Regioselective Ring Opening of Vinylcyclopropanes by Hydrogenation with Palladium on Activated Carbon

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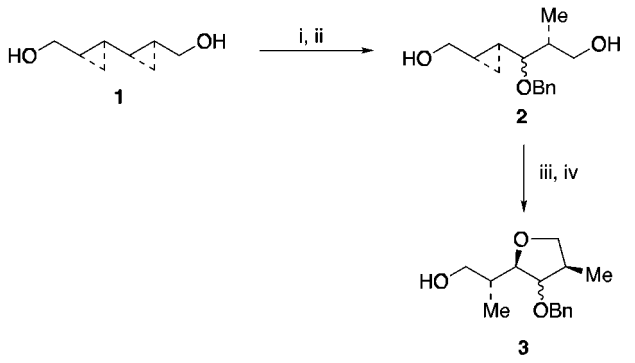
A highly regioselective reductive ring opening of vinylcyclopropanes induced by palladium on activated carbon has been investigated. High yields and excellent regioselectivities were observed in cleaving either the less hindered bond or the more hindered bond of the cyclopropane depending on whether the substituent on the vinylcyclopropane is capable of coordinating to Pd or not.

Introduction

The activation of cyclopropanes by transition metals is an important type of reaction that has attracted considerable interest.[1−9] Transition metals such as palladium,[2−4] platinum,[5] rhodium,[6] thallium,[7] and mercury[8,9] are known to promote cyclopropane ring opening. As most of these cyclopropane ring opening reactions are electrophilic in nature, high-valent metal complexes are usually required (most commonly Pd^{2+}, Pt^{2+}, Rh^{3+}, Tl^{3+} and Hg^{2+}). Although theoretical calculations showed that both Pd(II) and Pd(0) are capable of promoting the cleavage of cyclopropanes,[3,4] only Pd(II) complexes have been studied in the ring opening of vinylcyclopropanes.[2] Most of these studies on the Pd(II)-induced ring opening of vinylcyclopropanes concerned mainly with cyclic vinylcyclopropane systems, no systematic studies on Pd-induced cyclopropane ring opening on acyclic vinylcyclopropane systems have been reported.

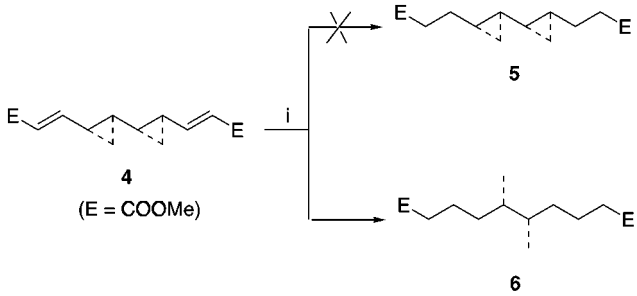
Scheme 1. Mercury(II)-Mediated Ring Opening of Bicyclopropane



1 2 3

i. $Hg(OCOCF_3)_2$, BnOH, 25 °C; NaCl, 80%; ii. $LiAlH_4$, THF, 0 °C, 86%; iii. $Hg(OCOCF_3)_2$, CH_2Cl_2, 25 °C, 61%; iv, $LiAlH_4$, THF, 0 °C, 58%

Scheme 2. Regioselective Reductive Ring Opening of 4



4 (E = COOMe) 5 6

i. 10% Pd/C, H_2, EtOH, 25 °C, 48 h, 78%

We have recently reported studies on mercury(II)-mediated opening of bi- and tercyclopropane arrays which lead to the formation of enantiomerically pure, highly functionalized tetrahydrofurans such as **3** (Scheme 1).[9] During the course of these studies, we attempted to synthesize substrates such as diester **5** from **4**. To our surprise, hydrogenation with 10% Pd/C in EtOH did not afford the expected product **5**. Instead, C_2-symmetric cyclopropane ring-opened product **6** was isolated in 78% yield (Scheme 2). To our knowledge, no systematic studies on the regioselectivity of ring opening of acyclic vinylcyclopropanes by hydrogenation has been reported. In this paper, we report our initial studies on a substrate-controlled, highly regioselective ring opening of vinylcyclopropanes by hydrogenation with palladium on activated carbon.

[⊗] Abstract published in *Advance ACS Abstracts*, September 1, 1997.

(1) For reviews on cleavage of cyclopropanes, see: (a) Preston, P. M.; Tennant, G. *Chem. Rev.* **1972**, *72*, 627. (b) DePuy, C. H. *Top. Curr. Chem.* **1973**, *40*, 73. (c) Gibson, D. H.; DePuy, C. H. *Chem. Rev.* **1974**, *74*, 605. (d) Crabtree, R. H. *Chem. Rev.* **1985**, *85*, 245. (e) Rappoport, Z., Ed. *The Chemistry of the Cyclopropyl Group*, Parts 1 and 2; J. Wiley and Sons: London, 1987.

(2) For examples of palladium induced ring opening of cyclopropanes, see: (a) Ahmad, M.; Bäckvall, J. E.; Nordberg, R.; Norin, T.; Strömberg, S. *J. Chem. Soc., Chem. Commun.* **1982**, 321. (b) Bäckvall, J. E.; Björkman, E. E. *J. Chem. Soc., Chem. Commun.* **1982**, 693. (c) Wihelm, D. Bäckvall, J. E.; Nordberg, R.; Norin, T. *Organometallics* **1985**, *4*, 1296.

(3) Bäckvall, J. E.; Björkman, E. E.; Pettersson, L.; Siegbahn, P.; Strich, A. *J. Am. Chem. Soc.* **1985**, *107*, 7408.

(4) Blomberg, M. R. A.; Siegbahn, P. E. M.; Bäckvall, J. E. *J. Am. Chem. Soc.* **1987**, *109*, 4450.

(5) For examples of platinum induced ring opening of cyclopropanes, see: (a) Dominelli, N.; Oehlschlager, A. C. *Can. J. Chem.* **1977**, *55*, 364. (b) Neilsen, W. D.; Larsen, R. D.; Jennings, P. W. *J. Am. Chem. Soc.* **1988**, *110*, 8657. (c) Hoberg, J. O.; Larsen, R. D.; Jennings, P. W. *Organometallics* **1990**, *9*, 1334. (d) Ikura, K.; Ryu, I.; Kambe, N.; Sonoda, N. *J. Am. Chem. Soc.* **1992**, *114*, 1520. (e) Stewart, F. F.; Neilsen, W. D.; Ekeland, R. E.; Larsen, R. D.; Jennings, P. W. *Organometallics* **1993**, *12*, 4858.

(6) For examples of rhodium-induced ring opening of cyclopropanes, see: (a) Gassman, P. G.; Atkins, T. J.; Lumb, J. T. *J. Am. Chem. Soc.* **1972**, *94*, 7757. (b) Wiberg, K. B.; Bishop, K. C., III. *Tetrahedron Lett.* **1973**, 2727. (c) Hidai, M.; Orisaku, M.; Uchida, Y. *Chem. Lett.* **1980**, 753. (d) Gassman, P. G.; Bonser, S. M. *Tetrahedron Lett.* **1983**, *24*, 3431.

(7) For examples of thallium-induced ring opening of cyclopropanes, see: (a) Kocovsky, P.; Pour, M.; Gogoll, A. Hanus, V.; Smrcina, M. *J. Am. Chem. Soc.* **1990**, *112*, 6735. (b) Kocovsky, P.; Srogl, J.; Pour, M.; Gogoll, A. *J. Am. Chem. Soc.* **1994**, *116*, 186.

(8) For examples in mercury-induced ring opening of cyclopropanes, see: (a) Lukina, R.; Gladshetein, M. *Dokl. Akad. Nauk SSSR* **1950**, *71*, 65. (b) DePuy, C. H.; McGirk, R. H. *J. Am. Chem. Soc.* **1973**, *95*, 2366. (c) Collum, D. B.; Mohamadi, F.; Hallock, J. S. *J. Am. Chem. Soc.* **1983**, *105*, 6882. (d) Collum, D. B.; Still, W. C.; Mohamadi, F. *J. Am. Chem. Soc.* **1986**, *108*, 2094. (e) Lambert, J. B.; Chelius, E. C.; Bible, R. H., Jr.; Hajdu, E. *J. Am. Chem. Soc.* **1991**, *113*, 1331. (f) Kocovsky, P.; Grech, J. M.; Mitchell, W. *J. Org. Chem.* **1995**, *60*, 1482. (g) Lautens, M.; Tam, W.; Blackwell, J. *J. Am. Chem. Soc.* **1997**, *119*, 623.

(9) Barrett, A. G. M.; Tam, W. *J. Org. Chem.* **1997** (in press).

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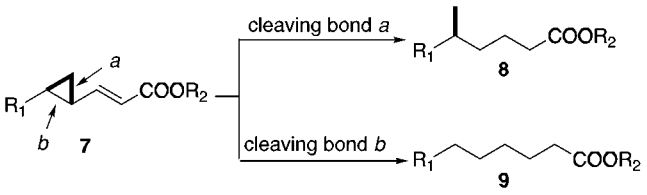
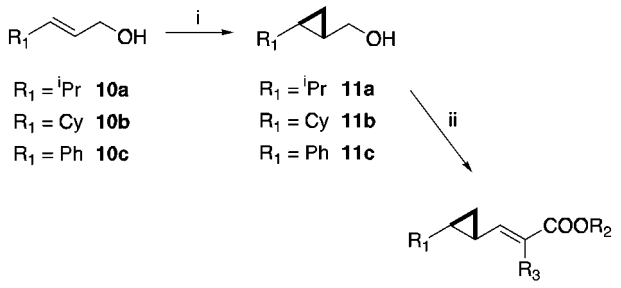
Scheme 3. Two Possible Regioisomers in the Ring Opening of a Vinylcyclopropane



Scheme 4. Synthesis of Vinylcyclopropanes



R_1 = ^{i}Pr, R_2 = Me, R_3 = H **12a**
R_1 = Cy, R_2 = Et, R_3 = H **12b**
R_1 = Ph, R_2 = Et, R_3 = H **12c**
R_1 = Cy, R_2 = Et, R_3 = Me *(E)* **13b**
R_1 = Cy, R_2 = Et, R_3 = Me *(Z)* **14b**
R_1 = Ph, R_2 = Et, R_3 = Me *(E)* **15c**
R_1 = Ph, R_2 = Et, R_3 = Me *(Z)* **16c**

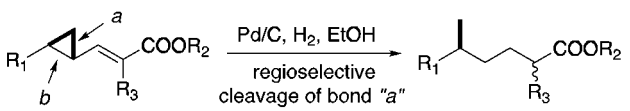
i. Et_2Zn, CH_2I_2, CH_2Cl_2, - 20 °C to 25 °C, 81-96%; ii. Dess-Martin periodinane, pyridine, CH_2Cl_2; PPh_3, 0 °C; Ph_3P=CHCOOMe or $(EtO)_2P(O)CH_2COOEt$, NaH, THF or $(EtO)_2P(O)CHMeCOOEt$, NaH, THF, 60 °C, 72-87%

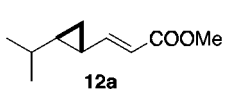
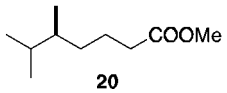
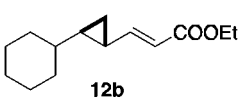
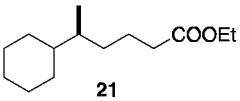
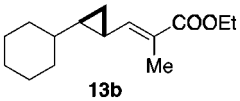
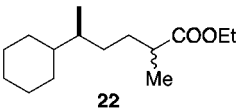
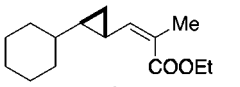
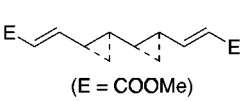
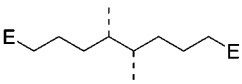
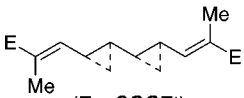
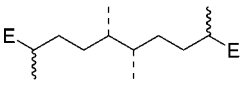
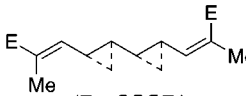
Results and Discussion

Two regioisomers could be formed in the opening of a vinylcyclopropane by hydrogenation (Scheme 3). Cleavage of bond "*a*" would lead to the formation of the regioisomer **8** while cleavage of bond "*b*" would produce regioisomer **9**. A series of vinylcyclopropanes were prepared from the corresponding allylic alcohols via cyclopropanation (Et_2Zn, CH_2I_2, CH_2Cl_2, −20−25 °C, 81−96%), Dess−Martin oxidation and Wittig or Wadsworth−Emmons olefination (72−87%) (Scheme 4), and the ring-opening reactions of these vinylcyclopropanes by hydrogenation with Pd/C were studied (Tables 1 and 2).

When $R_1 \neq$ Ph or vinyl groups, bond "*a*" was cleaved regioselectively, giving the ring-opening products in high yields (Table 1). Thus, under the usual hydrogenation conditions with 10% Pd/C at normal pressure and room temperature, vinylcyclopropanes **12a** and **12b** afforded **20** (90%) and **21** (94%) as the only ring-opened products (entries 1 and 2). Both of the *E* and *Z* geometrical isomers **13b** and **14b** provided the same products **22** as a 1:1 inseparable mixture of diastereomers in excellent yields (96% and 97%) (entries 3 and 4). Ring opening of the enantiomerically pure bicyclopropane (+)-**4**[10] gave the C_2-symmetric ring-opened product (−)-**6** (78%) (entry 5), and both of the optically active *E,E* and *E,Z* isomers (+)-**17** and (+)-**18** afforded **23** as a mixture of diastereoisomers (~10:1:1) in good yields (86% and 88%) (entries 6 and 7). The structure and the regiochemistry of these ring-opened products were determined by high-field NMR studies (HCOSY, HETCOR, and DEPT).

Table 1 Regioselective Ring Opening of Vinylcyclopropanes (with $R_1 \neq$ Ph or Vinyl)



Entry	Vinyl cyclopropane	Product	Yield
1	 **12a**	 **20**	90 %
2	 **12b**	 **21**	94 %
3	 **13b**	 **22**	96 %
4	 **14b**	**22**	97 %
5	 (E = COOMe) (+)-**4**	 (-)-**6**	78 %
6	 (E = COOEt) (+)-**17**	 **23**	86 %
7	 (E = COOEt) (+)-**18**	**23**	88 %

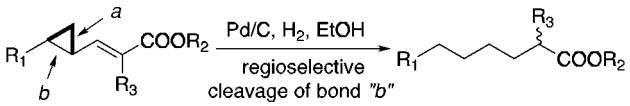
Unlike the cases shown in Table 1 ($R_1 \neq$ Ph or vinyl), when R_1 is a Ph or vinyl group (which can coordinate with Pd), bond "*b*" was cleaved regioselectively, giving the ring-opened products in high yields (Table 2). Thus, under the same hydrogenation conditions with Pd/C, vinylcyclopropane **12c** and the enantiomerically pure divinylcyclopropane (+)-**19**[11] gave **24** (82%) and **26** (90%) respectively as the only products (entries 1 and 4). Both of the *E* and *Z* geometrical isomers **15c** and **16c** afforded the same product **25** in good yields (80% and 85%) (entries 2 and 3).

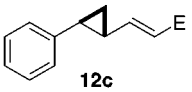
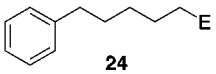
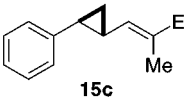
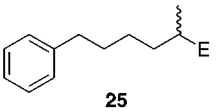
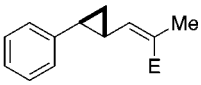
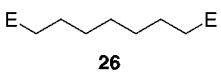
Our proposed mechanism for the Pd-catalyzed ring opening of vinylcyclopropane is shown in Scheme 5. Following coordination of Pd to the double bond in **27** to form the π-complex **28**, Pd can insert into either the less hindered bond "*a*" or the more hindered bond "*b*" of the cyclopropane. Due to the steric bulk of R_1 on the cyclopropane, Pd would prefer to insert into the less hindered bond "*a*", giving rise to the formation of the

(10) (a) Barrett, A. G. M.; Kasdorf, K. *Chem. Commun.* **1996**, 325. (b) Barrett, A. G. M.; Kasdorf, K. *J. Am. Chem. Soc.* **1996**, *118*, 11030.

(11) Barrett, A. G. M.; Hamprecht, D.; White, A. J. P.; Williams, D. J. *J. Am. Chem. Soc.* **1996**, *118*, 7863.

Table 2 Regioselective Ring Opening of Vinylcyclopropanes (with R_1 = Ph or Vinyl)

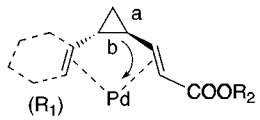


Entry	Vinylcyclopropane	Product	Yield
1	 **12c**	 **24**	82 %
2	 **15c**	 **25**	80 %
3	 **16c**	**25**	85 %
4	 (+)-**19** (E = COOEt)	 **26**	90 %

palladacyclobutane **29**. Addition of H_2 to the Pd followed by reductive cleavage of the palladacyclobutane would provide **31**. Reduction of the remaining double bond by H_2, Pd/C would provide the observed product **33**.

The double bond next to the cyclopropane is essential for this Pd metal-induced cyclopropane ring opening to occur. No cyclopropane ring opening was observed in the absence of the double bond. When cyclopropane **11b** and bicyclopropane **5** (prepared from **4** by diimide reduction, KOOCN=NCOOK, MeOH, AcOH, 70%) were subjected to the usual hydrogenation conditions with Pd/C, only starting materials were recovered. It is interesting to note that only phosphine-free palladium metal induces cyclopropane ring opening, as no cyclopropane ring opening was observed when vinylcyclopropane **13b** was treated with either a palladium(II) ($Pd(MeCN)_2Cl_2$) or palladium(0) ($Pd(PPh_3)_4$) catalyst. It is not too surprising that Pd(II) complexes did not cleave the cyclopropane ring, as all these vinylcyclopropanes contained electron-deficient double bond (as observed from the literature,[2] Pd(II)-induced ring opening of vinylcyclopropanes usually required electron-rich double bonds as these ring openings are electrophilic in nature).

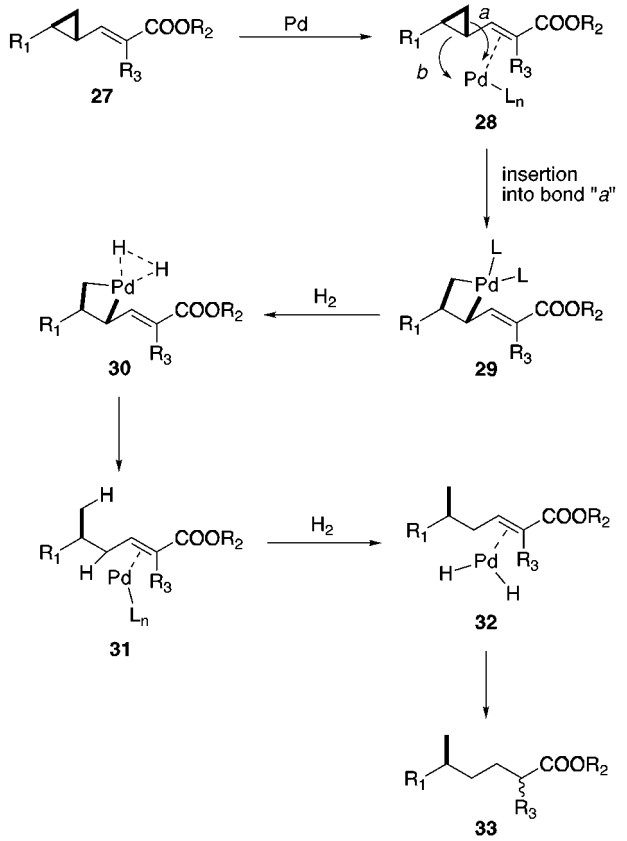
When R_1 = Ph or vinyl, excellent regioselectivity of the cleavage of bond "*b*" was observed (Table 2). As Ph and vinyl groups are capable of coordinating with Pd, a double coordination of the Pd with the π-bonds could occur which would lead to the formation of a transition state such as **34** (Figure 1). Thus, the Pd is locked in a position such that only insertion to bond "*b*" is possible which could account for the high regioselectivity in the cleavage of bond "*b*" over bond "*a*" when R_1 = Ph or vinyl groups. Poulter and Heathcock have previously reported similar regioselective hydrogenolyses of alkenylcyclopropanes over heterogeneous palladium catalysts.[12]



34

Figure 1.

Scheme 5. Proposed Mechanism of the Pd-Catalyzed Ring Opening of Vinylcyclopropanes



In conclusion, we have demonstrated a highly regioselective reductive ring opening of vinylcyclopropanes induced by palladium on activated carbon. High yields and excellent regioselectivities were observed in cleaving either the less hindered bond (bond "*a*") or the more hindered bond (bond "*b*") of the cyclopropane depending on whether the substituent on the vinylcyclopropane (R_1) is capable of coordinating to Pd or not.

Experimental Section

General. All reactions were carried out in an atmosphere of dry nitrogen at ambient temperature unless otherwise stated. Standard column chromatography was carried out on BDH silica gel 60, 230−400 mesh ASTM, using flash chromatography techniques (eluants are given in parentheses).[13] Analytical thin-layer chromatography (TLC) was performed on Merck precoated silica gel 60 F_{254} plates. All glassware was flame dried under an inert atmosphere of dry nitrogen. Hexanes refers to bp 40−60 °C redistilled petroleum. Solvents were purified by distillation under N_2 from CaH_2 (CH_2Cl_2, DMF, Et_3N, pyridine) and Ph_2CO−Na (diethyl ether (Et_2O)), Ph_2CO−K (tetrahydrofuran (THF)), and Mg and I_2 (methanol (MeOH)). Bicyclopropanedimethanol (**1**),[10] bicyclopropane **4**,[10]

(12) For previous studies on the regioselectivity of hydrogenolysis of alkenylcyclopropanes over palladium, see: (a) Poulter, S. R.; Heathcock, C. H. *Tetrahedron Lett.* **1968**, 5339. (b) Poulter, S. R.; Heathcock, C. H. *Tetrahedron Lett.* **1968**, 5343.

(13) Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

potassium azodicarboxylate,[14] allylic alcohol **10a**,[9] allylic alcohol **10b**,[15] 1-(hydroxymethyl)-3-isopropylcyclopropane (**11a**)[9] 1-(hydroxymethyl)-3-phenylcyclopropane (**11c**),[16] Dess−Martin periodinane[17] and divinylcyclopropane **19**[11] were prepared as described in the literature. All other reagents were obtained from commercial sources and used without further purification.

(1*S*,3*R*,4*R*,6*S*)-1,6-Bis(2-(methoxycarbonyl)ethyl)bicyclopropane (5). To a solution of (+)-**4**[10] (365 mg, 1.46 mmol) in dry MeOH (40 mL) was added potassium azodicarboxylate[14] (2.83 g, 14.6 mmol) at 0 °C. The mixture was stirred at room temperature for 15 min, and acetic acid (1.70 mL, 29.7 mmol) was added at 0 °C. The mixture was stirred at room temperature and was monitored by TLC. Potassium azodicarboxylate (2.83 g, 14.6 mmol) and acetic acid (1.70 mL, 29.7 mmol) was added every 3 h until all the starting material and the intermediate monohydrogenated product was consumed. After rotary evaporation of most of the MeOH, water was added and the aqueous layer was extracted into EtOAc (4×), and the combined organic layers were washed with saturated $NaHCO_3$ and brine and dried ($MgSO_4$). Rotary evaporation and chromatography (EtOAc:hexanes 0:1, 1:9) gave the product (+)-**5** (252 mg, 0.991 mmol, 68%) as a colorless viscous oil: R_f 0.25 (EtOAc:hexanes = 1:9); $[\alpha]^{25}_D = +35.8$ ($c = 1.30$, CH_2Cl_2); IR (film) 1739 (s), 1195 (s), 1173 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 3.67 (s, 6H), 2.36 (t, 4H, $J = 7.5$ Hz), 1.49 (m, 4H), 0.54 (m, 2H), 0.43 (m, 2H), 0.18 (m, 4H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 174.1, 51.5, 34.2, 29.5, 20.1, 16.7, 10.2; MS (CI, NH_3) m/z 272 $[M + NH_4]^+$, 255 $[M + H]^+$, 233, 191, 180, 121, 106, calcd for $C_{14}H_{23}O_4$ ($[M + H]^+$): 255.1596, found 255.1590.

***trans*-2-Cyclohexyl-1-(hydroxymethyl)cyclopropane (11b).** Et_2Zn (neat, 7.00 mL, 68.3 mmol, 3 equiv) was added slowly to CH_2Cl_2 (80 mL) when CH_2I_2 (5.60 mL, 69.4 mmol, 3 equiv) was added dropwise at −20 °C. The mixture was allowed to stir for 15 min at −15 °C before a solution of **10b**[15] (3.25 g, 23.2 mmol) in CH_2Cl_2 (80 mL) was added *via* cannula at −20 °C. The mixture was stirred at −20 °C for 2 h and at room temperature for 2 h. The mixture was quenched with saturated NH_4Cl solution at 0 °C followed by addition of 0.5 M HCl. The product was extracted into CH_2Cl_2 (4×) and the organic layer was washed with a saturated $NaHCO_3$ solution and brine, and dried ($MgSO_4$). Rotary evaporation and chromatography (EtOAc:hexanes 0:1, 1:4, 1:1) gave the product **11b** (3.44 g, 22.3 mmol, 96%) as a colorless oil: R_f 0.30 (Et_2O: hexanes = 1:1); IR (film) 3350 (br s), 1051 (s), 1031 (s), 1014 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 3.44 (m, 2H), 1.79−1.64 (m, 5H), 1.32 (br s, 1H), 1.24−1.02 (m, 5H), 0.88 (m, 1H), 0.58 (m, 1H), 0.48−0.31 (m, 3H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 67.3, 41.9, 33.1, 32.8, 26.5, 26.3, 24.4, 20.0, 8.7; MS (CI, NH_3) m/z 172 $[M + NH_4]^+$, 154 $[M + H]^+$, 136, 95, 81, calcd for $C_{10}H_{22}NO$ $[M + NH_4]^+$ 172.1701, found 172.1707.

***trans*-1-[(*E*)-2-(Methoxycarbonyl)ethenyl]-2-isopropylcyclopropane (12a).** To a solution of **11a** (718 mg, 6.29 mmol) in dry CH_2Cl_2 (40 mL) were added dry pyridine (5 mL) and Dess−Martin periodinane[17] (3.60 g, 8.49 mmol). The mixture was stirred at room temperature for 45 min, and TLC indicated that all starting material was consumed. PPh_3 (3.00 g, 11.4 mmol) was added at 0 °C. After 30 min, (carbomethoxymethylene)triphenylphosphorane (4.20 g, 12.6 mmol) was added at 0 °C and the mixture was stirred at room temperature for 1 h. After the solution was quenched with water, the aqueous layer was extracted into CH_2Cl_2, and the combined organic layers were washed with saturated $CuSO_4$, water, and brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O: hexanes 0:1, 1:9) gave the product **12a** (763 mg, 4.53 mmol, 72%) as a colorless oil: R_f 0.33 (Et_2O: hexanes = 1:9); IR (film) 1722 (s), 1645 (s), 1149 (m), 1048 (m) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.49 (dd, 1H, $J = 15.4$, 10.0 Hz), 5.83 (d, 1H, $J = 15.4$ Hz), 3.70 (s, 3H), 1.34 (m, 1H), 1.01−0.96 (m, 7H), 0.85−0.77 (m, 3H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 167.3, 154.2, 116.9, 51.2, 32.8, 31.3, 21.8, 21.3, 15.2; MS (CI, NH_3) m/z 186 $[M + NH_4]^+$, 169 $[M + H]^+$, 137, 111, 108, 81, calcd for $C_{10}H_{20}NO_2$ ($[M + NH_4]^+$) 186.1494, found 186.1500.

***trans*-2-Cyclohexyl-1-formylcyclopropane (11b′).** To a solution of **11b** (2.51 g, 16.3 mmol) in dry CH_2Cl_2 (110 mL) were added dry pyridine (18 mL) and Dess−Martin periodinane (10.4 g, 24.5 mmol). The mixture was stirred at room temperature for 2 h, and TLC indicated that all starting material was consumed. PPh_3 (8.51 g, 32.4 mmol) was added at 0 °C. After 30 min, water was added, the aqueous layer was extracted into CH_2Cl_2, and the combined organic layers were washed with saturated $CuSO_4$, water, and brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9, 1:3) gave the corresponding aldehyde **11b′** (2.25 g, 14.7 mmol, 90%) as a colorless oil: R_f 0.40 (Et_2O: hexanes = 1:3); IR (film) 2723 (m), 1710 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 9.00 (m, 1H), 1.75−1.72 (m, 6H), 1.66−1.15 (m, 7H), 1.00 (m, 1H), 0.81 (m, 1H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 201.4, 41.6, 33.0, 32.9, 29.7, 29.5, 26.6, 26.4, 26.3, 13.8; MS (CI, NH_3) m/z 170 $[M + NH_4]^+$, 135, 108, 95, 81, calcd for $C_{10}H_{20}NO$ ($[M + NH_4]^+$) 170.1545, found 170.1554.

***trans*-2-Cyclohexyl-1-[(*E*)-2-(ethoxycarbonyl)ethenyl]cyclopropane (12b).** Triethyl phosphonoacetate (1.0 mL, 5.1 mmol) was added dropwise to pentane-washed sodium hydride (121 mg, 5.04 mmol) and THF (10 mL). The mixture was stirred at room temperature for 30 min before a solution of the aldehyde **11b′** (500 mg, 3.29 mmol) in THF (8 mL) was added via cannula. The mixture was stirred at 60 °C for 1.5 h. After the mixture was quenched with water, the aqueous layer was extracted with ether, and the combined ether layer was washed with brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:19) gave the product **12b** (681 mg, 3.06 mmol, 93%) as a colorless oil: R_f 0.26 (Et_2O:hexanes = 1:9); IR (film) 1715 (s), 1145 (m), 1048 (m) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.49 (dd, 1H, $J = 15.4$, 10.0 Hz), 5.83 (d, 1H, $J = 15.4$ Hz), 4.18 (q, 2H, $J = 7.2$ Hz), 1.77−1.60 (m, 5H), 1.36 (m, 1H), 1.29 (t, 3H, $J = 7.2$ Hz), 1.23−1.05 (m, 5H), 0.93−0.75 (m, 3H), 0.69 (m, 1H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 166.9, 154.0, 117.3, 60.0, 42.4, 32.7, 32.6, 29.8, 26.4, 26.2, 26.1, 20.9, 14.8, 14.3; MS (CI, NH_3) m/z 240 $[M + NH_4]^+$, 223 $[M + H]^+$, 148, 134, 127, 81, calcd for $C_{14}H_{23}O$ ($[M + H]^+$) 223.1698, found 223.1692.

***trans*-1-Formyl-2-phenylcyclopropane (11c′).** To a solution of **11c** (4.60 g, 16.3 mmol) in dry CH_2Cl_2 (200 mL) were added dry pyridine (35 mL) and Dess−Martin periodinane (19.7 g, 46.5 mmol). The mixture was stirred at room temperature for 2 h, and TLC indicated that all starting material was consumed. PPh_3 (16.3 g, 62.1 mmol) was added at 0 °C. After 30 min, water was added, the aqueous layer was extracted into CH_2Cl_2, and the combined organic layers were washed with saturated $CuSO_4$, water, and brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O: hexanes 0:1, 1:9, 1:3) gave the corresponding aldehyde **11c′** (3.65 g, 25.0 mmol, 80%) as a colorless oil. Spectral data were in accord with those reported in the literature.[18]

***trans*-1-[(*E*)-2-(Ethoxycarbonyl)ethenyl]-2-phenylcyclopropane (12c).** Triethyl phosphonoacetate (1.0 mL, 5.13 mmol) was added dropwise to pentane-washed sodium hydride (123 mg, 5.13 mmol) and THF (10 mL). The mixture was stirred at room temperature for 30 min before a solution of the aldehyde **11c′** (500 mg, 3.42 mmol) in THF (8 mL) was added via cannula. The mixture was stirred at 60 °C for 1.5 h. After the mixture was quenched with water, the aqueous layer was extracted with ether, and the combined ether layer was washed with brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9) gave the product **12c** (711 mg, 3.29 mmol, 96%) as a colorless oil. Spectral data were in accord with those reported in the literature.[19]

Wadsworth−Emmons Olefination of Aldehyde 11b′ with Triethyl 2-Phosphonopropionate. Triethyl 2-phosphonopropionate (1.10 mL, 5.13 mmol) was added dropwise to

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pentane-washed sodium hydride (123 mg, 5.13 mmol) and THF (10 mL). The mixture was stirred at room temperature for 30 min before a solution of **11b′** (501 mg, 3.29 mmol) in THF (8 mL) was added via cannula. The mixture was stirred at 60 °C for 1.5 h. After the mixture was quenched with water, the aqueous layer was extracted with ether, and the combined ether layer was washed with brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:19) gave the products **13b** (700 mg, 2.96 mmol, 90%) and **14b** (55.2 mg, 0.234 mmol, 7%) both as colorless oils.

***trans*-2-Cyclohexyl-1-[(*E*)-2-(Ethoxycarbonyl)-2-propenyl]cyclopropane (13b):** R_f 0.30 (Et_2O : hexanes = 1:9); IR (film) 1711 (s), 1638 (m), 1177 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.16 (dd, 1H, J = 10.5, 0.9 Hz), 4.17 (q, 2H, J = 7.1 Hz), 1.94 (d, 3H, J = 0.9 Hz), 1.72 (m, 4H), 1.64 (m, 1H), 1.37 (m, 1H), 1.28 (t, 3H, J = 7.1 Hz), 1.21−1.05 (m, 5H), 0.88−0.63 (m, 4H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 168.3, 147.0, 124.3, 60.2, 42.3, 32.9, 32.7, 29.3, 26.5, 26.2(2), 18.2, 15.0, 14.7, 12.8; MS (CI, NH_3) m/z 254 $[M + NH_4]^+$, 237 $[M + H]^+$, 190, 140, 135, 112, 95, 81, calcd for $C_{15}H_{25}O_2$ ($[M + H]^+$) 237.1855, found 237.1846.

***trans*-2-Cyclohexyl-1-[(*Z*)-2-(ethoxycarbonyl)-2-propenyl]cyclopropane (14b):** R_f 0.51 (Et_2O:hexanes = 1:9); IR (film) 1706 (s), 1643 (m), 1261 (s), 1116 (s), 1099 (s) (m) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 5.26 (dd, 1H, J = 10.6, 1.1 Hz), 4.23 (qd, 2H, J = 7.1, 1,6 Hz), 2.40 (m, 1H), 1.87 (d, 3H, J = 1.1 Hz), 1.80−1.45 (m, 5H), 1.32 (t, 3H, J = 7.1 Hz), 1.27−1.03 (m, 5H), 0.77−0.68 (m, 3H), 0.58 (m, 1H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 168.5, 148.9, 123.5, 59.9, 42.2, 32.9, 32.7, 29.2, 26.5, 26.3, 26.2, 20.5, 18.5, 14.5, 14.3; MS (CI, NH_3) m/z 254 $[M + NH_4]^+$, 237 $[M + H]^+$, 190, 140, 135, 112, 95, 81, calcd for $C_{15}H_{25}O_2$ ($[M + H]^+$) 237.1855, found 237.1846. Anal. Calcd for $C_{15}H_{24}O_2$: C, 76.23; H, 10.23. Found: C, 76.04; H, 10.11.

Wadsworth−Emmons Olefination of 11c′ with Triethyl 2-Phosphonopropionate. Triethyl 2-phosphonopropionate (1.10 mL, 5.13 mmol) was added dropwise to pentane-washed sodium hydride (123 mg, 5.13 mmol) and THF (10 mL). The mixture was stirred at room temperature for 30 min before a solution of **11c′** (500 mg, 3.42 mmol) in THF (8 mL) was added via cannula. The mixture was stirred at 60 °C for 1.5 h. After the mixture was quenched with water, the aqueous layer was extracted with ether, and the combined ether layer was washed with brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:19, 1:9) gave the products **15c** (722 mg, 3.14 mmol, 92%) and **16c** (25.9 mg, 0.112 mmol, 3%) both as colorless oils.

***trans*-1-[(*E*)-2-(Ethoxycarbonyl)-2-propenyl]-2-phenylcyclopropane (15c):** R_f 0.22 (Et_2O:hexanes = 1:9); IR (film) 1705 (s), 1249 (s), 1174 (s), 1102 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.32 (t, 2H, J = 7.1 Hz), 7.24 (t, 1H, J = 7.2 Hz), 7.13 (d, 2H, J = 7.1 Hz), 6.33 (dd, 1H, J = 10.3, 1.1 Hz), 4.23 (q, 2H, J = 7.1 Hz), 2.19 (m, 1H), 1.96 (d, 3H, J = 1.1 Hz), 1.89 (m, 1H), 1.47 (dt, 1H, J = 8.2, 5.6 Hz), 1.33 (t, 3H, J = 7.1 Hz), 1.27 (m, 1H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 168.1, 144.9, 141.3, 128.5, 126.1, 125.9, 60.4, 26.4, 24.3, 17.8, 14.4, 12.7; MS (CI, NH_3) m/z 248 $[M + NH_4]^+$, 231 $[M + H]^+$, 157, 139, 126, calcd for $C_{15}H_{19}O_2$ ($[M + H]^+$) 231.1385, found 231.1388.

***trans*-1-[(*Z*)-2-Ethoxycarbonyl)-2-propenyl]-2-phenylcyclopropane (16c):** R_f 0.29 (Et_2O:hexanes = 1:9); IR (film) 1707 (s), 1243 (s), 1178 (s), 1108 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.28 (t, 2H, J = 7.7 Hz), 7.19 (d, 1H, J = 7.4 Hz), 7.13 (d, 2H, J = 7.3 Hz), 5.44 (d, 1H, J = 10.3 Hz), 4.20 (q, 2H, J = 7.2 Hz), 2.97 (m, 1H), 2.02 (m, 1H), 1.94 (d, 3H, J = 1.0 Hz), 1.37 (dt, 1H, J = 8.4, 5.6 Hz), 1.27 (t, 3H, J = 7.2 Hz), 1.14 (dt, 1H, J = 8.8, 5.3 Hz); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 168.2, 146.3, 141.6, 128.4, 126.0, 125.8, 125.5, 60.1, 26.5, 24.2, 20.6, 18.2, 14.2; MS (CI, NH_3) m/z 248 $[M + NH_4]^+$, 231 $[M + H]^+$, 126, calcd for $C_{15}H_{19}O_2$ ($[M + H]^+$) 231.1385, found 231.1383. Anal. Calcd for $C_{15}H_{18}O_2$: C, 78.23; H, 7.88. Found: C, 78.48; H, 7.60.

Dess−Martin Oxidation of Bicyclopropanedimethanol (1) and Subsequent Wadsworth−Emmons Olefination of the Resulting Dialdehyde with Triethyl 2-Phosphonopropionate. To a solution of bicyclopropanedimethanol (**1**)[10] (201 mg, 1.41 mmol) in dry CH_2Cl_2 (8 mL) were added dry pyridine (1.0 mL) and Dess−Martin periodinane (1.43 g, 3.37 mmol). The mixture was stirred at room temperature for 1 h, and TLC indicated that all starting material was consumed. PPh_3 (1.00 g, 3.80 mmol) was added at 0 °C. After 30 min, water was added, the aqueous layer was extracted into CH_2Cl_2, and the combined organic layers were washed with saturated $CuSO_4$, water, and brine and dried ($MgSO_4$). Rotary evaporation (at ∼200 mmHg/25 °C) afforded a pale yellow oil which was filtered through silica (Et_2O:hexanes 0:1, 1:9, 1:3, 1:1 discarded; Et_2O:hexanes 3:1 collected). Rotary evaporation (at ∼200 mmHg/25 °C) provided the crude bicyclopropane dialdehyde as a colorless oil: R_f 0.26 (Et_2O:hexanes = 3:1); ^1H NMR ($CDCl_3$, 300 MHz) δ 9.13 (d, 2H, J = 4.7 Hz), 1.77 (m, 2H), 1.57 (m, 2H), 1.26 (m, 2H), 0.95 (m, 2H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 200.3, 29.7, 23.4, 13.4. Without further purification and characterization, this bicyclopropane dialdehyde was subjected to the Wadsworth−Emmons olefination. Triethyl 2-phosphonopropionate (0.91 mL, 4.24 mmol) was added dropwise to pentane-washed sodium hydride (101 mg, 4.24 mmol) and THF (6 mL). The mixture was stirred at room temperature for 30 min before a solution of the above bicyclopropane dialdehyde in THF (3 mL) was added via cannula. The mixture was stirred at 60 °C for 1.5 h. After the mixture was quenched with water, the aqueous layer was extracted with ether, and the combined ether layer was washed with brine and dried ($MgSO_4$). Rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:19, 1:9) gave the products (+)-**17** (334 mg, 1.09 mmol, 77%) and (+)-**18** (24.9 mg, 0.0811 mmol, 6%) both as colorless oils. Recrystallization with 1:1 EtOAc/hexanes afforded white crystals.

(1*S*,3*R*,4*R*,6*S*)-1,6-Bis[(*E*,*E*)-2-(ethoxycarbonyl)-2-propenyl]bicyclopropane ((+)-17): mp 40−42 °C R_f 0.23 (EtOAc:hexanes = 1:9); $[\alpha]^{25}_D$ = +199.5 (c = 3.40, CH_2Cl_2); IR (film) 1707 (s), 1641 (s), 1301 (s), 1245 (s), 1179 (s), 1106 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.14 (dd, 2H, J = 10.3, 1.1 Hz), 4.17 (q, 4H, J = 7.1 Hz), 1.94 (d, 6H, J = 1.1 Hz), 1.47 (m, 2H), 1.28 (t, 6H, J = 7.1 Hz), 1.16 (m, 2H), 0.77 (m, 4H); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 168.1, 145.4, 125.5, 60.3, 23.5, 18.9, 14.3, 13.4, 12.5; MS (CI, NH_3) m/z 324 $[M + NH_4]^+$, 307 $[M + H]^+$, 278, 262, 249, 233, 179, 133, 126, 105, calcd for $C_{18}H_{27}O_4$ ($[M + H]^+$) 307.1909, found 307.1914. Anal. Calcd for $C_{18}H_{26}O_4$: C, 70.56; H, 8.55. Found: C, 70.56; H, 8.31%.

(1*S*,3*R*,4*R*,6*S*)-1,6-Bis[(*E*,*Z*)-2-(ethoxycarbonyl)-2-propenyl]bicyclopropane ((+)-18): mp 39−41 °C; R_f 0.29 (EtOAc:hexanes = 1:9); $[\alpha]^{25}_D$ = +74.4 (c = 3.40, CH_2Cl_2); IR (film) 1706 (s), 1643 (s), 1302 (s), 1247 (s), 1179 (s), 1103 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.14 (dd, 1H, J = 10.5, 1.1 Hz), 5.26 (dd, 1H, J = 10.5, 1.0 Hz), 4.23 (q, 2H, J = 7.1 Hz), 4.18 (q, 2H, J = 7.1 Hz), 2.47 (m, 1H), 1.94 (d, 3H, J = 1.0 Hz), 1.88 (d, 3H, J = 1.1 Hz), 1.45 (m, 1H), 1.32 (t, 3H, J = 7.1 Hz), 1.28 (t, 3H, J = 7.1 Hz), 1.18 (m, 1H), 0.92 (m, 1H), 0.82−0.67 (m, 3H), 0.58 (dt, 1H, J = 8.7, 4.9 Hz); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 168.2, 147.2, 145.8, 125.3, 124.8, 60.3, 60.1, 23.2, 23.1, 20.5, 18.9, 18.5, 14.3, 13.2, 13.1, 12.5; MS (CI, NH_3) m/z 324 $[M + NH_4]^+$, 307 $[M + H]^+$, 278, 261, 179, 133, 126, 105, calcd for $C_{18}H_{27}O_4$ ($[M + H]^+$) 307.1909, found 307.1908. Anal. Calcd for $C_{18}H_{26}O_4$: C, 70.56; H, 8.55. Found: C, 70.63; H, 8.30.

Methyl 5,6-Dimethylheptanoate (20). H_2(g) was attached to a flask containing **12a** (44.2 mg, 0.263 mmol) and Pd/C (10%, 40.0 mg) in absolute EtOH (1.5 mL), and the mixture was stirred for 44 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O: hexanes 0:1, 1:9) gave the product **20** (40.9 mg, 0.237 mmol, 90%) as a colorless oil: R_f 0.42 (Et_2O:hexanes = 1:9); IR (film) 1744 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 3.66 (s, 3H), 2.29 (td, 2H, J = 8.0, 2.3 Hz), 1.66 (m, 1H), 1.59−1.49 (m, 2H), 1.37−1.27 (m, 2H), 1.13 (m, 1H), 0.85 (d, 3H, J = 6.8 Hz), 0.80 (d, 3H, J = 6.7 Hz), 0.79 (d, 3H, J = 6.8 Hz); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 174.3, 51.4, 38.3, 34.5, 33.6, 31.8, 23.0, 20.2, 17.9, 15.3; MS (CI, NH_3) m/z 190 $[M + NH_4]^+$, 180, 173, 129, calcd for $C_{10}H_{24}NO_2$ ($[M + NH_4]^+$) 190.1807, found 190.1806.

Ethyl 5-Cyclohexylhexanoate (21). H_2(g) was attached to a flask containing **12b** (99.5 mg, 0.448 mmol) and Pd/C (10%, 65.3 mg) in absolute EtOH (2.5 mL) and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O:hexanes

0:1, 1:9) gave the product **21** (94.9 mg, 0.419 mmol, 94%) as a colorless oil: R_f 0.46 (Et_2O:hexanes = 1:9); IR (film) 1179 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 4.12 (q, 2H, J = 7.1 Hz), 2.26 (td, 2H, J = 7.7, 2.0 Hz), 1.74−1.50 (m, 7H), 1.35 (m, 1H), 1.25 (t, 3H, J = 7.1 Hz), 1.22−0.89 (m, 8H), 0.81 (d, 3H, J = 6.8 Hz); ^{13}C NMR ($CDCl_3$, 100.6 MHz) δ 173.9, 60.1, 42.5, 37.8, 34.7, 33.5, 30.6, 28.6, 26.9, 26.82, 26.76, 23.0, 16.0, 14.2; MS (CI, NH_3) m/z 244 $[M + NH_4]^+$, 227 $[M + H]^+$, 162, 143, 136, calcd for $C_{14}H_{30}NO_2$ ($[M + NH_4]^+$) 244.2277, found 244.2271.

Reductive Ring Opening of 13b with H_2 on Pd/C. H_2 (g) was attached to a flask containing **13b** (103 mg, 0.438 mmol) and Pd/C (10%, 65.1 mg) in absolute EtOH (2.5 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9) gave the product **22** (101 mg, 0.420 mmol, 96%, inseparable 1:1 mixture of diastereomers) as a colorless oil.

Reductive Ring Opening of 14b with H_2 on Pd/C. H_2 (g) was attached to a flask containing **14b** (45.1 mg, 0.191 mmol) and Pd/C (10%, 32.0 mg) in absolute EtOH (1.2 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9) gave the product **22** (44.5 mg, 0.185 mmol, 97%, inseparable 1:1 mixture of diastereomers) as a colorless oil.

Ethyl 5-cyclohexyl-2-methylhexanoate (22): R_f 0.49 (Et_2O:hexanes = 1:9); IR (film) 1736 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 4.12 (q, 4H, J = 7.1 Hz), 2.37 (m, 2H), 1.72−1.61 (m, 8H), 1.60−1.52 (m, 8H), 1.47−0.89 (m, 16H), 1.24 (t, 6H, J = 7.1 Hz), 1.132 (d, 3H, J = 7.0 Hz), 1.127 (d, 3H, J = 6.9 Hz), 0.80 (d, 6H, J = 6.7 Hz); ^{13}C NMR ($CDCl_3$, 100.6 MHz) δ 176.94, 176.89, 60.0, 42.5, 39.9, 38.0, 31.8, 31.7, 31.5, 30.7, 30.6, 28.6, 26.9, 26.82, 26.76, 17.2, 17.0, 16.0, 14.2; MS (CI, NH_3) m/z 258 $[M + NH_4]^+$, 241 $[M + H]^+$, 157, 136, 102, calcd for $C_{15}H_{32}NO_2$ ($[M + NH_4]^+$) 258.2433, found 258.2431. Anal. calcd for $C_{15}H_{28}O_2$: C, 74.95; H, 11.74. Found: C, 75.06; H, 11.87.

(5*S*,6*S*)-Dimethyl-1,10-decanedicarboxylic Acid Dimethyl Ester ((−)-6): H_2(g) was attached to a flask containing (+)-**4** (16.4 mg, 0.0655 mmol) and Pd/C (10%, 20.0 mg) in absolute EtOH (0.7 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9, 1:3) gave the product (−)-**6** (13.2 mg, 0.0511 mmol, 78%) as a colorless viscous oil: R_f 0.38 (Et_2O:hexanes = 1:3); $[\alpha]^{25}_D$ = −4.5 (c = 0.29, CH_2Cl_2); IR (film) 1740 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 3.67 (s, 6H), 2.29 (t, 4H, J = 7.5 Hz), 1.69−1.52 (m, 4H), 1.42 (m, 2H), 1.32−1.11 (m, 4H), 0.76 (d, 6H, J = 6.6 Hz); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 174.2, 51.4, 36.3, 34.4, 34.3, 23.1, 14.2; MS (CI, NH_3) m/z 276 $[M + NH_4]^+$, 259 $[M + H]^+$, 244, 229, 212, 185, 129, calcd for $C_{14}H_{30}NO_4$ ($[M + NH_4]^+$) 276.2175, found 276.2162, calcd for $C_{14}H_{27}O_4$ ($[M + H]^+$) 259.1909, found 259.1914.

Reductive Ring Opening of (+)-17 with H_2 on Pd/C. H_2(g) was attached to a flask containing (+)-**17** (100 mg, 0.327 mmol) and Pd/C (10%, 60.5 mg) in absolute EtOH (1.9 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (EtOAc:hexanes 0:1, 1:19, 1:9) gave the product **23** (88.4 mg, 0.281 mmol, 86%, inseparable mixture of diastereomers ∼ 5:5:2) as a colorless oil.

Reductive Ring Opening of (+)-18 with H_2 on Pd/C. H_2(g) was attached to a flask containing (+)-**18** (15.7 mg, 0.0512 mmol) and Pd/C (10%, 10.0 mg) in absolute EtOH (0.5 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (EtOAc:hexanes 0:1, 1:19, 1:9) gave the product **23** (14.2 mg, 0.0452 mmol, 88%, inseparable mixture of diastereomers ≈ 5:5:2) as a colorless oil.

(2*R/S*, 5*S*, 6*S*, 9*R/S*)-Tetramethyl-1,10-decanedicarboxylic acid dimethyl ester (23): R_f 0.39 (EtOAc:hexanes = 1:9); IR (film) 1735 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 4.14 (q, 4H, J = 7.1 Hz), 2.39 (m, 2H), 1.66 (m, 2H), 1.60−1.33 (m, 4H), 1.27 (t, 6H, J = 7.1 Hz), 1.28−1.18 (m, 4H), 1.16 (d, 6H, J = 6.9 Hz), 0.86 (d, 0.5H, J = 6.8 Hz), 0.83 (d, 0.5H, J = 6.5 Hz), 0.76 (d, 5H, J = 6.5 Hz); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ major peaks 176.89, 176.86, 60.04, 39.84, 39.78, 36.5, 32.2, 31.93, 31.88, 17.2, 17.1, 14.3, 14.2, minor peaks 39.5, 37.53, 37.48, 36.7, 34.3, 33.81, 33.79, 31.3, 31.2, 30.4, 30.3, 29.45, 29.38, 27.5, 27.2, 26.9, 19.5, 17.3, 17.0, 16.91, 16.89, 16.3; MS (CI, NH_3) m/z 332 $[M + NH_4]^+$, 315 $[M + H]^+$, 213, 157, 140, calcd for $C_{18}H_{38}NO_4$ ($[M + NH_4]^+$) 332.2801, found 332.2800, calcd for $C_{18}H_{35}O_4$ ($[M + H]^+$) 315.2535, found 315.2536.

Ethyl 6-Phenylhexanoate (24). H_2(g) was attached to a flask containing **12c** (90.3 mg, 0.418 mmol) and Pd/C (10%, 62.4 mg) in absolute EtOH (2.5 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9) gave the product **24** (75.8 mg, 0.344 mmol, 82%) as a colorless oil: R_f 0.36 (Et_2O:hexanes = 1:9); IR (film) 1735 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.33−7.19 (m, 5H), 4.15 (q, 2H, J = 7.1 Hz), 2.64 (t, 2H, J = 7.6 Hz), 2.32 (t, 2H, J = 7.5 Hz), 1.74−1.62 (m, 4H), 1.42 (m, 2H), 1.28 (t, 3H, J = 7.1 Hz); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 173.8, 142.5, 128.4, 128.3, 125.7, 60.2, 35.8, 34.3, 31.1, 28.8, 24.9, 14.3; MS (CI, NH_3) m/z 238 $[M + NH_4]^+$, 221 $[M + H]^+$, 174, 130, 91, calcd for $C_{14}H_{24}NO_2$ ($[M + NH_4]^+$) 238.1807, found 238.1803.

Reductive Ring Opening of 15c with H_2 on Pd/C. H_2 (g) was attached to a flask containing **15c** (100 mg, 0.435 mmol) and Pd/C (10%, 65.0 mg) in absolute EtOH (2.5 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9) gave the product **25** (81.5 mg, 0.348 mmol, 80%) as a colorless oil.

Reductive Ring Opening of 16c with H_2 on Pd/C. H_2(g) was attached to a flask containing **16c** (10.2 mg, 0.0443 mmol) and Pd/C (10%, 7.0 mg) in absolute EtOH (0.3 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O: hexanes 0:1, 1:9) gave the product **25** (8.8 mg, 0.0376 mmol, 85%) as a colorless oil.

Ethyl 2-methyl-6-phenylhexanoate (25): R_f 0.41 (Et_2O: hexanes = 1:9); IR (film) 1733 (s) cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.33−7.18 (m, 5H), 4.15 (q, 2H, J = 7.1 Hz), 2.64 (t, 2H, J = 7.6 Hz), 2.43 (m, 1H), 1.79−1.61 (m, 3H), 1.53−1.32 (m, 3H), 1.27 (t, 3H, J = 7.1 Hz), 1.17 (d, 3H, J = 7.0 Hz); ^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 176.8, 142.6, 128.4, 128.3, 125.7, 60.1, 39.5, 35.8, 33.7, 31.4, 26.9, 17.1, 14.3; MS (CI, NH_3) m/z 252 $[M + NH_4]^+$, 235 $[M + H]^+$, 188, 130, 91, calcd for $C_{15}H_{23}O_2$ ($[M + H]^+$) 235.1698, found 235.1699.

Diethyl Azelate (26). H_2(g) was attached to a flask containing (+)-**19** (31.1 mg, 0.131 mmol) and Pd/C (10%, 25.0 mg) in absolute EtOH (1 mL), and the mixture was stirred for 48 h. The mixture was filtered through silica, and rotary evaporation and chromatography (Et_2O:hexanes 0:1, 1:9, 1:3) gave the product **26** (28.8 mg, 0.118 mmol, 90%) as a colorless oil. ^1H and ^{13}C NMR spectra were identical to the commercially available (Aldrich) diethyl azelate.

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Supporting Information Available: ^1H and ^{13}C NMR spectra of **5**, **6**, **11b**, **11b′**, **12a**, **12b**, **13b**, **14b**, **15c**, **16c**, **17**, **18**, and **20**−**25** (36 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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