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Chemoenzymatic Routes to Enantiomerically Enriched and Polyoxygenated Perhydro-3,5a-methanoindeno[4,5-*c*]furans Related to the Tashironin Class of Sesquiterpenes

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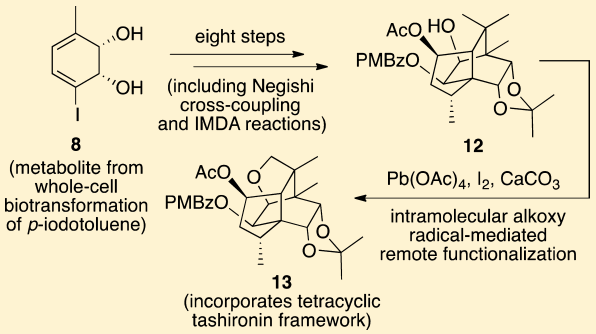
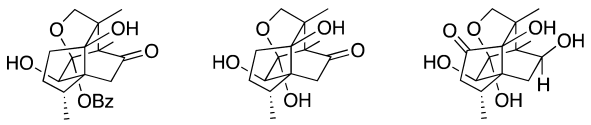
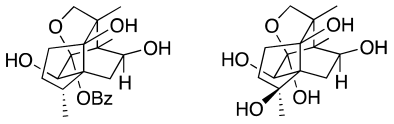
Supporting Information

ABSTRACT: The alcohol **12**, which is available in eight steps from the enzymatically derived *cis*-1,2-dihydrocatechol **8**, engages in an intramolecular alkoxy radical-mediated remote functionalization reaction to form the tetrahydrofuran **13**, thus establishing the perhydro-3,5a-methanoindeno[4,5-*c*]furan framework associated with the biologically active tashironins. Various manipulations of compound **13** and certain derivatives allow for the formation of compounds bearing strong structural resemblances to the title natural products.



The sesquiterpenoids **1**−**5** have been isolated from several species of the genus *Illicium* L. (Illiciaceae) and are representative members of a small but growing class of natural products that embody the *allo*-cedrane framework to which a tetrahydrofuran ring is annulated (presumably through a lactol-forming "event").[1] The structures of these compact and exceptionally highly oxygenated compounds were established through various detailed NMR spectroscopic studies, and that of congener **5** was confirmed by single-crystal X-ray analysis.[1c] The first member of the family to be identified was the benzoate **1**, and this was christened tashironin[1a] with the result that these compounds are now described collectively using this name.





The biological properties of certain of the tashironins are noteworthy. Thus, the parent compound **1** acts against the hepatitis B virus (HBV) at submicromolar concentrations and exerts these desirable effects by inhibiting HBV surface antigen secretions.[1g] 11-*O*-Debenzolytashironine (**2**), on the other hand, has been shown to induce neurite outgrowth in fetal rat neurons at similar concentrations.[1d] As such it is regarded as a possible lead for the development of new therapeutic agents for treating a range of neurological diseases.[2]

The biological profiles and synthetic challenges presented by the polycyclic and densely functionalized nature of the tashironins have attracted attention. In 2006 Danishefsky and co-workers reported a total synthesis of the racemic modification of compound **1**.[3] More recently, Mehta and Maity have described the synthesis of (±)-11-*O*-methyl-11-*O*-debenzoyltashironin and some related systems.[4] In both instances the oxidative dearomatization of an *o*-methoxyphenol in the presence of an unsaturated alcohol (the hydroxyl group of which serves as a trapping nucleophile) gave an *o*-quinone monoacetal that engaged in an intramolecular Diels−Alder (IMDA) reaction to afford the desired polyhydro-3,5a-methanoindeno[4,5-*c*]furan framework or an immediate precursor to it. Danishefsky has identified modifications to this type of approach that allow for the assembly of relevant IMDA adducts in enantiomerically enriched (up to 93% ee) form.[5] However, these were not carried forward in the production of more "tashironin-like" systems.

Herein we report a distinct approach to the tashironins wherein the requisite decahydro-3,5a-methanoindeno[4,5-*c*]furan framework **6** of these natural products was prepared from the corresponding tetramethylated (and oxygenated) hexahydro-3a,6a-ethanoindene **7** by applying, as the key step, an intramolecular alkoxy radical-mediated remote functionalization reaction.[6] A precursor to the substrate embodying the framework **7** was prepared previously from the *cis*-1,2-dihydrocatechol **8**,[7] a compound that is obtained in *ca.* 80%

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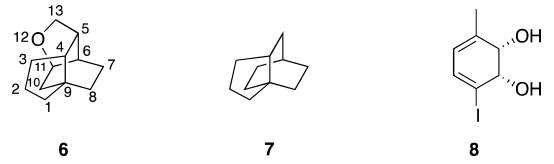
ee through the whole-cell biotransformation of *p*-iodotoluene using an organism that overexpresses the toluene dioxygenase enzyme.[7,8]



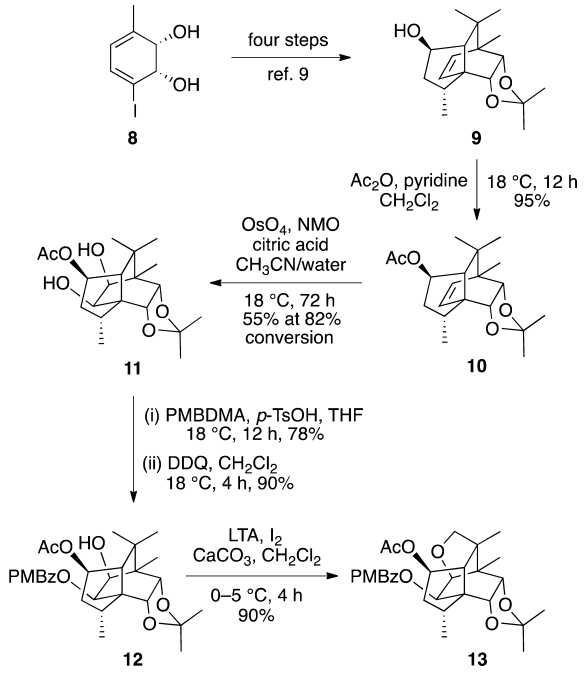
Details of the pathway used for constructing polyoxygenated forms of the title framework are shown in Scheme 1. So, the previously reported alcohol **9**,[9] obtained from diol **8** in four steps including ones involving Negishi cross-coupling and intramolecular Diels–Alder cycloaddition reactions,[10] was converted, by conventional means, into acetate **10** and its structure confirmed by single-crystal X-ray analysis.[11] Compound **10** could be diastereoselectively *cis*-dihydroxylated using the Sharpless modification of the Upjohn conditions[12] and so affording the diol **11** and this then converted into the corresponding *p*-methoxyphenylbenzylidene acetal through its reaction with *p*-methoxybenzaldehyde dimethylacetal (PMBDMA) in the presence of *p*-toluenesulfonic acid (*p*-TsOH). Oxidative cleavage of this acetal using 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ) then afforded the *p*-methoxybenzoate (PMBz) **12**.[13] When this last compound was exposed to a mixture of lead tetraacetate (LTA), molecular iodine, and $CaCO_3$ in dichloromethane under ultrasonic irradiation at 0–5 °C, then the desired intramolecular alkoxy radical-mediated cyclization reaction took place, thus generating the decahydro-3,5a-methanoindeno[4,5-*c*]furan **13**.[14] The structure of this follows from a single-crystal X-ray analysis.[11]

Selective manipulations of the oxygenated functionalities within compound **13** that should be useful in the production of tashironin analogues are shown in Scheme 2. So, for example, preferential hydrolysis of the acetate moiety within diester **13** afforded the corresponding alcohol that was readily oxidized to give ketone **14**. Furthermore, using the Rubottom oxidation protocol,[15] compound **14** could be converted into the corresponding C4-hydroxylated[16] derivative **15**, thereby establishing an acyloin residue as encountered, for example, in natural product **3**.

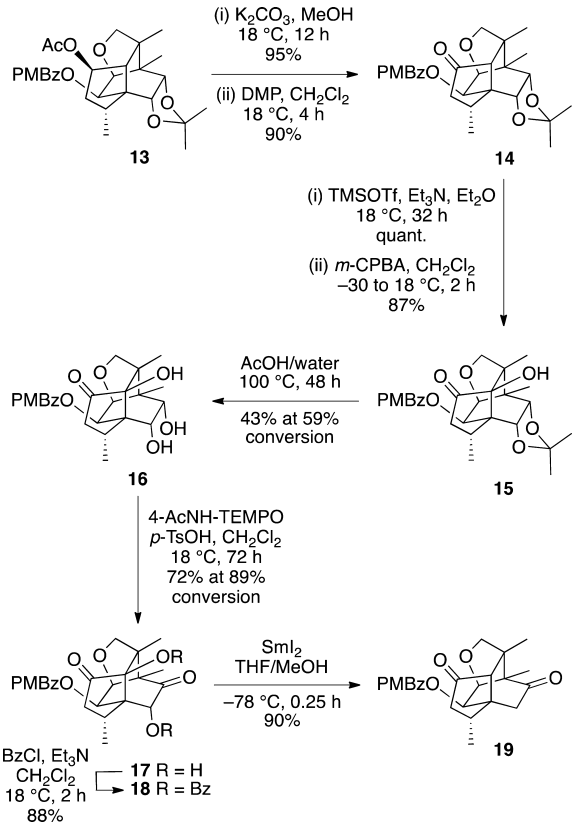
Relevant deoxygenation protocols could also be readily effected within this highly functionalized framework. So, hydrolysis of the acetonide residue associated with compound **15** afforded the diol **16** that could be selectively mono-oxidized using the sterically demanding oxammonium salt derived from the *p*-TsOH-promoted disproportionation of 4-acetamido-TEMPO[17] and thereby generating the bis-acyloin **17**. The structure of this last compound was also confirmed by single-crystal X-ray analysis.[11] Benzoylation of compound **17** then gave triester **18**, which upon reaction with samarium iodide in THF/methanol at −78 °C afforded the C4/C8-dideoxygenated compound **19**[18] embodying an "isolated" C7-carbonyl unit as encountered in natural products **1** and **2**.

An examination of the capacity of dimethyldioxirane (DMDO)[19] to selectively functionalize the decahydro-3,5a-methanoindeno[4,5-*c*]furan framework also proved fruitful. So when compound **13** was treated with this reagent (Scheme 3), then the lactol **20** was obtained as a single diastereoisomer

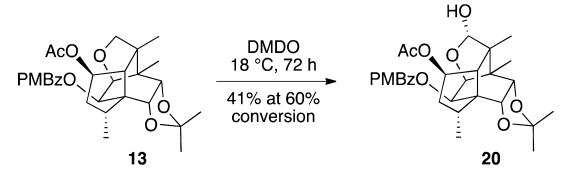
Scheme 1



Scheme 2



Scheme 3



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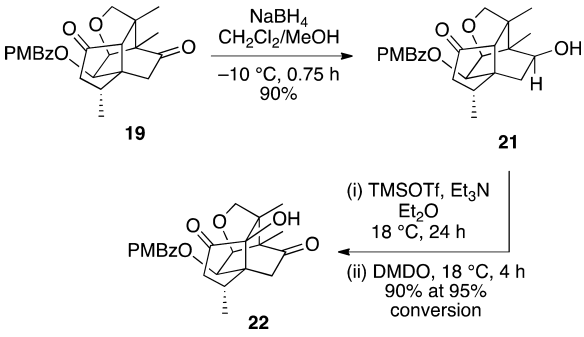
possessing, as established by single-crystal X-ray analysis,[11] the illustrated configuration at the new stereogenic center. Interestingly, no oxidation took place at C11, an outcome that could be attributed to the deactivating effect of the adjacent PMBzO moiety.

Selective reduction of the cyclohexanone residue within compound **19** was achieved by exposing it to sodium borohydride at −10 °C (Scheme 4). The alcohol **21** so formed

Scheme 4



could be treated with TMSOTf in the presence of triethylamine and then with DMDO to give the acyloin **22**[20] in which the hydroxyl group is reinstated at the tertiary position of the five-membered ring (C4), as required in all of the natural products **1**−**5**.

The protocols detailed here allow for the ready assembly of the title framework and for the establishment of functionality at almost every position within it. Furthermore, they should be capable of adaptation[21] to the introduction of substituents at C2, C3, and C11.[16] Given this and the enantiomerically enriched nature of the compounds reported here, the present work should provide an effective means for accessing a range of useful analogues of the structurally imposing tashironin class of natural product.

EXPERIMENTAL SECTION

General Protocols. Unless otherwise specified, proton (^{1}H) and carbon (^{13}C) NMR spectra were recorded at room temperature in base-filtered $CDCl_3$ on a spectrometer operating at 400 MHz for proton and 100 MHz for carbon nuclei. The signal due to residual $CHCl_3$ appearing at δ_H 7.26 and the central resonance of the $CDCl_3$ "triplet" appearing at δ_C 77.0 were used to reference ^{1}H and ^{13}C NMR spectra, respectively. ^{1}H NMR data are recorded as follows: chemical shift (δ) [multiplicity, coupling constant(s) J (Hz), relative integral] where multiplicity is defined as s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, or combinations of the above. Samples for infrared spectra (ν_{max}) were analyzed as thin films on KBr plates. Low-resolution ESI mass spectra were recorded on a single quadrupole liquid chromatograph−mass spectrometer, while high-resolution measurements were conducted on a time-of-flight instrument. Low- and high-resolution EI mass spectra were recorded on a magnetic-sector machine. Melting points were measured on an automated melting point system and are uncorrected. Analytical thin layer chromatography (TLC) was performed on aluminum-backed 0.2 mm thick silica gel 60 F_{254} plates. Eluted plates were visualized using a 254 nm UV lamp and/or by treatment with a suitable dip followed by heating. These dips included phosphomolybdic acid:ceric sulfate:sulfuric acid (concentrated):water [(37.5 g):(7.5 g):(37.5 g):(720 mL)] or potassium permanganate:potassium carbonate:5% sodium hydroxide aqueous solution:water [(3 g):(20 g):(5 mL):(300 mL)]. Flash chromatographic separations were carried out following protocols defined by Still et al.[22] with silica gel 60 (40−63 μm) as the stationary phase and using the AR- or HPLC-grade solvents indicated. Starting materials and reagents were generally available from commercial sources and used as supplied. Drying agents and other inorganic salts were purchased from commercial suppliers and were dried using a solvent purification system that is based upon a technology originally described by Grubbs et al.[23] Where necessary, reactions were performed under a nitrogen atmosphere.

Compound 10. A magnetically stirred solution of alcohol **9**[9] (51 mg, 0.17 mmol), acetic anhydride (24.5 μL, 0.26 mmol), and 4-(*N*,*N*-dimethylamino)pyridine (DMAP, 32 mg, 0.26 mmol) in pyridine (2 mL) was stirred at room temperature for 12 h and then quenched with $NaHCO_3$ (5 mL of a saturated aqueous solution). The aqueous layer was extracted with diethyl ether (3 × 5 mL), and the combined organic fractions were washed with water (1 × 5 mL) and then brine (1 × 5 mL) before being dried (Na_2SO_4), filtered, and concentrated under reduced pressure to give a clear, colorless oil. Subjection of this material to flash column chromatography (silica, 15:85 v/v ethyl acetate/hexane elution) and concentration of appropriate fractions (R_f = 0.5) afforded the title acetate **10** (54 mg, 95%) as a white, crystalline solid: mp 81−100 °C; $[\alpha]_D$ −13.7 (*c* 0.2, $CHCl_3$); ^{1}H NMR (400 MHz) δ 5.88 (d, J = 8.0 Hz, 1H), 5.78 (d, J = 8.0 Hz, 1H), 4.73 (m, 1H), 4.24 (d, J = 6.8 Hz, 1H), 4.05 (d, J = 6.8 Hz, 1H), 2.14 (m, 1H), 2.00 (s, 3H), 1.91 (m, 1H), 1.73 (m, 1H), 1.54 (d, J = 8.8 Hz, 1H), 1.27 (s, 3H), 1.26 (s, 3H), 1.19 (s, 3H), 1.13 (d, J = 6.8 Hz, 3H), 0.98 (s, 3H), 0.79 (s, 3H); ^{13}C NMR (100 MHz) δ 170.8, 138.7, 125.9, 108.5, 85.4, 81.4, 59.0, 51.9, 46.2, 40.9, 37.9, 37.6, 26.6, 25.6, 25.1, 22.2, 21.2, 15.6, 15.2 (one signal obscured or overlapping); IR (KBr) ν_{max} 3041, 2972, 2935, 2878, 1738, 1455, 1370, 1257, 1243, 1208, 1169, 1134, 1087, 1050, 1014, 886, 731 cm^{-1}; MS (EI, 70 eV) m/z 334 ($M^{+\bullet}$, <1%), 319 [$(M - CH_3^{\bullet})^+$, 15], 274 (9), 216 (80), 201 (46), 187 (34), 174 (74), 159 (100), 147 (29), 135 (34), 119 (22), 105 (19), 91 (23), 85 (17), 77 (10), 67 (7), 55 (12); HREIMS found ($M - CH_3^{\bullet}$)$^+$ 319.1909, $C_{19}H_{27}O_4$ requires 319.1909.

Compound 11. Following a protocol defined by Sharpless,[12a] a magnetically stirred solution of olefin **10** (430 mg, 1.29 mmol) and citric acid (540 mg, 2.57 mmol) in acetonitrile/water (10 mL of a 3:1 v/v mixture) maintained at room temperature was treated with potassium osmate (5 mg, 1 mol %) and *N*-methylmorpholine *N*-oxide (539 mg, 2.57 mmol). The ensuing mixture was stirred for 72 h and then treated with Na_2SO_3 (5 mL of a saturated aqueous solution) before being extracted with ethyl acetate (3 × 10 mL). The combined organic fractions were washed with brine (1 × 15 mL), then dried (Na_2SO_4), filtered, and concentrated under reduced pressure to give a clear, colorless oil. Subjection of this material to flash column chromatography (silica, 3:7 v/v ethyl acetate/hexane elution) gave two major fractions, A and B.

Concentration of fraction A (R_f = 0.7) afforded the starting alkene **10** (78 mg, 18% recovery) as a clear, colorless oil that was identical, in all respects, with an authentic sample.

Concentration of fraction B (R_f = 0.3) afforded title diol **11** (255 mg, 55% at 82% conversion) as a white, crystalline solid: mp 166−167 °C; $[\alpha]_D$ −46.8 (*c* 1.3, $CHCl_3$); ^{1}H NMR (100 MHz) δ 5.47 (dt, J = 8.8 and 3.2 Hz, 1H), 4.20 (d, J = 8.4 Hz, 1H), 4.14 (d, J = 8.0 Hz, 1H), 3.92 (broad d, J = 6.8 Hz, 1H), 3.88 (d, J = 8.0 Hz, 1H), 2.60 (broad s, 1H), 2.26−2.06 (complex m, 3H), 2.01 (s, 3H), 1.70 (m, 1H), 1.57 (d, J = 8.4 Hz, 1H), 1.42 (s, 3H), 1.29 (s, 3H), 1.13 (d, J = 7.2 Hz, 3H), 1.12 (s, 3H), 1.00 (s, 3H), 0.92 (s, 3H); ^{13}C NMR (100 MHz) δ 170.9, 108.8, 83.5, 78.8, 77.6, 68.5, 64.8, 56.2, 49.8, 43.3, 42.0, 40.6, 33.2, 28.2, 25.7, 23.7, 21.8, 21.4, 15.0, 12.5; IR (KBr) ν_{max} 3456, 2966, 2936, 2876, 1729, 1713, 1457, 1372, 1263, 1234, 1208, 1187, 1084, 1041 cm^{-1}; MS (EI, 70 eV) m/z 353 [$(M - CH_3^{\bullet})^+$, 19%], 308 (23), 290 (44), 250 (41), 232 (75), 217 (36), 203 (44), 189 (30), 175 (49), 159 (27), 150 (37), 123 (100), 109 (49), 97 (25), 82 (19), 69 (16), 55 (25); HREIMS found ($M - CH_3^{\bullet}$)$^+$ 353.1965, $C_{19}H_{29}O_6$ requires 353.1964.

Compound 12. *Step i.* A magnetically stirred solution of the diol **11** (250 mg, 0.69 mmol) and *p*-methoxybenzyldehyde dimethyl acetal (*p*-MBDMA, 188 mg, 1.03 mmol) in THF (10 mL) was cooled to 0 °C and then treated with *p*-toluenesulfonic acid monohydrate (5 mg, 4 mol %). The ensuing mixture was stirred at 0 °C for 12 h, then

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quenched with triethylamine (1 mL), and concentrated under reduced pressure to give a pale-yellow oil. Subjection of this material to flash column chromatography (silica, 1:9 v/v ethyl acetate/hexane elution) and concentration of appropriate fractions (R_f = 0.1) afforded the anticipated acetal (261 mg, 78%) as a clear, colorless oil. This unstable material was immediately committed to step ii.

Step ii. A magnetically stirred mixture of the acetal obtained via step i (240 mg, 0.49 mmol) in CH_2Cl_2/water (10 mL of a 19:1 v/v mixture) was treated with DDQ (111 mg, 0.49 mmol). The ensuing mixture was stirred at 18 °C for 4 h and then treated with $NaHCO_3$ (10 mL of a saturated aqueous solution) and the separated aqueous layer extracted with CH_2Cl_2 (3 × 10 mL). The combined organic phases were washed with brine (1 × 15 mL) before being dried ($MgSO_4$), filtered, and concentrated under reduced pressure to give a clear, colorless oil. Subjection of this material to flash column chromatography (silica 1:4 v/v ethyl acetate/hexane elution) gave alcohol **12** (228 mg, 90%) as a white, crystalline solid: $[\alpha]_D$ −16.1 (*c* 1.3, $CHCl_3$); ^{1}H NMR (400 MHz) δ 8.10 (d, *J* = 9.2 Hz, 2H), 7.01 (d, *J* = 9.2 Hz, 2H), 5.80 (dt, *J* = 9.6 and 4.4 Hz, 1H), 5.47 (d, *J* = 8.8 Hz, 1H), 4.18 (m, 2H), 3.98 (d, *J* = 8.8 Hz, 1H), 3.86 (s, 3H), 2.16 (m, 1H), 2.08 (s, 3H), 1.76 (m, 3H), 1.50 (s, 3H), 1.33 (s, 3H), 1.16 (s, 3H), 1.00 (s, 3H), 0.98 (s, 3H), 0.95 (d, *J* = 6.4 Hz, 3H); ^{13}C NMR (100 MHz) δ 171.0, 167.3, 163.7, 131.8, 121.9, 114.1, 109.2, 83.6, 78.6, 77.0, 69.5, 67.8, 55.8, 55.5, 48.4, 43.7, 41.4, 40.2, 33.5, 28.0, 25.8, 23.9, 21.7, 21.3, 14.9, 12.6; IR (KBr) ν_{max} 3514, 2965, 2936, 2877, 1712, 1606, 1580, 1512, 1458, 1419, 1370, 1283, 1260, 1168, 1111, 1086, 1034, 984, 955, 772 cm^{-1}; MS (EI, 70 eV) *m*/*z* 487 [(M − $CH_3^\bullet$)$^+$, 2%], 350 (3), 290 (4), 250 (9), 232 (16), 217 (12), 190 (80), 175 (55), 152 (28), 135 (100), 121 (10), 107 (13), 97 (15), 77 (16); HREIMS found (M − $CH_3^\bullet$)$^+$ 487.2334, $C_{27}H_{35}O_8$ requires 487.2332.

Compound 13. A solution of the alcohol **12** (74 mg, 0.15 mmol) and $CaCO_3$ (295 mg, 2.95 mmol) in dry CH_2Cl_2 (15 mL) was treated with lead tetraacetate (332 mg, 0.49 mmol) and molecular iodine (19 mg, 0.14 mmol). The resulting mixture was sonicated for 4 h at 0−5 °C and then treated with $Na_2S_2O_3$ (10 mL of a saturated aqueous solution). The separated aqueous layer was extracted with CH_2Cl_2 (3 × 10 mL), and the combined organic phases were washed with brine (1 × 15 mL) before being dried ($MgSO_4$), filtered, and concentrated under reduced pressure to give a clear, colorless oil. Subjection of this material to flash column chromatography (silica, 1:4 v/v ethyl acetate/hexane elution) and concentration of appropriate fractions (R_f = 0.1) afforded the title compound **13** (67 mg, 90%) as a white, crystalline solid: mp 160−167 °C; $[\alpha]_D$ +15.3 (*c* 1.2, $CHCl_3$); ^{1}H NMR (300 MHz) δ 8.05 (d, *J* = 9.0 Hz, 2H), 6.98 (d, *J* = 9.0 Hz, 2H), 5.67 (m, 1H), 5.20 (dd, *J* = 6.3 and 1.8 Hz, 1H), 4.26 (d, *J* = 6.3 Hz, 1H), 4.12 (d, *J* = 8.1 Hz, 1H), 3.95 (d, *J* = 8.1 Hz, 1H), 3.87 (d, *J* = 9.3 Hz, 1H), 3.85 (s, 3H), 3.55 (d, *J* = 9.3 Hz, 1H), 2.37−2.20 (complex m, 2H), 2.07 (s, 3H), 1.85 (m, 1H), 1.77 (dd, *J* = 9.9 and 1.8 Hz, 1H), 1.51 (s, 3H), 1.34 (s, 3H), 1.14 (s, 3H), 1.04 (d, *J* = 7.2 Hz, 3H), 0.99 (s, 3H); ^{13}C NMR (100 MHz) δ 170.9, 165.7, 163.4, 131.6, 122.3, 113.9, 108.7, 83.2, 78.3, 77.2, 75.9, 72.8, 71.4, 56.5, 55.4, 49.5, 45.6, 41.9, 40.9, 39.9, 25.9, 23.7, 21.2, 18.7, 16.5, 14.9; IR (KBr) ν_{max} 2977, 2937, 2881, 1714, 1606, 1580, 1511, 1456, 1419, 1375, 1314, 1277, 1258, 1209, 1166, 1102, 1084, 1057, 1030 1006, 936, 879, 770 cm^{-1}; MS (EI, 70 eV) *m*/*z* 500 ($M^{+\bullet}$, 5%), 485 [(M − $CH_3^\bullet$)$^+$, 4], 440 (3), 393 (6), 366 (20), 351 (6), 324 (4), 288 (6), 266 (11), 248 (19), 231 (17), 206 (5), 189 (8), 161 (8), 135 (100), 107 (8), 97 (22), 84 (11), 69 (9); HRESIMS found (M + Na)$^+$ 523.2309, $C_{28}H_{36}NaO_8$ requires 523.2308.

Compound 14. *Step i.* A magnetically stirred solution of the acetate **13** (285 mg, 0.57 mmol) in methanol (10 mL) was treated with K_2CO_3 (100 mg in 1 mL of H_2O). The ensuing mixture was stirred at room temperature for 12 h before being filtered through a thin pad of TLC-grade silica gel. The filtrate was concentrated under reduced pressure to give a clear, colorless oil, which was subjected to flash column chromatography (silica, 1:1 v/v ethyl acetate/hexane elution). Concentration of appropriate fractions (R_f = 0.2) afforded the anticipated alcohol (248 mg, 95%) as a white, crystalline solid, mp 87−106 °C. This material was immediately subjected to step ii of the reaction sequence as detailed below.

Step ii. A magnetically stirred solution of the alcohol obtained from step i (168 mg, 0.37 mmol) in CH_2Cl_2 (5 mL) was treated, in portions, with the Dess−Martin periodinane (170 mg, 0.40 mmol). The ensuing mixture was stirred at room temperature for 2 h and then diluted with CH_2Cl_2 (5 mL). The resulting solution was washed with NaS_2O_3 (1 × 5 mL of a saturated aqueous solution) and $NaHCO_3$ (1 × 5 mL of a saturated aqueous solution). The combined aqueous phases were extracted with CH_2Cl_2 (1 × 10 mL) and the combined organic phases washed with brine (1 × 10 mL) before being dried ($MgSO_4$), filtered, and concentrated under reduced pressure to give a clear, colorless oil. Subjection of this material to flash column chromatography (silica, 3:7 v/v ethyl acetate/hexane elution) and concentration of appropriate fractions (R_f = 0.2) afforded the title ketone **14** (152 mg, 90%) as a white, crystalline solid: mp 81−93 °C; $[\alpha]_D$ +28.2 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz) δ 7.83 (d, *J* = 8.8 Hz, 2H), 6.93 (d, *J* = 8.8 Hz, 2H), 5.40 (dd, *J* = 6.8, and 1.2 Hz, 1H), 4.22 (m, 2H), 4.11 (s, 2H), 3.85 (s, 3H), 3.54 (d, *J* = 10.4 Hz, 1H), 2.54 (m, 1H), 2.33 (m, 2H), 1.81 (m, 1H), 1.53 (s, 3H), 1.35 (s, 3H), 1.18 (d, *J* = 6.8 Hz, 3H), 1.16 (s, 3H), 1.12 (s, 3H); ^{13}C NMR (100 MHz) δ 215.6, 165.5, 163.4, 131.5, 122.1, 113.9, 109.2, 82.8, 77.8, 77.2, 72.9, 71.4, 60.9, 55.4, 50.1, 46.4, 44.9, 41.7, 37.5, 26.0, 23.6, 19.7, 16.0, 14.6; IR (KBr) ν_{max} 2976, 2937, 2884, 1716, 1606, 1580, 1512, 1459, 1382, 1315, 1259, 1210, 1167, 1101, 1086, 1033, 1005, 917, 878, 847, 774, 733, 696 cm^{-1}; MS (EI, 70 eV) *m*/*z* 456 ($M^{+\bullet}$, 54%), 441 [(M − $CH_3^\bullet$)$^+$, 27], 398 (2), 356 (5), 321 (30), 304 (30), 289 (7), 246 (27), 217 (27), 204 (41), 189 (15), 175 (13), 152 (13), 136 (42), 135 (100), 119 (10), 107 (24), 97 (17), 77 (24), 69 (15); HREIMS found $M^{+\bullet}$ 456.2148, $C_{26}H_{32}O_7$ requires 456.2148.

Compound 15. *Step i.* A magnetically stirred solution of ketone **14** (110 mg, 0.24) in anhydrous diethyl ether (5 mL) maintained at 18 °C was treated with triethylamine (270 μL, 1.92 mmol) and TMSOTf (170 μL, 0.96 mmol). After 32 h the reaction mixture was diluted with diethyl ether (10 mL) and then washed with $NaHCO_3$ (1 × 10 mL of a saturated aqueous solution) and brine (1 × 10 mL) before being dried (Na_2SO_4), filtered, and concentrated under reduced pressure to give the thermodynamically favored silyl enol ether (126 mg, quantitative) as a clear, light-yellow oil. This material was used directly in step ii as described below.

Step ii. A magnetically stirred solution of the above-mentioned silyl enol ether (126 mg, 0.24 mmol) in CH_2Cl_2 (5 mL) maintained at −30 °C was treated, in one portion, with *m*-CPBA (54 mg, 0.26 mmol). The resulting mixture was allowed to warm to room temperature over 12 h and then washed with $NaHCO_3$ (1 × 5 mL of a saturated aqueous solution). The separated aqueous phase was extracted with CH_2Cl_2 (2 × 5 mL), and the combined organic phases were dried (Na_2SO_4), filtered, and concentrated under reduced pressure to give a light-yellow oil. This material was dissolved in THF (5 mL) and the ensuing solution treated, at 18 °C, with TBAF. After 1 h the reaction mixture was concentrated under reduced pressure and the residue thus obtained subjected to flash column chromatography (silica, 3:7 v/v ethyl acetate/hexane elution). Concentration of appropriate fractions (R_f = 0.3) afforded the α-hydroxyketone **15** (98 mg, 87%) as a white, crystalline solid: $[\alpha]_D$ −14.2 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz) δ 7.81 (d, *J* = 9.2 Hz, 2H), 6.93 (d, *J* = 9.2 Hz, 2H), 5.51 (d, *J* = 7.2 Hz, 1H), 5.58 (d, *J* = 7.6 Hz, 1H), 4.30 (d, *J* = 7.6 Hz, 1H), 4.19 (d, *J* = 7.2 Hz, 1H), 4.12 (d, *J* = 9.6 Hz, 1H), 3.85 (s, 3H), 3.65 (d, *J* = 9.6 Hz, 1H), 2.80 (m, 2H), 2.33 (m, 1H), 2.01 (broad s, OH, 1H), 1.52 (s, 3H), 1.35 (s, 3H), 1.20 (s, 3H), 1.14 (d, *J* = 6.8 Hz, 3H), 1.11 (s, 3H); ^{13}C NMR (100 MHz) δ 213.3, 165.2, 163.5, 131.5, 121.9, 114.0, 108.9, 83.8, 76.7, 74.7, 69.5, 55.4, 50.2, 47.6, 45.5, 44.8, 34.8, 26.2, 23.8, 16.1, 14.2, 13.8 (two signals obscured or overlapping); IR (KBr) ν_{max} 3436, 2977, 2938, 1722, 1606, 1581, 1512, 1457, 1375, 1314, 1258, 1209, 1167, 1098, 1077, 1030, 1003, 915, 847, 732 cm^{-1}; MS (EI, 70 eV) *m*/*z* 472 ($M^{+\bullet}$, 13%), 457 [(M − $CH_3^\bullet$)$^+$, 16], 337 (43), 320 (6), 279 (8), 262 (6), 233 (5), 203 (4), 191 (5), 175 (5), 152 (7), 136 (36), 135 (100), 107 (12), 97 (12), 77 (15), 69 (13), 55 (12); HREIMS found $M^{+\bullet}$ 472.2096, $C_{26}H_{32}O_8$ requires 472.2097.

Compound 16. A magnetically stirred solution of acetonide **15** (118 mg, 0.25 mmol) in acetic acid/water (5 mL of a 4:1 v/v mixture) was heated to 100 °C for 24 h. The cooled reaction mixture was

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quenched with $NaHCO_3$ (5 mL of a saturated aqueous solution) and extracted with ethyl acetate (4 × 5 mL). The combined organic fractions were washed with brine (1 × 10 mL) before being dried (Na_2SO_4), filtered, and concentrated under reduced pressure to give a light-yellow oil. Subjection of this material to flash column chromatography (silica, 3:2 v/v ethyl acetate/hexane) afforded two fractions, A and B.

Concentration of fraction A (R_f = 0.6) afforded acetonide **15** (49 mg, 41% recovery) as a clear, colorless oil that was identical, in all respects, with an authentic sample.

Concentration of fraction B (R_f = 0.3) afforded the title triol **16** (46 mg, 43% at 59% conversion) as a white, crystalline solid: $[\alpha]_D$ −6.5 (*c* 0.4, $CHCl_3$); ^{1}H NMR (400 MHz) δ 7.83 (d, *J* = 8.4 Hz, 2H), 6.94 (d, *J* = 8.4 Hz, 2H), 5.62 (d, *J* = 7.2 Hz, 1H), 4.44 (d, *J* = 8.4 Hz, 1H), 4.26 (d, *J* = 7.2 Hz, 1H), 4.10 (d, *J* = 8.4 Hz, 1H), 4.06 (d, *J* = 10.4 Hz, 1H), 3.85 (s, 3H), 3.62 (d, *J* = 10.4 Hz, 1H), 2.80 (m, 3H), 2.29 (q, *J* = 12.8 Hz, 1H), 1.96 (s, 1H), 1.59 (broad s, OH, 1H), 1.20 (broad s, 6H), 1.08 (s, 3H); ^{13}C NMR (100 MHz) δ 213.4, 165.3, 163.5, 131.5, 121.8, 113.9, 83.0, 76.4, 74.3, 70.1, 69.3, 67.0, 55.4, 50.2, 48.6, 46.5, 45.0, 35.1, 15.9, 14.8, 13.6; IR (KBr) ν_{max} 3398, 2971, 2936, 2917, 1735, 1723, 1605, 1580, 1512, 1457, 1399, 1343, 1258, 1169, 1101, 1051, 1022, 914, 732 cm^{-1}; MS (EI, 70 eV) *m*/*z* 432 ($M^{+\bullet}$, 3%), 297 (12), 279 (4), 261 (3), 191 (4), 175 (5), 152 (19), 136 (25), 135 (100), 107 (7), 97 (11), 77 (11), 69 (7), 57 (5); HREIMS found $M^{+\bullet}$ 432.1785, $C_{23}H_{28}O_8$ requires 432.1784.

Compound 17. A magnetically stirred solution of the triol **16** (22 mg, 0.05 mmol) in CH_2Cl_2 (2 mL) was cooled to 0 °C while a solution of *p*-TsOH·H_2O (26.6 mg, 0.14 mmol) and 4-acetamido-TEMPO (32.6 mg, 0.15 mmol) in CH_2Cl_2 (1 mL) was prepared and stirred at 18 °C for 0.5 h. The latter solution was then added to the first over 1.5 h and the ensuing mixture stirred at 18 °C for 48 h before being quenched with $NaHCO_3$ (3 mL of a saturated aqueous solution). The separated aqueous phase was extracted with CH_2Cl_2 (3 × 5 mL), and the combined organic fractions were washed with water (1 × 5 mL) and brine (1 × 5 mL) before being dried (Na_2SO_4), filtered, and concentrated under reduced pressure to give light-yellow oil. Subjection of this material to flash column chromatography (silica, 2:3 v/v ethyl acetate/hexane elution) gave two fractions, A and B

Concentration of fraction A (R_f = 0.4) afforded acyloin **17** (15.8 mg, 72% at 89% conversion) as a white, crystalline solid: ^{1}H NMR (400 MHz) δ 7.86 (d, *J* = 9.2 Hz, 2H), 6.96 (d, *J* = 9.2 Hz, 2H), 5.70 (d, *J* = 7.2 Hz, 1H), 4.35 (s, 1H), 4.31 (d, *J* = 9.6 Hz, 1H), 4.28 (d, *J* = 7.2 Hz, 1H), 3.87 (s, 3H), 3.65 (d, *J* = 9.6 Hz, 1H), 2.88 (m, 2H), 2.80 (broad s, OH, 1H), 2.40 (m, 1H), 2.08 (s, OH, 1H), 1.24 (d, *J* = 6.8 Hz, 3H), 1.21 (s, 3H), 1.14 (s, 3H); ^{13}C NMR (100 MHz) δ 212.5, 165.1, 163.7, 131.5, 121.6, 114.1, 82.0, 80.0, 74.7, 73.5, 68.7, 58.7, 55.5, 52.0, 49.3, 44.9, 34.3, 14.7, 12.8 (two signals obscured or overlapping); IR (KBr) ν_{max} 3433, 2980, 1718, 1603, 1511, 1461, 1383, 1341, 1258, 1166, 1103, 1024, 937, 846, 736 cm^{-1}; MS (EI, 70 eV) *m*/*z* 430 ($M^{+\bullet}$, 3%), 278 (7), 135 (100), 107 (4), 97 (4), 84 (7), 77 (5), 69(4); HREIMS found $M^{+\bullet}$ 430.1628, $C_{23}H_{26}O_8$ requires 430.1628.

Concentration of fraction B (R_f = 0.3) afforded triol **16** (2.5 mg, 11% recovery) as a white, crystalline solid that was identical, in all respects, with an authentic sample.

Compound 18. A magnetically stirred solution of acyloin **17** (16 mg, 0.07 mmol), 4-(*N*,*N*-dimethylamino)pyridine (29 mg, 0.24 mmol) and triethylamine (300 μL) in CH_2Cl_2 (2 mL) was cooled to 0 °C and treated with benzoyl chloride (0.2 mL, 0.17 mmol). The resulting mixture was allowed to warm to 18 °C and stirred at this temperature for 18 h before being treated with HCl (5 mL of a 1 M aqueous solution) and extracted with CH_2Cl_2 (4 × 5 mL). The combined organic phases were washed with brine (1 × 10 mL), then dried (Na_2SO_4), filtered, and concentrated under reduced pressure. The resulting light-yellow oil was subjected to flash column chromatography (silica, 1:9 v/v ethyl acetate/hexane elution), and concentration of the appropriate fractions (R_f = 0.6 in 1:4 v/v ethyl acetate/hexane) gave the title triester **18** (21.0 mg, 88%) as white, crystalline solid: mp 91−105 °C; $[\alpha]_D$ −35.2 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz) δ 8.10−7.90 (complex m, 6H), 7.63 (m, 2H), 7.51 (m, 4H), 7.01 (d, *J* = 9.2 Hz, 2H), 6.18 (s, 1H), 5.82 (d, *J* = 6.8 Hz, 1H), 4.91 (d, *J* = 10.4 Hz, 1H), 4.53 (d, *J* = 6.8 Hz, 1H), 3.89 (s, 3H), 3.72 (d, *J* = 10.4 Hz, 1H), 3.16 (m, 1H), 2.93 (m, 1H), 2.41 (dd, *J* = 19.2 and 10.4 Hz, 1H), 1.26 (s, 3H), 1.25 (s, 3H), 1.03 (d, *J* = 6.8 Hz, 3H); IR (KBr) ν_{max} 2979, 1727, 1605, 1582, 1512, 1451, 1315, 1259, 1169, 1088, 1066, 1025, 937, 848, 767, 706 cm^{-1}; MS (ESI, +ve) *m*/*z* 661 [$(M + Na)^+$, 20%], 639 (25), 517 (53), 135 (100); HREIMS found $(M + Na)^+$ 661.2050, $C_{37}H_{34}NaO_{10}$ requires 661.2050. Solutions of this compound are rather unstable on prolonged standing.

Compound 19. A magnetically stirred solution of keto-benzoate **18** (18 mg, 0.017 mmol) in THF/methanol (3 mL of a 2:1 v/v mixture) was cooled to −78 °C, and then SmI_2 (0.1 M solution in THF) was added dropwise until a blue color persisted (depending on the quality of the samarium reagent up to 5 "equivalents" was required). The resulting mixture was stirred at −78 °C for 0.25 h, then poured into K_2CO_3 (3 mL of a saturated aqueous solution), and diluted with diethyl ether (5 mL). The separated aqueous phase was extracted with diethyl ether (4 × 5 mL), and the combined organic fractions were washed with water (1 × 10 mL) and brine (1 × 10 mL) before being dried (Na_2SO_4), filtered, and concentrated under reduced pressure. The resulting clear, colorless oil was subjected to flash column chromatography (silica, 3:7 v/v ethyl acetate/hexane elution), and concentration of the appropriate fractions (R_f = 0.2 in 1:4 v/v ethyl acetate/hexane) gave the title diketone **19** (10 mg, 90%) as a white, crystalline solid: mp 90−116 °C; $[\alpha]_D$ −18.6 (*c* 0.4, $CHCl_3$), ^{1}H NMR (400 MHz) δ 7.86 (d, *J* = 9.2 Hz, 2H), 6.96 (d, *J* = 9.2 Hz, 2H), 5.08 (dd, *J* = 6.8 and 1.2 Hz, 1H), 4.37 (d, *J* = 9.6 Hz, 1H), 4.26 (d, *J* = 6.8 Hz, 1H), 3.87 (s, 3H), 3.50 (d, *J* = 9.6 Hz, 1H), 2.65−2.50 (complex m, 2H), 2.45−2.05 (complex m, 4H), 1.16 (s, 3H), 1.14 (d, *J* = 7.2 Hz, 3H), 1.12 (s, 3H); ^{13}C NMR (100 MHz) δ 214.3, 210.5, 165.3, 163.8, 131.6, 121.5, 114.1, 78.5, 74.9, 72.5, 62.5, 60.0, 55.5, 49.7, 47.0, 46.0, 43.2, 37.0, 20.5, 13.0, 12.4; IR (KBr) ν_{max} 2964, 1718, 1605, 1512, 1455, 1382, 1318, 1259, 1168, 1099, 1061, 1030, 927, 848, 765 cm^{-1}; MS (EI, 70 eV) *m*/*z* 398 ($M^{+\bullet}$, 22%), 263 (4), 246 (10), 218 (5), 204 (19), 167 (5), 137 (30), 135 (100), 125 (7), 107 (9), 97 (10), 92 (9), 77 (15); HREIMS found $M^{+\bullet}$ 398.1729, $C_{23}H_{26}O_6$ requires 398.1729.

Compound 20. A magnetically stirred solution of bis-ester **13** (4 mg, 0.008 mmol) in acetone (200 μL) was treated with freshly prepared DMDO (2 mL of ∼0.08 M solution in acetone) and the reaction flask then capped, wrapped in aluminum foil (to exclude light), and stirred at room temperature for 72 h. The reaction mixture was then concentrated under reduced pressure to give a clear, colorless oil that was subjected to flash column chromatography (silica, 3:7 v/v ethyl acetate/hexane elution), affording two fractions, A and B.

Concentration of fraction A (R_f = 0.4 in 1:1 v/v ethyl acetate/hexane elution) afforded starting bis-ester **13** (1.6 mg, 40% recovery) as a clear, colorless oil that was identical, in all respects, with an authentic sample.

Concentration of fraction B (R_f = 0.3 in 1:1 v/v ethyl acetate/hexane elution) afforded hemiacetal **20** (1.7 mg, 41% at 60% conversion) as a white, crystalline solid: ^{1}H NMR (800 MHz) δ 8.03 (d, *J* = 9.6 Hz, 2H), 6.98 (d, *J* = 9.6 Hz, 2H), 5.72 (m, 1H), 5.34 (s, 1H), 5.17 (dd, *J* = 6.4 and 2.4 Hz, 1H), 4.44 (d, *J* = 6.4 Hz, 1H), 4.12 (d, *J* = 8.8 Hz, 1H), 3.93 (d, *J* = 8.8 Hz, 1H), 3.86 (s, 3H), 2.28 (m, 1H), 2.22 (m, 1H), 2.08 (s, 3H), 1.86 (m, 1H), 1.79 (dd, *J* = 9.2 and 2.4 Hz, 1H), 1.52 (s, 3H), 1.38 (s, 3H), 1.34 (s, 3H), 1.08 (s, 3H), 1.03 (d, *J* = 7.2 Hz, 3H) (signal due to OH group proton not observed); ^{13}C NMR (200 MHz) δ 170.9, 165.6, 163.5, 131.8, 122.2, 114.1, 108.6, 101.0, 83.3, 78.6, 74.6, 70.0, 56.3, 55.5, 48.9, 46.0, 45.1, 40.9, 39.8, 25.9, 23.7, 21.2, 17.6, 17.3, 14.7 (one signal obscured or overlapping); IR (KBr) ν_{max} 3436, 2978, 2937, 2883, 1713, 1606, 1580, 1512, 1456, 1376, 1260, 1211, 1167, 1102, 1086, 1056, 1027, 943, 914, 878, 847, 770, 733 cm^{-1}; MS (EI, 70 eV) *m*/*z* 516 ($M^{+\bullet}$, 2%), 501 [$(M - CH_3^{\bullet})^+$, 2], 455 (4), 410 (2), 276 (4), 246 (2), 218 (20, 200 (6), 173 95), 158 (19), 135 (100), 84 (36), 77 (6); HREIMS found $(M - CH_3^{\bullet})^+$ 501.2133, $C_{27}H_{33}O_9$ requires 501.2125.

Compound 21. A magnetically stirred solution of diketone **19** (5.0 mg, 0.013 mmol) in methanol/CH_2Cl_2 (1 mL of a 1:1 v/v mixture) was cooled to −10 °C and treated with $NaBH_4$ (0.5 mg, 0.014 mmol). After 1 h the reaction mixture was quenched with water (200 μL) and

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then concentrated under reduced pressure. The residue thus obtained was partitioned between half-brine (1 mL) and CH_2Cl_2 (1 mL) and the separated aqueous phase extracted with CH_2Cl_2 (3 × 1 mL). The combined organic fractions were washed with brine (1 × 2 mL) before being dried (Na_2SO_4), filtered, and concentrated under reduced pressure. Subjection of the resulting clear, colorless oil to flash column chromatography (silica, 3:2 v/v ethyl acetate/hexane) and concentration of the appropriate fractions (R_f = 0.3 in 3:7 v/v ethyl acetate/hexane) gave alcohol **21** (4.7 mg, 90%) as a white, semisolid: $[\alpha]_D$ −15.4 (*c* 0.18, $CHCl_3$); ^{1}H NMR (400 MHz) δ 7.84 (d, *J* = 8.8 Hz, 2H), 6.93 (d, *J* = 8.8 Hz, 2H), 4.81 (d, *J* = 6.8 Hz, 1H), 4.15 (d, *J* = 8.8 Hz, 1H), 4.01 (broad d, *J* = 9.2 Hz, 1H), 4.00 (d, *J* = 6.8 Hz, 1H), 3.85 (s, 3H), 3.48 (d, *J* = 8.8 Hz, 1H), 2.53 (complex m, 1H), 2.45 (s, 1H), 2.38−2.17 (complex m, 3H), 1.7 (broad s, OH, 1H), 1.52 (dd, *J* = 14.4 and 2.4 Hz, 1H), 1.36 (s, 3H), 1.16 (s, 3H), 1.07 (d, *J* = 6.4 Hz, 3H); ^{13}C NMR (100 MHz) δ 216.9, 165.6, 163.5, 131.6, 121.9, 113.9, 78.7, 75.6, 73.8, 70.5, 61.6, 55.4, 49.4, 46.2, 43.7, 43.5, 41.5, 37.3, 21.6, 17.1, 13.0; IR (KBr) ν_{max} 3472, 2964, 2878, 1715, 1605, 1580, 1512, 1458, 1259, 1168, 1101, 1064, 1030, 927, 847, 768, 735, 698 cm^{-1}; MS (EI, 70 eV) *m*/*z* 400 ($M^{+\bullet}$, 7%), 382 (16), 265 (4), 248 (7), 230 (2), 204 (7), 139 (7), 135 (35), 111 (4), 85 (63), 83 (100), 69 (11), 57 (14), 51 (42); HREIMS found $M^{+\bullet}$ 400.1886, $C_{23}H_{28}O_6$ requires 400.1886.

Compound 22. *Step i.* A magnetically stirred solution of hydroxyketone **21** (10 mg, 0.024 mmol) in dry diethyl ether (1 mL) maintained at 18 °C was treated with triethylamine (26 μL, 0.192 mmol) and TMSOTf (17 μL, 0.096 mmol). The resulting mixture was stirred at 18 °C for 32 h, then diluted with diethyl ether (4 mL), and washed with $NaHCO_3$ (1 × 4 mL of a saturated aqueous solution) and then with brine (1 × 4 mL) before being dried (Na_2SO_4), filtered, and concentrated under reduced pressure to give the anticipated, thermodynamically favored silyl enol ether as a light-yellow oil, which was used in step ii as described immediately below.

Step ii. A magnetically stirred solution of the enol ether obtained from step i in acetone (1 mL) maintained at 0 °C was treated with freshly prepared DMDO (1 mL). The reaction flask was capped, and the mixture was left to warm to 18 °C and then stirred at this temperature for 72 h. The resulting mixture was concentrated under reduced pressure to give a clear, colorless oil, which upon subjection to flash column chromatography (silica, 3:2 v/v ethyl acetate/hexane elution) afforded two fractions, A and B.

Concentration of fraction A (R_f = 0.3) gave the starting hydroxyketone **21** (0.5 mg, 5% recovery) as clear, colorless oil that was identical, in all respects, with an authentic sample.

Concentration of fraction B (R_f = 0.2) afforded compound **22** (5 mg, 90% at 95% conversion) as a white, crystalline solid: mp 203−217 °C; $[\alpha]_D$ −32.2 (*c* 0.2, $CHCl_3$); ^{1}H NMR (400 MHz) δ 7.86 (d, *J* = 8.8 Hz, 2H), 6.97 (d, *J* = 8.8 Hz, 2H), 5.16 (d, *J* = 7.2 Hz, 1H), 4.25 (m, 2H), 3.87 (s, 3H), 3.62 (d, *J* = 9.6 Hz, 1H), 2.82 (dd, *J* = 19.2 and 9.2 Hz, 1H), 2.75 (d, *J* = 18.4 Hz, 1H), 2.66 (m, 1H), 2.40 (dd, *J* = 19.2 and 9.2 Hz, 1H), 2.19 (d, *J* = 18.4 Hz, 1H), 2.09 (s, 1H), 1.20 (s, 3H), 1.11 (d, *J* = 7.2 Hz, 3H), 1.10 (s, 3H); ^{13}C NMR (100 MHz) δ 212.6, 210.4, 165.0, 163.8, 131.6, 121.3, 114.1, 81.3, 78.4, 74.4, 73.4, 58.9, 55.5, 52.2, 49.9, 44.4, 42.0, 34.3, 14.3, 12.8, 12.7; IR (KBr) ν_{max} 3435, 2970, 1721, 1605, 1512, 1456, 1258, 1168, 1098, 1064, 1030, 936, 847, 761; MS (EI, 70 eV) *m*/*z* 414 ($M^{+\bullet}$, 2%), 341 (3), 281 (10), 207 (65), 152 (9), 135 (100), 107 (5), 77 (8); HREIMS found $M^{+\bullet}$ 414.1681, $C_{23}H_{26}O_7$ requires 414.1679.

Crystallographic Data. *Compound 10.* $C_{20}H_{30}O_4$, *M* = 334.46, *T* = 200 K, triclinic, space group $P\bar{1}$, *Z* = 2, *a* = 7.1052(2) Å, *b* = 8.8559(3) Å, *c* = 15.3747(6) Å; α = 101.830(2)°, β = 92.394(2)°, γ = 98.705(3)°; *V* = 933.31(6) Å^3, D_x = 1.190 g cm^{-3}, 4289 unique data ($2\theta_{max}$ = 55°), *R* = 0.046 [for 3086 reflections with $I > 2.0\sigma(I)$]; R_w = 0.104 (all data), *S* = 0.97.

Compound 13. $C_{28}H_{36}O_8$, *M* = 500.59, *T* = 200 K, orthorhombic, space group $Pna2_1$, *Z* = 4, *a* = 17.5090(8) Å, *b* = 10.8113(6) Å, *c* = 13.8337(6) Å; *V* = 2618.7(2) Å^3, D_x = 1.270 g cm^{-3}, 2415 unique data ($2\theta_{max}$ = 50°), *R* = 0.048 [for 1982 reflections with $I > 2.0\sigma(I)$]; R_w = 0.096 (all data), *S* = 1.09.

Compound 17. $C_{23}H_{20}O_8 \cdot 0.5(C_2H_6O)$, *M* = 453.49, *T* = 200 K, triclinic, space group $P\bar{1}$, *Z* = 4, *a* = 7.6900(5) Å, *b* = 14.3594(9) Å, *c* = 20.4029(14) Å; α = 88.122(3)°, β = 87.959(4)°, γ = 88.679(4)°; *V* = 2249.8(3) Å^3, D_x = 1.339 g cm^{-3}, 10119 unique data ($2\theta_{max}$ = 55°), *R* = 0.085 [for 5868 reflections with $I > 2.0\sigma(I)$]; R_w = 0.216 (all data), *S* = 1.05.

Compound 20. $C_{28}H_{36}O_9$, *M* = 516.59, *T* = 200 K, monoclinic, space group $P2_1/c$, *Z* = 4, *a* = 11.8184(8) Å, *b* = 14.8204(10) Å, *c* = 15.3328(8) Å; β = 96.787(3)°; *V* = 2666.8(3) Å^3, D_x = 1.287 g cm^{-3}, 4705 unique data ($2\theta_{max}$ = 50.2°), *R* = 0.054 [for 3087 reflections with $I > 2.0\sigma(I)$]; R_w = 0.145 (all data), *S* = 0.97.

Structure Determinations. Images were measured on a Nonius Kappa CCD diffractometer (Mo Kα, graphite monochromator, λ = 0.71073 Å) and data extracted using the DENZO package.[24] Structure solution was by direct methods (SIR92).[25] The structure of compounds **10**, **13**, **17**, and **20** were refined using the CRYSTALS program package.[26] Atomic coordinates, bond lengths and angles, and displacement parameters have been deposited at the Cambridge Crystallographic Data Centre [CCDC numbers 1028238 (**10**), 1028241 (**13**), 1028242 (**17**), and 1028244 (**20**)]. These data can be obtained free-of-charge via www.ccdc.cam.ac.uk/data_request/cif, by e-mailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, U.K.; fax: +44 1223 336033.

■ ASSOCIATED CONTENT

Supporting Information

Crystallographic data (CIFs); anisotropic displacement ellipsoid plots derived from the single-crystal X-ray analyses of compounds **10**, **13**, **17**, and **20**; and ^{1}H and ^{13}C NMR spectra of compounds **10**−**22**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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