr)_2EtN$ and diisopropylamine were distilled from calcium hydride. Methanol was distilled from magnesium.

Methyl (2*R,3*R**)-2-Iodo-2-methyl-3-methoxy-3-phenylpropanoate (21).** White solid, mp 76−77 °C; ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.97 (s, 3H), 3.21 (s, 3H), 3.85 (s, 3H), 5.00 (s, 1H), 7.31−7.53 (m, 5H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 23.80, 42.37, 52.97, 57,75, 87.12, 127.45, 128.41, 129.91, 135.11, 172.67; IR ($CHCl_3$) 3030, 2960, 2940, 1735, 1455, 1250, 1100 cm^{-1}; MS (CI, CH_4) 335 (MH^+, 21), 303 (59), 207 (21), 175 (100), 121 (21); HRMS calcd for $C_{12}H_{15}IO_3$ (M^+) 334.0066, found 334.0082.

Methyl (2*R,3*R**)-2-Iodo-2-methyl-3-methoxybutanoate (24).** Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (t, J = 7.12 Hz, 3H), 1.46 (d, J = 6.3 Hz, 3H), 1.98 (s, 3H), 3.33 (s, 3H), 4.06 (q, J = 6.3Hz, 1H), 4.25 (m, J = 7.1 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.98, 14.02, 23.67, 43.19, 57.86, 61.90, 81.58, 172.54; IR (neat) 2980, 2825, 1732, 1378, 1252, 1132, 990 cm^{-1}; this compound would not give a satisfactory mass spectrum.

Methyl (2*R,3*R**)-2-Iodo-2, 4-dimethyl-3-methoxypentanoate (27).** Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.11 (t, J = 7Hz, 3H), 1.33 (t, J = 7 Hz, 3H), 1.49−1.74 (m, 1H), 1.97 (s, 3H), 2.15−2.35 (m, 1H), 3.47 (s, 3H), 3.83 (dd, J = 2, 10 Hz, 1H), 4.21−4.32 (m, 2H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 12.0, 13.6, 23.9, 24.9, 43.8, 60.9, 61.6, 87.5, 172.2; IR (neat) 1735 cm^{-1}; MS (CI, NH_3) m/e (relative intensity) 318 ($M^+ + NH_4$, 100), 301 ($M^+ + H$, 6); HRMS calcd for $C_9H_{17}O_3I$ (M^+) 300.0256, found 300.0240; Anal. Calcd for $C_9H_{17}IO_3$: C, 36.01; H, 5.71. Found: C, 35.99; H, 5.77.

General Procedure for the Preparation of Iodides 30 and 33. To a stirred solution of methyl 6-hydroxyhex-2-enoate (1.13 g, 7.87 mmol) in THF (30 mL) at room temperature was added $NaHCO_3$ (3.30 g, 39.3 mmol) and then iodine (10.0 g, 39.3 mmol). After 24 h of stirring the resultant mixture was diluted with ether, washed with 10% $Na_2S_2O_3$ and brine, and dried over $MgSO_4$. Removal of solvent gave an oil which was then purified by flash chromatography to give the desired product **33** (1.10 g, 51%). Iodides **30** and **33** are stable for several months if kept in a freezer.

Methyl (2*R,3*R**)-3-[Tetrahydropyran-2-yl]-2-iodopropanoate (30)**. Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.06−1.20 (m, 1H), 1.31−1.56 (m, 3H), 1.80−1.87 (m, 1H), 2.14−2.20 (m, 1H), 3.37−4.04 (m, 1H), 3.53−3.60 (m, 1H), 3.72 (s, 3H), 3.86−3.92 (m, 1H), 4.11 (d, J = 9.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 23.20, 24.06, 25.24, 30.05, 52.77, 68.94, 78.02, 171.20; IR (neat) 2960, 1730, 1430cm^{-1}; MS (FAB) 285 (MH, 100), 253 (18), 154(92), 137(77); HRMS calcd for $C_8H_{14}IO_3$ (MH) 284.9988, found 284.9960.

Methyl (2*R,3*R**)-3-[Tetrahydrofuran-2-yl]-2-iodopropanoate (33).** Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.80−1.87 (m, 1H), 1.88−1.98 (m, 2H), 2.25−2.30 (m, 2H), 3.76 (s, 3H), 3.87−3.97 (m, 2H), 4.20 (d, J = 9.5 Hz, 1H), 4.31−4.37 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.43, 25.92, 31.57, 52.83, 69.61, 79.72, 170.50; IR (neat) 2970, 1740, 1430, 1260, 1050 cm^{-1}; MS (FAB) 271 (MH, 100), 239 (8), 145 (14), 71 (14); Anal. Calcd for $C_7H_{11}IO_3$: C, 31.13; H, 4.11. Found: C, 30.78; H, 4.18.

Methyl (2*R,3*R**)-2-Bromo-3-methoxy-3-phenylpropanoate (36)**.[15] This material was prepared from methyl cinnamate using a procedure similar to that described above for compound **9**.

Methyl (2*R,3*R**)-2-Phenylseleno-3-methoxy-3-phenylpropanoate (37)**. To a solution of PhSeBr (2.04 g, 8.66 mmol) and methyl cinnamate (1.08 g, 6.66 mmol) in MeOH (30 mL) was added AgOTf (2.22 g, 8.66 mmol). After stirring at room temperature for 30 min, additional PhSeBr (0.31 g, 1.31 mmol) and AgOTf (0.34 g, 1.31 mmol) were added. The mixture was stirred at room temperature for 30 min at which time the reaction was judged to be complete by TLC. Filtration through Celite and evaporation of the solvent left a residue which was dissolved in EtOAc and washed with water and brine. The organic phase was collected and dried over $MgSO_4$. Flash chromatography (10% EtOAc in hexanes) afforded the pure selenide as a white solid. Mp 73−76 °C; ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.4−7.1 (m, 10 H), 4.54 (d, J = 10.5 Hz, 1H), 3.86 (d, J = 10.5 Hz, 1H), 3.63 (s, 3H), 3.16 (s, 3H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 50.23, 52.12, 57.12, 84.02, 127.77, 128.07, 128.24, 128.36, 128.59, 128.75, 135.51, 137.70, 171.97; IR (KBr) 3040, 2960, 1730, 1470, 1460, 1430, 1420, 1370, 1350, 1320, 1310, 1280, 1210 cm^{-1}; MS (EI) 350 (MH^+), 317 (M-32); Anal. Calcd for $C_{17}H_{18}O_3Se$: C, 58.28; H, 5.18. Found: C, 58.01; H, 5.08.

Methyl (2S*, 3R*)-2-Iodo-3-methoxy-3-phenylpropanoate (38). A solution of iodide **9** (691 mg, 2.16 mmol) and LiI·3H_2O (2.84 g, 15.1 mmol) in THF (30 mL) was refluxed overnight. The mixture was diluted with ether and successively washed with 10% aqueous $Na_2S_2O_3$, water, and brine. The organic layer was dried ($MgSO_4$), filtered, and concentrated to afford a 1:1 mixture of iodides **9** and **38**. Iodide **38** can be obtained in pure form by flash chromatography using CH_2Cl_2. White solid; mp 47−48 °C; ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.30−7.40 (m, 5 H), 4.52 (d, J = 9.9 Hz, 1H), 4.43 (d, J = 9.9 Hz, 1H), 3.54 (s, 3H), 3.27 (s, 3H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 26.42, 52.58, 57.06, 83.87, 127.43, 128.61, 128.81, 136.74, 164.60; IR (neat) 3060, 3025, 2985, 2940, 2815, 1735, 1490, 1455, 1435, 1350, 1295, 1265, 1165, 1005 cm^{-1}; HRMS calcd for $C_{11}H_{13}IO_3$, 319.9909, found 319.9885.

Methyl (2S*, 3R*)-2-Bromo-3-methoxy-3-phenylpropanoate (39). To a solution of *Z*-methyl cinnamate (0.63 g, 3.9 mmol) in methanol (20 mL) was successively added $AgNO_3$ (2.0 g, 11.7 mmol) and bromine (0.6 mL, 11.7 mmol). The reaction mixture was stirred at room temperature in the dark for 0.5 h, then filtered through Celite, and concentrated. The residue was taken up in ether and washed with 10% $Na_2S_2O_3$, water, and brine. The organic layer was dried ($MgSO_4$), filtered and concentrated to afford a residue which was purified by flash chromatography to afford the bromide as a colorless oil (0.83 g, 78%). Bromides prepared in this manner were stable for several months if kept in a freezer. Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.30 (s, 3H), 3.56 (s, 3H), 4.39 (d, J = 8.9 Hz, 1H), 4.55 (d, J = 8.9 Hz, 1H), 7.33−7.36 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 49.75, 52.64, 57.14, 83.37, 127.54, 128.54, 128.93, 136.58, 167.96; IR (neat) 2950, 2826, 1744, 1494, 1454, 1300, 1100, 980 cm^{-1}; MS (FAB) 273 (MH, 68), 243 (69), 217 (100), 163 (31), 121 (69); HRMS calcd for $C_{11}H_{14}BrO_3$ (MH) 273.0126, found 273.0115; Anal. Calcd for $C_{11}H_{13}BrO_3$: C, 48.37; H, 4.80. Found: C, 48.43; H, 4.74.

Methyl (2S*, 3R*)-2-Phenylseleno-3-methoxy-3-phenylpropanoate (40). This material was prepared from *cis* methyl cinnamate using the method described above for compound **37** (93%). Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.24 (s, 3H), 3.27 (s, 3H), 4.11 (d, J = 9.6 Hz, 1H), 4.49 (d, J = 9.6 Hz, 1H), 7.35−7.27 (m, 8H), 7.67−7.64 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 50.58, 51.51, 56.86, 82.45, 127.33, 127.44, 128.36, 128.52, 128.70, 136.37, 138.50, 170.18; IR (neat) 2940, 2820, 1730, 1435, 1270, 1100 cm^{-1}; MS (FAB) 350 (MH, 18), 319 (26), 121 (100); HRMS calcd for $C_{17}H_{18}SeO_3$ (MH) 350.0421, found 350.0422.

General Procedure for the Allylation of α-Iodoesters under Chelation Controlled Conditions. Compounds 7, 10, 13, 16, 19, 22, 25, 28, 31, and 34. To a suspension of $MgBr_2$·OEt_2 (116 mg, 0.456 mmol) in CH_2Cl_2 (3 mL) at −78 °C was added dropwise a solution of iodide **9** (146 mg, 0.456 mmol) in CH_2Cl_2 (1.5 mL). Allyltrimethylsilane (0.145 mL, 0.912 mmol) and Et_3B (0.09 mL of a 1.0 M solution in hexanes) were added to the mixture after stirring for 10 min at −78 °C. The resulting suspension was stirred for an additional 3 h at this temperature, and then 0.2 equiv of Et_3B were added each hour until the reaction was judged to be complete by TLC. The reaction mixture was then poured into a saturated $NaHCO_3$ solution and extracted with CH_2Cl_2. The combined organic extracts were washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude product was purified by flash chromatography (CH_2Cl_2) to afford the *anti* product **10**.

Methyl 2-[Propen-3-yl]-3-[((1,1-dimethylethyl)dimethylsilyl)oxy]-3-phenylpropanoate (7 and 8). (Mixture of isomers). Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ **7**: −0.23 (s, 3H), −0.03 (s, 3H), 0.88 (s, 9H), 2.41−2.57 (m, 2H), 2.70−2.76 (m, 1H), 3.45 (s, 3H), 4.82 (d, J = 7.5 Hz, 1H), 4.95−5.03 (m, 2H), 5.69−5.79 (m, 1H), 7.21−7.33 (m, 5H), **8**: −0.31 (s, 3H), −0.02 (s, 3H), 0.80 (s, 9H), 2.41−2.57 (m, 2H), 2.70−2.76 (m, 1H), 3.70 (s, 3H), 4.73 (d, J = 9 Hz, 1H), 4.95−5.05 (m, 2H), 5.69−5.79 (m, 1H), 7.21−7.33 (m, 5H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ **7**: −5.32, −4.71, 18.00, 25.64, 32.53, 51.04, 55.51, 75.74, 116.25, 126.39, 127.44, 127.88, 135.69, 142.67, 173.24, **8**: −5.56, −4.80, 17.96, 25.44, 33.20, 51.21, 75.74, 116.48, 127.01, 128.13, 134.69, 142.08, 174.58; IR (neat) 2950, 2860, 1736, 1471, 1435, 1360, 1255, 1165, 1070, 1005 cm^{-1}; MS (FAB) 335 (MH), 319, 277; Anal. Calcd for $C_{19}H_{30}SiO_3$: C, 68.22; H, 9.05. Found: C, 67.85; H, 9.17.

Methyl (2S*, 3R*)-2-[Propen-3-yl]-3-methoxy-3-phenylpropanoate (10). Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.75−1.87 (m, 1H), 2.05−2.22 (m, 1H), 2.73−2.86 (m, 1H), 3.13 (s, 3H), 3.73 (s, 3H),4.26 (d, J = 9.9 Hz, 1H), 4.89−5.02 (m, 2H), 5.48−5.68 (m, 1H), 7.26−

7.42 (m, 5H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 33.34, 51.56, 52.99, 56.76, 84.99, 116.86, 127.66, 128.37, 128.52, 134.44, 138.81, 174.44; IR (neat) 2980, 1740, 1650, 1440, 1170, 1100, 790 cm^{-1}; MS (FAB) 235, 202 (10), 171 (15), 143 (20), 121 (100); HRMS calcd for $C_{14}H_{19}O_3$ (MH) 235.1334, found 235.1341; Anal. Calcd for $C_{14}H_{18}O_3$: C, 71.77; H, 7.74. Found: C, 71.50; H, 7.68.

Methyl (2S*, 3R*)-2-[Propen-3-yl]-3-methoxybutanoate (13). Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.14 (d, J = 6.2 Hz, 3H), 2.20−2.28 (m, 1H), 2.30−2.38 (m, 1H), 2.58 (ddd, J = 5.6, 7.6, 8.8 Hz, 1H), 3.29 (s, 3H), 3.50 (dd, J = 6.2, 7.6 Hz, 1H), 3.66 (s, 3H), 4.96−5.09 (m, 2H), 5.62−5.82 (m, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 16.19, 32.17, 51.45, 51.54, 56.62, 77.44, 116.73, 135.13, 174.20; IR (neat) 2840, 1735, 1640, 1435, 1375, 1100, 990 cm^{-1}; MS (FAB) 249 (MH + C_3H_8S, 100), 173 (MH, 40), 141 (39), 127 (16), 115 (32); HRMS calcd for $C_9H_{17}O_3$ (MH) 173.1178, found 173.1170.

Methyl (2S*, 3R*)-2-[Propen-3-yl]-3-methoxy-3-cyclohexylpropanoate (16). Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.13−1.28 (m, 5H), 1.47 (s, 1H), 1.65−1.72 (m, 5H), 2.17−2.25 (m, 1H), 2.30−2.38 (m, 1H), 2.71 (ddd, J = 5.0, 7.9, 9.7 Hz, 1H), 3.16 (s, 3H), 3.67 (s, 3H), 5.00 (d, J = 10.1 Hz, 1H), 5.06 (m, 2H), 5.73 (m, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 26.20, 26.41, 26.58, 30.45, 33.29, 40.50, 48.11, 51.42, 61.06, 86.72, 116.77, 135.17, 174.60; IR (neat) 2920, 1740, 1440, 1170, 1110 cm^{-1}; MS (CI,CH_4) 241 (MH^+, 53), 209 (100), 177 (27), 149 (49), 127 (21); HRMS calcd for $C_{14}H_{25}O_3$ (MH) 241.1804, found 241.1794.

Methyl (2S*, 3R*)-2-[Propen-3-yl]-3-methoxy-4-methylpentanoate (19). Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 0.89 (d, J = 6.8 Hz, 3H), 0.99 (d, J = 6.8 Hz, 3H), 1.86 (m, 1H), 2.16−2.24 (m, 1H), 2.31−2.39 (m, 1H), 2.64 (ddd, J = 5.0, 8.1, 9.7 Hz, 1H), 3.20 (dd, J = 3.9, 8.1 Hz, 1H), 3.40 (s, 3H), 4.15 (q, J = 7.1 Hz, 2H), 4.97−5.10 (m, 2H), 5.64−5.80 (m, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 14.31, 16.04, 20.18, 30.16, 33.37, 48.84, 60.21, 61.11, 86.92, 116.75, 135.10, 174.10; IR (neat) 2980, 1740, 1650, 1470, 1380, 1180, 1100, 920 cm^{-1}; MS (CI, CH_4) 215 (MH^+, 81), 197 (18), 183 (95), 169 (70), 149 (23), 137 (29), 129 (20), 109 (100); HRMS calcd for $C_{11}H_{21}O_3$ (MH) 201.1491, found 201.1495.

Methyl (2S*, 3R*)-2-[Propen-3-yl]-2-methyl-3-methoxy-3-phenylpropanoate (22). Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.04 (s, 3H), 1.72 (dd, J = 7.6, 13.3 Hz, 1H), 2.45 (dd, J = 7.0, 13.5 Hz, 1H), 3.16 (s, 3H), 3.71 (s, 3H), 4.48 (s, 1H), 4.92−5.00 (m, 2H), 5.54−5.60 (m, 1H), 7.25−7.35 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.85, 41.10, 51.62, 52.06, 57.18, 88.00, 118.16, 127.78, 128.43, 133.12, 137.04, 175.70; IR (neat) 2980, 2840, 1745, 1460, 1220, 1100, 940 cm^{-1}; MS (FAB) 249 (MH, 12), 217 (10), 189 (8), 157 (43), 121 (100); HRMS calcd for $C_{15}H_{21}O_3$ (MH) 249.1491, found 249.1503.

Methyl (2S*, 3R*)-2-[Propen-3-yl]-2-methyl-3-methoxybutanoate (25). Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.10 (d, J = 6.3 Hz, 3H), 1.12 (s, 3H), 1.28 (t, J = 7.1 Hz, 3H), 2.04 (dd, J = 7.5, 13.5 Hz, 1H), 2.34 (dd, J = 7.1, 13.5 Hz, 1H), 3.31 (s, 3H), 3.60 (q, J = 6.3 Hz, 1H), 4.12−4.22 (m, 2H), 5.03−5.08 (m, 2H), 5.65−5.75 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.54, 14.16, 15.04, 40.70, 56.94, 60.10, 81.03, 117.78, 133.53, 175.17; IR (neat) 2983, 2937, 1723, 1464, 1383, 1236 cm^{-1}; MS (FAB) 201 (MH, 100), 169 (83), 141 (37), 132 (87), 129 (37); HRMS calcd for $C_{11}H_{21}O_3$ (MH) 201.1491, found 201.1499.

Methyl (2S*, 3R*)-2-[Propen-3-yl]-2, 4-dimethyl-3-methoxypentanoate (28). Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.02 (t, J = 7.4 Hz, 3H), 1.10 (s, 3H), 1.26 (t, J = 7.1 Hz, 3H), 1.38−1.55 (m, 2H), 2.05 (dd, J = 7.5, 13.5 Hz, 1H), 2.38 (dd, J = 7.1, 13.3 Hz, 1H), 3.30−3.34 (m, 1H), 3.40 (s, 3H), 4.10−4.17 (m, 2H), 5.00−5.05 (m, 2H), 5.64−5.71 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 11.66, 14.16, 16.04, 23.70, 40.48, 51.14, 60.14, 60.87, 88.06, 117.73, 133.74, 175.36; IR (neat) 2980, 2810, 1720, 1450, 1210, 1090 cm^{-1}; MS (FAB) 215 (MH, 100), 183 (37), 169 (33), 109 (53); HRMS calcd for $C_{12}H_{23}O_3$ (MH) 215.1647, found 215.1633; Anal. Calcd for $C_{12}H_{22}O_3$: C, 67.26; H, 10.35. Found: C, 67.12; H, 10.13.

Methyl (2S*, 3R*)-3-[Tetrahydropyran-2-yl]-2-[propen-3-yl]-propanoate (31). Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27−1.37 (m, 1H), 1.46−1.61 (m, 3H), 1.67−1.76 (m, 1H), 1.84−1.89 (m, 1H), 2.27−2.33 (m, 1H), 2.37−2.41 (m, 1H), 2.50−2.58 (m, 1H), 3.36−3.51 (m, 2H), 3.69 (s, 3H), 3.93−3.99 (m, 1H), 4.99−5.11 (m, 2H), 5.69−5.77 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 23.08, 25.64, 28.88, 32.16, 51.08, 51.42, 68.46, 78.18, 116.51, 134.81, 174.21; IR (neat) 2920, 2800, 1720, 1415, 1140, 1065 cm^{-1}; MS (FAB) 199 (MH, 100), 185 (19), 167 (47), 137 (35); HRMS calcd for $C_{11}H_{21}O_3$ (MH) 199.1334, found 199.1323.

Methyl (2S*, 3R*)-3-[Tetrahydrofuran-2-yl]-2-[propen-3-yl]-propanoate (34). Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.51−1.59 (m, 1H), 1.80−1.93 (m, 2H), 1.98−2.05 (m, 1H), 2.16−2.22 (m, 1H), 2.30−2.37 (m, 1H), 2.47−2.55 (m, 1H), 3.68 (s, 3H), 3.71−3.76 (m, 1H), 3.80−3.88 (m, 1H), 3.97−4.02 (m, 1H), 4.97−5.09 (m, 2H), 5.65−5.77 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.45, 29.52, 33.31, 51.20, 51.43, 67.91, 79.66, 116.72, 134.70, 174.20; IR (neat) 2950, 2880, 1745, 1440, 1200, 1170, 1070 cm^{-1}; MS 185 (MH, 2), 143 (12), 111 (7), 71 (100); HRMS calcd for $C_{10}H_{17}O_3$ (MH) 185.1178, found 185.1167.

Methyl (2S*, 3R*)-2-[2-Phenylselenyl-3-trimethylsilylpropanyl]-3-methoxy-3-phenylpropanoate (57). To a suspension of $MgBr_2$·OEt_2 (51.6 mg, 0.20 mmol) in CH_2Cl_2 (1 mL) at −78 °C was added dropwise a solution of phenylselenide **37** (54.5 mg, 0.20 mmol) in CH_2Cl_2 (1 mL). Allyltrimethylsilane (0.065 mL, 0.40 mmol) and Et_3B (0.04 mL of a 1.0 M solution in hexanes) were added to the mixture after stirring for 10 min at −78 °C. The resulting suspension was stirred for an additional 6 h at this temperature, and then 0.2 equiv of Et_3B were added each hour until the reaction was judged to be complete by TLC. The reaction mixture was then poured into saturated $NaHCO_3$ and extracted with CH_2Cl_2. The combined organic extracts were washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude product was carefully purified by flash chromatography (CH_2Cl_2) using silica neutralized with Et_3N to afford the *anti* product **57** (46.4 mg, 50%). Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ −0.04 (s, 9H), 0.74 (dd, J = 9.9, 9.9 Hz, 1H), 1.08 (dd, J = 4.8, 4.8 Hz, 1H), 1.22 (m, 1H), 1.79 (m, 1H), 3.87−3.96 (m, 1H), 3.14 (s, 3H), 3.32 (td, J = 3.0, 9.8 Hz, 1H), 3.75 (s, 3H), 4.23 (d, J = 9.8 Hz, 1H), 7.10−7.40 (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.34, 36.62, 40.21, 51.60, 52.08, 56.68, 85.07, 127.48, 127.72, 128.24, 128.48, 134.34, 136.10, 138.78, 174.83; IR (neat) 3060, 2950, 1732, 1580, 1435, 1370, 1250, 1165, 845 cm^{-1}; MS (FAB) 463.3 (MH, 8), 433.3 (94), 307.4 (46), 275 (36), 143 (80), 121 (100); HRMS calcd for $C_{23}H_{33}O_3$-SeSi (MH) 464.1286, found 464.1309.

Methyl (2S*, 3R*)-2-Propyl-3-methoxy-3-phenylpropanoate (58). To a suspension of $MgBr_2$·OEt_2 (194 mg, 0.75 mmol) in CH_2Cl_2 (5 mL) at −78 °C was added dropwise a solution of bromide **36** (202 mg, 0.738 mmol) in CH_2Cl_2 (1.5 mL). Allyltrimethylsilane (0.235 mL, 1.48 mmol) and Et_3B (0.150 mL of a 1.0 M solution in hexanes) were added to the mixture after stirring for 10 min at −78 °C. The resulting suspension was stirred for an additional 1.5 h at this temperature, and then tributyltin hydride (0.20 mL, 0.75 mmol) was added to the reaction mixture. Subsequently 0.2 equiv of Et_3B were added each hour until the reaction was judged to be complete by TLC. The reaction mixture was then poured into saturated $NaHCO_3$ and extracted with CH_2Cl_2. The combined organic extracts were washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude product was purified by flash chromatography (CH_2Cl_2) to afford the *anti* product (87.8 mg, 39%). Colorless oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ −0.12 (s, 9H), 0.27−0.38 (m, 2H), 0.96−1.17 (m, 3H), 1.46−1.55 (m, 1H), 2.68−2.78 (m, 1H), 3.13 (s, 3H), 3.77 (s, 3H), 4.23 (d, J = 10 Hz, 1H), 7.29−7.40 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.18, 21.47, 32.63, 51.48, 52.96, 56.60, 85.46, 127.57, 128.13, 128.35, 139.09, 175.39; IR (neat) 3028, 2950, 1739, 1494, 1248, 1164, 1103 cm^{-1}; MS (FAB) 308.9 (MH, 29), 276.9 (35), 145 (71), 121 (100); HRMS calcd for $C_{17}H_{29}O_3Si$ (MH) 309.1886, found 309.1869; Anal. Calcd for $C_{17}H_{20}O_3Si$: C, 66.19; H, 9.15. Found: C, 66.42; H, 8.88.

General Procedure for the Allylation of α-Iodoesters. Compounds 11, 14, 17, 20, 23, 26, 29, 32, and 35: To a solution of iodide **9** (83.2 mg, 0.259 mmol) in CH_2Cl_2 (2.5 mL) at −78 °C were added allyltributyltin (0.08 mL, 0.52 mmol) and Et_3B (55 μL of a 1.0 M solution in hexanes). The reaction mixture was then stirred for an additional 3 h at this temperature. After concentration, the residue was purified by flash chromatography (CH_2Cl_2) to afford the desired *syn* adduct **11**.

Methyl (2*R,3*R**)-2-[Propen-3-yl]-3-methoxy-3-phenylpropanoate (11).** Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 2.46−2.52 (m, 1H), 2.61−2.68 (m, 1H), 2.81 (ddd, J = 3.8, 8.4, 10.1 Hz, 1H), 3.19 (s, 3H), 3.40 (s, 3H), 4.27 (d, J = 8.6 Hz, 1H), 4.97−5.11 (m, 2H), 5.66−5.78 (m, 1H), 7.25−7.37 (m, 5H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ

33.10, 50.88, 53.38, 56.52, 83.58, 116.40, 126.97, 127.79, 127.87, 128.02, 135.09, 139.16, 172.69; IR (neat) 3000, 1740, 1650, 1450, 1180, 1110, 790 cm^{-1}; MS (CI, CH_4): 235 (MH^+, 4), 203 (45), 143 (100), 121 (22); HRMS calcd for $C_{14}H_{19}O_3$ (MH) 235.1334, found 235.1323.

Methyl (2*R,3*R**)-2-[Propen-3-yl]-3-methoxybutanoate (14).** Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.09 (d, J = 6.2 Hz, 3H), 2.35−2.40 (m, 1H), 2.39−2.45 (m, 1H), 2.54 (ddd, J = 5.2, 7.3, 9.1 Hz, 1H), 3.27 (s, 3H), 3.38 (dd, J = 6.2, 7.3 Hz, 1H), 3.60 (s, 3H), 4.89−5.03 (m, 2H), 5.57−5.78 (m, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 16.49, 32.95, 51.17, 51.31, 56.41, 77.07, 116.43, 135.35, 173.73; IR (neat) 2980, 1740, 1650, 1440, 1385, 1135, 1105, 920 cm^{-1}; MS (CI, CH_4) 173 (MH^+,45), 141 (100); HRMS calcd for $C_9H_{17}O_3$ $(MH)^+$ 173.1178, found 173.1168.

Methyl (2*R,3*R**)-2-[Propen-3-yl]-3-methoxy-3-cyclohexylpropanoate (17).** Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 0.99−1.27 (m, 6H), 1.61−1.82 (m, 5H), 2.37−2.42 (m, 1H), 2.42−2.48 (m, 1H), 2.66 (ddd, J = 5.6, 7.2, 8.8 Hz, 1H), 3.40 (s, 3H), 3.65 (s, 3H), 4.97 (dd, J = 1.6, 10.1 Hz, 1H), 5.05 (m, 2H), 5.76 (m, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 26.21, 26.35, 27.32, 30.10, 32.24, 41.74, 48.74, 48.42, 51.39, 61.22, 86.73, 116.27, 135.98, 174.65; IR (neat) 2920, 1740, 1450, 1160, 1100 cm^{-1}; MS (CI, CH_4) 241 (MH^+, 100), 177 (33), 149 (54), 127 (18); HRMS calcd for $C_{14}H_{25}O_3$ (MH) 241.1804, found 241.1817.

Methyl (2*R,3*R**)-2-[Propen-3-yl]-3-methoxy-4-methylpentanoate (20).** Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 0.92 (d, J = 6.8 Hz, 3H), 0.97 (d, J = 6.8 Hz, 3H), 1.24 (t, J = 7.1 Hz, 3H), 1.65−1.75 (m, 1H), 2.37−2.42 (m, 1H), 2.43−2.49 (m, 1H), 2.55−2.66 (m, 1H), 3.19 (dd, J = 4.2, 7.7 Hz, 1H), 3.44 (s, 3H), 4.12 (q, J = 7.1 Hz, 2H), 5.01−5.11 (m, 2H), 5.67−5.84 (m, 1H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 14.17, 16.49, 19.95, 31.55, 32.73, 49.23, 60.16, 61.33, 86.97, 116.28, 135.87, 174.03; IR (neat) 2980, 1740, 1650, 1475, 1380, 1160, 1100, 920 cm^{-1}; MS (CI, CH_4) 215 (MH^+, 59), 183 (100), 169 (48), 137 (24), 109 (78), 87 (30); HRMS calcd for $C_{11}H_{21}O_3$ (MH) 201.1491, found 201.1497; Anal. Calcd for $C_{11}H_{20}O_3$: C, 65.95; H, 10.07. Found: C, 65.49; H, 9.66.

Methyl (2*R,3*R**)-2-[Propen-3-yl]-2-methyl-3-methoxy-3-phenylpropanoate (23).** Colorless oil; ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.04 (s, 3H), 2.30 (dd, J = 7.9, 13.6 Hz, 1H), 2.67 (dd, J = 6.8, 13.6 Hz, 1H), 3.21 (s, 3H), 3.61 (s, 3H), 4.45 (s, 1H), 4.99−5.08 (m, 2H), 5.65−5.86 (m, 1H), 7.20−7.37 (m, 5H); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ 16.04, 40.54, 51.38, 52.44, 57.41, 87.48, 117.79, 127.74, 127.83, 128.05, 134.58, 137.79, 175.08; IR (neat) 3000, 2960, 1750, 1650, 1460, 1290, 1235, 1105, 920 cm^{-1}; MS (CI, CH_4) 249 (MH^+, 19), 217 (80), 212 (15), 185 (9), 175 (10), 157 (100), 130 (9), 121 (41); HRMS calcd for $C_{11}H_{21}O_3$ (MH) 201.1491, found 201.1497; Anal. Calcd for $C_{15}H_{20}O_3$: C, 72.55; H, 8.12. Found: C, 72.50; H, 8.02.

Methyl (2*R,3*R**)-2-[Propen-3-yl]-2-methyl-3-methoxybutanoate (26)**. Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.07 (d, J = 6.4 Hz, 3H), 1.08 (s, 3H), 1.25 (t, J = 7.1 Hz, 3H), 2.31 (dd, J = 6.7, 13.7 Hz, 1H), 2.49 (dd, J = 6.8, 13.8 Hz, 1H), 3.33 (s, 3H), 3.50 (q, J = 6.2 Hz, 1H), 4.12 (q, J = 7.1 Hz, 2H), 5.01−5.07 (m, 2H), 5.70−5.77 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.86, 14.13, 15.32, 40.90, 51.19, 57.22, 60.19, 80.53, 117.53, 134.35, 175.11; IR (neat) 2928, 2856, 1718, 1602, 1465, 1380 cm^{-1}; MS (CI, CH_4) 155 (M − OC_2H_5, 31), 142 (47), 113 (21), 95 (34), 59 (100); HRMS calcd for $C_9H_{16}O_2$ (M - OC_2H_5) 155.1072, found 155.1072.

Methyl (2*R,3*R**)-2-[Propen-3-yl]-2, 4-dimethyl-3-methoxypentanoate (29)**. Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.98 (t, J = 7.4 Hz, 3H), 1.06 (s, 3H), 1.24 (t, J = 7.1 Hz, 3H), 1.28−1.36 (m, 1H), 1.45−1.55 (m, 1H), 2.30 (dd, J = 6.7, 13.6 Hz, 1H), 2.50 (dd, J = 6.8, 13.6 Hz, 1H), 3.26−3.31 (m, 1H), 3.48 (s, 3H), 4.11 (q, J = 7.1 Hz, 2H), 5.01−5.07 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 11.58, 14.12, 15.11, 25.09, 41.40, 52.87, 60.16, 61.28, 87.94, 117.69, 134.13, 175.11; IR (neat) 2980, 1735, 1460, 1100, 920 cm^{-1}; MS (FAB) 215 (MH, 100), 183 (29), 154 (89), 137 (95), 123 (50); HRMS calcd for $C_{10}H_{17}O_2$ (M − OC_2H_5) 169.1229, found 169.1223.

Methyl (2*R,3*R**)-3-[Tetrahydropyran-2-yl]-2-[propen-3-yl]propanoate (32).** Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.34−1.57 (m, 5H), 1.81−1.87 (m, 1H), 2.20−2.26 (m, 1H), 2.28−2.35 (m, 1H), 2.34−2.50 (m, 1H) 3.38−3.45 (m, 2H), 3.67 (s, 3H), 3.97−4.02 (m, 1H), 4.98−5.10 (m, 2H), 5.68−5.80 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 23.12, 25.79, 29.41, 32.87, 51.28, 51.51, 68.64, 77.62, 116.39, 135.40, 173.87; IR (neat) 2900, 2800, 1720, 1420, 1070 cm^{-1}; MS (FAB) 199 (MH, 100), 171 (29), 167 (51), 137 (34); HRMS calcd for $C_{11}H_{19}O_3$ (MH) 199.1334, found 199.1342.

Methyl (2*R,3*R**)-3-[Tetrahydrofuran-2-yl]-2-[propen-3-yl]propanoate (35)**. Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.64−1.73 (m, 1H), 1.83−2.00 (m, 3H), 2.37−2.43 (m, 1H), 2.42−2.51 (m, 1H), 2.54−2.62 (m, 1H), 3.66 (s, 3H), 3.71−3.86 (m, 2H), 3.93−4.00 (m, 1H), 4.99−5.11 (m, 2H), 5.70−5.81 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.50, 29.25, 33.83, 50.67, 51.38, 67.90, 79.04, 116.54, 135.18, 173.74; IR (neat) 2960, 2880, 1440, 1070 cm^{-1}; MS (FAB) 185 (MH, 100), 152 (41), 143 (8), 71 (28); HRMS calcd for $C_{10}H_{17}O_3$ (MH) 185.1178, found 185.1175.

Proof of Stereochemistry for Compound 14. To a solution of alcohol **43**[17] (56.0 mg, 0.354 mmol) and Proton Sponge (759 mg, 3.54 mmol) in CH_2Cl_2 (1 mL) at 25 °C was added methyl triflate (400 μL, 3.54 mmol). When TLC indicated that the reaction was complete, the solution was diluted with ether, washed successively with water, 10% HCl, water, and brine, and dried ($MgSO_4$). Flash chromatography afforded the desired methyl ether (36.3 mg, 59%). The NMR spectrum of this compound was identical to that obtained for adduct **14**. ^{1}H NMR (200 MHz, $CDCl_3$) δ 1.09 (d, J = 6.2 Hz, 3H), 2.22−2.44 (m, 2H), 2.54 (ddd, J = 5.2, 7.3,9.1 Hz, 1H), 3.27 (s,3H), 3.38 (dd, J = 6.2,7.3 Hz, 1H), 3.60 (s, 3H), 4.89−5.03 (m, 2H), 5.57−5.78 (m, 1H).

Proof of Stereochemistry for Compounds 25 and 26. A 1.34 M solution of Me_2BBr (620 μL, 2 equiv) in CH_2Cl_2 was added dropwise to a cold (0 °C) solution of compound **25** in CH_2Cl_2 (129 mg, 0.64 mmol) and triethylamine (20 μL, 0.2 equiv). The resulting mixture was stirred at 0 °C for 10 min and for 3 h at room temperature until reaction completion and then the mixture was poured into a solution of NH_4Cl:NH_4OH (4:1), diluted with EtOAc, and stirred at room temperature for 15 min. Brine was added, the phases were separated, and the aqueous layer was extracted with EtOAc. The combined organic extracts were washed with brine, dried ($MgSO_4$), filtered, and concentrated to afford β-hydroxyester **44** (65.6 mg, 55%) after purification by flash chromatography. The NMR spectrum of this compound was identical to that previously reported.[17] ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.10 (s, 3H), 1.12 (d, J = 6.5 Hz, 3H), 1.25 (t, J = 7.1 Hz, 3H), 2.23−2.29 (dd, J = 7.4 and 13.7 Hz, 1H), 2.38−2.43 (dd, J = 7.4 and 13.7 Hz, 1H), 2.64 (bs, 1H, OH), 3.83−3.87 (q, J = 6.5 Hz, 1H), 4.12−4.18 (q, J = 7.1 Hz, 2H), 5.02−5.07 (m, 2H), 5.65−5.72 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.11, 16.90, 17.58, 40.86, 50.88, 60.56, 71.14, 118.11, 133.31, 176.49; IR (neat) 3700−3300, 3000, 2960, 1725, 1640, 1380, 1300, 1230, 1150, 1090, 920 cm^{-1}; MS (FAB) 187(MH,100), 169(22), 154(23), 137(26), 123(16); HRMS calcd for $C_{10}H_{19}O_3$ (MH) 187.13342, found 187.13390. The β-hydroxyester **45** was obtained in a similar manner from compound **26**. The NMR spectrum of this compound was identical to that previously reported.[17] ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.13 (s, 3H), 1.15 (d, J = 6.4 Hz, 3H), 1.26 (t, J = 7.1 Hz, 3H), 2.22−2.27 (dd + bs, J = 7.8 and 13.8 Hz, 2H), 2.49−2.54 (dd, J = 7.0 and 13.8 Hz, 1H), 3.88−3.93 (q, J = 6.4 Hz, 1H), 4.12−4.17 (q, J = 7.1 Hz, 2H), 5.04−5.10 (m, 2H), 5.74−5.81 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.12, 17.24, 18.16, 39.62, 50.60, 60.56, 71.80, 117.91, 134.09, 176.12; IR (neat) 3700−3200, 3000, 1720, 1640, 1460, 1380, 1220, 920 cm^{-1}; MS (FAB) 187(MH,100), 169(20), 154(18), 137(21), 123(17); HRMS calcd for $C_{10}H_{19}O_3$ (MH) 187.1334, found 187.1337.

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Supporting Information Available: General experimental procedures and spectral data for compounds **47** and **49**, NMR spectra for those compounds for which elemental analysis is not available, and tables of NMR chemical shift correlations for allylated products (32 pages). See any current masthead page for ordering and Internet access instructions.

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