butyl phenyl ketone in previous literature.[9]

α-(Trimethylsiloxy)-1-cyclohexyl Phenyl Ketone. Using the same procedure, from the reaction of diethyl 1-phenyl-1-(trimethylsiloxy)methanephosphonate (3.16 g, 10.0 mmol), lithium diisopropylamide (2 M in cyclohexane; 5 mL, 10.0 mmol), and cyclohexanone (0.98 g, 10.0 mmol) was obtained the corresponding α-(trimethylsiloxy)-1-cyclohexyl phenyl ketone (2.24 g, 8.1 mmol, 81% yield from pinacolone). All spectra data were consistent with those given for α-(trimethylsiloxy)-1-cyclohexyl phenyl ketone in previous literature.[9]

α-(Trimethylsiloxy)-1-phenylmethyl Phenyl Ketone. Using the same procedure, from the reaction of diethyl 1-phenyl-1-(trimethylsiloxy)methanephosphonate (3.16 g, 10.0 mmol), lithium diisopropylamide (2 M in cyclohexane; 5 mL, 10.0 mmol), and benzaldehyde (1.06 g, 10.0 mmol) was obtained α-(trimethylsiloxy)-1-phenylmethyl phenyl ketone (2.67 g, 9.4 mmol, 94% yield from benzaldehyde). All spectral data were consistent with those given for the α-(trimethylsiloxy)-1-phenylmethyl phenyl ketone in previous literature.[9]

α-(Trimethylsiloxy)-1,1-diphenylmethyl Phenyl Ketone. Using the same procedure, from the reaction of diethyl 1-phenyl-1-(trimethylsiloxy)methanephosphonate (3.16 g, 10.0 mmol), lithium diisopropylamide (2 M in cyclohexane; 5 mL, 10.0 mmol), and benzophenone (1.82 g, 10.0 mmol) was obtained α-(trimethylsiloxy)-1,1-diphenylmethyl phenyl ketone (4.42 g, 8.2 mmol, 82% yield from benzophenone). All spectral data were consistent with those given for α-(trimethylsiloxy)-1,1-diphenylmethyl phenyl ketone in previous literature.[9]

α-Hydroxy-2-adamantyl Phenyl Ketone. A 10% aqueous solution (w/w; 50 mL) of sodium acetate and α-(trimethylsiloxy)-2-adamantyl phenyl ketone (3.28 g, 10.0 mmol) was stirred at ambient temperature for 2 h. After usual workup and extraction with ether the combined ethereal layer was dried over anhydrous magnesium sulfate, filtered, and evaporated in vacuo to give α-hydroxy-2-adamantyl phenyl ketone (2.36 g, 9.2 mmol, 92% yield from α-(trimethylsiloxy)-2-adamantyl phenyl ketone) as colorless crystals: mp 95–96 °C; IR (KBr) 1760 (s) cm^{-1}; ^{13}C NMR (50 MHz, $CDCl_3$) δ 201.98 (s), 144.29 (s), 129.94 (d), 129.30 (d), 128.89 (d), 61.82 (s), 42.91 (d), 38.81 (t), 36.92 (t), 36.27 (t), 30.26 (d), 28.61 (d); GC/MS (70 eV) *m/e* 256 (M^+, 1.7), 135 (2.7), 105 (54.9), 73 (100.0). Anal. Calcd for $C_{17}H_{20}O_2$: C, 79.69; H, 7.81. Found: C, 79.52; H, 7.92.

α-Hydroxy-1-neopentyl Phenyl Ketone. Using the previously described procedure, from the reaction of α-(trimethylsiloxy)-1-neopentyl phenyl ketone (2.64 g, 10.0 mmol) with aqueous sodium acetate solution was obtained α-hydroxy-1-neopentyl phenyl ketone (1.69 g, 8.8 mmol, 88% yield from α-(trimethylsiloxy)-1-neopentyl phenyl ketone). All spectra data were consistent with those given for α-hydroxy-1-neopentyl phenyl ketone in previous literature.[9]

α-Hydroxy-3,3-dimethyl-2-butyl Phenyl Ketone. Using the previously described procedure, from the reaction of α-(trimethylsiloxy)-3,3-dimethyl-2-butyl phenyl ketone (2.78 g, 10.0 mmol) with aqueous sodium acetate was obtained α-hydroxy-3,3-dimethyl-2-butyl phenyl ketone (1.87 g, 9.1 mmol, 91% yield from α-(trimethylsiloxy)-3,3-dimethyl-2-butyl phenyl ketone). All spectral data were consistent with those given for α-hydroxy-3,3-dimethyl-2-butyl phenyl ketone in previous literature.[9]

α-Hydroxy-1-cyclohexyl Phenyl Ketone. Using the same procedure, from the reaction of α-(trimethylsiloxy)-1-cyclohexyl phenyl ketone (2.76 g, 10.0 mmol) with aqueous sodium acetate was obtained α-hydroxy-1-cyclohexyl phenyl ketone (1.75 g, 8.6 mmol, 86% yield from α-(trimethylsiloxy)-1-cyclohexyl phenyl ketone). All spectral data were consistent with those given for α-hydroxy-1-cyclohexyl phenyl ketone in previous literature.[9]

Benzoin. Using the same procedure, from the reaction of α-(trimethylsiloxy)-1-phenylmethyl phenyl ketone (2.84 g, 10.0 mmol) with aqueous sodium acetate was obtained benzoin (1.89 g, 8.9 mmol, 89% yield from α-(trimethylsiloxy)-1-phenylmethyl phenyl ketone). All spectral data were consistent with those given for benzoin in previous literature.[9]

α-Hydroxy-1,1-diphenylmethyl Phenyl Ketone. Using the same procedure, from the reaction of α-(trimethylsiloxy)-1,1-diphenylmethyl phenyl ketone (3.60 g, 10.0 mmol) with aqueous sodium acetate was obtained α-hydroxy-1,1-diphenylmethyl phenyl ketone (2.36 g, 8.2 mmol, 82% yield from α-(trimethylsiloxy)-1,1-diphenylmethyl phenyl ketone). All spectral data were consistent with those given for α-hydroxy-1,1-diphenylmethyl phenyl ketone in previous literature.[9]

General Procedure of Protolysis of α-Hydroxy Ketones with Triflic Acid. To a solution of the corresponding α-hydroxy ketone (generally 10 mmol) in dry methylene chloride (50 mL) was slowly added a catalytic amount, ca. 0.1–0.2 mL, of freshly distilled trifluoromethanesulfonic acid (triflic acid) with stirring under nitrogen atmosphere at 0 °C (ice bath). The cooling bath was then removed, and the reaction mixture was stirred for an additional 16 h at ambient temperature. After quenching with 10% aqueous sodium bicarbonate (50 mL), the usual workup was carried out with extraction with methylene chloride (30 mL × 3). The combined organic layer was dried over anhydrous magnesium sulfate, filtered, and vacuum evaporated to give the crude material. Purification was usually carried out by column chromatography on silica gel (10% ether–petroleum ether as eluent) to give the pure reaction product (Table I). All physical and spectral data of the reaction products, including GC/MS and NMR, were consistent and in accordance with those reported previously.

Acknowledgment. Support of our work by the National Institutes of Health is gratefully acknowledged.

Straightforward Synthesis of 1,2,3-Tricarbonyl Systems

Robert G. Linde II, Lucio O. Jeroncic, and Samuel J. Danishefsky*

Department of Chemistry, Yale University, New Haven, Connecticut 06511-8118

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A simple two-step protocol for the preparation of α,β-diketo amides is described. The first step involves condensation of the anion of an α-phenylthio amide with an aldehyde. This is followed by oxidation of the resulting β-hydroxy α-sulfide with the Dess–Martin periodinane. The vicinal tricarbonyl system is obtained in good to excellent yields.

Two considerations have increased interest in the preparation of 1,2,3-tricarbonyl compounds (cf. 1, Scheme I). From the chemical standpoint, Wasserman and coworkers have identified fascinating applications of such

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Scheme I

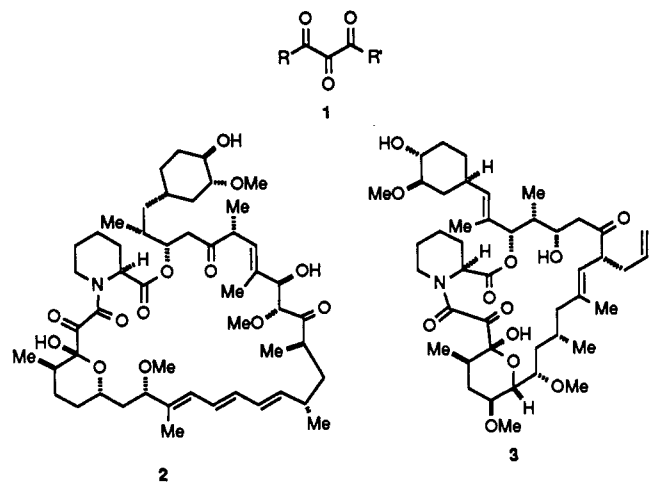
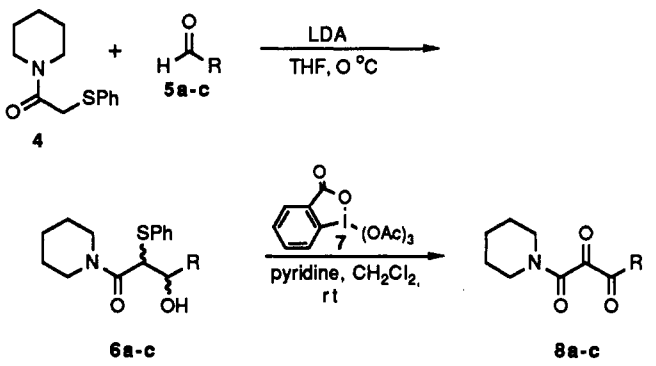


Table I



aldehyde	t, h	yield of 6, %	ratio of diastereomers	t, h	yield of 8, %
5a, R = 2-furyl	1	87	3.6:1	2	80
5b, R = heptyl	1	82	1:1	2	75
5c, R = cyclohexyl	1.5	81	3.5:1	12	70

moieties as building blocks for various syntheses.[1] Through this research has evolved an insight as to how the array of reactive functionality of vicinal tricarbonyl arrangements can be orchestrated. Moreover, the immunomodulating natural products rapamycin (**2**)[2] and FK-506 (**3**)[3] contain this substructure (albeit in a latent state wherein one potential terminal carbonyl group is engaged as a hemiacetal). While the role of this unit in endowing **2** and **3** with their T-cell deactivating properties awaits full explication,[4] its presence in these important molecules has added to interest in the vicinal tricarbonyl area.[5,6]

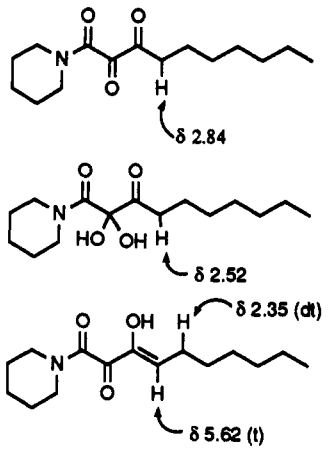
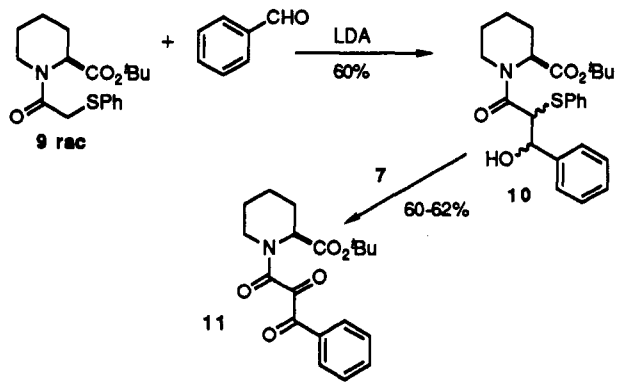


Figure 1.

Scheme II



Herein we describe a concise route to α,β-diketo amides. The method involves the coupling of lithiated α-phenylthio-substituted amides with aldehydes to provide aldol-like adducts. The key finding is that these adducts are smoothly converted to the target systems by oxidation with the Dess–Martin periodinane (**7**).[7]

The method is demonstrated with *N*-[2-(phenylthio)-acetyl]piperidine (**4**) (Table I). The best results for the coupling in the casse of aldehydes **5a–c** involved treatment of a 1:1–1.1 mixture of **4**:**5** with 1.05 equiv of lithium diisopropylamide (LDA) in tetrahydrofuran (THF) at 0 °C. After 1 h, the reaction is worked up and a diastereomeric mixture of products **6** is isolated by column chromatography. No attempt was made to assign stereochemistry to the individual stereoisomers.

While it was possible to carry out the aldol condensation in the conventional way, i.e., by prior deprotonation of **4** followed by coupling with aldehydes at 0 °C, the yields obtained by the first method were generally superior. (We have no data to address the interesting possibility that the presence of the aldehyde electrophile actually activates the relevant carbon hydrogen bond to deprotonation.) In the case of amide **9** and aldehyde **12**, it will be demonstrated

(1) For examples of vicinal tricarbonyls as intermediates, see: (a) Wasserman, H. H. *Aldrichimica Acta* **1987**, *20*, 63 and references therein. (b) Wasserman, H. H.; Amici, R.; Frechette, R.; van Duzer, J. H. *Tetrahedron Lett.* **1989**, *30*, 869. (c) Wasserman, H. H.; Kuo, G.-H. *Tetrahedron Lett.* **1989**, *30*, 873. (d) Wasserman, H. H.; Cook, J. D.; Fukuyama, J. M.; Rotello, V. M. *Tetrahedron Lett.* **1989**, *30*, 1721. (e) Wasserman, H. H.; Lombardo, L. J. *Tetrahedron Lett.* **1989**, *30*, 1725. (f) Wasserman, H. H.; Fukuyama, J.; Murugesan, N.; van Duzer, J.; Lombardo, L.; Rotello, V.; McCarthy, K. *J. Am. Chem. Soc.* **1989**, *111*, 371. (g) Wasserman, H. H.; Amici, R. M. *J. Org. Chem.* **1989**, *54*, 5843. (h) Wasserman, H. H.; Cook, J. D.; Vu, C. B. *J. Org. Chem.* **1990**, *55*, 1701.

(2) Swindells, D. C. N.; White, P. S.; Findlay, J. A. *Can. J. Chem.* **1978**, *56*, 2491.

(3) Tanaka, H.; Kuroda, A.; Marusawa, H.; Hatanaka, H.; Kino, T.; Goto, T.; Hashimoto, M.; Taga, T. *J. Am. Chem. Soc.* **1987**, *109*, 5031.

(4) Rosen, M. K.; Standaert, R. F.; Galat, A.; Nakatsuka, M.; Schreiber, S. L. *Science* **1990**, *248*, 863 and references therein.

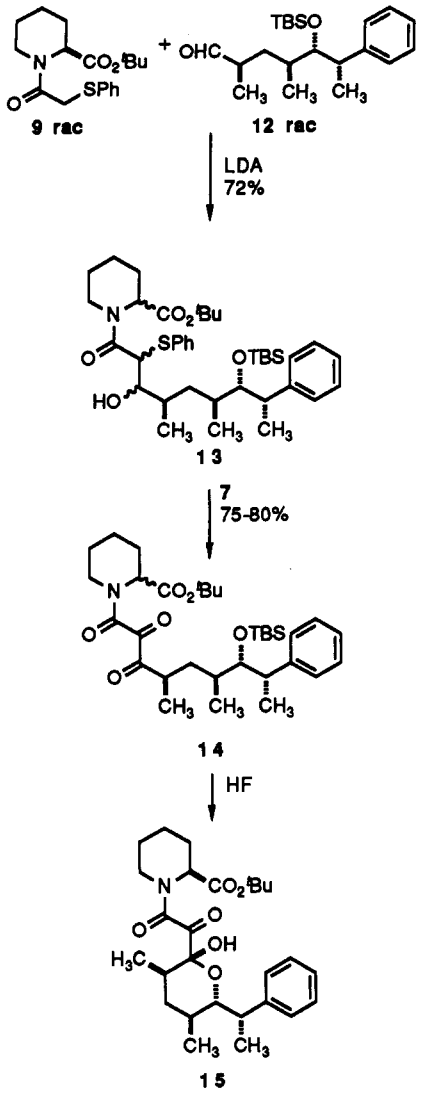
(5) For the preparation of vicinal tricarbonyl in general, see: (a) Hoffman, R. V.; Wilson, A. L.; Kim, H.-O. *J. Org. Chem.* **1990**, *55*, 1267. (b) Hoffman, R. V.; Kim, H.-O.; Wilson, A. L. *J. Org. Chem.* **1990**, *55*, 2820. (c) Shank, K.; Lick, C. *Synthesis* **1983**, 392.

(6) For tricarbonyl syntheses related to FK-506, see: (a) Williams, D. R.; Benbow, J. W. *J. Org. Chem.* **1988**, *53*, 4644. (b) Kocienski, P.; Stocks, M.; Donald, D.; Cooper, M.; Manners, A. *Tetrahedron Lett.* **1988**, *29*, 4481. (c) Egbertson, M.; Danishefsky, S. *J. Org. Chem.* **1989**, *54*, 12. (d) Wasserman, H. H.; Rotello, V. M.; Williams, D. R.; Benbow, J. W. *J. Org. Chem.* **1989**, *54*, 2785. (e) Jones, T. K.; Reamer, R. A.; Desmond, R.; Mills, S. G. *J. Am. Chem. Soc.* **1990**, *112*, 2998 and references therein.

(7) Dess, D. B.; Martin, J. C. *J. Org. Chem.* **1983**, *48*, 4155. For a report of relevant safety concerns regarding the Dess–Martin reagent, see: Plumb, J. B.; Harper, D. J. *Chem. Eng. News* **1990**, *68*(29), 3.

(8) For a related observation, see: Ikeda, M.; Harada, S.; Yamasaki, A.; Kinouchi, K.; Ishibashi, H. *Heterocycles* **1988**, *27*, 943.

Scheme III

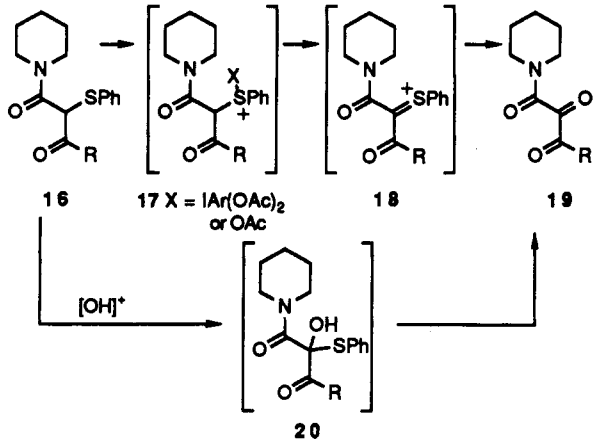


that the aldehyde is not substantially deprotonated under these conditions (vide infra).

The mixtures **6a–c** were subjected to the action of **7**. The tricarbonyl products **8a–c** were isolated by chromatography. These compounds were characterized by their ^{1}H NMR, IR, and mass spectra. Due to the tendency of the central carbonyl group to undergo partial hydration, we were unable to obtain staisfactory combustion analyses.[5c] The parent peaks in the high-resolution mass spectra (HRMS) of compounds **8a–c**, **11**, and **14** were consistent with those calculated for the tricarbonyl compounds. Ions corresponding to the ketone hydrates were not observed. The infrared spectra of apparently dry samples of these products exhibited a broad stretch at ~3500 cm^{-1} raising the possibility of hydration. The presence of hydrate forms was further suggested by their ^{1}H NMR spectra. For instance, in the case of **8b**, the resonance at δ = 2.84 can be assigned to the proton at C_4 of the 2,3-diketononanoyl group. The chemical shift for the same proton in the hydrated molecule is observed at δ = 2.52. The resonances for the hydroxy-bound water incorporated into the tricarbonyl are generally found in the region δ = 5.0–6.0. The presence of an enol tautomer of **8b** is suggested by the presence of a broad singlet at δ = 6.01, a triplet at δ = 5.64, and a doublet of triplets at δ = 2.35 in its ^{1}H NMR spectrum (Figure 1).

We also examined the applicability of the method to *tert*-butyl *N*-[2-(phenylthio)acetyl]pipecolinate (**9**)

Scheme IV



(Scheme II). This was a particularly interesting case in that a Dieckmann reaction might have been expected to compete with the aldol coupling. In the event, condensation of **9** with benzaldehyde, conducted under the conditions used for **4**, afforded a 60% yield of diastereomers **10**. Oxidation of the mixture with **7** gave **11** in 62% yield.

We also studied the condensation of **9** with **12** (Scheme III). Aldol adducts **13** were isolated in 72% yield. The adduct mixture in this case is more complicated in that it had arisen from coupling of the racemic aldehyde with the racemic amide based enolate. Oxidation of the gross mixture with **7** afforded a two-component mixture of diketo amides, **14**. The mixture (**14**), derived from the coupling of the pipecolinate (**9** rac) with aldehyde **12**, was converted to the previously described[6c] mixture of hemiacetals **15**. One of these components, which was isolated in homogeneous form, was identical with an authentic sample.[6c]

We note that the aldehyde recovered from condensation with **9** was unreacted **12** accompanied by ca. 10% of what is possibly its C_2 epimer. Barring the unlikely possibility of a highly stereoselective protonation of the **12**-enolate to restore **12**, it would seem that the coupling reaction does not inolve significant competitive deprotonation α to the aldehyde.

Two qualitative mechanistic approaches can be advanced to account for the conversion of **6** and **13** to **8** and **14**, respectively. For the sake of simplicity, though not central to the argument, we focus on intermediate **16**, wherein the hydroxyl group had been oxidized first. One possibility envisions oxidation of sulfide (cf. **17**, X = I or O) followed by Pummerer-type conversion to thionium species **18** and thence to product **19** (Scheme IV). Alternatively, overall C_2 hydroxylation of the 1,3-dicarbonyl would lead to **20** and thence to **19**.

In summary, it is expected that this simply executed two-step conversion from aldehyde to amide tricarbonyls will find application in synthesizing candidate compounds which might have immunomodulative prospects.

Experimental Section

General Procedures. Flash chromatography was performed on EM Kieselgel 60 (230–400 mesh). All reactions were carried out under a positive pressure of N_2. Tetrahydrofuran (THF) was distilled immediately before use from sodium benzophenone ketyl. CH_2Cl_2 was distilled immediately before use from calcium hydride. Lithium diisopropylamide (LDA) was prepared fresh for each reaction. Piperidine, 1-[3-(dimethylamino)propyl]-3-ethylcarbodiimide hydrochloride (EDCI), octanal (**5b**), cyclohexanecarboxaldehyde (**5c**), and (phenylthio)acetic acid were purchased from Aldrich Chemical Co. and used without further purification. Furfural (**5a**) was distilled and used within 1 week. Dess–Martin

periodinane (DMP) was prepared according to the known procedure.[7] Microanalyses were performed by Robertson Laboratories, Inc.

***N*-[2-(Phenylthio)acetyl]piperidine (4).** EDCI (2.8 g, 15 mmol, 1.2 equiv) was added to a solution of piperidine (1.2 mL, 12 mmol, 1.0 equiv), (phenylthio)acetic acid (2.25 g, 13 mmol, 1.1 equiv), and 4-(dimethylamino)pyridine (0.5 g, 0.3 equiv) in CH_2Cl_2 (13 mL, 1 M) at room temperature. TLC showed that reaction was complete after $^3/_4$ h, and the solution was diluted with CH_2Cl_2 and washed sequentially with dilute HCl, saturated $NaHCO_3$, and brine. The organic portion was dried ($MgSO_4$) and concentrated, and the resulting oil was crystallized from pentane/ether to give 2.5 g of **4** as colorless needles. The mother liquor was concentrated and chromatographed to give another 100 mg of **4**, for a combined yield of 2.6 g, (92%); mp 72–72.5 °C; ^{1}H NMR (250 MHz) δ 7.42–7.46 (m, 2 H), 7.21–7.33 (m, 3 H), 3.75 (s, 2 H), 3.54 (br t, J = 5.7 Hz, 2 H), 3.41 (br t, J = 5.7, 2 H), 1.53–1.62 (m, 6 H); IR ($CHCl_3$) 3000, 2940, 2855, 1630, 1465, 1440, 1270, 1020 cm^{-1}; CILRMS m/e (relative intensity) 236 (100), 85 (28.5), 79 (35.7), 69 (71.4); CIHRMS calcd for $C_{13}H_{18}ONS$ (M + H) 236.1110, found 236.1108.

Anal. Calcd for $C_{13}H_{17}ONS$: C, 66.35; H, 7.28; N, 5.95; S, 13.62. Found: C, 66.40; H, 6.89; N, 5.74; S, 13.31.

***tert*-Butyl *N*-[2-(Phenylthio)acetyl]pipecolinate (9).** EDCI (397 mg, 2.07 mmol) was added to a solution of (±)-*tert*-butyl *N*-[2-(phenylthio)acetyl]pipecolinate (320 mg, 1.7 mmol) and (phenylthio)acetic acid (319 mg, 1.9 mmol) in CH_2Cl_2 (5 mL) at room temperature for 1 h. The solution was diluted with EtOAc and washed with water, dilute HCl, saturated $NaHCO_3$, and brine. The combined organic solutions were dried ($MgSO_4$) and concentrated to afford a pale yellow oil, which solidified upon standing at 0 °C: yield 0.504 g (87%) mp 84.5–86.0 °C; ^{1}H NMR (250 MHz) δ 7.40–7.50 (m, 2 H), 7.18–7.34 (m, 3 H), [5.18 (br d, J = 5.7 Hz), 4.41–4.53 (m); 1 H], 3.78, 3.77, 3.69 (3 s, 2 H), [3.34 (dt, J = 12.7, 2.9 Hz), 2.68–2.80 (m); 1 H], 2.10–2.31 (m, 1 H), 2.30–2.80 (m, 15 H); IR 2890, 2925, 1730, 1641, 1445, 1375, 1165 cm^{-1}; CILRMS m/e (relative intensity) 336 (100), 280 (95.6), 234 (30.2), 123 (5.2), 84 (41.3); EIHRMS calcd for $C_{18}H_{25}O_3NS$ 335.1557, found 335.1551.

Anal. Calcd for $C_{18}H_{25}O_3NS$: C, 64.45; H, 7.51; N, 4.17; S, 9.55. Found: C, 64.14; H, 7.80; N, 4.16; S, 9.35.

Furfural Adducts 6a. LDA (1.4 mL of a 0.98 M solution, 1.1 equiv) was added to a solution of **4** (300 mg, 1.27 mmol) in THF (1.27 mL, 1 M) at −78 °C. The flask was transferred to an ice/water bath for 10 min. Furfural (**5a**) [116 μL, 1.4 mmol, 1.2 equiv in THF (1.2 mL)] was slowly added at 0 °C, and the resulting solution was stirred for 1 h. The reaction was quenched with saturated NH_4Cl, the layers were partitioned, and the aqueous portion was extracted with EtOAc (2×). The combined organic extracts were dried ($MgSO_4$), concentrated, and chromatographed to afford 288 mg of less polar compound A and 80 mg of its more polar diastereomer B; thus these adducts were obtained in a combined yield of 87%. The less polar major compound, a pale yellow solid, recrystallized from CH_2Cl_2/pentane: mp 112–112.5 °C; ^{1}H NMR ($CDCl_3$, 250 MHz) δ 7.50–7.55 (m, 2 H), 7.24–7.32 (m, 3 H), 4.41 (br s, 1 H), 4.00–4.05 (m, 1 H), 3.86 (d, J = 4.1 Hz, 1 H), 3.40–3.58 (m, 2 H), 3.01–3.27 (m, 2 H), 1.20–1.85 (m, 18 H), 0.85–0.97 (m, 3 H); IR (thin film) 3380, 2920, 2840, 1620, 1440, 1220, and 1020 cm^{-1}; CILRMS m/e (relative intensity) 364 (66.7), 346 (21.0), 236 (100), 235 (61.5), 202 (12.2), 126 (12.2), 112 (35.7); CIHRMS calcd for $C_{21}H_{34}O_2SN$ (M + H) 364.2312, found 364.2300.

Anal. Calcd for $C_{21}H_{33}O_2SN$: C, 69.38; H, 9.15; N, 3.85; S, 8.82. Found: C, 69.28; H, 9.21; N, 3.96; S, 8.94.

Characteristic ^{1}H NMR data for the more polar diastereomer: δ 4.01 (br d, J = 6.2 Hz, 1 H), 3.90–4.01 (m, 1 H), 3.76 (d, J = 6.2 Hz, 1 H), 3.50–3.66 (m, 2 H), 3.22–3.31 (m, 2 H).

General Procedure for Aldol Additions. 6c. LDA (1.43 mL of a 1 M solution in THF) was added to a solution of **4** (327 mg, 1.38 mmol) and **5c** (170 μL, 1.4 mmol) in THF (6.9 mL) at 0 °C. NH_4Cl (saturated solution) was added after 1 h, the mixture was allowed to warm to room temperature, then aqueous and organic layers were partitioned, and the aqueous layer was extracted with EtOAc (2×). The combined organics were dried ($MgSO_4$), concentrated, and chromatographed (SiO_2, 4:1 → 3:1 hexane:EtOAc) to give 437 mg (88%) of a separable 3.5:1 mixture of diastereomers **6c**. The major, less polar compound, a pale yellow oil, was characterized: ^{1}H NMR ($CDCl_3$, 250 MHz) δ 7.52–7.58 (m, 2 H), 7.25–7.34 (m, 3 H), 4.55 (d, J = 1.4 Hz, 1 H), 4.10 (br d, J = 3.9 Hz, 1 H), 3.70 (ddd, J = 5.2, 3.9, and 1.3 Hz, 1 H), 3.42–3.51 (m, 1 H), 3.10–3.22 (m, 1 H), 2.98–3.04 (m, 1 H), 2.00–2.11 (m, 1 H), 1.01–1.85 (m, 16 H); IR (thin film) 3390, 2930, 2855, 1620, 1445, 1215, 1025, 1015 cm^{-1}; CILRMS m/e (relative intensity) 348 (8.5), 235 (3.4), 167 (4.0), 123 (16.1), 83.0 (100): CIHRMS calcd for $C_{20}H_{30}NO_2S$ (M + H) 348.1999, found 348.2020.

Anal. Calcd for $C_{20}H_{29}NO_2S$: C, 69.12; H, 8.41; N, 4.03; S, 9.23. Found: C, 68.97; H, 8.64; N, 4.17; S, 8.93.

Characteristic ^{1}H NMR data for the more polar diastereomer: δ 4.34 (d, J = 7.9 Hz, 1 H), 4.01 (d, J = 5.2 Hz, 1 H), 3.66 (dt, J = 7.9, 5.3 Hz, 1 H), 3.42–3.56 (m, 2 H), 3.6–3.26 (m, 1 H), 3.02–3.15 (m, 1 H); mp 122–122.5 °C.

Octanal Adduct 6b. LDA (240 μL, 0.95 M, THF), **4** (51 mg, 0.22 mmol), and **5b** (37 μL, 0.34 mmol) in THF (1 mL) gave 65 mg (82%) of a separable 2.5:1 mixture of diastereomers after 1.5 h. The less polar compound was characterized: ^{1}H NMR ($CDCl_3$, 250 MHz) δ 7.50–7.55 (m, 2 H), 7.24–7.32 (m, 3 H), 4.41 (br s, 1 H), 4.00–4.05 (m, 1 H), 3.86 (d, J = 4.1 Hz, 1 H), 3.40–3.58 (m, 2 H), 3.01–3.27 (m, 2 H), 1.20–1.85 (m, 16 H), 0.85–0.97 (m, 3 H); IR (thin film) 3380, 2920, 2840, 1620, 1440, 1220, 1020 cm^{-1}; CILRMS m/e (relative intensity) 364 (66.7), 3.46 (21.0), 236 (100), 235 (61.5), 202 (12.2), 126 (12.2), 112 (35.7); CIHRMS (M + H) calcd for $C_{21}H_{34}O_2SN$ 364.2312, found 364.2300.

Anal. Calcd for $C_{21}H_{33}O_2SN$: C, 69.38; H, 9.15; N, 3.85; S, 8.82. Found: C, 69.28; H, 9.21; N, 3.96; S, 8.94.

Characteristic ^{1}H NMR data for the more polar diastereomer: δ 4.01 (br d, J = 6.2 Hz, 1 H), 3.90–4.01 (m, 1 H), 3.76 (d, J = 6.2 Hz, 1 H), 3.50–3.66 (m, 2 H), 3.22–3.31 (m, 2 H).

Aldol Products 10. LDA (330 μL, in THF), **9** (104 mg, 0.31 mmol), and benzaldehyde (35 μL, 0.34 mmol) in THF (1.0 mL) after 45 min at 0 °C gave 76 mg (55%) of **10** plus 38 mg (36%) of unreacted **9** as an inseparable mixture: characteristic ^{1}H NMR data for the mixture ($CDCl_3$, 490 MHz) δ 7.14–7.48 (m, 10 H), 5.22 (d, J = 1.0, 0.5 H), 5.16 (m, 0.25 H), 5.05–5.08 (m, 1 H), 4.98 (d, J = 7.1 Hz, 0.5 H), 4.63–4.68 (m, 0.25 H), 4.46 (d, J = 2.1 Hz, 0.5 H), 4.37 (d, J = 4.9 Hz, 0.25 H), 4.12 (d, J = 3.3 Hz, 0.75 H), 3.83 (d, J = 7.6 Hz, 0.25 H), 3.70 (br d, J = 12.2 Hz, 0.25 H), 3.39 (br d, J = 12.6 Hz, 0.75 H), 3.10–3.18 (m, 0.75 H), 2.63–2.69 (m, 0.25 H), 2.07–2.21 (m, 1 H), 1.47, 1.44, 1.41 (3 s, 9 H); IR 3400, 3005, 2960, 1725, 1630, 1440, 1320, 1150 cm^{-1}; CILRMS m/e (relative intensity) 442 (5.2), 378 (5.5), 376 (11.9), 368 (6.5), 337 (26.1), 336 (78.0), 335 (59.5), 320 (29.5), 290 (27.0), 280 (100), 279 (40.0), 234 (87.7); CIHRMS (M + H) calcd for $C_{25}H_{32}O_4NS$ 442.2054; found 442.2070.

Aldol Products 13. Reaction of **9** (70 mg, 0.21 mmol), **12** (46 mg, 0.21 mmol), and LDA (154 μL of a 1.5 M solution, 0.23 mmol) in THF (2.0 mL) gave 64 mg (71%) of an inseparable mixture of β-hydroxy amides **13** as a clear oil. The mixture was characterized: ^{1}H NMR data for the mixture ($CDCl_3$, 250 MHz) δ 5.13–5.30 (m, 1 H), 4.43–4.44, 4.03–4.14 (2 m, 1 H), 3.54–3.88 (m, 3 H), 2.87–3.33 (m, 2 H), 2.07–2.30 (m, 1 H), 1.22–1.75 (m, 20 H), 0.81–1.05 (m, 16 H), 0.01–0.04 (m, 3 H), −0.07 to −0.05 (m, 3 H); IR 3694, 2955, 2928, 2855, 1730, 1636, 1603, 1257, 1150 cm^{-1}; CILRMS m/e (relative intensity) 684 (10), 405 (27.1), 349 (61.2), 291 (49.7), 243 (85.3), 217 (100), CIHRMS calcd for $C_{39}H_{62}O_5NSSi$ (M + H) 684.4118, found 684.4098.

General Procedure for Dess–Martin Oxidation: Tricarbonyl 8a. DMP (126 mg, 0.297 mmol) was added in one portion to a solution of **6a** (48.6 mg, 0.15 mmol) and pyridine (98 μL, 1.21 mmol) in CH_2Cl_2 (2.5 mL) at room temperature. After 2 h the yellow mixture was diluted with Et_2O and filtered. A solution of $NaHCO_3/Na_2S_2O_3$ (5:1 v/v) was added to the filtrate and stirred for 10 min. The aqueous and organic layers were partitioned, and the aqueous layer was extracted with EtOAc (2×). The combined organics were dried ($MgSO_4$), concentrated, and chromatographed to afford 28.2 mg (80%) of an inseparable mixture of **8a** as a yellow oil: characteristic ^{1}H NMR data of the tricarbonyl form ($CDCl_3$, 250 MHz) δ 7.80 (dd, J = 1.5, 0.9 Hz, 1 H), 7.73 (dd, J = 3.6, 0.7 Hz, 1 H), 6.66 (dd, J = 3.7, 1.7 Hz, 0.1 H), 3.60–3.69 (m, 1 H), 3.38–3.42 (m, 2 H), 1.20–1.36, 1.48–1.60, 1.67–1.78 (3 m, 6 H); characteristic ^{1}H NMR data for the hydrated form δ 7.71 (dd, J = 1.8, 0.9 Hz, 1 H), 7.40 (dd, J = 3.7, 0.7 Hz, 1 H), 6.58 (dd, J = 3.7, 1.6 Hz, 1 H), 5.92 (br s, 2 H), 3.6–3.69 (m,

2 H), 3.28, (t, J = 5.5 Hz, 2 H); IR ($CHCl_3$) 3440, 3305, 3020, 2940, 2355, 1640, 1560, 1465, 1350, 1260, 1105, 1040 cm^{-1}; CILRMS m/e (relative intensity) 236 (56.9), 219 (17.2), 112 (15.4), 83 (100), CIHRMS calcd for $C_{12}H_{14}O_4N$ (M + H) 236.0923, found 236.0922.

Tricarbonyl 8b. DMP (163 mg, 0.38 mmol), **6b** (70 mg, 0.19 mmol), pyridine (125 μL, 1.55 mmol), and CH_2Cl_2 (1.9 mL) after 1 h at room temperature provided 38 mg (75%) of an inseparable mixture **8b** as a yellow oil: characteristic ^1H NMR data of the tricarbonyl form ($CDCl_3$, 250 MHz) δ 3.58–3.65 (m, 2 H), 3.20–3.29 (m, 2 H), 2.84 (t, J = 7.3 Hz, 2 H), 1.16–1.78 (m, 16 H), 0.84–0.91 (m, 3 H); characteristic ^1H NMR data for the hydrated form δ 5.60 (br s, 2 H), 3.58–3.65 (m, 2 H), 3.20–3.29 (m, 2 H), 2.52 (t, J = 7.4 Hz, 2 H); characteristic ^1H NMR data for the enol form δ 6.01 (br s, 1 H), 5.64 (t, J = 7.6 Hz, 1 H), 3.58–3.65 (m, 2 H), 3.20–3.29 (m, 2 H), 2.35 (dt, J = 7.4, 7.2 Hz, 2 H); IR ($CHCl_3$) 3440, 3310, 3000, 2905, 2840, 1715, 1645, 1450, 1120; CILRMS m/e (relative intensity) 268 (55.0), 142 (25.0), 112 (25.0), 91 (25.0), 79 (55.0), 69 (100); CIHRMS (M + H) calcd for $C_{15}H_{26}O_3N$ 268.1913, found 268.1915.

Tricarbonyl 8c. DMP (122 mg, 0.28 mmol), **6c** (50.0 mg, 0.14 mmol), pyridine (93 μL, 1.15 mmol), and CH_2Cl_2 (1.4 mL) provided 26 mg (73%) of an inseparable mixture **8c** as a yellow oil: characteristic ^1H NMR data of the tricarbonyl form ($CDCl_3$, 250 Mz) δ 3.57–3.61 (m, 2 H), 3.27–3.31 (m, 2 H), 3.06–3.13 (m, 1 H), 1.20–1.95 (m, 16 H); characteristic ^1H NMR data the hydrated form δ 5.68 (br s, 2 H), 3.57–3.61 (m, 2 H), 3.27–3.31 (m, 2 H), 2.60–2.76 (m, 1 H); IR 3410, 3020, 2950, 2870, 1715, 1650, 1460, 1290, 970 cm^{-1}; CILRMS m/e (relative intensity) 252 (100), 223 (20.5), 129 (8.0), 112 (20.5), 83 (11.5); CIHRMS calcd for $C_{14}H_{22}O_3N$ (M + H) 252.1600, found 252.1610.

Tricarbonyl 11. DMP (85 mg, 0.2 mmol), **10** (44 mg, 0.1 mmol), and pyridine (65 μL, 0.8 mmol) in CH_2Cl_2 (1.6 mL) after 1.5 h gave 23 mg (66%) of a yellow oil: ^1H NMR ($CDCL_3$, 490 MHz) 8.0–8.08, 7.66–7.70, 7.58–7.64, 7.48–7.55, 7.42–7.48 (5 m, 5 H), 5.80–5.96 (m, 0.5 H), 5.14–5.22 (m, 0.5 H), 4.40–4.60 (m, 0.5 H), 3.76–3.80 (br d, 0.5 H), 3.43–3.58 (m, 0.5 H), 2.98–3.13 (m, 0.5 H), 2.05–2.38 (m, 1 H), [1.28–1.88 (m), 1.52 (s), 1.50 (s), 14 H]; IR 3005, 2970, 2940, 1725, 1675, 1645, 1450, 1370, 1160 cm^{-1}; CILRMS m/e (relative intensity) 346 (6.2), 330 (14.1), 290 (100), 272 (35.8), 244 (28.8), 216 (30.5), 156 (52.8), 128 (68.1), 105 (83.1); CIHRMS calcd for $C_{19}H_{24}O_5N$ (M + H) 346.1655, found 2346.1659.

Tricarbonyl 14. DMP (68 mg, 0.16 mmol), **13** (55 mg, 0.08 mmol), and pyridine (50 μL, 0.64 mmol) in CH_2Cl_2 (1.0 mL) after 12 h gave 53 mg (77%) of a yellow oil: ^1H NMR ($CDCl_3$, 250 MHz) δ 7.11–7.39 (m, 5 H), 5.12 (br dd, J = 4.7, 4.3 Hz, 1 H), 3.67 (ddd, J = 7.3, 2.5, and 1.6 Hz, 1 H), 3.22–3.35 (m, 2 H), 2.92 (t, J = 7.2 Hz, 1 H), [2.26–2.32 (m), 1.58 (s), 1.51 (s), 1.50 (s), 1.49 (s), 1.25 (d, J = 6.9 Hz), 1.10 (d, J = 7.1 Hz), 0.92 (s), 0.88–1.92 (m), 37 H], −0.09 to 0.02 (m, 6 H); IR 3400, 2945, 2930, 1720, 1715, 1645, 1640, 1460, 1455, 1260, 1160 cm^{-1}; FABLRMS m/e (relative intensity) 610 (4.0), 588 (2.2), 577 (2.3), 530 (14.3), 492 (13.9), 474 (19.7), 456 (11.0), 401 (28.1), 400 (100), 382 (15.1), 347 (23.9), 294 (23.6), 249 (27.3), 185 (6.9); FABHRMS calcd for $C_{33}H_{53}O_6NSiNa$ (M + Na) 610.3542, found 610.3478.

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Supplementary Material Available: ^1H NMR spectra for compounds **4**, **6a–c**, **8a–c**, **9–11**, **13**, and **14** (15 pages). Ordering information is given on any current masthead page.

Preparation and Some Reactions of Allylic Indium Reagents

Shuki Araki, Toshio Shimizu, Perminder S. Johar, Shun-Ji Jin, and Yasuo Butsugan*

Department of Applied Chemistry, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466, Japan

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A variety of allylic indium sesquihalides were readily prepared by the reaction of indium powder with allylic halides in DMF at room temperature. Protonation of the allylindium reagents proceeded regiospecifically at the γ-position of the allylic group to give 1-propenes. A facile transformation of α-pinene to β-pinene was achieved via a myrtenylindium intermediate. Oxygenation of the allylic indium reagents gave mixtures of allylic alcohol isomers in moderate yields. The coupling of the allylindium reagents with cyclic imides gave diverse products depending on the structures of the substrates and the reagents. Stannylation with tributylchlorostannane occurred exclusively at the α-carbon, yielding allyltributylstannanes; *E*, *Z* isomerization of the allylic double bond depended largely upon the substitution pattern on the allylic moiety.

Despite the intensive use of boron, aluminum, and thallium reagents in synthetic chemistry, the other group XIII elements, gallium and indium, have received little attention. Although reaction of triphenylindium toward electrophiles was described as early as 1940,[1] few investigations on the synthetic use of organoindium compounds have been done until recently.[2] In 1988, we reported that indium metal is effective for the allylation of carbonyl compounds[3] and for the Reformatsky reaction,[4] and since then several interesting transformations of organic compounds have been carried out with indium metal[5] and indium(I) iodide.[6]

Here we describe the preparation of allylic indium reagents and their reactions, i.e., protolysis and oxygenation as well as couplings with imides and chlorostannanes.

Results and Discussion

Preparation. When indium powder was stirred with allylic iodides or bromides **1** in DMF at room temperature,

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