Diethylamino(trimethyl)silane-mediated direct 1,4-addition of naked aldehydes to electron-deficient olefins

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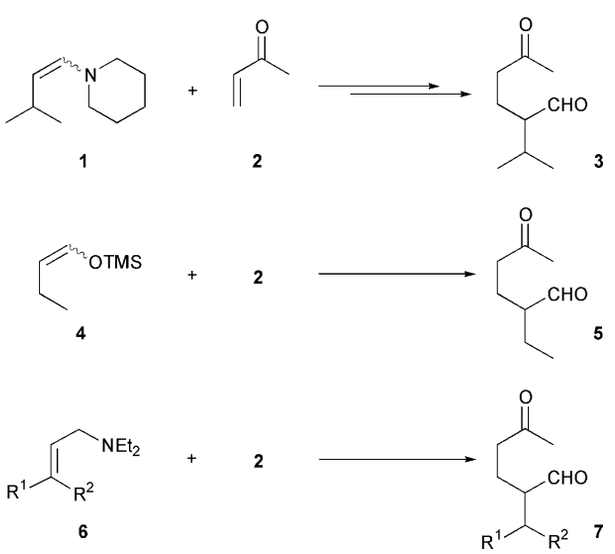
Aldehydes directly add in a 1,4-manner to electron-deficient olefins in the presence of diethylamino(trimethyl)silane.

Introduction

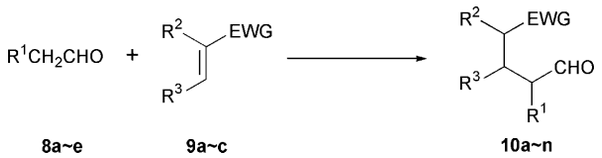
Clean and quantitative generation of enolates or enols of aldehydes has been difficult because of the high reactivity of the formyl group under either basic or acidic reaction conditions. Such lability of the formyl group imposes a difficulty to the control of nucleophilic reactions of aldehydes. In order to solve such problems, aldehydes were transformed to stable synthons which were then treated with electrophiles. After the reaction, the latent formyl groups were transformed back to aldehydes. In the case of conjugate addition of aldehydes to electron-deficient olefins, there have been no successful precedents of direct 1,4-addition of naked aldehydes. The products, substituted 5-keto aldehydes such as **3**, **5** or **7** (Scheme 1), have been important



Scheme 1

compounds, especially for syntheses of substituted cyclohex-2-enone derivatives[1] which have themselves been versatile starting materials for syntheses of natural products such as terpenoids. So far, these 5-ketoaldehydes have been prepared mainly by the 1,4-addition of masked aldehydes, *i.e.* piperidinoenamine **1**[2] of an aldehyde, trimethylsilylenol ether **4** of an aldehyde in the presence of Lewis acid,[3] or diethylallylamine **6** in the presence of a catalytic amount of Ru complex,[4] to but-3-en-2-one **2** (Scheme 1).

We disclose herein a novel protocol for direct 1,4-addition of naked aldehydes **8** to electron-deficient olefins **9** to give



8a~e **9a~c** **10a~n**

Scheme 2

substituted aldehydes **10** (Scheme 2).[5] To the best of our knowledge, this is the first example of the synthesis of 5-keto- or other substituted aldehydes by 1,4-addition of naked aldehydes. Though there are several examples of a one-pot procedure for 1,4-addition of naked aldehydes followed by intramolecular aldol condensation,[6] intermediary 5-keto aldehydes have never been isolated under the reaction conditions.

Results and discussion

As new reagents for such purposes, we paid attention to aminosilane derivatives which so far have been underdeveloped as reagents for carbon–carbon bond-forming reactions other than silylation of an alcohol[7] or amine,[8] dealkylation of an ester,[9] ring opening of oxiranes,[10] and synthesis of a silylenol ether[11] or enamine,[12] though during the course of our study, Saidi *et al.*[13] reported some synthetic applications in C–C bond-forming reactions *via* iminium cation intermediates generated by diethylamino(trimethyl)silane (DEATMS).

Conjugate addition of decanal **8a** to but-3-en-2-one **9a** (≡**2**) was at first investigated as a probe to investigate optimized reaction conditions (Scheme 2, $R^1 = C_8H_{17}$, $R^2 = R^3 = H$, EWG = COMe). The results are listed in Table 1. Among the reagents tested, DEATMS[14] was found to give the best result (Table 1, entry 8). Use of chlorotrimethylsilane, triethylamine or tris(trimethylsilyl)amine led to only recovered aldehyde **8a** (Table 1, entry 2, 3 or 4). Other silylamine derivatives such as trimethylsilylpyrrolidine or bis(dimethylamino)dimethylsilane provided 2-(3-oxobutyl)decanal **10a** in lower yield (Table 1, entry 5 or 7). Diethylamine (Et_2NH) also gave an unsatisfactory result (Table 1, entry 6).

Further tuning of the reaction conditions revealed that 0.5 mol equiv. of DEATMS was enough (Table 2, entries 1 and 2). In entries 2–8, starting aldehyde **8** was recovered without any side product. The reaction was carried out simply by stirring the reaction mixture at room temperature overnight under nitrogen atmosphere, and evaporation of excessive reagents *in vacuo* followed by purification by medium-pressure liquid chromatography of the residue provided 5-keto aldehydes **10**. Some

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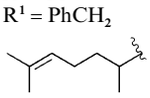
Table 1 Investigation of reagents for 1,4-addition[a]

Entry	Reagent	2-(3-Oxobutyl)decanal **10a** Yield (%)[b]
1	None	0[c]
2	$ClSiMe_3$	0[c]
3	Et_3N	0[c]
4	$N(SiMe_3)_3$	0[c]
5	$C_4H_8NSiMe_3$	29
6	Et_2NH	35
7	$Me_2Si(NMe_2)_2$	46 (80)[d]
8	DEATMS	67

[a] Reaction was carried out without solvent. [b] Yield is based on initial aldehyde **8a**. [c] Decanal was recovered completely. [d] Yield in parentheses based on the aldehyde consumed.

Table 2 1,4-Addition of aldehydes **8** to vinyl ketones **9**[a]

Entry	Aldehyde **8**	Vinyl ketone **9** (EWG = COMe)	5-Keto aldehyde **10a–e** Yield (%)[b]	
1	**8a** $R^1 = C_8H_{17}$	**9a** $R^2 = R^3 = H$ (≡ **2**)	**10a**	67
2	**8a** $R^1 = C_8H_{17}$	**9a** $R^2 = R^3 = H$ (≡ **2**)	**10a**	22[c]
3	**8a** $R^1 = C_8H_{17}$	**9b** $R^2 = H$, $R^3 = Me$	**10b**	15
4	**8b** $R^1 = C_6H_{13}$	**9a** $R^2 = R^3 = H$ (≡ **2**)	**10c**	49
5	**8a** $R^1 = C_8H_{17}$	**9c** $R^2 = Me$, $R^3 = H$	**10d**	35
6	**8c** $R^1 = Pr^i$	**9a** $R^2 = R^3 = H$ (≡ **2**)	**10e** (≡ **3**)	22
7	**8d** $R^1 = PhCH_2$	**9a** $R^2 = R^3 = H$ (≡ **2**)	**10f**	58
8	**8e** 	**9a** $R^2 = R^3 = H$ (≡ **2**)	**10g**	13

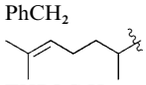
[a] All reactions were conducted at room temp. overnight with 0.5 mol equiv. of DEATMS without solvent unless otherwise indicated. All reagents were used directly from bottles. [b] Yield is based on initial aldehyde **8**. [c] DEATMS (0.2 mol equiv.) was used.

representative results of the present reaction are shown in Table 2. Conjugate addition of the diethylamino group of DEATMS to but-3-en-2-one **9a** (≡ **2**) was not a serious side reaction in spite of the report by Hosomi and co-workers,[15] probably due to the lower reaction temperature used here.

Though the reaction without solvent satisfies the demands of environmentally benign 'green' chemistry, the reactions with aldehydes having substituents at the β position to the formyl group such as isovaleraldehyde **8c** (Table 2, entry 6), citronellal **8e** (Table 2, entry 8), or with less reactive olefins such as **9b** or **9c** (Table 2, entry 3 or 5), were sluggish and gave lower yields. Our continuing efforts to improve the reaction conditions revealed that the reaction in refluxing acetonitrile solution provided improved yields, thereby expanding the generality of the present reaction as shown in Table 3. The reaction in dichloromethane gave lower yields (Table 3, entries 1 and 2). Not only isovaleraldehyde **8c** but also citronellal **8e** provided 1,4-addition product **10e** (≡**3**) or **10g** in good yield (Table 3, entry 4 or 6). For medium-scale reaction of citronellal **8e** (100 mmol) (Table 3, entry 6), addition of 10 mol% of DEATMS was sufficient to achieve satisfactory yield after simple bulb-to-bulb distillation (see Experimental section). The mildness of the reaction is well exemplified by the successful results of the reaction with acid- or base-sensitive aldehydes having tetrahydropyran-2-yl (THP) or acetyl protecting groups (Table 3, entries 7 or 8).

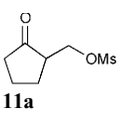
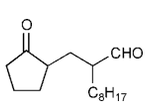
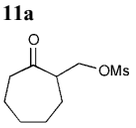
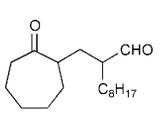
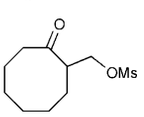
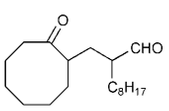
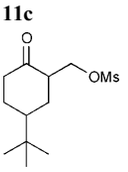
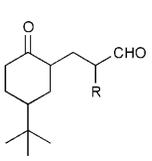
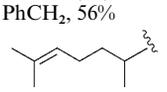
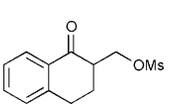
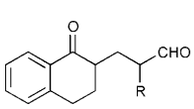
Then, conjugate addition to enones having a fixed *s-cis* configuration was investigated. Reaction of aldehydes **8** with α-methylenecycloalkanones **12** generated *in situ* from the corresponding mesyl ester **11** and DEATMS in CH_2Cl_2 provided keto aldehydes **13** in good yield irrespective of ring size (Scheme 3, Table 4). Initial formation of the α-methylenecyclohexanone from the mesyl ester **11d** with 1,8-diazabicyclo-[5.4.0]undec-7-ene (DBU) followed by addition of aldehyde

Table 3 1,4-Addition of aldehydes **8** with electron-deficient olefins **9** in CH_3CN at reflux[a]

Entry	Aldehyde **8** R^1	Olefin **9** ($R^3 = H$) EWG	R^2	Product **10** Yield (%)[b]	
1	C_8H_{17}	COMe	H	**10a**	54[c]
2	C_8H_{17}	COMe	H	**10a**	66[d]
3	C_8H_{17}	COMe	H	**10a**	78
4	Pr^i	COMe	H	**10e** (≡ **3**)	64
5	$PhCH_2$	COMe	H	**10f**	59
6		COMe	H	**10g**	96[d]
7	$THPOC_3H_6$	COMe	H	**10h**	89
8	$AcOC_8H_{16}$	COMe	H	**10i**	76
9	C_8H_{17}	COEt	H	**10j**	76
10	$PhCH_2$	COEt	H	**10k**	68
11	C_8H_{17}	SO_2Ph	H	**10l**	32
12	$PhCH_2$	SO_2Ph	H	**10m**	34
13	C_8H_{17}	CO_2Me	H	**10n**	55
14	C_8H_{17}	COMe	Me	**10d**	20

[a] 1 mol equiv. of DEATMS was used. [b] Yield is based on aldehyde **8**. [c] Dichloromethane was employed as solvent. [d] 10 mol% of DEATMS was used.

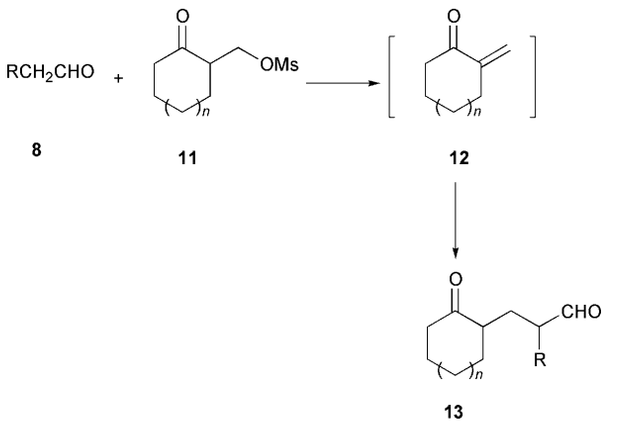
Table 4 1,4-Addition of aldehydes **8** with α-methylenecycloalkanones[a]

Entry	Mesyl ester **11**	Product **13**[b,c]
1	 **11a**	 **13a** 67% (46%)[d]
2	 **11b**	 **13b** 47%
3	 **11c**	 **13c** 69%
4	 **11d**	 **13d** R = C_8H_{17}, 77% (52%[e])
5	**11d**	**e** R = $AcOC_8H_{16}$, 67%
6	**11d**	**f** R = $THPOC_3H_6$, 65%
7	**11d**	**g** R = $PhCH_2$, 56%
8	**11d**	**h** R =  , 45%
9	 **11e**	 **13i** R = C_8H_{17}, 83%
10	**11e**	**j** R = $PhCH_2$, 76%

[a] DEATMS (2.4 mol equiv.) was used in CH_2Cl_2. [b] Yield is based on initial mesyl **11**. [c] A mixture of diastereomers was obtained. [d] The reaction was carried out in CH_3CN. [e] Equivalent amounts of DBU and DEATMS were used in CH_2Cl_2.

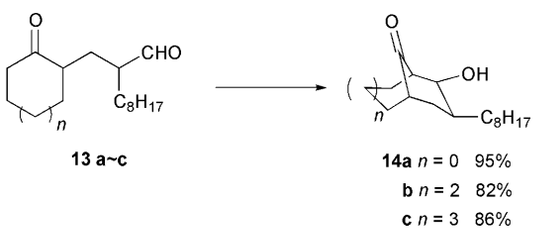
and DEATMS did not give any better yield (Table 4, entry 4). Products were mixtures of diastereomers. These reactions proceeded well in CH_2Cl_2 rather than in CH_3CN (Table 4, entry 1).

The 5-keto aldehydes **10a–k** and **13a–h** thus obtained are useful precursors for several carbocyclic compounds. Intra-



Scheme 3

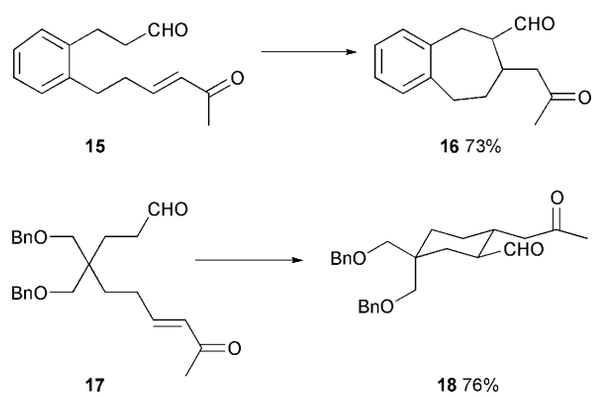
molecular aldol condensation of the 5-keto aldehyde **10g** followed by dehydration provided a 4-substituted cyclohex-2-enone which has been applied to the syntheses of bisabolane sesquiterpenoids.[16] The result will be reported in due course. Similarly, treatment of the keto aldehydes **13a–c** with potassium hydroxide in methanol (Scheme 4) furnished in



Scheme 4

satisfactory yield diastereomeric mixtures of aldols **14a–c** having bicyclo[*n* + 2.3.1]carbon frameworks which are also useful core units for terpenoid syntheses. An attempt to equilibrate the aldols into thermodynamically more stable diastereomers by prolonging the reaction time did not diminish the amount of initial diastereomer.

Intramolecular 1,4-conjugate addition was also possible, as shown in Scheme 5. Treatment of aldehydic enone **15**



Scheme 5

with DEATMS in MeCN at room temperature afforded keto aldehyde **16** in 73% yield as a 7:3 diastereomeric mixture. In the formation of a six-membered ring, the thermodynamically more stable keto aldehyde **18** was obtained as a single diastereomer by similar 1,4-conjugate addition of the starting material **17**.

Details regarding mechanistic considerations are yet to be discussed. One obvious question regarding the reaction pathway is the role of DEATMS. Initially, the ability of DEATMS as a base was estimated. Comparison of Mulliken populations of dimethylamino(trimethyl)silane and dimethylamine by *ab initio* calculations at the MP2/6-31G(d) level[17] indicated that the electron densities on the nitrogen atoms of both molecules were the same (−0.59). On the other hand, charge separation between nitrogen and heteroatoms of Me_2NSiMe_3 was greater than that of $FSiMe_3$ which was a stronger Lewis acid. This result alludes to the postulate that DEATMS works as both Lewis base and Lewis acid. However, treatment of decanal **8a** with DEATMS in the presence of D_2O in deuteriochloroform in an NMR tube revealed no deuterium incorporation at the α position to the formyl group of decanal **8a**. Thus, formation of the enolate of decanal **8a** by DEATMS did not occur.

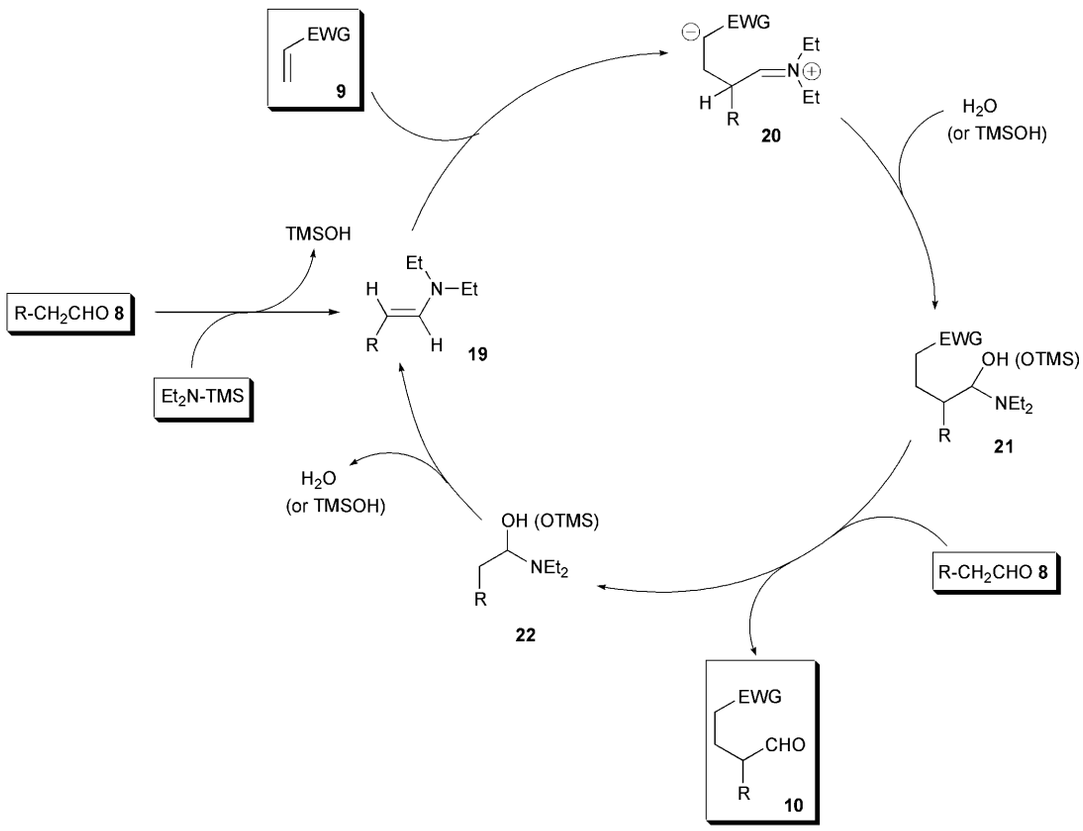
On the reactivity of aminotrimethylsilanes toward carbonyl compounds, two inconsistent papers appeared at the same time. Hellberg and Juarez[11a] reported trimethylsilyl enol ether formation in the presence of a catalytic amount of toluene-*p*-sulfonic acid. On the other hand, Weinreb and co-workers[12] reported enamine formation under the same reaction conditions. The reaction was repeated again and it was found that decanal **8a** reacted with DEATMS in deuteriochloroform in an NMR tube to give enamine **19** (R = C_8H_{17}) at room temperature after 22 h as shown by the chemical-shift data [δ 4.18 (dt, *J* 13.8 and 7 Hz) and 5.86 (d, *J* 13.8 Hz)][4,18] of olefinic protons (Scheme 6). The ratio of diethylaminoenamine of decanal **19** (R = C_8H_{17}) to decanal **8a** was 1.3:1 according to peak area. Addition of D_2O to this enamine mixture did not show any decrease of peak area for proton(s) α to the formyl group probably due to trimethylsilanol (TMSOH) or water generated. Formation of the silyl enol ether of decanal **8a** was not observed. These results suggest the intervention of an enamine intermediate in the present reaction.

Only 0.1 equiv. of DEATMS was sufficient to promote the 1,4-addition reaction in 96% yield (Table 3, entry 6; see Experimental section). This result suggests that DEATMS or related intermediates work catalytically, though Et_2NH itself did not give a satisfactory yield of 1,4-addition product **10a** (Table 1, entry 6).

Important support for the reaction pathway was obtained by the following experiment. Diethylaminoenamine **19** of decanal **8a** (R = C_8H_{17}) was prepared according to the procedure of Stork.[2] NMR measurement of diethylaminoenamine **19** soon after Kugelrohr distillation revealed that the distillate was obtained as a mixture of enamine **19**, decanal **8a** (**19**:**8a** = 1.3:1) and diethylamine. In view of the highly volatile nature of diethylamine, the present NMR observation indicates that diethylamine was generated by hydrolysis of diethylaminoenamine **19** by moisture during transfer in spite of initial drying of the NMR tube under vacuum.[18] Reaction of decanal **8a**, but-3-en-2-one **2** and a catalytic amount of mixture of the enamine **19** and **8a** in refluxing acetonitrile provided 1,4-addition product **10a** in 74% yield. Thus, the present reaction seems to proceed by recycling enamine **19** generated initially by DEATMS or Et_2NH. Since it is known that TMSOH dehydrates to trimethylsiloxane under either acidic or basic conditions,[19] the resulting water co-catalysed the cycle. Actually, in the presence of molecular sieves powder 4 Å and 0.2 equiv. of DEATMS in refluxing CH_3CN, citronellal **8e** provided only 20% of 1,4-addition product **10g** along with 48% recovery of **8e**. Extensive efforts to trap trimethylsiloxane at liquid nitrogen temperature failed during Kugelrohr distillation.

Thus, a plausible reaction pathway for the present 1,4-conjugate addition is drawn by regenerating diethylaminoenamine **19** as shown in Scheme 6. A fair degree of instability[18] of diethylaminoenamine **19** might drive the catalytic cycle forward.

In summary, a new practical entry to direct 1,4-conjugate addition of naked aldehydes to electron deficient olefins was realized for the first time. At the same time, new reactivity of



Scheme 6 Plausible reaction pathway.

DEATMS which has been quite limited so far in organic synthesis was developed. The novelty as well as mildness of the reaction conditions and simplicity of operation should make the present reaction highly synthetically useful.[20]

Experimental

IR spectra were recorded on a JASCO FT/IR 8300 or a Shimadzu FT/IR-4200 spectrophotometer for solutions in tetrachloromethane. ^{1}H NMR spectra were obtained for solutions in deuteriochloroform with JEOL FX 90Q (90 MHz) or Varian Gemini 200H (200 MHz) instruments with tetramethylsilane as internal standard. *J*-Values are given in Hz. ^{13}C NMR spectra were measured with a Varian Gemini 200H (50 MHz) instrument. Mass spectral data were run on a JEOL JMS-DX300, a JEOL JMS-GCMATE or Hitachi M-80B instrument. Medium-pressure liquid chromatography (MPLC) was carried out on a JASCO PRC-50 instrument with a silica gel packed column.

Repeated elemental analyses of the compounds in this section provided no satisfactory results probably due to instabilites of the formyl groups. Efforts to get high-resolution mass spectral data were also in vain because of the low intensity of molecular peaks. We are ready to supply copies of NMR spectral charts for verification of the purity of our samples.

Commercially available aldehydes, electron-deficient olefins and DEATMS were used as purchased. Commercially available special-grade MeCN was used directly from the bottle. CH_2Cl_2 was distilled from calcium hydride prior to use.

2-(3-Oxobutyl)decanal 10a

Reaction without solvent. To a stirred mixture of decanal (0.190 cm^3, 1 mmol) and DEATMS (0.085 cm^3, 0.5 mmol) was added but-3-en-2-one (0.100 cm^3, 1.2 mmol) at 0 °C under a nitrogen atmosphere. The resulting mixture was stirred at room temperature overnight. Evaporation of excess of reagents *in vacuo* followed by MPLC purification (eluent: *n*-hexane–ethyl acetate = 4 : 1) provided the keto aldehyde **10a** (150 mg, 67%), ν_{max}/cm^{-1} 2958, 2929, 2857, 1724, 1466, 1457, 1366 and 1163; δ_H (200 MHz) 0.88 (t, *J* 6.2, 3H), 1.20–1.50 (br s, 12H), 1.60–2.00 (m, 4H), 2.14 (s, 3H), 2.30 (m, 1H), 2.46 (br t, 2H) and 9.55 (d, *J* 2.8, 1H); δ_C (50 MHz) 13.9, 22.1, 22.5, 26.8, 28.8, 29.0, 29.2, 29.5, 29.8, 31.6, 40.5, 51, 204.6 and 207.6; *m*/*z* 226 (M$^+$, 3%), 208 (4), 198 (6), 127 (18), 114 (22), 86 (21), 71 (24), 59 (43), 58 (100) and 43 (50) (Found: M$^+$, 226.1906. Calc. for $C_{14}H_{26}O_2$: *M*, 226.1933).

2-(1-Methyl-3-oxobutyl)decanal 10b

Yield 15% (a mixture of inseparable diastereomers); ν_{max}/cm^{-1} 2928, 2710, 1741, 1721, 1466, 1373, 1240, 1164, 1048 and 909; δ_H (90 MHz) 0.7–1.04 (br, t + d, 6H), 1.05–1.8 (m, 15H), 2.13 (s, 3H), 2.1–2.7 (m, 3H) and 9.6 (d, *J* 3, 1H); *m*/*z* 240 (M$^+$, 6%), 183 (19), 154 (18), 128 (19), 110 (22), 109 (29), 97 (29), 95 (33), 85 (68), 83 (29), 71 (42), 70 (29), 69 (56), 67 (30), 59 (86), 58 (100), 57 (55), 56 (33), 55 (75) and 41 (68).

2-(3-Oxobutyl)octanal 10c

Yield 49%; ν_{max}/cm^{-1} 2931, 1721, 1467, 1457, 1414, 1366, 1162 and 908; δ_H (90 MHz) 0.87 (br t, *J* 6.1, 3H), 1.1–2.3 (m, 5H), 1.27 (br s, 10H), 2.14 (s, 3H) and 9.55 (d, *J* 2.6, 1H); *m*/*z* 196 (M$^+$ − 2 , 8%), 168 (15), 139 (13), 110 (15), 98 (37), 84 (22), 83 (17), 71 (22), 69 (25), 58 (23), 55 (36) and 43 (100).

2-(2-Methyl-3-oxobutyl)octanal 10d

Two diastereomers were isolated and are listed in their order of elution. Isomer I, yield 17%; ν_{max}/cm^{-1} 2957, 2726, 1718 and 1707; δ_H (200 MHz) 0.88 (t, *J* 6.1, 3H), 1.10 (d, *J* 7.0, 3H), 1.20–1.45 (br s, 14H), 1.50–1.71 (m, 2H), 2.15 (s, 3H), 2.25 (m, 1H), 2.50–2.70 (br q, 1H) and 9.54 (d, *J* 3.1, 1H).

Isomer II, yield 17%; ν_{max}/cm^{-1} 2957, 2693, 1718 and 1707; δ_H (200 MHz) 0.88 (t, *J* 6.2, 3H), 1.14 (d, *J* 7.0, 3H), 1.20–1.40 (br s, 14H), 1.40–1.70 (m, 2H), 2.16 (s, 3H), 2.30 (br s, 1H), 2.54

(q, *J* 7.0, 1H) and 9.52 (d, *J* 3.1, 1H); *m*/*z* 128 (4%), 110 (6), 85 (10), 72 (100), 57 (30) and 55 (37).

2-Isopropyl-5-oxohexanal 10e (≡3)

Reaction in MeCN. A stirred solution of isovaleraldehyde (0.107 cm^3, 1 mmol), but-3-en-2-one (0.100 cm^3, 1.2 mmol) and DEATMS (0.189 cm^3, 1 mmol) in MeCN (4 cm^3) was heated at reflux for 9 h. The resulting solution was passed through a short silica gel column and the residue was purified by MPLC (eluent: *n*-hexane–ethyl acetate = 4 : 1) to give the keto aldehyde **10e** (≡ **3**) (101 mg, 64%), ν_{max}/cm^{-1} 2965, 2710, 1723 and 1710; δ_H (200 MHz) 0.97 (d, *J* 6.6, 3H), 0.99 (d, *J* 6.0, 3H), 1.70–2.10 (m, 3H), 2.13 (s, 3H), 2.28–2.63 (m, 3H) and 9.61 (d, *J* 2.8, 1H); *m*/*z* 154 ($M^+ - 2$, 10%), 126 (35), 111 (18), 87 (22), 84 (44), 69 (46), 58 (40) and 43 (100).

2-Benzyl-5-oxohexanal 10f

Yield 58%; ν_{max}/cm^{-1} 3031, 2930, 2710, 1720, 1497, 1456, 1356 and 1160; δ_H (200 MHz) 1.65–2.05 (m, 2H), 2.09 (s, 3H), 2.43 (dd, *J* 14.0, 6.3, 1H), 2.55–2.80 (m, 3H), 3.02 (dd, *J* 14.0, 6.3, 1H), 7.10–7.40 (m, 5H) and 9.64 (d, *J* 2.2, 1H); δ_C (50 MHz) 22.1, 29.8, 35.2, 40.4, 52.3, 128.3, 128.5, 128.6, 128.8, 203.8 and 207.6; *m*/*z* 204 (M^+, 9%), 176 (10), 146 (15), 118 (44), 117 (40), 92 (21), 91 (94), 58 (32) and 43 (100) [Found: ($M^+ - H_2O$), 186.1055. Calc. for $C_{13}H_{14}O$: ($M - H_2O$), 186.1045].

(2*RS*,3*R*)-3,7-Dimethyl-2-(3-oxobutyl)oct-6-enal 10g

Medium-scale preparation. A solution of citronellal **8e** (18.1 cm^3, 100 mmol), DEATMS (1.9 cm^3, 10 mmol) and but-3-en-2-one (12.5 cm^3, 150 mmol) in MeCN (400 cm^3) was refluxed for 46 h under a nitrogen atmosphere. Evaporation of MeCN *in vacuo* followed by Kugelrohr distillation (120–140 °C at 1.9 mmHg) afforded the keto aldehyde **10g** (21.6 g, 96%), ν_{max}/cm^{-1} 2930, 2709, 1722, 1450, 1376, 1240 and 1164; δ_H (200 MHz) 0.89 (d, *J* 6.9, 1.5H), 0.99 (d, *J* 6.9, 1.5H), 1.60 (s, 3H), 1.69 (s, 3H), 1.08–2.10 (m, 7H), 2.13 (s, 3H), 2.26–2.65 (m, 3H), 5.68 (m, 1H), 5.68 (m, 1H), 9.60 (d, *J* 2.4, 0.5H) and 9.64 (d, *J* 2.9, 0.5H); δ_C (50 MHz) 15.9, 16.7, 17.6, 18.0, 19.7, 25.1, 25.6, 29.9, 32.2, 33.3, 33.8, 34.4, 41.36, 41.42, 55.9, 56.2, 123.7, 131.9, 204.9, 205.2, 207.9 and 208.0; *m*/*z* 224 (M^+, 0.1%), 148 (32), 109 (26), 95 (38), 82 (32), 71 (25), 69 (52), 58 (28), 56 (37), 43 (100) and 41 (68) (Found: M^+, 224.1798. Calc. for $C_{14}H_{24}O_2$: *M*, 224.1776).

5-Oxo-2-[3-(tetrahydropyran-2-yloxy)propyl]hexanal 10h

Yield 89%; ν_{max}/cm^{-1} 2948, 2720, 1723, 1138, 1123, 1078 and 1036; δ_H (200 MHz) 1.50–2.00 (m, 12H), 2.14 (s, 3H), 2.30 (m, 1H), 2.46 (br t, 2H), 3.30–3.55 (m, 2H), 3.60–3.90 (m, 2H), 4.56 (br t, *J* 4.1, 1H) and 9.58 (d, *J* 2.6, 1H); δ_C (50 MHz) 19.4, 22.0, 25.2, 25.5, 26.9, 29.7, 30.5, 40.3, 50.6, 62.1, 66.7, 98.6, 204.2 and 207.5; *m*/*z* 256 (M^+, 0.5%), 228 (1.5), 155 (14), 154 (19), 101 (11), 97 (100), 85 (88), 88 (45) and 55 (55) (Found: M^+, 256.1620. Calc. for $C_{14}H_{24}O_4$: *M*, 256.1674).

10-Acetoxy-2-(3-oxobutyl)decanal 10i

Yield 76%; ν_{max}/cm^{-1} 2934, 2708, 1740, 1724, 1230 and 1165; δ_H (200 MHz) 1.25–1.50 (br s, 13H), 1.55–2.00 (m, 4H), 2.05 (s, 3H), 2.13 (s, 3H), 2.30 (m, 1H), 2.46 (br t, 2H), 4.05 (t, *J* 6.7, 1H) and 9.55 (d, *J* 2.8, 1H); δ_C (50 MHz) 20.6, 22.0, 25.5, 26.6, 28.2, 28.6, 28.8, 28.9, 29.2, 40.3, 50.8, 64.2, 170.7, 204.4 and 207.4; *m*/*z* 256 (10%), 149 (10), 139 (18), 138 (44), 114 (20), 109 (21), 97 (54), 95 (42), 83 (83), 81 (56), 71 (52), 69 (59), 67 (50), 58 (95) and 55 (100) [Found: ($M^+ - 1$), 283.1960. Calc. for $C_{16}H_{27}O_4$: ($M - 1$), 283.1908].

2-(3-Oxopentyl)decanal 10j

Yield 76%; ν_{max}/cm^{-1} 2930, 2857, 1720, 1680, 1458, 1379 and 1113; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.05 (t, *J* 7.3, 3H), 1.20–1.60 (br s, 18H), 1.70–2.00 (m, 2H), 2.26 (m, 1H), 2.35–2.50 (m, 2H), 2.42 (q, *J* 7.3, 2H) and 9.55 (d, *J* 2.3, 1H); *m*/*z* 240 (M^+, 14%), 222 (20), 183 (33), 123 (22), 109 (26), 95 (33), 85 (20), 83 (20), 82 (28), 81 (27), 73 (34), 72 (100), 57 (86), 55 (42), 43 (33) and 41 (40).

2-Benzyl-5-oxoheptanal 10k

Yield 68%; ν_{max}/cm^{-1} 3067, 3031, 2940, 2710 and 1722; δ_H (200 MHz) 1.02 (t, *J* 7.3, 3H), 1.70–2.00 (m, 2H), 2.36 (q, *J* 7.2, 2H), 2.44 (m, 1H), 2.55–2.80 (m, 3H), 3.02 (dd, *J* 13.0, 6.6, 1H), 7.10–7.35 (m, 5H) and 9.64 (d, *J* 2.3, 1H); δ_C (50 MHz) 7.8, 22.3, 35.4, 35.9, 39.2, 52.6, 126.6, 128.6, 128.9, 138.3, 204.0 and 210.5; *m*/*z* 216 ($M^+ - 2$, 6%), 188 (44), 159 (15), 131 (34), 117 (50), 104 (24), 91 (100) and 57 (73) (Found: M^+, 218.1337. Calc. for $C_{14}H_{18}O_2$: *M*, 218.1306).

2-[2-(Phenylsulfonyl)ethyl]decanal 10l

Yield 32%; ν_{max}/cm^{-1} 3070, 2930, 2716, 1728, 1323 and 1154; δ_H (200 MHz) 0.88 (t, *J* 6.3, 3H), 1.20–1.50 (br s, 14H), 1.80–2.13 (m, 2H), 2.45 (br t, 1H), 3.10 (t, *J* 9.8, 1H), 3.13 (t, *J* 8.6, 1H), 7.53–7.72 (m, 3H), 7.91 (dd, *J* 8.2, 1.6, 2H) and 9.57 (d, *J* 1.6, 1H); δ_C (50 MHz) 14.0, 21.1, 22.6, 26.6, 28.6, 29.1, 29.2, 29.5, 31.7, 49.9, 53.6, 127.9, 129.3, 133.8, 138.8 and 203.2; *m*/*z* 324 (M^+, 0.5%), 183 (26), 143 (89), 125 (20), 83 (38), 81 (20), 78 (26), 77 (37), 71 (33), 69 (54), 57 (60), 55 (94), 43 (100) and 41 (93) (Found: M^+, 324.1805. Calc. for $C_{18}H_{28}O_3S$: *M*, 324.1776).

2-Benzyl-4-(phenylsulfonyl)butanal 10m

Yield 34%; ν_{max}/cm^{-1} 3088, 3069, 2930, 2718, 1728, 1605, 1497, 1323 and 1088; δ_H (200 MHz) 1.75–2.15 (m, 2H), 2.68 (dd, *J* 13.0, 7.3, 1H), 2.80–3.23 (m, 4H), 7.05–7.45 (m, 5H), 7.50–7.70 (m, 3H), 7.79 (dd, *J* 7.0, 1.6, 2H) and 9.66 (d, *J* 1.2, 1H); δ_C (50 MHz) 21.2, 35.2, 51.3, 53.4, 126.9, 128.0, 128.8, 128.84, 129.3, 133.8, 137.3, 138.6 and 202.6; *m*/*z* 302 (M^+, 0.3%), 301 (4), 274 (23), 252 (45), 159 (31), 143 (33), 132 (45), 104 (100) and 91 (99) (Found: M^+, 302.0911. Calc. for $C_{17}H_{18}O_3S$: *M*, 302.0976).

Methyl 4-formyldodecanoate 10n

Yield 55%; ν_{max}/cm^{-1} 2930, 2736, 1741 and 1709; δ_H (200 MHz) 0.88 (t, *J* 6.3, 3H), 1.20–1.40 (br s, 14H), 1.75–2.10 (m, 2H), 2.25–2.50 (m, 3H), 3.67 (s, 3H) and 9.59 (d, *J* 2.5, 1H); δ_C (50 MHz) 14.1, 22.6, 23.5, 26.8, 28.8, 29.2, 29.3, 29.6, 31.4, 31.8, 51.0, 51.6, 76.4, 77.0, 77.7, 173.4 and 204.4; *m*/*z* 235 (9%), 227 (6), 208 (11), 184 (13), 152 (43), 146 (57), 138 (32), 128 (79), 114 (31), 100 (59), 74 (59) and 55 (100) [Found: ($M^+ - CH_3$), 227.1657. Calc. for $C_{13}H_{23}O_3$: ($M - CH_3$), 227.1646].

2-(2-Oxocyclopentylmethyl)decanal 13a

To a stirred solution of mesyl ester **11a** (106 mg, 0.55 mmol) and decanal (0.124 cm^3, 0.66 mmol) in CH_2Cl_2 (2 cm^3) was added DEATMS (0.250 cm^3, 1.3 mmol) at 0 °C under a nitrogen atmosphere and the resulting solution was stirred at room temperature for 17 h. The solution was passed through a short column of silica gel and evacuated *in vacuo*. The resulting residue was separated by MPLC (eluent: ethyl acetate–hexane = 1 : 9) to give two diastereomers of **13a** (93 mg, 67%). The two diastereomers are listed in their order of elution. Isomer I, yield 29%; ν_{max}/cm^{-1} 2928, 2708, 1744 and 1734; δ_H (200 MHz) 0.80 (t, *J* 6.4, 3H), 1.10–1.45 (br s, 14H), 1.45–1.92 (m, 6H), 1.92–2.32 (m, 4H) and 9.56 (d, *J* 3.0, 1H).

Isomer II, yield 38%; δ_H (200 MHz) 0.88 (t, *J* 6.5, 3H), 1.15–1.40 (br s, 14H), 1.40–1.95 (m, 6H), 1.95–2.43 (m, 4H) and 9.54 (d, *J* 3.3, 1H); *m*/*z* 252 (M^+, 12%), 250 (23), 233 (10), 222 (7), 194 (8), 166 (22), 154 (13), 138 (16), 123 (29), 110 (18), 97 (77), 84 (100), 67 (52) and 55 (51).

2-(2-Oxocycloheptylmethyl)decanal 13b

Two diastereomers were isolated and are listed in their order of elution. Isomer I, yield 23%; ν_{max}/cm^{-1} 2930, 2720, 1725 and 1705; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.20–1.40 (br s, 14H), 1.40–1.95 (m, 10H), 2.24 (m, 1H), 2.40–2.51 (m, 2H), 2.60 (m, 1H) and 9.54 (d, *J* 3.0, 1H).

Isomer II, yield 24%; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.40–1.95 (m, 10H), 2.30–2.63 (m, 4H) and 9.49 (d, *J* 3.3, 1H).

2-(2-Oxocyclooctylmethyl)decanal 13c

Two diastereomers were isolated and are listed in their order of elution. Isomer I, yield 27%; ν_{max}/cm^{-1} 2930, 2705, 1726 and 1701; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.05–1.38 (br s, 14H), 1.38–1.87 (m, 12H), 1.87–2.20 (m, 3H), 2.36 (dd, *J* 7.5, 4.3, 1H) and 9.52 (d, *J* 3.3, 1H).

Isomer II, yield 42%; ν_{max}/cm^{-1} 2944, 2705, 1726 and 1703; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.08–1.35 (br s, 14H), 1.35–2.30 (m, 15H), 2.37 (dd, *J* 7.0, 4.8, 1H) and 9.45 (d, *J* 3.1, 1H); *m*/*z* 294 (M^+, 3%), 292 ($M^+ - 2$, 6), 264 (8), 252 (44), 235 (46), 139 (36), 126 (47), 121 (29), 98 (100), 95 (44), 81 (45), 69 (56) and 55 (95).

2-(5-*tert*-Butyl-2-oxocyclohexylmethyl)decanal 13d

A mixture of diastereomers was obtained in 77% yield, ν_{max}/cm^{-1} 2955, 2720 and 1715; δ_H (200 MHz) 0.80–1.00 (m, 3H), 0.90 (s, 5H), 0.91 (s, 4H), 1.18–1.40 (br s, 14H), 1.40–1.80 (m, 7H), 2.20–2.50 (m, 4H), 9.51 (d, *J* 3.3, 0.5H) and 9.62 (d, *J* 2.1, 0.5H): total 1H; *m*/*z* 320 ($M^+ - 2$, 19%), 305 (10), 292 (36), 279 (21), 252 (41), 250 (40), 235 (36), 233 (39), 167 (80), 154 (93), 139 (100), 109 (60), 98 (75), 81 (56), 69 (48) and 57 (51).

10-Acetoxy-1-(5-*tert*-butyl-2-oxocyclohexylmethyl)decanal 13e

Three groups of diastereomers were isolated and are listed in their order of elution. Group I, yield 25%; ν_{max}/cm^{-1} 2934, 2720, 1742, 1717 and 1238; δ_H (200 MHz) 0.90 (s, 9H), 1.10–1.50 (br s, 16H), 1.50–1.72 (m, 7H), 2.05 (s, 3H), 2.27–2.50 (m, 4H), 4.05 (t, *J* 6.6, 2H) and 9.54 (d, *J* 3.0, 1H).

Group II, yield 28%; ν_{max}/cm^{-1}; δ_H (200 MHz) 0.90 (s, 9H), 1.20–1.82 (m, 23H), 2.05 (s, 3H), 2.25–2.50 (m, 4H), 4.05 (t, *J* 6.7, 2H) and 9.62 (d, *J* 2.2, 1H).

Group III, yield 13%; ν_{max}/cm^{-1} 2934, 2716, 1742, 1715 and 1243; δ_H (200 MHz) 0.90 (s, 9H), 1.20–1.88 (m, 23H), 2.05 (s, 3H), 2.20–2.47 (m, 4H), 4.05 (t, *J* 6.7, 2H) and 9.51 (d, *J* 3.2, 1H); *m*/*z* 378 ($M^+ - 2$, 7%), 363 (4), 350 (24), 335 (4), 321 (5), 294 (14), 250 (49), 235 (70), 207 (46), 154 (60), 139 (80), 109 (35), 95 (58), 83 (52) and 55 (100).

2-(5-*tert*-Butyl-2-oxocyclohexylmethyl)-5-(tetrahydropyran-2-yloxy)pentanol 13f

Two groups of diastereomers were isolated and are listed in their order of elution. Group I, yield 42%; ν_{max}/cm^{-1} (neat) 2948, 2811, 1721, 1713, 1138, 1123, 1078 and 1034; δ_H (200 MHz) 0.90 (s, 9H), 1.35–1.95 (m, 11H), 2.20–2.55 (m, 4H), 3.30–3.55 (m, 2H), 3.67–3.93 (m, 2H), 4.55 (br t, 1H) and 9.57 (d, *J* 2.9, 1H); *m*/*z* 352 (M^+, 1%), 324 (1), 250 (60), 191 (22), 167 (61), 154 (759), 139 (52), 109 (38), 98 (81), 79 (68) and 69 (100).

Group II, yield 23%; ν_{max}/cm^{-1} (neat) 2940, 2722, 1723, 1711, 1138, 1123, 1078 and 1034; δ_H (200 MHz) 0.90 (s, 9H), 1.40–1.90 (m, 11H), 2.15–2.55 (m, 4H), 3.30–3.60 (m, 2H), 3.70–3.95 (m, 2H), 4.55 (br t, 1H), 9.58 (d, *J* 2.3, 0.3H) and 9.65 (d, *J* 2.0, 0.7H).

2-(5-*tert*-Butyl-2-oxocyclohexylmethyl)-3-phenylpropanol 13g

Three groups of diastereomers were isolated and are listed in their order of elution. Group I, yield 26%; δ_H (200 MHz) 0.88 (s, 9H), 1.03–1.63 (m, 7H), 2.24–2.45 (m, 3H), 2.76 (dd, *J* 11.9, 6.4, 1H), 2.88 (m, 1H), 3.00 (dd, *J* 11.9, 6.4, 1H), 7.15–7.38 (m, 5H) and 9.64 (d, *J* 2.1, 1H).

Group II, yield, 18%; ν_{max}/cm^{-1} (neat) 3063, 3027, 2955, 2716, 1722 and 1713; δ_H (200 MHz) 0.88 (s, 9H), 0.95–1.60 (m, 7H), 1.95–2.45 (m, 4H), 2.73 (dd, *J* 16.3, 9.5, 1H), 3.02 (dd, *J* 16.3, 9.5, 1H), 7.10–7.35 (m, 5H) and 9.62 (d, *J* 2.8, 1H).

Group III, yield 12%; δ_H (200 MHz) 0.88 (s, 9H), 1.40–2.50 (m, 11H), 2.67 (m, 1H), 3.02 (m, 1H), 7.10–7.35 (m, 5H) and 9.71 (d, *J* 1.3, 1H).

2-(5-*tert*-Butyl-2-oxocyclohexylmethyl)-3,7-dimethyloct-6-enal 13h

Three groups of diastereomers were isolated and are listed in their order of elution. Group I, yield 21%; δ_H (200 MHz) 0.90 (s, 9H), 1.03 (d, *J* 6.9, 3H), 1.10–2.20 (m, 12H), 1.61 (s, 3H), 1.69 (s, 3H), 2.25–2.50 (m, 4H), 5.07 (br t, 1H) and 9.64 (d, *J* 1.7, 1H); *m*/*z* 320 (M^+, 36%), 302 (54), 167 (100), 154 (100), 149 (100), 139 (100), 135 (92), 123 (53), 111 (57), 109 (100), 107 (60), 97 (100), 95 (100), 93 (74), 80 (93), 69 (100), 57 (100), 55 (100) and 41 (100).

Group II, yield 21%; δ_H (200 MHz) 0.90 (s, 4.5H), 0.91 (s, 4.5H), 0.96 (d, *J* 6.9, 3H), 1.60 (s, 3H), 1.69 (s, 3H), 1.20–2.40 (m, 16H), 5.05 (m, 1H), 9.59 (d, *J* 3.3, 0.5H) and 9.70 (d, 0.5H).

Group III, yield 3%; ν_{max}/cm^{-1} 2965, 2728, 1723 and 1711; δ_H (200 MHz) 0.91 (s, 9H), 0.97 (d, *J* 7.0, 3H), 1.20–1.80 (m, 12H), 1.61 (s, 3H), 1.70 (s, 3H), 2.00–2.60 (m, 4H), 5.08 (br s, 1H), 9.58 (d, *J* 1.7, 0.4H) and 9.63 (d, 0.6H).

2-(1-Oxo-1,2,3,4-tetrahydro-2-naphthylmethyl)decanal 13i

Yield 83% (a mixture of inseparable diastereomers); ν_{max}/cm^{-1} 3074, 3028, 2930, 2720, 1726 and 1692; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.10–1.45 (br s, 14H), 1.45–2.35 (m, 6H), 2.53 (m, 1H), 3.02 (m, 1H), 7.23 (d, *J* 7.6, 1H), 7.32 (d, *J* 7.6, 1H), 7.46 (dt, *J* 7.5, 1.5, 1H), 8.01 (dd, *J* 7.8, 1.5, 1H), 9.59 (d, *J* 2.9, 0.4H) and 9.64 (d, *J* 2.7, 0.6H); *m*/*z* 314 (M^+, 10%), 159 (45), 146 (100), 131 (35), 118 (18), 91 (22), 55 (20), 43 (20), 41 (21) and 32 (74).

2-(1-Oxo-1,2,3,4-tetrahydro-2-naphthyl)-3-phenylpropanol 13j

Yield 76% (a mixture of inseparable diastereomers); ν_{max}/cm^{-1} 3067, 3031, 2934, 2720, 1726 and 1709; δ_H (200 MHz) 1.40–2.25 (m, 4H), 2.35–2.63 (m, 2H), 2.75–3.15 (m, 4H), 7.14–7.35 (m, 7H), 7.45 (dt, *J* 7.9, 1.3, 1H), 7.97 (dd, *J* 7.7, 1.3, 0.4H) and 7.99 (dd, *J* 7.9, 1.3, 0.6H), 9.68 (d, *J* 2.8, 0.6H) and 9.72 (d, *J* 2.0, 0.4H); *m*/*z* 292 (M^+, 4%), 264 (4), 252 (4), 235 (3), 159 (20), 146 (100), 131 (24), 115 (26), 105 (22), 91 (55) and 77 (31).

2-Hydroxy-3-octylbicyclo[3.2.1]octan-8-one 14a

To a solution of keto aldehyde **13a** (64 mg, 0.25 mmol) in methanol (10 cm^3) was added potassium hydroxide (70 mg, 1.2 mmol) at 0 °C. The resulting solution was stirred at room temperature for 23 h. After addition of aq. ammonium chloride, product was extracted with ethyl acetate twice and the combined organic layer was washed successively with water and brine. Evaporation of the solvent followed by MPLC purification (eluent: ethyl acetate–*n*-hexane = 1 : 3) of the residue provided the aldol product as two groups of diastereomers (combined yield 61 mg, 95%) which are listed in their order of elution. Group I, yield 5%; ν_{max}/cm^{-1} 3440, 2957 and 1746; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.15–1.40 (br s, 14H), 1.60–2.09 (m, 8H), 2.24 (m, 1H), 2.35 (m, 1H) and 4.10 (m, 1H); *m*/*z* 252 (M^+, 2%), 112 (8), 97 (17), 96 (22), 84 (100), 83 (16), 69 (9), 67 (13), 57 (13), 55 (28), 43 (16), 41 (38) and 39 (7).

Group II, yield 90%; ν_{max}/cm^{-1} 3625, 3504, 2928 and 1755; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.10–1.50 (br s, 14H), 1.60–2.14 (m, 8H), 2.25 (m, 1H), 2.36 (m, 1H) and 4.10 (m, 1H).

7-Hydroxy-8-octylbicyclo[4.3.1]decan-10-one 14b

Three groups of diastereomers were isolated and are listed in their order of elution. Group I, yield 29%; ν_{max}/cm^{-1} 3630, 3482, 2926 and 1709; δ_H (200 MHz) 0.89 (t, *J* 6.4, 3H), 1.20–1.50 (br s, 14H), 1.50–2.10 (m, 11H), 2.38 (m, 1H), 2.71 (m, 1H), 3.0 (m, 1H) and 3.55 (dd, *J* 10.7, 5.8, 1H).

Group II, yield 16%; ν_{max}/cm^{-1} 3625, 3438, 2928 and 1709; δ_H (200 MHz) 0.89 (t, *J* 6.4, 3H), 1.20–1.97 (br s, 14H), 1.97–2.20 (m, 11H), 2.35 (m, 1H), 2.65–2.87 (m, 2H), 3.56 (dd, *J* 10.6, 5.8, 0.3H) and 3.93 (br s, 0.7H).

Group III, yield 37%; ν_{max}/cm^{-1} 3625, 3456, 2930 and 1715; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.15–1.45 (br s, 14H), 1.45–2.18 (m, 12H), 2.43–2.68 (m, 2H) and 3.71 (dd, *J* 7.9, 3.1, 1H).

8-Hydroxy-9-octylbicyclo[5.3.1]undecan-11-one 14c

Three groups of diastereomers were isolated and are listed in their order of elution. Group I, yield 57%; ν_{max}/cm^{-1} 3620, 3470, 2928 and 1703; δ_H (200 MHz) 0.89 (t, *J* 6.3, 3H), 1.10–1.60 (br s, 14H), 1.60–2.20 (m, 14H), 2.43 (m, 1H), 2.75 (m, 1H) and 3.56 (dd, *J* 10.3, 5.0, 1H).

Group II, yield 12%; ν_{max}/cm^{-1} 3625, 3420, 2930 and 1703; δ_H (200 MHz) 0.89 (t, *J* 6.4, 3H), 1.20–1.50 (br s, 14H), 1.50–2.10 (m, 14H), 2.30 (m, 1H), 2.50 (m, 1H) and 3.93 (m, 1H); *m*/*z* 294 (M^+, 7%), 139 (29), 126 (33), 98 (100), 97 (26), 95 (26), 83 (52), 81 (32), 71 (32), 69 (36), 67 (52), 57 (50), 55 (98), 43 (66) and 41 (95).

Group III, yield 17%; ν_{max}/cm^{-1} 3455, 2928 and 1703; δ_H (200 MHz) 0.88 (t, *J* 6.4, 3H), 1.15–1.45 (br s, 14H), 1.45–1.90 (m, 11H), 1.90–2.20 (m, 3H), 2.31 (m, 1H), 2.48 (m, 1H) and 3.75 (dd, *J* 8.3, 5.4, 1H).

3-Acetonyl-2,3,4,5-tetrahydro-1*H*-benzocycloheptene-2-carbaldehyde 16

To a stirred solution of formyl enone **15** (46 mg, 0.2 mmol) and DEATMS (0.046 cm^3, 0.24 mmol) in MeCN (5 cm^3) was stirred at room temperature for 22 h. The resulting solution was passed through a short silica gel column and evaporated to dryness. MPLC purification of the residue (eluent: ethyl acetate–hexane = 1 : 3) provided aldehyde **16** as an inseparable mixture of diastereomers (33 mg, 73%); ν_{max}/cm^{-1} 3069, 3025, 2921, 2710 and 1723; δ_H (200 MHz) 2.13 (s, 2H) and 2.15 (s, 1H), 2.35–3.20 (m, 10H), 7.10–7.20 (m, 4H), 9.45 (br s, 0.3H) and 9.60 (d, *J* 3.3, 0.7H); δ_C 30.2, 30.5, 30.7, 32.3, 33.4, 33.8, 36.0, 48.5, 55.0, 126.38, 126.42, 127.0, 128.7, 129.2, 129.3, 129.6, 138.2, 142.3, 142.6, 203.2, 204.2 and 207.3; *m*/*z* 228 ($M^+ - 2$, 78%), 200 (56), 188 (27), 157 (20), 143 (100), 130 (42), 91 (18) and 43 (44) (Found: M^+, 230.1341. Calc. for $C_{15}H_{18}O_2$: *M*, 230.1306).

(1*R,2*S**)-2-Acetonyl-5,5-bis(benzyloxymethyl)cyclohexane-carbaldehyde 18**

To a stirred solution of formyl enone **17** (40 mg, 0.098 mmol) and DEATMS (0.023 cm^3, 0.12 mmol) in acetonitrile (5 cm^3) was stirred at room temperature for 22 h. The resulting solution was passed through a short silica gel column and evaporated to dryness. MPLC purification of the residue (eluent: ethyl acetate–hexane = 1 : 5) provided aldehyde **18** as a single diastereomer (31 mg, 76%); ν_{max}/cm^{-1} 3090, 3067, 2926, 2710 and 1723; δ_H (200 MHz) 1.20–1.90 (m, 7H), 2.00–2.20 (m, 2H), 2.09 (s, 3H), 2.50 (dt, *J* 16.6, 2.9, 1H), 3.26 (d, *J* 4.7, 2H), 3.42 (s, 2H), 4.48 (s, 4H), 7.20–7.45 (br s, 10H) and 9.41 (d, *J* 2.9, 1H); δ_C 26.6, 28.9, 29.6, 30.5, 32.0, 38.2, 48.1, 50.8, 69.7, 73.2, 76.6, 127.3, 127.4, 127.5, 128.3, 204.3 and 207.6; *m*/*z* 317 (12%), 211 (20), 135 (6), 91 (100) and 43 (9) [Found: ($M^+ - C_2H_4$), 380.1984. Calc. for $C_{24}H_{28}O_4$: ($M^+ - C_2H_4$), 380.1986].

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References and notes

1 A. J. Waring, in *Comprehensive Organic Synthesis*, ed. J. F. Stoddart, Pergamon Press, Oxford, 1979, vol. 1, p. 1055.
2 G. Stork, A. Brizzolara, H. Landesman, J. Szmuszkovicz and R. Terrell, *J. Am. Chem. Soc.*, 1963, **85**, 207; M. Brown, *J. Org. Chem.*, 1968, **33**, 162.
3 P. Duhamel, L. Hennequin, J. M. Poirier, G. Tavel and C. Vottero, *Tetrahedron*, 1986, **42**, 4777.
4 T. Nakajima, Y. Maruyama and I. Shimizu, *Abstracts of Papers of 65th Annual Meeting of Chemical Society of Japan*, Tokyo, 1993, vol. II, p. 335.
5 Preliminary communication: H. Hagiwara and M. Kato, *Tetrahedron Lett.*, 1996, **37**, 5139.
6 W. Franke and J. Bueren, *Chem. Abstr.*, 1953, **47**, 2205a; E. Eliel and C. A. Lukach, *J. Am. Chem. Soc.*, 1957, **79**, 5986; K. L. Cook and A. J. Waring, *J. Chem. Soc., Perkin Trans. 1*, 1973, 529; M. Pesaro and J.-P. Bachman, *J. Chem. Soc., Chem. Commun.*, 1978, 203.
7 I. Weisz, K. Felfoldi and K. Kovacs, *Acta Chim. Acad. Sci. Hung.*, 1968, **58**, 189; D. A. Evans and J. Bartoli, *Tetrahedron Lett.*, 1982, **23**, 807; G. Stork and S. D. Rychnovsky, *J. Am. Chem. Soc.*, 1987, **109**, 1564.
8 Y. Hamada, Y. Yamamoto and H. Shimizu, *J. Organomet. Chem.*, 1996, **510**, 1.
9 Y. Yamamoto, H. Shimizu and Y. Hamada, *J. Organomet. Chem.*, 1996, **509**, 119.
10 A. Papini, A. Ricci, M. Taddei, G. Seconi and P. Dembech, *J. Chem. Soc., Perkin Trans. 1*, 1984, 2261; J. Ipaktschi and A. Heydari, *Chem. Ber.*, 1993, **126**, 1905; Y. Yamamoto, H. Shimizu, C. Matui and M. Chinda, *Main Group Chem.*, 1996, **1**, 409.
11 (*a*) L. H. Hellberg and A. Juarez, *Tetrahedron Lett.*, 1974, 3553; (*b*) M. Fiorenza, A. Ricci, M. N. Romanelli, M. Taddei, P. Dembech and G. Seconi, *Heterocycles*, 1982, **19**, 2327; (*c*) Y. Yamamoto and C. Matui, *Organometallics*, 1997, **16**, 2204.
12 R. Comi, R. W. Franck, M. Reitano and S. M. Weinreb, *Tetrahedron Lett.*, 1973, 3107.
13 M. R. Saidi, M. M. Mojtahedi and M. Bolourtchian, *Tetrahedron Lett.*, 1997, **38**, 8071; M. R. Saidi, A. Heydari and J. Ipaktschi, *Chem. Ber.*, 1994, **127**, 1761; M. R. Saidi, H. R. Khalaji and J. Ipaktschi, *J. Chem. Soc., Perkin Trans. 1*, 1987, 1983.
14 W. J. Middleton and E. M. Bingham, *Org. Synth.*, 1988, **Coll. Vol. VI**, 440.
15 M. Hojo, M. Nagayoshi, A. Fujii, T. Yanagi, N. Ishibashi, K. Miura and A. Hosomi, *Chem. Lett.*, 1994, 719.
16 H. Hagiwara, V. P. Kamat, H. Ono, T. Hoshi, T. Suzuki and M. Ando, *Abstracts of Papers of 43rd Symposium on Flavour, Terpenoids and Essential oils*, 1999, p. 108.
17 We thank Mrs F. Yoshii for these calculations.
18 K. Tani, T. Yamagata, S. Otshuka, H. Kumobayashi and S. Akutagawa, *Org. Synth.*, 1993, **Coll. Vol. VIII**, 183.
19 L. Birkofer and O. Stuhl, in *The Chemistry of Organosilicon Compounds Part 1*, ed. S. Patai and Z. Rappoport, Wiley, Chichester, New York, Brisbane, Toronto, Singapore, 1989, p. 655.
20 Our recent results using DEATMS in nucleophilic reaction of naked aldehydes: H. Hagiwara, N. Komatsubara, T. Hoshi, T. Suzuki and M. Ando, *Tetrahedron Lett.*, 1999, **40**, 1523; H. Hagiwara, H. Ono, N. Komatsubara, T. Hoshi, T. Suzuki and M. Ando, *Tetrahedron Lett.*, 1999, **40**, 6627.