Nucleophilic Addition Reactions of 1,4-Diketones Derived from Tartaric Acid: Synthesis of TADDOL Analogues

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Respectfully dedicated to Prof. Dr. Dieter Hoppe on the occasion of his 65th birthday

Abstract: A systematic investigation of the reduction and Grignard reagents addition to 1,4-diketones derived from tartaric acid was carried out. It was found that the reduction proceeded with high selectivity using K-Selectride as the reducing agent; while Grignard reagent addition was highly dependent on structure of the dione as well as on the Grignard reagent. The resultant 1,4-diols represent a series of novel TADDOL analogues.

Key words: asymmetric synthesis, TADDOL, stereoselective addition

Synthesis of biologically active compounds in enantiomerically pure form is of pivotal importance in organic chemistry.[1] There has been a surge to develop chiral processes based either on chiral auxiliaries or with the aid of chiral catalysts derived from cheap chiral pool sources.[2] In the context of asymmetric catalysis, TADDOL (**1**) ligand developed by Seebach et al. has attracted much attention.[3] The varied utility and ability of TADDOL as a catalyst in a number of asymmetric reactions established TADDOL as one of the most privileged ligands.[4] However, many of the TADDOL ligands have limited variations and the synthesis and structural diversity of their analogues have been limited to simple variations around the aromatic ring in the core structure.[5] As a part of our program in asymmetric catalysis, we were interested in a general approach for the synthesis of diverse TADDOL analogues and their possible use in asymmetric catalysis. New feature of the proposed TADDOL analogues is the synthesis of diastereomerically different 1,4-diols (replacement of one of the aryl groups of TADDOL with an alkyl group), possessing varied sense of chirality at the 1,4-positions, keeping the inherent tartrate backbone intact (Figure 1). The availability of a number of analogues of TADDOL is expected to have application in fine tuning of the existing catalysts.

We reasoned that the addition of nucleophiles (hydride and Grignard reagents) to the diketones **3a**–**h** should produce the corresponding secondary or tertiary alcohols (Scheme 1). In this context, we have recently disclosed a high diastereoselective reduction of 1,4-diketones **3a**–**d**.[6] Herein, we report the detailed investigation concerning

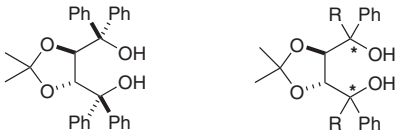
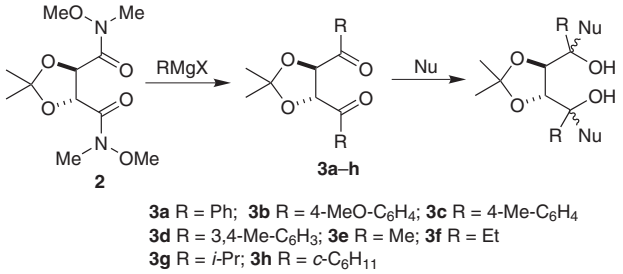


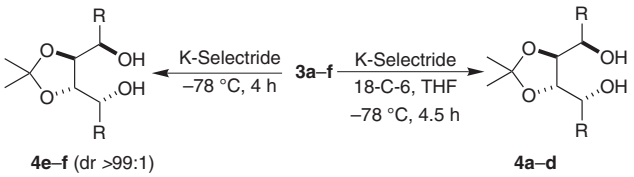
Figure 1 TADDOL and its analogues



Scheme 1 Synthesis of TADDOL analogues by addition of nucleophiles to 1,4-diketones derived from L-(+)-tartaric acid

the reduction and addition of Grignard reagents to the 1,4-diketones leading to the synthesis of TADDOL analogues.

We initiated our study by the synthesis of 1,4-diketones **3a**–**h** which are obtained by respective Grignard reagent addition to the bis-Weinreb amide **2** derived from tartaric acid.[7] Reduction of the 1,4-diaryl diketones **3a**–**d** with K-Selectride pre-complexed with 18-C-6 proceeded with good diastereoselectivity (dr = 91:9) affording the C_2-symmetric alcohols **4a**–**d** as the major product. Use of K-Selectride as the reducing agent without 18-C-6 decreased the dr to 71:29. Reduction with other reducing agents such as $NaBH_4$, $LiAlH_4$, DIBAL-H and L-Selectride lowered the diastereomeric ratio. While the reduction of diaryl diketones **3a**–**d** is in acceptable diastereomeric ratios, reduction of 1,4-dialkyldiones **3e**,**f** either with K-Selectride or with L-Selectride furnished a single diastereomer of the product alcohols **4e**,**f** (Scheme 2, Table 1).



Scheme 2 Stereoselective reduction of 1,4-diketones **3a**–**f** derived from L-(+)-tartaric acid

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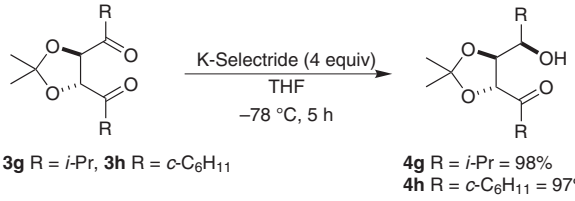
Table 1 Reduction of 1,4-Diketones Derived from L-(+)-Tartaric Acid

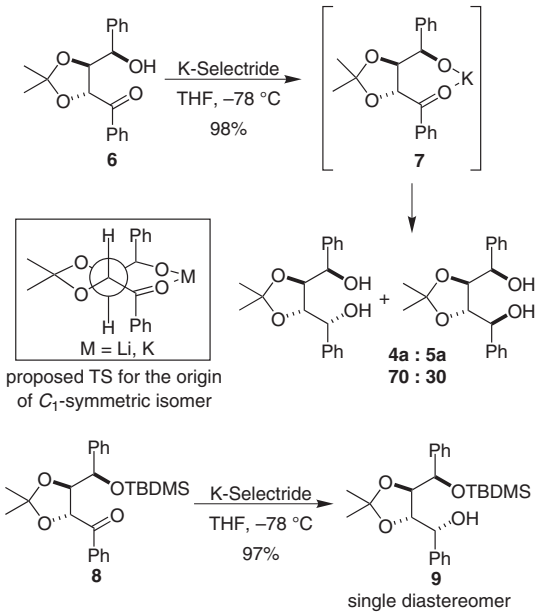
1,4-Diol	**4a**	**4b**	**4c**	**4d**	**4e**	**4f**
dr	91:9	86:14	89:11	91:9	>99:1	>99:1

Interestingly, reduction of diketones **3g**,**h** possessing a bulky isopropyl and cyclohexyl group produced the corresponding hydroxy ketones **4g**,**h** as a single diastereomer under similar conditions (Scheme 3).



Scheme 3 Stereoselective reduction of 1,4-diketones **3g–h**

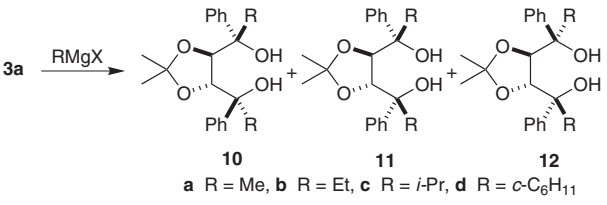
Although the diasteroemeric ratio was satisfactory in the reduction of 1,4-diaryl diketones **3a–d**, we were puzzled by the origin of the C_1-symmetric diastereomer **5a–d**, which can be attributed to the following. In the reduction of diketones **3a–d**, the reduction takes place via a stepwise manner in which one of the keto groups of the diketone is reduced first to yield the potassium alkoxide **7**, which exerts a 1,4-asymmetric control in the reduction of the second keto group. Potassium ion being mild chelating group has a little effect in the 1,4-chelation, thus leading to a low amount of the C_1-symmetric diol **5a–d**.[8] A convincing insight in support of this postulate was provided by the following experiment. Reduction of hydroxy ketone **6**[9] was performed under similar conditions that were employed for the diketones **3a–d**. It was anticipated that the hydroxy ketone **6** should produce a single diastereomer if the ketone reduction is independent of the hydroxy group in **6** or should produce diastereomeric mixture of alcohols similar to that observed in the reduction of diketone **3a–d** if a 1,4-stereocontrol is present. Reduction of hydroxy ketone **6** with K-Selectride produced a mixture of alcohols in a ratio 70:30 (similar to that observed in diketone reduction), clearly indicating the influence of the initially formed potassium alkoxide **7**. In another experiment, the silyloxy ketone **8** was subjected to reduction with K-Selectride. It was anticipated that the silyloxy group being non-chelating in nature will exert no chelation on the metal ion and hence reduction of the keto group in **8** would be independent of stereogenic character of the chiral center bearing the silyloxy group. This was indeed the case and the reduction of **8** proceeded with very high selectivity affording the alcohol **9** as a single diastereomer (Scheme 4). This clearly shows that the initial reduction of the ketone **3a** produces the alkoxide **7**, which forms a chelate with the carbonyl oxygen thus partially forcing the approach of the nucleophile from the *re* face. Diminishing the chelation partially by the addition of 18-C-6 led to a considerable improvement in the diastereo-



Scheme 4 Proposed transition state for the origin of the C_1-symmetric isomer in the reduction of 1,4-diketones **3a–d**

meric ratio. The high selectivity observed in the case of alkyl ketones perhaps is a result of less chelation and faster reactivity of the alkyl ketones. No epimerization of the chiral center adjacent to the keto group is observed in the reduction of either alkyl or aryl diketones.

We then turned our attention to the addition of alkyl Grignard reagents to diketone **3a**. The results are summarized in Table 2. It was found that the solvent and temperature had a significant effect on the addition of alkylmagnesium halides to diketone **3a**. Thus addition of methylmagnesium bromide to ketone **3a** resulted in the C_1-symmetric diastereomer **11** as the major product when the reaction was performed in THF as solvent at –78 °C. Change of solvent from THF to diethyl ether improved the selectivity towards the formation of C_2-symmetric diastereoemer **10**. A refinement of dr (84:16) was observed when the reaction was performed in diethyl ether with the addition of diphenyl ketone **3a** to the Grignard reagent. A moderate ratio of 75:25 was observed in the addition of EtMgBr in dichloromethane (Scheme 5).



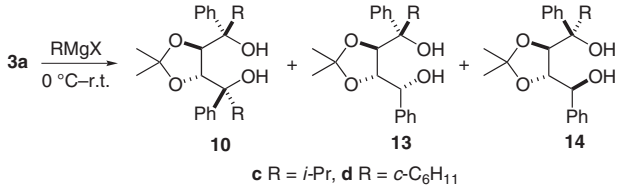
Scheme 5 Addition of alkylmagnesium bromides to the diketone **3a**

Table 2 Stereoselective Addition of Grignard Reagents to 4,5-Dibenzoyl-2,2-dimethyl-1,3-dioxolane (**3a**)

Entry	RMgX	Solvent	Temp (°C)	dr by ^{1}H NMR			Yield (%)[a]
				10	**11**	**12**	
1	MeMgBr	THF	–78	9	81	10	91
2	MeMgBr	THF	–15	37	57	6	84
3	MeMgBr	Et_2O	0	64	36	0	95
4	MeMgBr[b]	Et_2O	0	84	16	0	94
5	EtMgBr	THF	–78	23	77	0	95
6	EtMgBr	Et_2O	0	71	29	0	93
7	EtMgBr[b]	Et_2O	0	72	28	0	94
8	EtMgBr[b]	CH_2Cl_2	0	75	25	0	92
9	*i*-PrMgBr	Et_2O	0	100	0	0	21
10	*c*-C_6H_{11}MgCl	THF	0	100	0	0	54

[a] Refers to isolated yield of a mixture of all diastereomers.
[b] Addition of diphenyl ketone to Grignard reagent.

It is interesting to note that the addition of much bulkier isopropylmagnesium bromide and cyclohexylmagnesium chloride to diketone **3a** resulted in the formation C_2-symmetric diastereomer **10c** and **10d** in 21 and 54% yields, respectively (Table 2, entries 9 and 10). Other products **13** and **14** formed in the reaction are the reduction products arising from the β-hydride transfer of the Grignard reagent (Scheme 6 and Table 3).



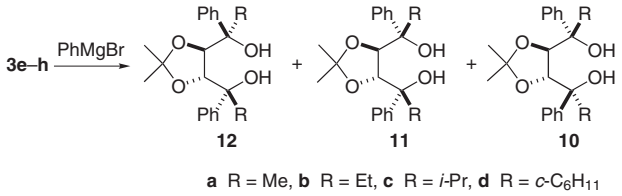
Scheme 6 Addition of isopropyl and cyclohexyl Grignard reagents to **3a**

Table 3 Addition of Isopropyl and Cyclohexyl Grignard Reagents to **3a**

Entry	RMgX[a]	Yield (%)[b]		
		10	**13**	**14**
1	*i*-PrMgBr	21	38	19
2	*c*-C_6H_{11}MgCl	54	30	15

[a] Four equiv of Grignard reagent was employed.
[b] Refers to isolated yield.

To prepare the C_2-symmetric diastereomer **12** as the major product, addition of PhMgBr to 1,4-dialkyl diketones **3e**,**f** was undertaken (Scheme 7). Unlike the addition of alkyl Grignard reagents to the diaryl diketones **3a**–**d**, addition of PhMgBr to dialkyl diketones **3e**,**f** was strongly dependent on the temperature as well as the solvent. Of the various conditions examined, THF was found be the best solvent and at –78 °C the addition afforded the C_2-symmetric compound **12a** as the major diastereomer (dr = 95:5, Table 4, entry 3). Addition of PhMgBr to the diketone **3f** lowered the dr to 75:25 in favor of the C_2-symmetric diastereomer **12b**. A dramatic reversal in the selectivity was found with bulkier diketones **3g** and **3h**, where addition of PhMgBr led to the formation of C_1-symmetric diastereomers **11c** and **11d** respectively as the exclusive product. All these results are summarized in Table 4. Origin of the C_1-symmetric diastereomer can be attributed to a strong 1,4-stereoinduction similar to that proposed for reduction (see above) forced by the bulky substituents present in the system.



Scheme 7 Addition of PhMgBr to alkyl diketones **3e–h**

Figure 2 summarizes some of the TADDOL analogues prepared by the reduction and addition of Grignard reagents to the 1,4-diketones derived from L-(+)-tartaric acid.

In a preliminary investigation of the prepared TADDOL analogues in asymmetric catalysis, four representative TADDOLs **I**–**IV** (Figure 2) were examined in enantioselective vinylogous Mukaiyama aldol addition reaction of silyldienol ethers to aldehydes reported by Rawal et al.[10] It was found that TADDOL analogue **I** catalyzed the addition of silyldienol ether **15** to ethyl glyoxalate (**16**) af-

Table 4 Addition of PhMgBr to 1,4-Dialkyldiketones **3e–h** Derived from Tartaric Acid

Entry	R	Solvent	Temp (°C)	dr by ^{1}H NMR			Yield (%)[a]
				12	**11**	**10**	
1	Me	Et_2O	0	35	35	30	84
2	Me	THF	0	67	22	11	62
3	Me	THF	−78	95	5	0	89
4	Et	Et_2O	0	18	51	31	81
5	Et	Et_2O	−78	40	56	4	87
6	Et	THF	0	44	56	0	31
7	Et	THF	−78	75	25	0	57
8	*i*-Pr	THF	0 to r.t.	0	100	0	94
9	*c*-C_6H_{11}	Et_2O	0 to r.t.	0	100	0	95

[a] Refers to isolated yield of a mixture of all diastereomers.

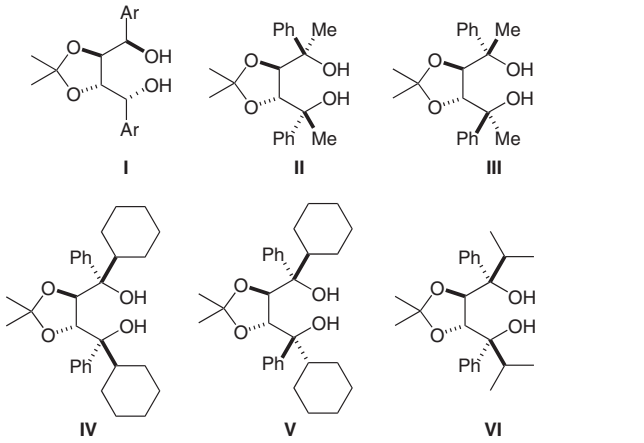
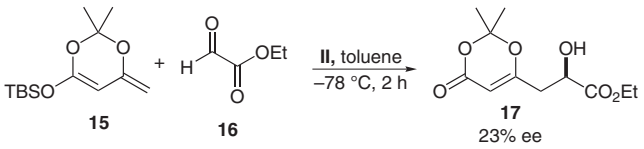


Figure 2 TADDOL analogues prepared by reduction and Grignard reagent addition to 1,4-diketones derived from tartaric acid



Scheme 8 Vinylogous Mukaiyama aldol reaction catalyzed by TADDOL analogues

fording product **17** in 10% ee, while **III** and **IV** afforded the product with 5% ee. TADDOL analogue **II** yielded the product with 23% ee (Scheme 8).

In summary, a systematic investigation of the nucleophilic addition reactions to the 1,4-diketones derived from L-(+)-tartaric acid was examined. Reduction of these diketones proceeded with very high selectivity with Selectride as the reducing agent. Addition of alkylmagnesium halides to the 1,4-diaryl diketones was strongly dependent on solvent, temperature, while the addition of PhMgBr on 1,4-dialkyl diketones derived from tartaric acid is dependent on alkyl group of the ketone. The diastereomeric 1,4-diols (Figure 2) represent a new class of analogues of TADDOL ligands. Further application of these ligands in catalytic asymmetric reactions is under way.

Column chromatography was performed on silica gel, Acme grade 100–200 mesh. TLC plates were visualized either with UV, in an iodine chamber, or with phosphomolybdic acid spray, unless otherwise noted. Unless stated otherwise, all reagents were purchased from commercial sources and used without additional purification. THF was freshly distilled over Na-benzophenone ketyl. Melting points were uncorrected. Petroleum ether used had bp range 60–80 °C. Unless stated otherwise, all the reactions were performed under an inert atmosphere.

(4*R*,5*R*)-4,5-Diacyl-2,2-dimethyl-1,3-dioxolanes 3a–h; General Procedure

In an oven-dried two-neck, 100-mL, round-bottom flask equipped with a magnetic stir bar, rubber septum, and argon inlet, was placed (4*R*,5*R*)-*N*,*N*′-dimethoxy-*N*,*N*′,2,2-tetramethyl-1,3-dioxolane-4,5-dicarboxamide (**2**; 0.55 g, 2.0 mmol) dissolved in THF (10 mL). The solution was cooled to –78 °C and a THF (or Et_2O) solution of RMgX (8 mmol) was added slowly and stirred at the same temperature. After the reaction was complete (disappearance of starting diamide was monitored by TLC), it was cautiously quenched by addition of cold aq sat. solution of NH_4Cl (10 mL). It was then poured into H_2O (15 mL) and extracted with Et_2O (3 × 20 mL). The combined Et_2O extracts were washed with brine (20 mL) and dried (Na_2SO_4). After removal of the solvent, the residue was purified by silica gel column chromatography using petroleum ether and EtOAc as an eluent to yield **3a–h**.

(4*R*,5*R*)-4,5-Dibenzoyl-2,2-dimethyl-1,3-dioxolane (3a)

Yield: 86%; mp 57–58.5 °C; $[\alpha]_D^{25}$ –78.3 (*c* = 1.2, $CHCl_3$) [Lit.[5a] $[\alpha]_D^{25}$ –78.4 (*c* = 1, $CHCl_3$)].

IR (KBr): 3060, 2989, 1686, 1598, 1449, 1210, 1153 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.12–8.10 (m, 4 H), 7.62–7.46 (m, 6 H), 5.85 (s, 2 H), 1.43 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 196.3, 134.8, 133.8, 129.5, 128.6, 113.3, 79.0, 26.7.

HRMS: *m*/*z* calcd for $C_{19}H_{18}O_4$ + Na: 333.1103; found: 333.1098.

(4*R*,5*R*)-4,5-Bis(4-methoxybenzoyl)-2,2-dimethyl-1,3-dioxolane (3b)
Yield: 83%; mp 118.7–120 °C; $[\alpha]_D^{25}$ –60 (*c* = 1.1, $CHCl_3$).

IR (neat): 3066, 2988, 2936, 1678, 1599, 1511, 835, 735, 619 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 8.11 (d, 4 H, *J* = 9 Hz), 6.95 (d, 4 H, *J* = 9 Hz), 5.79 (s, 2 H), 3.87 (s, 6 H), 1.44 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 194.7, 164.0, 131.9, 127.8, 113.8, 78.8, 55.4, 26.6.

Anal. Calcd for $C_{21}H_{22}O_6$ (370.4): C, 68.10; H, 5.99. Found: C, 68.22; H, 6.12.

(4*R*,5*R*)-2,2-Dimethyl-4,5-bis(4-methylbenzoyl)-1,3-dioxolane (3c)
Yield: 89%; mp 127–129 °C; $[\alpha]_D^{25}$ –70 (*c* = 1, $CHCl_3$).

IR (neat): 2986, 1680, 1603, 1321, 1284, 1144, 1091, 840, 724 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 8.00 (d, 4 H, *J* = 8.4 Hz), 7.48 (d, 4 H, *J* = 8.4 Hz), 5.81 (s, 2 H), 2.41 (s, 6 H), 1.42 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 195.9, 144.8, 132.3, 129.6, 129.3, 113.2, 79.0, 26.7, 21.8.

Anal. Calcd for $C_{21}H_{22}O_4$ (338.4): C, 74.54; H, 6.55. Found: C, 74.79; H, 6.68.

(4*R*,5*R*)-2,2-Dimethyl-4,5-bis(3,4-dimethylbenzoyl)-1,3-dioxolane (3d)
Yield: 85%; mp 137.2–138.4 °C; $[\alpha]_D^{25}$ –66.9 (*c* = 1.3, $CHCl_3$).

IR (neat): 2983, 2931, 1681, 1606, 1454, 1211, 862 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.84–7.81 (m, 4 H), 7.21 (d, 2 H, *J* = 7.5 Hz), 5.81 (s, 2 H), 2.30 (s, 12 H), 1.43 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 196.0, 143.4, 137.0, 132.7, 130.3, 129.8, 127.2, 113.1, 78.9, 26.7, 20.1, 19.7.

Anal. Calcd for $C_{23}H_{26}O_4$ (366.5): C, 75.38; H, 7.15. Found: C, 75.37; H, 7.03.

(4*R*,5*R*)-4,5-Diacetyl-2,2-dimethyl-1,3-dioxolane (3e)
Yield: 93%; $[\alpha]_D^{25}$ +30 (*c* = 1.5, $CHCl_3$).

IR (neat): 2991, 1726, 1377, 1358, 1259, 1095, 860 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 4.56 (s, 2 H), 2.31 (s, 6 H), 1.44 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 206.5, 112.5, 81.7, 26.5, 26.1.

HRMS: *m*/*z* calcd for $C_9H_{14}O_4$ + Na: 209.0790; found: 209.0788.

(4*R*,5*R*)-2,2-Dimethyl-4,5-dipropionyl-1,3-dioxolane (3f)
Yield: 89%; $[\alpha]_D^{25}$ +32 (*c* = 1, $CHCl_3$).

IR (neat): 2981, 2885, 1721, 1462, 1381, 1215, 1088, 1025, 977 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 4.58 (s, 2 H), 2.82–2.57 (m, 4 H), 1.43 (s, 6 H), 1.10 (t, 6 H, *J* = 7.2 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 209.2, 112.3, 81.4, 32.4, 26.1, 7.1.

HRMS: *m*/*z* calcd for $C_{11}H_{18}O_4$ + Na: 237.1103; found: 237.1105.

(4*R*,5*R*)-4,5-Di(isobutyryl)-2,2-dimethyl-1,3-dioxolane (3g)
Yield: 17%; $[\alpha]_D^{25}$ +64 (*c* = 0.5, $CHCl_3$).

IR (neat): 2974, 2875, 1716, 1467, 1383, 1259, 1211, 1072, 864 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 4.74 (s, 2 H), 3.12 (sept, 2 H, *J* = 6.9 Hz), 1.43 (s, 6 H), 1.70 (d, 6 H, *J* = 6.9 Hz), 1.20 (d, 6 H, *J* = 6.9 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 212.3, 112.2, 80.1, 37.1, 26.1, 18.3, 17.5.

HRMS: *m*/*z* calcd for $C_{13}H_{22}O_4$ + Na: 265.1416; found: 265.1396.

(4*R*,5*R*)-4,5-Bis(cyclohexylcarbonyl)-2,2-dimethyl-1,3-dioxolane (3h)
Yield: 6%; $[\alpha]_D^{25}$ +20 (*c* = 1, $CHCl_3$).

IR (neat): 2931, 2854, 1707, 1450, 1375, 1259, 1211, 1078, 860 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 4.72 (s, 2 H), 2.89–2.81 (m, 2 H), 1.94–1.19 (m, 20 H), 1.42 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 211.4, 112.2, 80.1, 46.9, 28.6, 27.7, 26.2, 25.8, 25.7, 25.3.

HRMS: *m*/*z* calcd for $C_{19}H_{30}O_4$ + Na: 345.2042; found: 345.2039.

(4*S*,5*S*)-4,5-Bis[(*R*)-hydroxy(aryl)methyl]-2,2-dimethyl-1,3-dioxolanes 4a–d; General Procedure
To a solution of 18-C-6 (793 mg, 3 mmol) in THF (5 mL) was added K-Selectride (444.5 mg, 2 mmol, 2 mL of 1 M solution in THF) at r.t. and the mixture was stirred for 5 min. Then, a solution of 4,5-di(aroyl)-2,2-dimethyl-1,3-dioxolane (0.5 mmol) in THF (5 mL) was added at –78 °C dropwise under argon. The mixture was stirred for 4.5 h at the same temperature and quenched with aq 2 N NaOH (2 mL) and 30% (w/v) H_2O_2 in H_2O (1 mL). It was then allowed to warm up to r.t. and stirred for 3 h. The suspension was filtered through a pad of Celite and the Celite pad was washed with Et_2O (20 mL). The filtrate was washed with brine and dried (Na_2SO_4). After evaporation of the solvent, the residue was purified by silica gel column chromatography using petroleum ether and EtOAc as an eluent to afford **4a–d**.

(4*S*,5*S*)-4,5-Bis[(*R*)-hydroxy(phenyl)methyl]-2,2-dimethyl-1,3-dioxolane (4a)
Yield: 82%; mp 110.5–112.3 °C; $[\alpha]_D^{25}$ –3.8 (*c* = 1.3, $CHCl_3$).

IR (neat): 3426, 2985, 2911, 1454, 1078, 766, 702 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.31–7.17 (m, 10 H), 4.16–4.13 (m, 4 H), 2.79 (br s, 2 H), 1.48 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 139.9, 128.5, 128.2, 126.6, 110.4, 81.5, 74.1, 27.5.

HRMS: *m*/*z* calcd for $C_{19}H_{22}O_4$ + Na: 337.1416; found: 337.1384.

(4*S*,5*S*)-4,5-Bis[(*R*)-hydroxy(4-methoxyphenyl)methyl]-2,2-dimethyl-1,3-dioxolane (4b)
Yield: 71%; $[\alpha]_D^{25}$ +24 (*c* = 0.5, $CHCl_3$).

IR (neat): 3453, 2928, 1612, 1513, 1248, 1032, 833, 621cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.08 (d, 4 H, *J* = 8.7 Hz), 6.79 (d, 4 H, *J* = 8.7 Hz), 4.16 (dd, 2 H, *J* = 3.8, 1.6 Hz), 4.07 (dd, 2 H, *J* = 3.8, 1.6 Hz), 3.78 (s, 6 H), 2.74 (br s, 2 H), 1.49 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 159.4, 131.9, 127.9, 113.8, 110.5, 81.8, 73.9, 55.2, 27.8.

HRMS: *m*/*z* calcd for $C_{21}H_{26}O_6$ + Na: 397.1627; found: 397.1604.

(4*S*,5*S*)-4,5-Bis[(*R*)-hydroxy(4-methylphenyl)methyl]-2,2-dimethyl-1,3-dioxolane (4c)
Yield: 65%; $[\alpha]_D^{25}$ +18 (*c* = 1, $CHCl_3$).

IR (neat): 3424, 2984, 2923, 1514, 1379, 1235, 1051, 818, 658 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.11–7.04 (m, 8 H), 4.14–4.09 (m, 4 H), 2.72 (br s, 2 H), 2.32 (s, 6 H), 1.47 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.8, 136.9, 129.1, 126.5, 110.4, 81.7, 74.0, 27.6, 21.1.

HRMS: *m*/*z* calcd for $C_{21}H_{26}O_4$ + Na: 365.1729; found: 365.1727.

(4*S*,5*S*)-4,5-Bis[(*R*)-hydroxy(3,4-dimethylphenyl)methyl]-2,2-dimethyl-1,3-dioxolane (4d)
Yield: 82%; $[\alpha]_D^{25}$ +25.7 (*c* = 0.7, $CHCl_3$).

IR (neat): 3441, 2923, 1505, 1455, 1381, 1238, 1062, 818 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.05–6.89 (m, 6 H), 4.13–4.08 (m, 4 H), 2.82 (br s, 2 H), 2.22 (s, 6 H), 2.21 (s, 6 H), 1.48 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.3, 136.6, 136.4, 129.6, 127.7, 124.0, 110.4, 81.9, 74.1, 27.7, 19.7, 19.5.

HRMS: *m*/*z* for $C_{23}H_{30}O_4$ + Na: 393.2042; found: 393.2066.

(4*S*,5*S*)-4,5-Bis[(*R*)-1-hydroxyalkyl)-2,2-dimethyl-1,3-dioxolanes 4e,f and Ketones 4g,h; General Procedure
To a solution of **3e–h** (1 mmol) in THF (5 mL) was added K-Selectride (4 mL, 1 M solution in THF) dropwise at –78 °C over 5 min under argon. The mixture was stirred for 4 h (for **4e**,**f** and 5 h for **4g**,**h**) at the same temperature and quenched with aq 2 N NaOH (2 mL) and 30% (w/v) H_2O_2 in H_2O (1 mL). It was then allowed to warm up to r.t. and stirred for 3 h. The suspension was filtered through a pad of Celite and the Celite pad was washed with Et_2O (20 mL). The filtrate was washed with brine and dried (Na_2SO_4). After evaporation of the solvent, the residue was purified by silica gel column chromatography using petroleum ether and EtOAc as an eluent to afford **4e–h**.

(4*S*,5*S*)-4,5-Bis[(*R*)-1-hydroxyethyl]-2,2-dimethyl-1,3-dioxolane (4e)
Yield: 92%; $[\alpha]_D^{25}$ –26 (*c* = 0.5, $CHCl_3$) [Lit.[11] $[\alpha]_D$ +26.1 (*c* = 0.44, $CHCl_3$) for the enantiomer].

IR (neat): 3413, 2985, 1373, 1234, 1074, 1014, 883 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 3.91–3.75 (m, 4 H), 2.32 (br s, 2 H), 1.44 (s, 6 H), 1.25 (d, 6 H, *J* = 6 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 109.4, 81.3, 67.0, 27.4, 20.1.

(4*S*,5*S*)-4,5-Bis[(*R*)-1-hydroxypropyl]-2,2-dimethyl-1,3-dioxolane (4f)
Yield: 98%; $[\alpha]_D^{25}$ –16.2 (*c* = 0.8, $CHCl_3$).

IR (neat): 3460, 2967, 2933, 1460, 1379, 1241, 1072, 977, 860 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 3.94 (s, 2 H), 3.43 (t, 2 H, *J* = 6.6 Hz), 2.02 (br s, 2 H), 1.60–1.51 (m, 4 H), 1.43 (s, 6 H), 1.02 (t, 6 H, *J* = 7.2 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 109.2, 79.6, 71.5, 27.8, 27.3, 10.2.

HRMS: *m*/*z* calcd for $C_{11}H_{22}O_4$ + Na: 241.1416; found: 241.1423.

1-{(4*R*, 5*S*)-5-[(*R*)-1-Hydroxy-2-methylpropyl]-2,2-dimethyl-1,3-dioxolan-4-yl}-2-methylpropan-1-one (4g)
Yield: 98%; $[\alpha]_D^{25}$ +45.5 (*c* = 1.8, $CHCl_3$).

IR (Neat): 3514, 2935, 1712, 1469, 1383, 1215, 1076, 883 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 4.48 (d, 1 H, *J* = 7.2 Hz), 4.20 (dd, 1 H, *J* = 7.5, 2.1 Hz), 3.32 (br s, 1 H), 3.14 (sept, 1 H, *J* = 6.9 Hz), 1.91 (br s, 1 H), 1.76 (sept, 1 H, *J* = 6.9 Hz), 1.37 (s, 3 H), 1.26 (s, 3 H), 1.15 (d, 3 H, *J* = 6.9 Hz), 1.09 (d, 3 H, *J* = 6.9 Hz), 1.02 (d, 3 H, *J* = 6.9 Hz), 0.09 (d, 3 H, *J* = 6.9 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 214.4, 110.3, 80.5, 78.0, 75.2, 36.8, 32.2, 26.7, 26.1, 22.5, 19.1, 18.5, 17.2.

HRMS: *m*/*z* calcd for $C_{13}H_{24}O_4$ + Na: 267.1572; found: 267.1573.

Cyclohexyl{(4*R*,5*S*)-5-[(*R*)-cyclohexyl(hydroxy)methyl]-2,2-dimethyl-1,3-dioxolan-4-yl}methanone (4h)
Yield: 85%; $[\alpha]_D^{25}$ +20.8 (*c* = 1.2, $CHCl_3$).

IR (neat): 3460, 2927, 1707, 1450, 1380, 1373, 1213, 1161, 1078, 877 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 4.46 (d, 1 H, *J* = 7.2 Hz), 4.21 (dd, 1 H, *J* = 7.5, 1.8 Hz), 3.32 (t, 1 H, *J* = 5.1 Hz), 2.93–2.84 (m, 1 H), 2.00–0.97 (m, 22 H), 1.47 (s, 3 H), 1.37 (s, 3 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 213.4, 110.2, 80.4, 77.6, 74.3, 46.6, 41.7, 29.2, 28.9, 28.7, 27.3, 26.7, 26.3, 26.1, 26.0, 25.9, 25.8, 25.2.

HRMS: *m*/*z* calcd for $C_{19}H_{32}O_4$ + Na: 347.2198; found: 347.2211.

Addition of RMgX to (4*R*,5*R*)-4,5-Dibenzoyl-2,2-dimethyl-1,3-dioxolane (3a); General Procedure
In a two-neck 100-mL, round-bottom flask equipped with a magnetic stir bar, rubber septum, and argon inlet was placed **3a** (0.77 g, 2.5 mmol). This was dissolved in THF (10 mL) and cooled to the temperature as mentioned in the Table 2. A THF (or Et_2O) solution of RMgX (10 mmol) was added slowly and the mixture was stirred until the reaction was complete (disappearance of starting diketone was monitored by TLC). It was then cautiously quenched by addition of aq sat. cold solution of NH_4Cl (10 mL). The mixture was then poured into H_2O (20 mL) and extracted with Et_2O (3 × 25 mL). The combined Et_2O extracts were washed with brine (30 mL) and dried (Na_2SO_4). After evaporation of the solvent, the crude residue was subjected to silica gel column chromatography to yield α,α′-dialkyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanols **10–14** listed below.

(α*S*,α′*S*,4*R*,5*R*)-α,α′,2,2-Tetramethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (10a)
Yield: 76%; mp 131–133 °C [Lit.[5a] mp 131–133 °C]; $[\alpha]_D^{25}$ –24.5 (*c* = 2, $CHCl_3$) [Lit.[5a] $[\alpha]_D^{25}$ –24.6 (*c* = 0.618, $CHCl_3$)].

IR (KBr): 3232, 2985, 1495, 1377, 1240, 1068 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.43–7.18 (m, 10 H), 4.18 (s, 2 H), 3.76 (br s, 2 H), 1.46 (s, 6 H), 1.31 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 146.1, 127.9, 127.0, 125.7, 109.6, 83.4, 74.1, 27.7, 24.3.

Anal. Calcd for $C_{21}H_{26}O_4$ (342.4): C, 73.66; H, 7.65. Found: C, 73.65; H, 7.66.

(α*S*,α′*R*,4*R*,5*R*)-α,α′,2,2-Tetramethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (11a)
Yield: 15%; $[\alpha]_D^{25}$ +2 (*c* = 2, $CHCl_3$).

IR (KBr): 3263, 2985, 1495, 1373, 1244, 1219, 1173, 1066 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.57–6.96 (m, 10 H), 4.27 (d, 1 H, *J* = 7.8 Hz), 3.61 (d, 1 H, *J* = 7.8 Hz), 1.70 (s, 3 H), 1.63 (br s, 1 H), 1.42 (s, 3 H), 1.14 (s, 3 H), 1.26 (s, 3 H), 1.08 (s, 3 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 146.2, 144.0, 128.0, 127.5, 127.2, 126.8, 126.5, 125.8, 108.6, 83.7, 83.0, 73.9, 73.8, 28.5, 27.5, 27.2, 23.6.

(α*S*,α′*S*,4*R*,5*R*)-α,α′-Diethyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (10b)
Yield: 93% (mixture of 75:25 **10b** and **11b**); mp 128–130 °C; $[\alpha]_D^{25}$ –12.8 (*c* = 0.7, $CHCl_3$).

IR (neat): 3514, 3377, 2972, 1446, 1369, 1232 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.23–7.16 (m, 10 H), 4.30 (s, 2 H), 2.30 (br s, 2 H), 1.83–1.69 (m, 4 H), 1.38 (s, 6 H), 0.55 (t, 6 H, *J* = 7.2 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.4, 128.0, 126.8, 126.3, 110.6, 84.4, 77.4, 29.9, 28.2, 7.2.

Anal. Calcd for $C_{23}H_{30}O_4$ (370.4): C, 74.56; H, 8.16. Found: C, 74.82; H, 8.53.

(αS,α′S,4R,5R)-α,α′-Diisopropyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (10c)
Yield: 21%; mp 143.5–144.8 °C; $[\alpha]_D^{25}$ –10 (*c* = 1.2, $CHCl_3$).

IR (neat): 3567, 3058, 2969, 1444, 1366, 1241 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.06–6.92 (m, 10 H), 4.72 (s, 2 H), 2.10 (s, 2 H), 2.06 (sept, 2 H, *J* = 7.2 Hz), 1.49 (s, 6 H), 0.79 (d, 6 H, *J* = 7.2 Hz), 0.48 (d, 6 H, *J* = 7.2 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 139.3, 127.2, 126.4, 126.3, 109.9, 81.9, 79.4, 36.3, 28.3, 18.2, 16.7.

Anal. Calcd for $C_{25}H_{34}O_4$ (398.4): C, 75.34; H, 8.60. Found: C, 75.19; H, 8.56.

(αS,α′S,4R,5R)-α,α′-Dicyclohexyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (10d)
Yield: 54%; mp 212.5–213.5 °C; $[\alpha]_D^{25}$ +18 (*c* = 0.5, $CHCl_3$).

IR (neat): 3560, 2926, 2853, 1444, 1371, 1240, 1046, 888 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.05–6.93 (m, 10 H), 4.71 (s, 2 H), 2.11 (s, 2 H), 2.11 (s, 2 H), 1.75–1.37 (m, 4 H), 1.51 (s, 6 H), 1.19–0.99 (m, 4 H), 0.91–0.76 (m, 4 H), 0.29–0.15 (m, 2 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.1, 127.3, 126.3, 126.1, 110.0, 81.6, 79.3, 46.9, 28.4, 28.1, 26.8, 26.7, 26.4, 26.3.

Anal. Calcd for $C_{31}H_{42}O_4$ (478.7): C, 77.79; H, 8.84. Found: C, 77.75; H, 8.81.

(αS,α′R,4R,5S)-α-Isopropyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (13c)
Yield: 38%; mp 126.0–128.2 °C; $[\alpha]_D^{25}$ –10.7 (*c* = 1.4, $CHCl_3$).

IR (neat): 3568, 2966, 2931, 1496, 1444, 1379, 1240, 1159, 1039, 748 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.53–6.76 (m, 10 H), 4.63 (d, 1 H, *J* = 8.1 Hz), 3.95 (d, 1 H, *J* = 8.1 Hz), 3.36 (d, 1 H, *J* = 9.9 Hz), 2.61 (d, 1 H, *J* = 13.2 Hz), 2.58 (s, 1 H), 2.29–2.23 (m, 1 H), 1.51 (s, 3 H), 1.41 (s, 3 H), 0.94 (d, 3 H, *J* = 6.9 Hz), 0.90 (d, 3 H, *J* = 6.9 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.3, 140.1, 128.2, 128.0, 127.3, 127.1, 126.1, 125.6, 109.1, 80.8, 70.9, 38.1, 27.5, 27.4, 18.2, 17.2.

Anal. Calcd for $C_{22}H_{28}O_4$ (356.5): C, 74.13; H, 7.92. Found: C, 74.20; H, 8.32.

(αS,α′R,4R,5S)-α-Cyclohexyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (13d)
Yield: 30%; mp 200–201 °C; $[\alpha]_D^{25}$ +27.7 (*c* = 0.9, $CHCl_3$).

IR (neat): 3566, 2985, 2931, 1448, 1371, 1242, 1219, 1601, 1099, 1070, 1018, 987, 822, 756, 706 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.52–7.10 (m, 8 H), 6.78–6.75 (m, 2 H), 4.64 (d, 1 H, *J* = 8.1 Hz), 3.94 (d, 1 H, *J* = 8.1 Hz), 3.39 (d, 1 H, *J* = 10.2 Hz), 2.60 (d, 1 H, *J* = 9.9 Hz), 2.58 (s, 1 H), 2.10–0.97 (m, 10 H), 1.51 (s, 3 H), 1.40 (s, 3 H), 0.84–0.70 (m, 1 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.3, 140.3, 128.1, 128.0, 127.3, 127.0, 126.1, 125.6, 109.0, 80.8, 80.4, 76.7, 70.9, 48.7, 27.8, 27.5, 27.4, 27.3, 26.8, 26.7, 26.4.

Anal. Calcd for $C_{25}H_{32}O_4$ (396.5): C, 75.73; H, 8.13. Found: C, 75.65; H, 7.98.

(αS,α′S,4R,5S)-α-Isopropyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (14c)
Yield: 19%; mp 111–112 °C; $[\alpha]_D^{25}$ –46.9 (*c* = 1.6, $CHCl_3$).

IR (neat): 3419, 2983, 2929, 1495, 1452, 1381, 1244, 1215, 1163, 1066, 1022, 895, 748, 704 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.53–7.01 (m, 10 H), 4.26 (dd, 1 H, *J* = 8.1, 4.2 Hz), 4.00 (d, 1 H, *J* = 8.1 Hz), 3.37 (d, 1 H, *J* = 4.2 Hz), 2.67 (s, 1 H), 2.28–2.14 (m, 1 H), 1.45 (s, 3 H), 1.09 (s, 3 H), 0.90 (d, 3 H, *J* = 6.9 Hz), 0.80 (d, 3 H, *J* = 6.9 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 141.1, 139.7, 128.5, 128.2, 128.0, 127.5, 126.3, 109.5, 82.6, 80.7, 76.7, 74.2, 37.4, 27.4, 27.2, 18.3, 17.3.

Anal. Calcd for $C_{22}H_{28}O_4$ (356.5): C, 74.13; H, 7.92. Found: C, 74.25; H, 8.02.

(αS,α′S,4R,5S)-α-Cyclohexyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (14d)
Yield: 15%; $[\alpha]_D^{25}$ –11.6 (*c* = 2.5, $CHCl_3$).

IR (neat): 3419, 2929, 2852, 1495, 1448, 1381, 1242, 1163, 1070, 877, 758, 704 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.52–7.25 (m, 10 H), 4.25 (dd, 1 H, *J* = 8.1, 3.9 Hz), 4.02 (d, 1 H, *J* = 8.1 Hz), 3.39 (d, 1 H, *J* = 3.9 Hz), 2.70 (s, 1 H), 2.00–0.78 (m, 11 H), 1.45 (s, 3 H), 1.09 (s, 3 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 141.4, 139.9, 128.5, 128.2, 128.0, 127.9, 127.4, 126.3, 109.5, 82.3, 80.7, 74.3, 47.9, 27.8, 27.4, 27.3, 27.2, 26.8, 26.6, 26.4.

HRMS: *m*/*z* calcd for $C_{25}H_{32}O_4$ + Na: 419.2198; found: 419.2215.

Addition of PhMgBr to 4,5-Diacyl-2,2-dimethyl-1,3-dioxolanes 3e–h; General Procedure
In a two-neck 100-mL, round-bottom flask equipped with a magnetic stir bar, rubber septum, and argon inlet was placed **3e–h** (2 mmol). This was dissolved in THF (10 mL) and cooled to the temperature as mentioned in Table 3. A THF (or Et_2O) solution of PhMgBr (8 mmol) was added slowly and the mixture was stirred for the specified time. After the reaction was complete (disappearance of starting diketone indicated by TLC), it was cautiously quenched by addition of aq sat. cold solution of NH_4Cl (10 mL) and poured into H_2O (20 mL). The mixture was extracted with Et_2O (3 × 25 mL) and the combined Et_2O extracts were washed with brine (30 mL) and dried (Na_2SO_4). After evaporation of the solvent, the crude residue was subjected to silica gel column chromatography to yield **12a–d**.

(αR,α′R,4R,5R)-α,α′,2,2-Tetramethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (12a)
Yield: 89%; mp 196.0–196.5 °C [Lit.[5a] mp 192–193 °C]; $[\alpha]_D^{25}$ +46 (*c* = 1, $CHCl_3$) {Lit.[5a] $[\alpha]_D^{25}$ +46.4 (*c* = 0.627, $CHCl_3$)}.

IR (neat): 3294, 2985, 1595, 1371, 1216, 1071, 880, 773 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.57–7.25 (m, 10 H), 4.84–4.81 (m, 2 H), 3.48 (s, 2 H), 1.55 (s, 6 H), 1.01 (s, 6 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.3, 127.5, 127.0, 126.9, 108.3, 83.6, 74.1, 29.1, 27.0.

(αR,α′R,4R,5R)-α,α′-Diethyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (12b)
Yield: 87% (75:25 mixture of **12b**:**11b**); $[\alpha]_D^{25}$ +29.2 (*c* = 1.2, $CHCl_3$).

IR (neat): 3346, 2983, 1446, 1242, 1072, 985, 887, 760 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.55–7.26 (m, 10 H), 4.15 (s, 2 H), 3.48 (s, 2 H), 2.19–2.06 (m, 2 H), 1.82–1.67 (m, 2 H), 1.05 (s, 6 H), 0.70 (t, 6 H, *J* = 7.2 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 141.8, 127.5, 127.2, 126.9, 108.1, 82.3, 76.5, 33.3, 27.1, 7.0.

HRMS: *m*/*z* calcd for $C_{23}H_{30}O_4$ + Na: 393.2042; found: 393.2035.

(αR,α′R,4R,5S)-α,α′-Diisopropyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (11c)
Yield: 94%; mp 89.7–90.3 °C; $[\alpha]_D^{25}$ –10 (*c* = 0.8, $CHCl_3$).

IR (neat): 3554, 3305, 2976, 1446, 1378, 1242, 1171, 1063, 891, 739 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.34–7.19 (m, 10 H), 4.42 (d, 1 H, *J* = 8.1 Hz), 3.83 (d, 1 H, *J* = 8.1 Hz), 2.46 (s, 1 H), 2.34–2.17 (m, 2 H), 1.44 (s, 3 H), 1.36 (s, 3 H), 1.16 (s, 1 H), 1.01 (d, 3 H, *J* = 6.6 Hz), 0.75 (d, 3 H, *J* = 6.9 Hz), 0.68 (d, 3 H, *J* = 7.2 Hz), 0.41 (d, 3 H, *J* = 6.6 Hz).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.3, 140.5, 128.1, 127.6, 127.2, 126.8, 126.7, 126.6, 107.0, 82.2, 80.1, 77.7, 76.8, 37.1, 36.0, 27.4, 27.1, 18.3, 17.1, 16.6, 16.3.

Anal. Calcd for $C_{25}H_{34}O_4$ (398.4): C, 75.34; H, 8.60. Found: C, 75.14; H, 8.43.

(α*R*,α′*R*,4*R*,5*S*)-α,α′-Dicyclohexyl-2,2-dimethyl-α,α′-diphenyl-1,3-dioxolane-4,5-dimethanol (12d)
Yield: 95%; $[\alpha]_D^{25}$ +11 (*c* = 2, $CHCl_3$).

IR (neat): 3550, 2931, 2852, 1493, 1446, 1379, 1238, 1057, 891, 758, 708 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 7.38–7.14 (m, 10 H), 4.43 (d, 1 H, *J* = 8.1 Hz), 3.84 (d, 1 H, *J* = 8.1 Hz), 2.37 (s, 1 H), 1.92–0.78 (m, 21 H), 1.42 (s, 3 H), 1.38 (s, 3 H), 0.42–0.30 (m, 1 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.3, 140.8, 128.2, 127.6, 127.2, 126.8, 126.7, 126.5, 107.0, 81.5, 79.8, 77.6, 48.0, 45.7, 28.1, 27.5, 27.2, 27.1, 26.8, 26.6, 26.5, 26.4, 26.3, 26.2, 26.0.

HRMS: *m*/*z* calcd for $C_{31}H_{42}O_4$ + Na: 501.2981; found: 501.2969.

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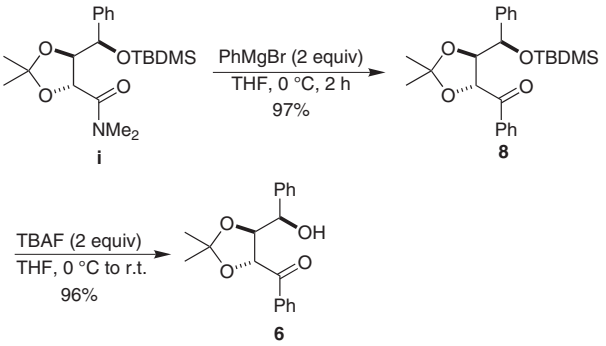

Scheme 9

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