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Convenient Access to Functionalized Vinylcyclopentenols from Alkynyloxiranes

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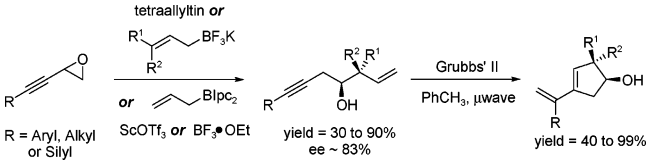
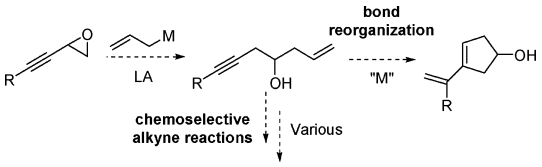


β,γ-Alkynyl aldehydes, generated in situ by treatment of alkynyloxiranes with a catalytic amount of $Sc(OTf)_3$ or $BF_3{\cdot}OEt_2$, are effectively trapped by a variety of allyl nucleophiles to afford homopropargylic homoallylic alcohols in good yield and selectivity. Such products are used as substrates for the synthesis of functionalized vinylcyclopentenols via enyne metathesis.

We report on a two-step method to prepare alkylidene cyclopentanes abstaining from alkynyloxiranes and using an enyne metathesis[1] as a key step. In recent years, enyne metathesis (bond reorganization) employing a variety of metal catalysts has emerged as an efficient method for the preparation of this motif from readily available precursors. Functionalized dienes which contain a hydroxyl group in close proximity are of interest as stereocontrol in subsequent cycloadditions is often possible.[2]

Our previous experience[3] with the Lewis acid (LA) catalyzed in situ generation,[4] and trapping, of β,γ-alkenyl aldehydes from 2-vinyloxiranes led us to speculate that an analogous transformation applied to alkynyloxiranes might readily afford the desired precursors to the functionalized carbocyclic dienes (Scheme 1) that would be useful in Diels−Alder reactions.[5]

SCHEME 1. General Approach to Carbocyclic Dienes



Several methods for the preparation of β,γ-alkynyl aldehydes are known,[6] but they are reported to be quite sensitive,[7] and the direct approach outlined in Scheme 1 would avoid their isolation and simplify experimental protocols. The resulting homopropargylic homoallylic alcohols should be of value for other applications given the easily differentiated double bond and triple bond in the molecule and the numerous types of reactions 1,6-enynes are known to undergo.[8] This report summarizes our efforts to affect a rearrangement/allylation−crotylation sequence on alkynyloxiranes and the subsequent conversion to functionalized carbocyclic dienes via enyne metathesis.

A series of aryl-, alkyl-, and silylalkynyloxiranes were prepared according to modified literature protocols.[9] In contrast to many terminal 2-vinyloxiranes,[3] the alkynyloxiranes prepared in our study could be purified by flash chromatography and generally exhibited good stability. The simple 4-phenyl-substituted substrate **1** was selected for optimization in reactions with tetraallyltin and potassium allyltrifluoroborate.[10]

Of the Lewis acids screened, $BF_3{\cdot}OEt_2$ and $Sc(OTf)_3$ emerged as the most efficient catalysts for this transformation in accord with previous observations.[3] The addition of $Sc(OTf)_3$ to a mixture of **1** and tetraallyltin in THF was effective (Table 1, entry 1). However, these conditions were not general with other substrates, and a variety of different LA, solvent, and temperature protocols were studied (Table 1). When appropriate modifications were made, yields employing tetraallyltin were moderate to good for a range of substrates (Table 1). In general, electron-rich systems where rearrangement should be favored afforded higher yields of the desired products (**10** to **12**) than the electron-deficient systems (Table 1, entries 1−3, vs entries

(1) For reviews, see: (a) Diver, S. T.; Giessert, A. J. *Chem. Rev.* **2004**, *104*, 1317. (b) Mori, M. *Top. Organomet. Chem.* **1998**, *1*, 133. (c) Poulsen, C. S.; Madsen, R. *Synthesis* **2003**, 1.

(2) For illustrative examples, see: (a) Fisher, M. J.; Hehre, W. J.; Kahn, S. D.; Overman, L. E. *J. Am. Chem. Soc.* **1988**, *110*, 4625. (b) Barriault, L.; Thomas, J. D. O.; Clement, R. *J. Org. Chem.* **2003**, *68*, 2317. (c) Fensterbank, L.; Malacria, M.; Sieburth, S. McN. *Synthesis* **1997**, *8*, 813. (d) Bols, M.; Skrydstrup, T. *Chem. Rev.* **1985**, *95*, 1253.

(3) (a) Racemic allylation and crotylation: Lautens, M.; Ouellet, S. G.; Raeppel, S. *Angew. Chem., Int. Ed.* **2000**, *39*, 4079. (b) Enantioselective allylation: Lautens, M.; Maddess, M. L.; Sauer, E. L. O.; Ouellet, S. G. *Org. Lett.* **2002**, *4*, 83. (c) Racemic and enantioselective propargylation: Maddess, M. L.; Lautens, M. *Org. Lett.* **2005**, *7*, 3557.

(4) For additional examples, see: (a) Hertweck, C.; Boland, W. *J. Org. Chem.* **2000**, *65*, 2458. (b) Bideau, F. L.; Gilloir, F.; Nilsson, Y.; Aubert, C.; Malacria, M. *Tetrahedron* **1996**, *52*, 7487. (c) Wipf, P.; Xu, W. *J. Org. Chem.* **1993**, *53*, 825.

(5) (a) Diels, O.; Alder, K. *Justus Liebigs Ann. Chem.* **1928**, *460*, 98. For reviews, see: (b) Nicolaou, K. C.; Snyder, S. A.; Montagnon, T.; Vassilikogiannakis, G. *Angew. Chem., Int. Ed.* **2002**, *41*, 1668. (c) Oppolzer, W. In *Comprehensive Organic Synthesis*; Trost, B. M., Flemming, T., Eds.; Pergamon: Oxford, 1991; Vol. 5, p 315.

(6) (a) Viala, J.; Santelli, M. *J. Org. Chem.* **1988**, *53*, 6121. (b) Michaud, S.; Wavrin, L.; Viala, J. *Synth. Commun.* **2002**, *32*, 1563. (c) Barbot, F.; Miginiac, P. *Synthesis* **1983**, 651. (d) Corey, E. J.; Lansbury, P. T. *J. Am. Chem. Soc.* **1983**, *105*, 4093. (e) Jain, S. C.; Dussourd, D. E.; Conner, W. E.; Eisner, T.; Guerrero, A.; Meinwald, J. *J. Org. Chem.* **1983**, *48*, 2266. (f) Corey, E. J.; Wright, S. W. *J. Org. Chem.* **1990**, *55*, 1670.

(7) Wavrin, L.; Viala, J. *Synthesis* **2002**, 326. (b) Roush, W. R.; Park, J. C. *Tetrahedron Lett.* **1991**, *32*, 6285.

(8) For a review, see: (a) Corinne, A.; Olivier, B.; Malacria, M. *Chem. Rev.* **2002**, *102*, 813. For typical applications, see: (b) Pauson−Khand reaction: Blanco-Urgoiti, J.; Anorbe, L.; Perez-Serrano, L.; Dominquez, G.; Perez-Castells, J. *Chem. Soc. Rev.* **2004**, *33*, 32. (c) [4 + 2 + 2] cycloadditions: Evans, P. A.; Baum, E. W.; Fazal, A. N.; Pink, M. *Chem. Commun.* **2005**, 63 and references cited therein. (d) Diver, S.; Giessert, A. *Chem. Rev.* **2004**, *104*, 1317.

(9) Details are provided in the Supporting Information.

(10) Potassium allyl and crotyl triflouroborates are readily prepared air- and moisture-insensitive solids; see: (a) Batey, R. A.; Thadani, A. N.; Smil, D. V. *Tetrahedron Lett.* **1999**, *40*, 4289. (b) Thadani, A. N.; Batey, R. A. *Org. Lett.* **2002**, *4*, 3827.

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TABLE 1. Allylation of in Situ Generated β,γ-Alkynyl Aldehydes

				yield[a] (%)			
entry	compd	R	prod	solvent	**A**	solvent	**B**
1	**1**	Ph	**10**	THF	92	CH_2Cl_2	71
2	**2**	*p*-MeO-C_6H_4	**11**	Et_2O	79[b]	CH_2Cl_2	73
3	**3**	*m*-Me-C_6H_4	**12**	THF	83[b]	CH_2Cl_2	70
4	**4**	*p*-CN-C_6H_4	**13**	THF	67[b]	CH_2Cl_2	67
5	**5**	*p*-NO_2-C_6H_4	**14**	THF	45[b]	CH_2Cl_2	49
6	**6**	*p*-Cl-C_6H_4	**15**	THF	65[b]	CH_2Cl_2	71
7	**7**	C_6H_{13}	**16**	Et_2O	71[c]	CH_2Cl_2	77
8	**8**	$TBDPSO(CH_2)_3$	**17**	Et_2O	51[c]	CH_2Cl_2	49
9	**9**	TBDPS	**18**	Et_2O	48	Et_2O	61[b]

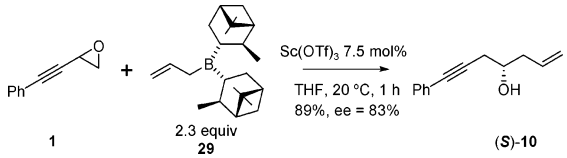
[a] Isolated yield. [b] 15 mol % $BF_3{\cdot}OEt_2$ used in place of $Sc(OTf)_3$. [c] Reaction started at −78 °C then warmed to 0 °C.

4−6). The silyl terminated substrate (**9**) was noticeably less reactive (Table 1, entry 9). In contrast, the alkyl systems (**7** and **8**) required lower temperatures in ether to give acceptable yields of the homopropargylic homoallylic alcohols (**16** and **17**).

Reaction with potassium allyltrifluoroborate was best conducted in dichloromethane and afforded the desired products (**10**−**18**) in comparable yields to tetraallyltin with $Sc(OTf)_3$ as catalyst. The one exception was the 4-silyl-substituted alkynyloxirane, which failed to give more than a trace of product under the optimized conditions. Employing a combination of $BF_3{\cdot}OEt_2$ and Et_2O resolved this issue and afforded **18** in reasonable yield (Table 1, entry 9). Once again, electron-rich systems (Table 1, entries 1−3) performed best.

Extension to crotylation was easily accomplished by switching from potassium allyltrifluoroborate to either potassium (*E*)- or (*Z*)-crotyltrifluoroborate (Table 2). Either *syn*- or *anti*-addition products can be prepared for a range of substrates (Table 2, entries 1, 3, 5, 7, and 9 vs entries 2, 4, 6, 8, and 10, respectively). The products (**19** − **28**) were all single diastereomers by ^1H NMR, consistent with the documented cyclic transition state for these nucleophiles.[10] In contrast to the allylation chemistry, $BF_3{\cdot}OEt_2$ and $Sc(OTf)_3$ are often interchangeable, and in some cases, diethyl ether was found to be a superior solvent system (Table 2, entries 5−10). The silyl-terminated alkynyloxirane (**9**) remains a problematic substrate and affords the desired products (**27** and **28**) in low yield. Based on our previous success[3b] with allylB(Ipc)$_2$[11] (**29**) for asymmetric allylation of β,γ-ethylenic aldehydes, we tested this reagent with the corresponding alkynyl analogues. No reaction was observed at low temperature (−78 °C) consistent with a marked decrease of reactivity of alkynyloxiranes versus the corresponding 2-vinyloxiranes. It proved necessary to increase the reaction temperature to effect an efficient reaction, and at 20 °C the desired product ((*S*)-**10**) is isolated in good yield (Scheme 2). Unfortunately the enantioselectivity is lower as a result of the increase in reaction temperature consistent with the result in allylation of β,γ-ethylenic aldehydes with allylB(Ipc)$_2$.[12,13]

SCHEME 2. Asymmetric Allylation



Turning our attention to the application of these products, we subjected the enynes to Grubbs' second-generation catalyst under microwave conditions[14,15] and were pleased to observe the formation of the desired functionalized dienes (Table 3). In general, substrates lacking an allylic methyl group proceeded in high yield after 5 min (Table 3, entries 1−5). An electron-deficient silyl-substituted substrate (**18**) returned unreacted starting material even with an extended reaction time (Table 3, entry 6). The crotylated substrates (Table 3, entries 6−11) bearing an allylic methyl group reacted at a significantly decreased rate. Electron-withdrawing substitutents on the alkyne exacerbated this trend, giving moderate product yields (Table 3, entries 7−9 and 11). Fortunately, in most cases (Table 3, entries 7−10), the remainder of the mass balance is starting material. Only the electron-rich aliphatic crotylated substrate (**26**) gave full conversion after 10 min of heating. In some cases, catalyst loading and reaction temperature can be decreased and others overcome problems associated with chelation of the Boc moiety with the metathesis catalyst.[16] For example, treatment of the BOC protected analogue of **10** (**41**) with 1 mol % of Grubbs' II catalyst at 100 °C in a sealed tube was sufficient to yield the desired enyne product (**42**) in 93% isolated yield.

In summary, alkynyl epoxides are effectively converted to β,γ-alkynyl aldehydes by treatment with a catalytic amount of Lewis acid. In situ trapping with variety of allyl nucleophiles affords homopropargylic homoallylic alcohols in moderate to good yields, and as single diastereomers in the case of crotylation. An enantioselective version has been demonstrated for allylation which allows for formation of enantioenriched products of either antipode. The products are useful for the rapid construction of a variety of carbocyclic dienes. Further study of utilizing the hydroxyl functionality to control facial selectivity in Diels−Alder reactions is underway.

Experimental Section

(±)-2-(Phenylethynyl)oxirane (1)[17] (General Procedure A). To a solution of phenylacetylene (8.0 mL, 72.8 mmol) in Et_3N (50 mL) were added CuI (138 mg, 0.72 mmol), $Pd(Ph_3P)_2Cl_2$ (156 mg, 0.22 mmol), and vinyl bromide (8.0 mL, ρ = 1.52 at 4 °C, 114 mmol). After being stirred for 16 h at 50 °C, the mixture was allowed to cool to rt and then filtered through a pad of Celite with Et_2O (100 mL). The ether solution was washed with water (3 × 100 mL), dried over Na_2SO_4, and concentrated in vacuo. The crude residue was then taken up in CH_2Cl_2 (150 mL) and cooled to 0 °C, and *m*-CPBA (33 g, 134 mmol) was added. After 30 min, the

(11) Racherla, U. S.; Brown, H. C. *J. Org. Chem.* **1991**, *56*, 401.

(12) Either antiopode is readily accessible by modification of the nucleophile, *ent*-**32** gave (*R*)-**10** in 83% yield and 77% ee.

(13) The absolute configuration may be predicted from analogy with previous results. Compound **32** is known to give *re* face attack, while *ent*-**32** provides the enantiomer; see: (a) Brown, H. C.; Jadhav, P. K. *J. Am. Chem. Soc.* **1983**, *105*, 2092. (b) Vulpetti, A.; Gardner, M.; Gennari, C.; Bernardi, A.; Goodman, J. M.; Paterson, I. *J. Org. Chem.* **1993**, *58*, 1711.

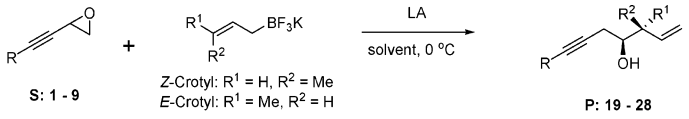
(14) For examples of microwave-assisted metathesis reactions, see: (a) Balan, D.; Adolfsson, H. *Tetrahedron Lett.* **2004**, *45*, 3089. (b) Garbacia, S.; Desai, B.; Lavastre, O.; Kappe, C. O. *J. Org. Chem.* **2003**, *68*, 9136. For a review, see: Lidstrom, P.; Tierney, J.; Wathey, B.; Westman, J. *Tetrahedron* **2001**, *57*, 9225.

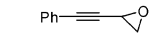
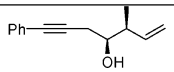
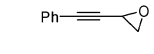
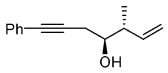
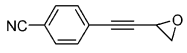
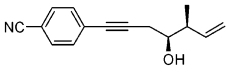
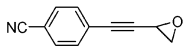
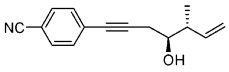
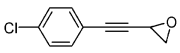
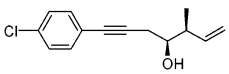
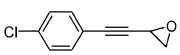
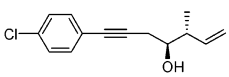
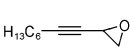
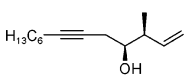
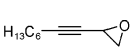
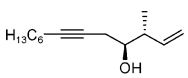
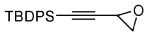
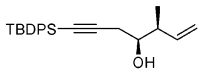
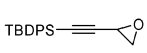
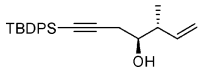
(15) Control experiments using microwave vials under thermal conditions indicated no appreciable difference in reaction yield or rate.

(16) For other examples of oxygen chelation effects in metathesis events, see: Maddess, M. L.; Lautens, M. *Org. Lett.* **2004**, *6*, 1883 and references cited therein.

(17) Eisch, J. J.; Galle, J. E. *J. Org. Chem.* **1990**, *55*, 4835.

TABLE 2. Crotylation of in Situ Generated β,γ-Alkynyl Aldehydes



entry	substrate S	substrate structure	Nuc.	LA (mol%)	solvent	product P	product structure	yield (%)[a]
1	**1**		*Z*-Crotyl	$Sc(OTf)_3$ (20)	CH_2Cl_2	**19**		72
2	**1**		*E*-Crotyl	$Sc(OTf)_3$ (20)	CH_2Cl_2	**20**		70
3	**4**		*Z*-Crotyl	$Sc(OTf)_3$ (20)	CH_2Cl_2	**21**		65
4	**4**		*E*-Crotyl	$Sc(OTf)_3$ (20)	CH_2Cl_2	**22**		67
5	**6**		*Z*-Crotyl	$BF_3{\bullet}OEt_2$ (15)	Et_2O	**23**		66
6	**6**		*E*-Crotyl	$BF_3{\bullet}OEt_2$ (15)	Et_2O	**24**		63
7	**7**		*Z*-Crotyl	$BF_3{\bullet}OEt_2$ (15)	Et_2O	**25**		75
8	**7**		*E*-Crotyl	$BF_3{\bullet}OEt_2$ (15)	Et_2O	**26**		78
9	**9**		*Z*-Crotyl	$BF_3{\bullet}OEt_2$ (15)	Et_2O	**27**		24
10	**9**		*E*-Crotyl	$BF_3{\bullet}OEt_2$ (15)	Et_2O	**28**		26

[a] Isolated yields.

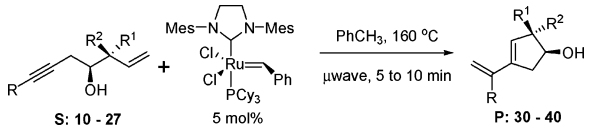
reaction mixture was warmed to rt, stirred for 12 h, and then poured into a beaker that contained satd aq $NaHCO_3$ (200 mL) and ice (100 mL) and stirred for 10 min. The organic layer was isolated and washed with $Na_2S_2O_8$ (50 mL) and then brine (100 mL). After concentration in vacuo, the crude residue was purified by flash chromatography to afford **1** (yield = 48%).

(±)-7-Phenylhept-1-en-6-yn-4-ol (10) (General Procedure B). To a cooled (0 °C) solution of **1** (186.3 mg, 1.0 mmol) and potassium allyltrifluoroborate (222 mg, 1.5 mmol) in CH_2Cl_2 was added $Sc(OTf)_3$ (98 mg, 0.2 mmol). After the mixture was stirred for 15 min, additional potassium allyltrifluoroborate (222 mg, 1.5 mmol) was added, and then the reaction mixture warmed to rt where it was stirred for 2 h. Ether (10 mL) was added, and the organics were washed with satd aq $NaHCO_3$ (10 mL) and then brine (10 mL). After drying with Na_2SO_4 and concentration in vacuo, the crude residue was purified by flash chromatograpy to afford **10** (yield = 71%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45−7.40 (m, 2H), 7.31−7.27 (m, 3H), 5.87 (ddt, J = 17.2, 10.0, 6.8 Hz, 1H), 5.22−5.13 (m, 2H), 3.95−3.85 (m, 1H), 2.66 (dd, J = 16.8, 5.6 Hz, 1H), 2.61 (dd, J = 16.8, 6.4 Hz, 1H), 2.50 − 2.42 (m, 1H), 2.40−2.31 (m, 1H), 2.24 (d, J = 4.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 134.4, 131.9, 128.5, 128.2, 123.6, 118.6, 83.2, 83.3, 69.6, 41.0, 27.8; FTIR (neat) ν 3382, 3077, 2907, 2228, 1641, 1598, 1490, 1442, 1070, 917, 756 cm^{-1}; HRMS (*m/z*) calcd for $C_{13}H_{13}O$ (EI, M − H$^+$) 185.0966, found 185.0971.

(4*S*)-7-Phenylhept-1-en-6-yn-4-ol ((*S*)-10). To a solution of **1** (100 mg, 0.69 mmol) and $Sc(OTf)_3$ (25.6 mg, 0.05 mmol) in Et_2O (2 mL) was added **29** (0.77 M in ether, 2.08 mL, 1.6 mmol). The reaction mixture was stirred at rt for 1 h and then quenched by the sequential addition of 3 N NaOH (1 mL) and 30% H_2O_2 (1 mL, warning! effervescence upon addition). After being stirred for 14 h at rt, the reaction contents were transferred to a separatory funnel with satd aq NH_4Cl (20 mL) and Et_2O (25 mL). The organic layer was isolated, the aqueous layer was extracted 2× with Et_2O (15 mL), and the combined organics were dried with $MgSO_4$, filtered, and concentrated in vacuo. The crude residue was purified by flash chromatography to afford (*S*)-**10** (yield = 89%): HPLC (CHIRALCEL OD, 1 mL/min, 95 Hex/5 *i*-PrOH, 30 °C, 1 μL injection) t_{R1} = 16.3 min (minor), t_{R2} = 32.6 min (major); ee = 83%. For other characterization data, see above.

(±)-7-(4-Methoxyphenyl)hept-1-en-6-yn-4-ol (11). To a cooled (0 °C) solution of **2** (174.2 mg, 1.0 mmol) and tetraallyltin (168

TABLE 3. Enyne Metathesis of Homopropargylic Homoallylic Alcohols



	substrate				time	product	
entry	**S**	R	R^1	R^2	(min)	**P**	yield[a–c] (%)
1	**10**	Ph	H	H	5	**30**	94
2	**11**	*p*-MeO-C_6H_4	H	H	5	**31**	92
3	**12**	*m*-Me-C_6H_4	H	H	5	**32**	86
4	**13**	*p*-CN-C_6H_4	H	H	5	**33**	93
5	**16**	C_6H_{13}	H	H	5	**34**	76
6	**18**	TBDPS	H	H	10	**35**	64[b]
7	**22**	*p*-CN-C_6H_4	Me	H	10	**36**	41[b]
8	**23**	*p*-Cl-C_6H_4	H	Me	5	**37**	32[b]
9	**24**	*p*-Cl-C_6H_4	Me	H	10	**38**	43[b]
10	**26**	C_6H_{13}	Me	H	10	**39**	86
11	**27**	TBDPS	H	Me	10	**40**	46[c]

[a] Yields are isolated yields. [b] Incompletion. [c] Complex mixture

μL, 0.70 mmol) in Et_2O (2.0 mL) was added $BF_3{\cdot}OEt_2$ (19 μL, 0.15 mmol). After 2 h, aq KF (2 M, 2 mL) and satd aq $NaHCO_3$ (5 mL) were added, and the mixture was stirred for 12 h at rt. The reaction mixture was filtered through a pad of Celite with ether (20 mL), and the organics were washed with water (10 mL) and then dried with Na_2SO_4. After filtration and concentration in vacuo, the crude residue was purified by flash chromatography to afford **11** (yield = 79%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 (d, J = 9.2 Hz, 2H), 6.83 (d, J = 9.2 Hz, 2H), 5.87 (ddt, J = 17.6, 10.4, 7.2 Hz, 1H), 5.23 − 5.14 (m, 2H), 3.94 − 3.85 (m, 1H), 3.81 (s, 3H), 2.64 (dd, J = 16.4, 5.2 Hz, 1H), 2.59 (dd, J = 16.4, 6.4 Hz, 1H), 2.50 − 2.42 (m, 1H), 2.39 − 2.31 (m, 1H), 2.05 (d, J = 4.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.5, 134.4, 133.2, 118.5, 115.7, 114.1, 84.4, 83.1, 69.6, 55.5, 41.0, 27.9; FTIR (neat) ν 3405, 2926, 2049, 1607, 1510, 1248, 1033, 832 cm^{-1}; HRMS (*m/z*) calcd for $C_{14}H_{16}O_2$ (EI, M$^+$) 216.1150, found 216.1154.

(±)-7-(3-Methylphenyl)hept-1-en-6-yn-4-ol (12) (General Procedure C). To a cooled (0 °C) solution of **3** (158.2 mg, 1.0 mmol) and tetraallyltin (168 μL, 0.70 mmol) in THF (2.0 mL) was added $BF_3{\cdot}OEt_2$ (19 μL, 0.15 mmol). After 2 h, aq KF_{aq} (2 M, 2 mL) and satd aq $NaHCO_3$ (5 mL) were added, and the mixture was stirred for 12 h at rt. The reaction mixture was filtered through a pad of Celite with ether (20 mL), and the organics were washed with water (10 mL) and then dried with Na_2SO_4. After filtration and concentration in vacuo, the crude residue was purified by flash chromatography to afford **12** (yield = 83%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.26−7.10 (m, 4H), 5.94−5.80 (m, 1H), 5.23−5.15 (m, 2H), 3.93−3.87 (m, 1H), 2.64−2.61 (m, 2H), 2.51−2.35 (m, 1H), 2.32 (s, 3H), 2.04 (d, J = 4.8 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.1, 134.4, 132.5, 129.0, 128.9, 128.3, 123.3, 118.5, 85.7, 83.5, 69.6, 40.9, 27.8, 21.4; FTIR (neat) ν 3388, 2922, 1602, 1485, 1047, 917, 783 cm^{-1}; HRMS (*m/z*) calcd for $C_{14}H_{17}O$ (EI, M + H$^+$) 201.1279, found 201.1279.

(3S*,4S*)-3-Methyl-7-phenylhept-1-en-6-yn-4-ol (19) (General Procedure D). To a cooled (0 °C) solution of **1** (168.3 mg, 1.0 mmol) and potassium (*Z*)-crotyltrifluoroborate (243 mg, 1.5 mmol) in CH_2Cl_2 was added $Sc(OTf)_3$ (98 mg, 0.20 mmol). After the mixture was stirred for 15 min, additional potassium (*Z*)-crotyltrifluoroborate (243 mg, 1.5 mmol) was added and then the reaction mixture warmed to rt where it was stirred for 2 h. Ether (10 mL) was added, and the organics were washed with satd aq $NaHCO_3$ (10 mL) and then brine (10 mL). After drying with Na_2SO_4 and concentration in vacuo, the crude residue was purified by flash chromatograpy to afford **19** (yield = 72%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.38−7.43 (m, 2H), 7.26−7.33 (m, 2H), 5.81 (ddt, J = 17.2, 10.7, 7.0 Hz, 1H), 5.08−5.18 (m, 2H), 3.66−3.73 (m, 1H), 2.65 (ddd, J = 16.8, 10.3, 5.7 Hz, 1H), 2.43−2.50 (m, 1H), 2.04 (bsd, J = 4.8 Hz, 1H), 1.13 (d, J = 6.9 Hz 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.5, 131.8, 128.4, 128.1, 123.6, 115.9, 86.5, 83.3, 73.3, 43.1, 26.0, 15.1; FTIR (neat) ν 3425, 3078, 2972, 1639, 1598, 1490, 1043, 916, 755 cm^{-1}; HRMS (*m/z*) calcd for $C_{19}H_{19}OSi$ (EI, M) 200.1198, found 200.1201.

(3S*,4S*)-7-(4-Chlorophenyl)-3-methylhept-1-en-6-yn-4-ol (23) (General Procedure E). To a cooled (0 °C) solution of **6** (178.6 mg, 1.0 mmol) and potassium *Z*-crotyltrifluoroborate (243 mg, 1.5 mmol) in Et_2O was added $BF_3{\cdot}OEt_2$ (19 μL, 0.15 mmol). After the mxture was stirred for 15 min, additional potassium (*Z*)-crotylltrifluoroborate (243 mg, 1.5 mmol) was added, and then the reaction mixture warmed to rt where it was stirred for 2 h. Ether (10 mL) was added, and the organics were washed with satd $NaHCO_3$ (10 mL) and then brine (10 mL). After drying with Na_2SO_4 and concentration in vacuo, the crude residue was purified by flash chromatograpy to afford **23** (yield = 66%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.31 (d, J = 3.4 Hz, 2H), 7.24 (d, J = 3.4 Hz, 2H), 5.85−5.73 (m, 1H), 5.19−5.09 (m, 2H), 3.73−3.66 (m, 1H), 2.71−2.52 (m, 2H), 2.48−2.42 (m, 1H), 2.00 (d, J = 5.1 Hz, 1H), 1.11 (d, J = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.4, 134.1, 133.1, 128.8, 122.1, 116.1, 87.7, 82.1, 73.3, 43.1, 26.0, 15.1; FTIR (neat) ν 3418, 2965, 2930, 2234, 1640, 1604, 1489, 1462, 1418, 1398, 1091, 1014, 919, 828 cm^{-1}; HRMS (*m/z*) calcd for $C_{14}H_{15}ClO$ (EI, M$^+$) 234.0811, found 234.0805.

(±)-3-(1-Phenylvinyl)cyclopent-3-en-1-ol (30) (General procedure F). A microwave vial equipped with a stir bar was charged with **10** (37 mg, 0.2 mmol) along with tricyclohexylphosphine-[1,3-bis(2,4,6-trimethylphenyl)-4,5-dihydroimidazol-2-ylidene][benzylidine]ruthenium(IV) dichloride (8.5 mg, 0.01 mmol, 5 mol %). The resulting mixture was diluted with $PhCH_3$ (0.7 mL), and a cap was affixed and then crimped to seal the vessel. The reaction was then heated to 160 °C employing microwave heating (30 s prestir) and held for 5 min. After the reaction vessel had cooled, it was opened, and the reaction contents were loaded directly upon a column of silica gel and purified by flash chromatography to afford **30** (yield = 94%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.35−7.30 (m, 5H), 5.55 (brs, 1H), 5.20 (s, 1H), 5.14 (s, 1H), 4.68−4.60 (m, 1H), 2.95 (dd, J = 16.2, 6.3 Hz, 1H), 2.81 (dd, J = 18.3, 6.3 Hz, 1H), 2.61 (d, J = 16.2 Hz, 1H), 2.44 (d, J = 18.3 Hz, 1H), 1.87 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 146.4, 141.7, 141.2, 128.7, 128.2, 128.1, 127.5, 72.0, 43.7, 43.2; FTIR (neat) ν 3354, 3057, 2924, 1681, 1589, 1494, 1043 cm^{-1}; HRMS (*m/z*) calcd for $C_{13}H_{14}O_2$ (EI, M + O, oxidation product) 202.0994, found 202.0990.

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Supporting Information Available: Full characterizations of compounds (**1**−**9**, **13**−**18**, **20**−**22**, **24**−**28**, and **31**−**42**) are included. This material is available free of charge via the Internet at http://pubs.acs.org.

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