Intramolecular and Intermolecular Mn(III)-Induced Carbon Monoxide Trapping Reactions of Alkynes with Malonate and Cyano Ester Units

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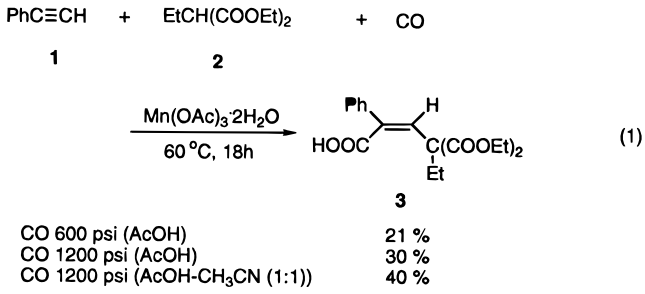
Intra- and intermolecular carbon monoxide trapping reactions of alkynes with malonates and cyano esters were developed using a Mn(III)-induced oxidative system. Phenylacetylene was treated with diethyl ethylmalonate in the presence of $Mn(OAc)_3 \cdot 2H_2O$, in AcOH−CH_3CN (1:1) under carbon monoxide, affording (*Z*)-4,4-dicarbethoxy-2-phenyl-2-hexenoic acid. Similarly, intramolecular reactions of 4-alkynylmalonates and cyanoacetates proceeded regio- and stereoselectively under the same conditions to afford the corresponding methylenecycloalkanecarboxylic acids in moderate yields. The reaction involves carbon monoxide trapping of vinyl radicals which are formed by the addition of malonate or cyanoacetate radicals induced by Mn(III) to alkynes.

Manganese(III) acetate is well-known as a strong oxidizing agent for enolizable carbonyl compounds to produce α-oxoalkyl radicals. Reactions involving such species with olefins or alkynes have attracted considerable attention during the last decade because of the prospects of new carbon−carbon bond-forming processes.[1] In particular, Mn(III)-induced intramolecular cyclization reactions have been successfully utilized for the synthesis of a variety of compounds,[2] including biologically active ones.[3]

Although metal-catalyzed carbonylation reactions have been extensively investigated,[4] comparatively few reports have appeared on radical-mediated carbonylation reactions. Examples include the tin hydride-mediated free radical carbonylation of halides[5] and AIBN-initiated reaction of alkynes with thiols.[6] Recently, one of us demonstrated the first examples of a manganese(III)-induced carbon monoxide trapping reaction of dimethyl malonate and ethyl acetoacetate derivatives with olefins.[7] This process is believed to proceed via a radical pathway where manganese(III) initiates the oxidation of enolizable compounds to give radicals which undergo addition to olefins to form new alkyl radicals which can trap carbon monoxide. It seemed reasonable to anticipate the carbonylation of alkynes in a manganese(III)-induced oxidative system, where carbon monoxide trapping by a vinyl radical is the key step in the process. Indeed, radical carbonylation via a vinyl radical has been described.[6] Herein we report the manganese(III)-induced intramolecular and intermolecular carbonylation of alkynes with malonate esters and cyanoesters.

Results and Discussion

Treatment of phenylacetylene (**1**) (1.5 mmol) with diethyl ethylmalonate (**2**) (3.0 mmol) in the presence of $Mn(OAc)_3 \cdot 2H_2O$ (4.0 mmol) in acetic acid (10 mL) at 60 °C for 18 h under 600 psi of carbon monoxide gave the desired carbon monoxide trapping compound **3** in 21% yield (eq 1). The structure of the product was established



(1)

by spectroscopic methods including NOE measurements (selective irradiation of the vinylic proton enhanced the integration of the aromatic and ethyl protons at C-2) which were of value in assigning stereochemistry. When the reaction was repeated under 1200 psi of carbon

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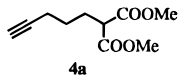
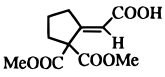
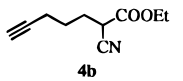
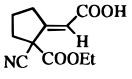
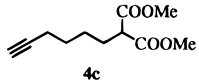
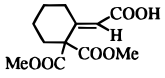
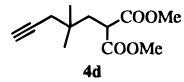
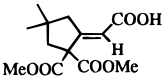
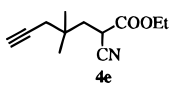
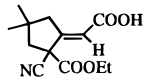
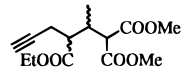
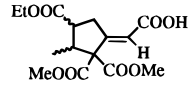
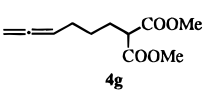
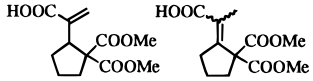
monoxide, the yield was improved somewhat to 30%, while an increase in temperature to 100 °C afford 21% of **3**. While the reaction proceeded in acetonitrile alone as a solvent (10%), the mixed-solvent system of acetic acid−acetonitrile (1:1) gave the best results, the yield of pure **3** being 40%. No simple oxidative addition products such as ethyl 2-carbethoxy-2-ethyl-5-phenyl-3-butenecarboxylic acid were observed in these reactions. No reaction occurred when 1-decyne was used instead of phenylacetylene. Para-substituted phenylacetylenes (−CN, −OMe, and −Pr^i) and 2-naphthylacetylene reacted with ethyl diethylmalonate (**2**) and carbon monoxide to some extent, but the yields of the desired products were too low (4−12%) to be of synthetic use. Therefore, we turned our attention to the intramolecular reaction which we expected to be more efficient than the intermolecular process.

Methyl 2-carbomethoxy-6-heptynoate (**4a**) was subjected to the optimum conditions used for the $Mn(OAc)_3$-induced reaction of **1** with **2**, and (*E*)-dimethyl 2-[(hydroxycarbonyl)methylene]-1,1-cyclopentanedicarboxylate (**5a**) was formed as the only product in 27% yield (Table 1).[8] In contrast to the intermolecular reaction, the yield of **5a** increased substantially (to 44%) when the reaction was carried out at 90 °C.[10] While other enolizable analogs such as ethyl 2-acetyl-6-heptynoate, 6,6-dicyano-1-hexynoate, and 2-(4-toluenesulfonyl)-6-heptynoate did not undergo reaction, ethyl cyanoacetate derivatives were successfully employed in the $Mn(OAc)_3$-induced carbonylation reaction. For instance, when ethyl 2-cyano-6-heptynoate (**4b**) was treated with carbon monoxide and $Mn(OAc)_3 \cdot 2H_2O$ under the standard conditions, the corresponding conjugated acid **5b** was formed in 43% isolated yield. The results of other cyclization reactions are listed in Table 1. Methyl 2-carbomethoxy-7-octynoate, (**4c**), which has four methylene units between the reactive centers, also underwent carbonylation to selectively afford the six-membered ring compound **5c**. Also, the presence of a *gem*-dimethyl group in the reactant (**4d** and **4e**) has no effect (**4e**), or can be beneficial (**4d**), in terms of the yield. Similarly, a 58:42 mixture of diastereomers **4f**, underwent carbonylation to give a 64:36 mixture of the stereoisomers **5f**. It should be noted that these reactions are both regio- and stereoselective in nature. The ^{1}H-NMR spectrum of crude material obtained in each reaction indicated the exclusive formation of the exo-type product. The stereochemistry of this reaction is apparently kinetically controlled since the vinyl radical is known to rapidly undergo stereoisomeric equilibration.[11] It seems likely that carbon monoxide is trapped by the stereoisomer with the less sterically hindered site (i.e. **A** in Scheme 1). If electron transfer from the acyl radical to the Mn(III) species leading to an acyl cation (**B** → **C** and **B′** → **C′**) takes place by complexation, the conversion of **B** → **C** may be more facile than that of **B′** → **C′** since steric repulsion may occur between the substituents E, E′ and Mn(III) in the case of intermediate **B′**. The intramolecular reaction is also applicable to the allenic diester **4g**, affording **5g** and **5g′** as the byproduct, the latter being derived from **5g** by isomerization.

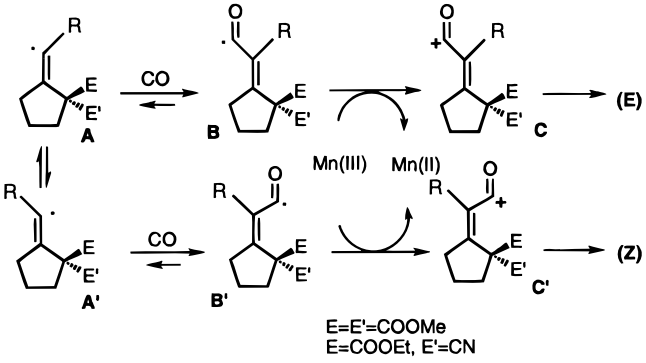
Several internal alkynes were used as reactants for the Mn(III)-induced process. Methyl 2-carbomethoxy-4-undecynoate (**4h**) reacted with carbon monoxide in the same manner as terminal alkynes affording the acid **5h** in 40% yield (eq 2). However, methyl 2-carbomethoxy-7-phenyl-6-heptynoate (**4i**) reacted to give three compounds **6** (17%), **7** (26%), and **8** (yield was not determined) in which no CO incorporation took place (eq 3). The same products

Table 1. Carbon Monoxide Trapping of Alkynyl Malonate and Cyanoacetate Derivatives by Mn(III)[a]

Substrate	Product(s)		Isolated yield (%)
 **4a**		**5a**	44(27)[b]
 **4b**		**5b**	43
 **4c**		**5c**	35
 **4d**		**5d**	68
 **4e**		**5e**	43
 **4f**[c]		**5f**	49 (Trans: cis =64:36)
 **4g**	 **5g** **5g'**		26 (**5g**:**5g'**=4:1)

[a] Reaction conditions: [substrate]/[$Mn(OAc)_3 \cdot 2H_2O$] (1:2.7), CO 1200 psi, 90 °C, CH_3COOH/CH_3CN (1:1) (10 mL), 15 h. [b] Reaction at 60 °C. [c] The ratio of two diastereoisomers was determined on the basis of the ^{1}H-NMR spectra of methyl protons at C-3. (R*,S*)/(R*,R*) (58:42).

Scheme 1

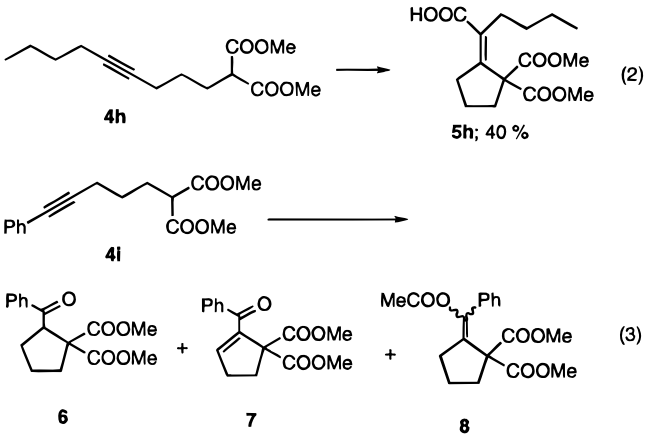


(8) To confirm the five-membered ring structure, the compound obtained from the carbonylation of **4a** was subjected to oxidation with $RuCl_3-NaIO_4$ in $CH_3CN-CCl_4-H_2O$ at room temperature for 30 min under N_2,[9] affording 2,2-bis(methoxycarbonyl)cyclopentanone in 20% isolated yield as the sole product. The low yield is probably due to the strong oxidation conditions used: ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.99 (tt, 2 H, J = 7.0, 7.5 Hz), 2.43 (t, 2 H, J = 7.5 Hz), 2.63 (t, 2 H, J = 7.0 Hz), 3.79 (s, 3 H), 3.80 (s, 3 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 20.27, 33.51, 38.04, 53.92, 68.55, 167.97, 207.41; MS *m/z* 200 (M^+).

(9) Carlsen, P. H. J.; Katsuki, T.; Martin, V. S.; Sharpless, K. B. *J. Org. Chem.* **1981**, *46*, 3936.

(10) The yield was 47% when the reaction temperature was increased to 120 °C.

(11) (a) Kampmeier, J. A.; Fantazier, R. M. *J. Am. Chem. Soc.* **1966**, *88*, 1959. (b) Singer, L. A.; Kong, N. P. *J. Am. Chem. Soc.* **1966**, *88*, 5213. (c) Bentrude, W. G. *Annu. Rev. Phys. Chem.* **1967**, *18*, 283.



were also observed under N_2 (**6**, 30%; **7**, 44%; **8**, 9%). The carbonyl oxygen of the benzoyl group in **6** and **7** may originate from water contained in manganese(III) acetate. The formation of these products could be rationalized as follows. The cyclopentylidene vinyl radical formed from **4i** may be oxidized by Mn(III) to the corresponding vinyl cation much faster than the trapping of carbon monoxide, and reaction of the cation with water or acetic acid gives **6** or **8**, respectively. It is conceivable that further oxidation of **6** to **7** by Mn(III) can occur since **6** still has an enolizable hydrogen. However, **6** was recovered unchanged when treated with manganese(III) acetate under the same conditions. Similarly, **7** was not detected on exposure of **8** to manganese(III) acetate. Therefore, **7** is not formed from **6** or **8**.

In conclusion, the regio- and stereoselective manganese(III)-induced carbon monoxide trapping reaction of alkynyl malonate and cyano ester derivatives has been established, affording functionalized methylenecycloalkanes in moderate yields. [(Hydroxycarbonyl)methylene]cycloalkanes obtained in this work are of considerable utility in the organic synthesis. For example, they serve as reactants with dihydroxybenzenes in the synthesis of 2-spirobenzopyrans, some of which are biologically active.[12]

Experimental Section

General. Proton and carbon magnetic resonance spectra were recorded on a 500 MHz spectrometer. Preparative high-performance liquid chromatography was carried out using a JAI LC-908 instrument containing a JAIGEL 2H column. Elemental analyses were performed by the elemental analysis service of the department of chemistry at the University of Ottawa.

Glacial acetic acid and acetonitrile were used as received. Manganese(III) acetate dihydrate was purchased from Aldrich and was used as received. Phenylacetylene (**1**) and diethyl ethylmalonate (**2**) were purchased from Aldrich and were distilled prior to use. The reactants **4a**,[13] **4b**,[13] **4c**,[14] and **4g**[14] were prepared according to the previously reported methods.

Synthesis of Methyl 2-Carbomethoxy-4,4-dimethyl-6-heptynoate (4d). To a solution of 2,2-dimethyl-4-pentyn-1-ol[15] (20 mmol, 2.24 g) in anhydrous dichloromethane (15 mL) were added pyridine (25 mmol, 2.0 g) and trifluoromethanesulfonic anhydride (22.3 mmol, 6.3 g) at 0 °C. The mixture was stirred for 2 h at room temperature under N_2 and diluted with dichloromethane; it was then washed with diluted hydrochloric acid. The organic layer was dried over Na_2SO_4 and concentrated. The resulting crude product was treated with dimethyl malonate according to the procedure previously reported:[13] yield 49%; oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 0.67 (s, 6 H), 2.01−2.11 (m, 5 H), 3.45 (t, 1 H, J = 6.4 Hz), 3.74 (s, 6 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 26.09, 31.72, 33.19, 39.35, 47.99, 52.59, 70.55, 81.38, 170.29; MS (CI) m/z 227 (M + 1); HRMS (EI) calcd for $C_{11}H_{15}O_3$(M − OCH_3) 195.1021, found 195.1013.

Synthesis of Ethyl 2-Cyano-4,4-dimethyl-6-heptynoate (4e). The trifluoromethanesulfonyl ester of 2,2-dimethyl-4-pentyn-1-ol[15] (20 mmol, 2.24 g) was reacted with ethyl cyanoacetate (20 mmol, 2.26 g) in the same manner as **4a**:[13] yield 37%; oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.09 (s, 6 H), 1.33 (t, 3 H, J = 7.1 Hz), 2.02−2.22 (m, 5 H), 3.51 (dd, 1 H, J = 5.0, 8.5 Hz), 4.27 (q, 2 H, J = 7.1 Hz); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 13.84, 26.18, 26.37, 26.54, 31.73, 33.36, 40.32, 62.91, 71.21, 80.74, 117.42, 166.50; MS (CI) m/z 208 (M + 1); Anal. Calcd for $C_{12}H_{17}NO_2$: C, 69.52; H, 8.28; N, 5.47. Found: C, 69.67; H, 8.18; N, 5.37.

Synthesis of Methyl 4-Carbethoxy-2-carbomethoxy-3-methyl-6-heptynoate (4f). To a suspension of NaH (80% in mineral oil, 80 mmol, 2.4 g) in THF (50 mL) was added ethyl cyanoacetate (80 mmol, 10.4 g) under N_2. Propargyl bromide (80% toluene solution, 80 mmol, 12 g) was then added to this solution and the mixture was refluxed for 20 h under N_2. After the usual workup, 4-carbethoxy-5-oxo-1-heptyne (45 mmol, 7.47 g) was obtained by distillation under reduced pressure. To a solution of 4-carbethoxy-5-oxo-1-heptyne in MeOH (20 mL) was added $NaBH_4$ (60 mmol, 2.28 g) at 0 °C. The mixture was stirred for 30 min at room temperature. Water was added, and the solution was extracted with ether. After the organic layer was dried over Na_2SO_4 and evaporated, the corresponding alcohol (6.0 g, 36 mmol) was obtained by distillation under reduced pressure. Its trifluoromethanesulfonyl ester was reacted with dimethyl malonate in the same manner as **4a**:[13] yield 55% ; oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 0.95 (d, 3 H, J = 6.8 Hz), 1.04 (d, 3 H, J = 6.6 Hz), 1.29 (t, 3 H, J = 7.1 Hz), 2.02−2.07 (m, 1 H), 2.43−2.80 (m, 4 H), 3.55−3.61 (m, 1 H), 3.75 (s, 6 H), 4.14−4.21 (m, 2 H); ^{13}C-NMR (50 Mz, $CDCl_3$) (R*, S*) δ 12.70, 13.94, 19.25, 34.02, 45.92, 52.26, 55.07, 60.48, 70.08, 80.55, 168.29, 171.89; (R*, R*) 13.14, 13.94, 17.47, 33.94, 46.69, 52.05, 54.14, 60.61, 70.08, 80.71, 168.41, 172.73; MS (CI) m/z 285 (M + 1); HRMS (EI) calcd for $C_{13}H_{17}O_5$(M − OCH_3) 253.1076, found 253.1091.

Synthesis of Methyl 2-Carbomethoxy-6-undecynoate (4h). 1-Chloro-4-nonyne (15.12 mmol, 2.4 g) was reacted with dimethyl malonate (18.16 mmol, 2.4 g) using NaH (80% in mineral oil, 16.64 mmol, 500 mg) and KI (7.52 mmol, 1.26 g) in DMF/THF (15 mL/15 mL) in the same manner as **4a**,[13] yield 64%, oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 0.90 (t, 3 H, J = 7.1 Hz), 1.38−1.55 (m, 6 H), 1.95−2.22 (m, 6 H), 3.41 (t, 1 H, J = 7.6 Hz), 3.74 (s, 3 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 13.49, 18.30, 21.80, 26.62, 27.87, 31.02, 51.13, 52.34, 78.75, 80.88, 169.61; MS (CI) m/z 255 (M + 1); HRMS (EI) calcd for $C_{13}H_{19}O_3$(M − OCH_3): 223.1334; Found: 223.1318.

Synthesis of Methyl 2-Carbomethoxy-7-phenyl-6-heptynoate (4i). 1-Chloro-5-phenyl-4-pentyne (15.2 mmol, 2.7 g), obtained from the reaction of iodobenzene with 4-chloro-1-pentyne using $PdCl_2(PPh)_3$[16] as a catalyst, was reacted with dimethyl malonate (18.3 mmol, 2.42 g) using NaH (80% mineral oil, 16.8 mmol, 502 mg) and KI (7.2 mmol, 1.2 g) in THF / DMF (1:1) (30 mL) in a similar manner to that of **4a**:[13] yield 88%; oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.60−1.71 (m, 2 H), 2.02−2.14 (t, 2 H, J = 7.0 Hz), 2.44 (t, 2 H, J = 7.0 Hz), 3.73 (s, 6H), 7.25−7.41 (m, 5 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 18.96, 26.26, 27.92, 51.11, 52.37, 81.13, 88.89, 123.63, 127.51, 127.77, 128.06, 131.41, 169.53; MS (EI) m/z 274 (M^+); HRMS $C_{16}H_{18}O_4$ calcd 274.1205, found 274.1227.

Carbonylation of Phenylacetylene (1) with Diethyl Ethylmalonate (2). Deaerated acetic acid−acetonitrile (1:1) (10 mL), $Mn(OAc)_3 \cdot 2H_2O$ (4.0 mmol, 1074 mg), phenylacetylene **1** (1.5 mmol, 152 mg), and diethyl ethylmalonate (3.0 mmol, 565 mg) were placed in a 50 mL stainless steel autoclave containing a glass liner. The autoclave was pressurized to

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1200 psi with carbon monoxide and then heated with stirring at 60 °C for 15 h. After the reaction, the mixture was diluted with ether and washed twice with water, and the aqueous layer was extracted with ether. The combined organic extracts were washed with aqueous potassium carbonate. The organic layer was dried over Na_2SO_4 and concentrated by rotary evaporation to give recovered starting material. The aqueous layer was acidified with dilute HCl and then extracted with ether. The organic layer was washed twice with water and dried over Na_2SO_4. The acid **3** (205 mg, 40%) was obtained by flash chromatography on silica gel with hexane/EtOAc/MeOH (8:2:1) as an eluant. This procedure was used for the intramolecular reactions.

(*Z*)-4,4-Dicarbethoxy-2-phenyl-2-hexenoic acid (3): oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 0.92 (t, 3 H, J = 7.5 Hz), 1.25 (t, 3 H, J = 7.1 Hz), 2.34 (q, 2 H, J = 7.5 Hz), 4.22 (q, 2 H, J = 7.1 Hz), 6.86 (s, 1 H), 7.33−7.46 (m, 5H), 9.83 (brs, 1 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 9.28, 13.88, 29.32, 60.09, 61.84, 127.75, 128.21, 128.28, 135.20, 137.12, 137.53, 169.73, 171.87; MS (CI) m/z 335 (M + 1); HRMS Calcd for $C_{18}H_{22}O_6$ 334.1416, found 334.1410.

(*E*)-Dimethyl 2-(Hydroxycarbonylmethylene)-1,1-cyclopentanedicarboxylate (5a): mp 76−77 °C; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.82 (tt, 2 H, J = 7.0, 7.0 Hz), 2.38 (t, 2 H, J = 7.0 Hz), 2.93 (dt, 2 H, J = 2.0, 7.0 Hz), 3.77 (s, 6 H), 6.15 (s, 1 H), 9.55 (brs, 1 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 23.73, 32.97, 35.18, 53.02, 66.06, 117.44, 128.11, 163.18, 169.62; MS (CI) m/z 243 (M + 1). Anal. Calcd for $C_{11}H_{14}O_6$: C, 54.53; H, 5.84. Found: C, 54.61; H, 5.85.

(*E*)-Ethyl 2-[(hydroxycarbonyl)methylene]-1-cyano-1-cyclopentanecarboxylate (5b): mp 238−241 °C decomposition; ^{1}H-NMR (200 MHz, acetone-d_6) δ 1.32 (t, 3 H, J = 7.1 Hz), 1.91−2.01 (m, 2 H), 2.18−2.29 (m, 1 H), 2.47−2.53 (m, 1 H), 2.89−2.97 (m, 2 H), 4.28 (q, 2 H, J = 7.1 Hz), 6.19 (s, 1 H), 9.81 (brs, 1 H). ^{13}C-NMR (50 MHz, acetone-d_6) δ 13.96, 24.89, 31.80 37.26, 53.48, 63.50, 119.44, 122.64, 157.01, 167.65, 172.02. This acid was converted to the corresponding methyl ester[17] using MeI and $KHCO_3$, which was characterized as follows. ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.34 (t, 3 H, J = 7.1 Hz), 1.98−2.09 (m, 2 H), 2.23−2.33 (m, 1 H), 2.50−2.60 (m, 1 H), 2.97−3.04 (m, 2 H), 3.75 (s, 3 H), 4.30 (q, 2 H, J = 7.1 Hz), 6.25 (t, 1 H, J = 2.6 Hz); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 13.85, 24.35, 31.72, 36.34, 51.52, 52.96, 63.48, 117.74, 118.33, 160.10, 165.77, 166.45; MS (CI) m/z 238 (M + 1); HRMS calcd for $C_{12}H_{15}NO_4$ 237.1001, found 237.0982.

(*E*)-Dimethyl 2-[(hydroxycarbonyl)methylene]-1,1-cyclohexanedicarboxylate (5c): mp 141−142 °C; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.56−1.64 (m, 2 H), 1.76−1.89 (m, 2 H), 2.05−2.25 (m, 2 H), 2.48−2.53 (m, 2 H), 3.78 (s, 6 H), 7.24 (s, 1 H), 9.85 (brs, 1 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 25.17, 25.37, 25.81, 31.76, 53.13, 60.05, 137.07, 140.62, 170.27, 173.04; MS (CI) m/z 257 (M + 1). Anal. Calcd for $C_{12}H_{16}O_6$: C, 56.24; H, 6.31. Found: C, 56.40; H, 6.24.

(*E*)-Dimethyl 2-[(Hydroxycarbonyl)methylene]-4,4-dimethyl-1,1-cyclopentanedicarboxylate (5d): mp 132−134 °C; ^{1}H-NMR (500 MHz, $CDCl_3$) δ 1.00 (s, 6 H), 2.36 (s, 2 H), 2.79 (d, 2 H, J =2.5 Hz), 3.75 (s, 6 H), 6.15 (t, 1 H, J = 2.5 Hz), 10.31 (brs, 1 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 28.21, 38.29, 47.60, 47.66, 53.34, 66.05, 118.81, 163.40, 170.22, 171.75; MS (CI) m/z 271 (M + 1); Anal. Calcd for $C_{13}H_{18}O_6$: C, 57.76; H, 6.73. Found: C, 58.10; H, 6.45.

(*E*)-Ethyl 2-[(hydroxycarbonyl)methylene]-1-cyano-4,4-dimethyl-1-cyclopentanecarboxylate (5e): ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.14 (s. 3H), 1.21 (s, 3 H), 1.35 (t, 3 H, J = 7.1 Hz) 2.23 (dd, 1 H, J = 11.7, 1.8 Hz), 2.43−2.54 (m, 2 H), 3.25 (dd, 1 H, J = 16.2, 1.8 Hz), 4.33 (q, 2 H, J = 7.2 Hz), 6.27−6.30 (m, 1 H), 10.15 (brs, 1 H); ^{13}C-NMR (50 Mz, $CDCl_3$) δ 13.88, 27.95, 28.10, 39.88, 46.39, 48.64, 52.45, 63.90, 118.69, 119.29, 162.84, 166.86, 170.24. This acid was converted to the methyl ester[17] using MeI and $KHCO_3$,which was characterized as follows: ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.13 (s, 3 H), 1.21 (s, 3 H), 1.34 (t, 3 H, J = 7.1 Hz), 2.20 (dd, 1 H, J = 11.6, 2.0 Hz), 2.44−2.53 (m, 2 H), 3.24 (dd, 1 H, J = 16.0 Hz, 2.0 Hz), 3.75 (s, 3 H), 4.28 (q, 2 H, J = 7.1 Hz), 6.25−6.28 (m, 1 H); ^{13}C-NMR (50 Mz, $CDCl_3$) δ 13.84, 27.85, 28.05, 39.76, 46.00, 48.63, 51.58, 52.19, 63.71, 118.94, 119.48, 160.17, 165.84, 166.42; MS m/z 250 (M − CH_3); HRMS calcd for $C_{14}H_{19}NO_4$ 265.1314; found 265.1305.

(*E*)-1,1-Dimethyl-3-ethyl 5-[(hydroxycarbonyl)methylene]-2-methyl-1,1,3-cyclopentanetricarboxylate (5f): ^{1}H-NMR (500 MHz, $CDCl_3$) δ trans, 1.01 (d, 3 H, J = 6.6 Hz), 1.27 (t, 3 H, J = 7.1 Hz), 2.70−2.76 (m, 1 H), 2.92−3.03 (m, 2 H), 3.46−3.52 (m, 1 H), 3.72 (s, 3 H), 3.73 (s, 3 H), 4.17 (q, 2 H, J = 7.1 Hz), 6.21 (t, 1 H, J = 2.5 Hz), 10.02 (brs, 1 H); cis 0.76 (d, 3 H, J = 7.2 Hz), 3.16−3.25 (m, 3 H), 3.33−3.38 (m, 1 H), 3.73 (s, 3 H), 3.81 (s, 3 H), 6.21 (t, 1 H, J = 2.5 Hz), 10.02 (brs, 1 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ trans 14.10, 14.21, 36.67, 44.47, 48.17, 52.69, 53.18, 60.94, 68.90, 117.14, 120.98, 160.91, 168.34, 171.39, 173.52; cis 11.72, 14.21, 32.42, 41.42, 45.97, 52.69, 53.49, 60.71, 70.09, 120.90, 128.28, 168.47, 168.61, 171.39, 172.07; MS (CI) m/z 329 (M + 1); Anal. Calcd for $C_{15}H_{20}O_8$: C, 54.87; H, 6.15; found: C, 55.01; H, 6.13.

Dimethyl 2-[1-(hydroxycarbonyl)ethenyl]-1,1-cyclopentenedicarboxylate (5g): mp 94−95 °C; ^{1}H-NMR (200 MMz, $CDCl_3$) δ 1.67−1.97 (m, 5 H), 2.01−2.18 (m, 1 H), 3.60 (s, 3 H), 2.72 (s, 3 H), 3.93 (t, 1 H, J = 7.6 Hz), 5.72 (s, 1 H), 6.38 (s, 1 H), 9.10 (brs, 1 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 23.45, 31.65, 35.10, 45.83, 52.03, 52.65, 64.09, 127.59, 140.36, 170.76, 172.21, 172.56; MS (CI) m/z 257 (M + 1); Anal. Calcd for $C_{12}H_{16}O_6$: C, 56.24; H, 6.31. Found: C, 56.67; H, 6.23.

(*E*)-Dimethyl 2-[(Hydroxycarbonyl)butylmethylene]-1,1-cyclopentanedicarboxylate (5h): mp 94−96 °C; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 0.89 (t, 3 H, J = 6.8 Hz), 1.29−1.32 (m, 4 H), 1.74 (tt, 2 H, J = 7.0, 7.0 Hz), 2.26−2.32 (m, 2 H), 2.41 (t, 2 H, J = 7.0 Hz), 2.86 (t, 2 H, J = 7.0 Hz), 3.76 (s, 6 H), 10.12 (brs, 1 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 13.89, 23.11, 24.76, 29.67, 31.76, 34.89, 38.96, 52.91, 65.38, 131.05, 151.81, 170.79, 174.26; MS (CI) m/z 299 (M + 1). Anal. Calcd for $C_{15}H_{22}O_6$: C, 60.38; H, 7.45. Found: C, 60.45; H, 7.51.

Dimethyl 2-Benzoyl-1,1-cyclopentanedicarboxylate (6): oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.69−1.74 (m, 1 H), 1.84−1.97 (m, 2 H), 2.18−2.31 (m, 2 H), 2.68−2.74 (m, 1 H), 3.56 (s, 3 H), 3.76 (s, 3 H), 4.70 (dd, 1 H, J = 4.4 , 8.9 Hz), 7.42−7.60 (m, 3 H), 7.97−8.01 (m, 2 H); ^{13}C-NMR (50 Mz, $CDCl_3$) δ 23.51, 30.81, 34.06, 51.87, 52.29, 53.01, 63.86, 128.54, 128.60, 133.10, 133.31, 136.07, 170.71, 172.28, 200.47. MS (EI) m/z 290 (M^+); HRMS calcd for $C_{16}H_{18}O_5$ 290.1154, found 290.1153.

Dimethyl 2-Benzoyl-2-cyclopentene-1,1-dicarboxylate (7): oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 2.70−2.76 (m, 4 H), 3.78 (s, 6 H), 6.57 (dd, 1 H, J = 1.4, 2.1 Hz), 7.40−7.56 (m, 3 H), 7.76−7.82 (m, 2 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 32.35, 34.15, 52.82, 66.53, 127.56, 128.19, 128.51, 129.15, 132.37, 137.73, 142.27, 146.82, 171.63, 191.91; MS m/z 288 (M^+); HRMS calcd for $C_{16}H_{16}O_5$ 288.0998, found 288.0979.

Dimethyl 2-(1-Acetoxybenzylidene)cyclopentane-1,1-dicarboxylate (8): oil; ^{1}H-NMR (200 MHz, $CDCl_3$) δ 1.71 (tt, 2 H, J = 7.0, 7.0 Hz), 2.10 (s, 1 H), 2.45 (t, 2 H, J = 7.0 Hz), 2.57 (t, 2 H, J = 7.0 Hz), 3.42 (s, 6 H), 7.27−7.32 (m, 3 H), 7.45−7.50 (m, 2 H); ^{13}C-NMR (50 MHz, $CDCl_3$) δ 20.76, 22.66, 29.58, 39.81, 52.50, 64.18, 127.63, 128.26, 128.38, 128.58, 129.23, 134.59, 168.31, 170.45; MS m/z 322 (M^+); HRMS (EI) calcd for $C_{16}H_{17}O_5$ (M − $COCH_3$) 289.1076, found 289.1074.

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Supporting Information Available: ^{1}H NMR spectra of **3, 4d−f, h−i, 5b,** methyl ester of **5b**, **5e,** methyl ester of **5e,** and **6−8** (13 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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