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A New Entry to β-Functionalization of Enones: Pentyloxy Group Incorporation in the TBSOTf-Mediated Ring-Opening Reaction of Epoxides with Ylides Derived from the Phosphoniosilylation Products of Enones in Tetrahydropyran

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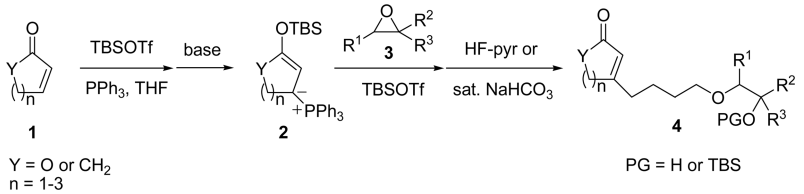
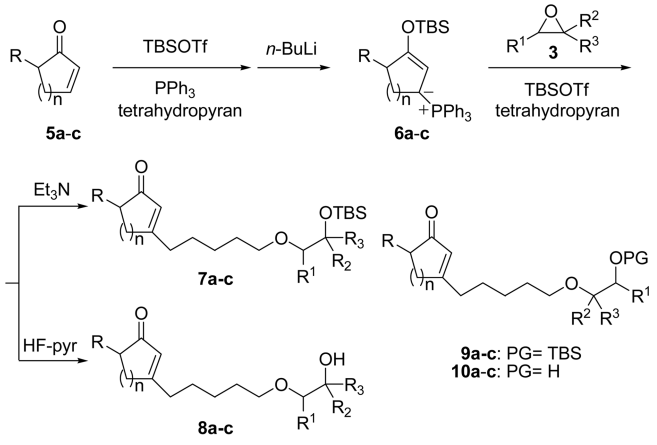
The development of new methods for the β-functionalization of α,β-unsaturated carbonyl compounds has been an important subject in synthetic organic chemistry. Our group has been interested in developing new methods for the β-functionalization of α,β-unsaturated carbonyl compounds based on the phosphoniosilylation process.[1-3] In continuation of research program involving this process, we have examined the TBSOTf-assisted[4] ring-opening reactions of epoxides with ylides **2** derived from α,β-unsaturated carbonyl compounds through the phosphoniosilylation reaction[5] followed by base treatment (Scheme 1). In this examination we have observed very interesting results such that the solvent, THF, participates in the ring-opening process of epoxides with ylides **2** to provide three-component coupling products **4**.[2b,6] These results prompted us to study the possibility of three-component coupling reactions of epoxides, ylides **2**, and other solvent such as tetrahydropyran (THP). We now wish to report some of the results in these studies.

At the outset, scrutinizing the whole process of three-component coupling of epoxides, ylides **2**, and THF,[2b] our first concern was whether THP is suitable as a solvent for the phosphoniosilylation reaction of enones with triphenylphosphine (Ph_3P) and TBSOTf. To test the feasibility of the phosphonoisilylation process in THP, 2-cyclohexenone **5b** was reacted with Ph_3P and TBSOTf in THP, and was followed by deprotonation with *n*-BuLi at –45 °C (Scheme 2). The resulting dark brown-colored solution indicated the formation of the ylide **6b**, which in turn suggested that the phosphoniosilylation reaction proceeded. The formation of the Wittig reagent **6b** was further confirmed by smooth reaction with benzaldehyde.[5] With these successful test results it was next examined that THP would also participate in the ring-opening reactions of epoxides **3** with ylides **6** to provide three-component coupling products **7** and **8**. Upon examining various reaction conditions using ylide **6b** and 1,2-epoxybutane **3p** as model substrates it was found that successful three-component coupling of **6b**, **3p** and THP could be achieved. When the ylide **6b** was reacted with an epoxide **3p** in the presence of TBSOTf in THP at the bath temperature of –78 °C and the reaction mixture was subsequently treated with triethylamine (Et_3N), the pentyloxy group incorporated product **7bp** was obtained in 65% yield (Table 1, entry 7).

Encouraged by the success of three-component coupling using model substrates, the process was employed to various ylides and epoxides (Scheme 2). The whole procedure involves four steps: (1) phosphoniosilylation of enones **5** with Ph_3P and TBSOTf, (2) ylide formation with *n*-BuLi, (3) reaction with epoxides **3** in the presence of TBSOTf and (4) desilylative elimination of Ph_3P. Similar to other β-functionalization using the phosphoniosilylation process,[1-3] this four-step sequence is carried out in the single reaction vessel. Thus, the resulting three-component coupling products can be obtained in very efficient and practical sense. The selected results are shown in Table 1. The formation of products TBS ethers **7** or alcohols **8**, could be controlled by the choice of a desilylating agent, similar to the results in the reaction in THF.[2b] Acquisition of TBS ethers **7** as products was most satisfactory with the use of Et_3N as a desilylating reagent, compared to the use of saturated sodium bicarbonate solution in the similar process in THF. In the present process the significant degree of desilylation of TBS ethers **7** was occasionally accompanied when saturated sodium bicarbonate solution was employed. Alcohol products **8** were obtained without any difficulty by treatment of the epoxide opening reaction mixtures with HF-pyridine, similarly in the formation of alcohols **4**.[2b] This process works well in 2-cyclopentenone and 2-cyclohexenone series such as **5a-c**.[7] With



Scheme 1



For **5-8**, **a**: n = 1, R = H; **b**: n = 2, R = H; **c**: n = 2, R = $PhCH_2$

For **3**, **7-10**, **p**: R^1=R^2= H; R^3= CH_3CH_2; **q**: R^1=R^2= H; R^3= $PhCH_2$; **r**: R^1=R^2= H; R^3= 4-$OCH_3C_6H_4CH_2$; **s**: R^1=R^2= H; R^3= $(CH_3)_2CHOCH_2$; **t**: R^1=R^2= H; R^3= 4-^{t}Bu$C_6H_4CO_2CH_2$; **u**: R^1= R^2= $(CH_2)_4$;R^3=H,

Scheme 2

various epoxides **3p-t** possessing an alkyl substituent at the 2-position, the TBS ethers **7a-c** were obtained in reasonable yields (50-77%). The yields of alcohols **8a-c** were slightly lower (47-60%) than those of **7a-c**. In the formation of **7a-c** and **8a-c** no significant amounts of regioisomeric products **9-10** were obtained. The results indicate that the pentyloxy group incorporated ring-opening of these epoxides also proceed with high regioselectivities, which is well compared to those observed in the three-component reactions of ylides **2**, epoxides **3** and THF (Scheme 1).[2b] It is of value to note that epoxides **3s-t** possessing ether or carboxy groups also attend the process very well (entries 4, 5, 9, and 11). With a cyclic epoxide **5u** (entry 6) the coupling reaction proceeded as well. To test the applicability of this process the reaction sequence was also employed to acyclic enones such as 3-buten-2-one and trans-3-nonen-2-one and α,β-unsaturated lactones such as 5,6-dihydro-2*H*-pyran-2-one (**1**, Y = O and n = 2). However, the results were rather disappointing. Either no significant amounts or poor yields of products were obtained. It is interesting to note that the rate of three-component coupling in THP is much slower than that in THF. When the sequence of reactions was carried out, using **5b** and **3p** as substrates, in 1:1 mixture of THF and THP, the butyloxy group incorporated product **4** (X= CH_2, n = 2, PG = TBS) was obtained exclusively.

Table 1. β-Pentyloxy Group Incorporated Epoxide Opening of Enones in THP

Entry	Starting material	Epoxide	Product[a,b]	Yield (%)[c,d]
1	**5a**	**3p**	**7ap** (**8ap**)	71 (58)
2	**5a**	**3q**	**7aq** (**8aq**)	77 (52)
3	**5a**	**3r**	**7ar** (–)	51 (–)
4	**5a**	**3s**	**7as** (**8as**)	62 (60)
5	**5a**	**3t**	**7at** (–)	53 (–)
6	**5a**	**3u**	**7au** (**8au**)	55 (55)
7	**5b**	**3p**	**7bp** (**8bp**)	65 (52)
8	**5b**	**3q**	**7bq** (**8bq**)	56 (47)
9	**5b**	**3s**	**7bs** (**8bs**)	50 (58)
10	**5c**	**3q**	**7cq** (–)	62 (–)
11	**5c**	**3s**	**7cs** (–)	50 (–)

[a]Products when Et_3N was used in the desilylation step. [b]Products in parentheses refer to products when HF-pyridine was used in the desilylation step. [c]Overall isolated yields of TBS ethers. [d]Yields in parentheses refer to overall isolated yields of alcohols.

In summary, reactions of ylides **6**, derived from the phosphoniosilylation products of enones, with epoxides in the presence of TBSOTf in THP proceed with incorporation of the pentyloxy group to give three-component products **7** and **8**. The results illustrate further unusual example that a reaction solvent, THP participates in the ring-opening process of epoxides with ylides **6**. Furthermore, the whole process provides a new entry to β-fuctionalization of enones.

Experimental Section

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-phenylpropoxy]-pentyl}-cyclopent-2-enone (7aq, entry 2, general procedure). To a solution of triphenylphosphine (144 mg, 0.55 mmol) in tetrahydropyran[8] (2.0 mL) were added TBSOTf (126 μL, 0.55 mmol) and 2-cyclopenten-1-one **5a** (42 μL, 0.50 mmol). After being stirred at room temperature for 1.5 h, the reaction mixture was cooled to −45 °C and *n*-butyllithium (419 μL, 1.55 M in hexanes, 0.65 mmol) was added dropwise to give a dark brown-colored solution. After the mixture being stirred for 1 h, (2,3-epoxypropyl)benzene **3q** (132 μL, 1.00 mmol) and TBSOTf (230 μL, 1.00 mmol) were added dropwise at −78 °C (bath temperature). The reaction mixture was stirred for 1 h, and then water (1 mL) and triethylamine (209 μL, 1.50 mmol) were added. After being warmed to room temperature, the reaction mixture was stirred for 1 h. The usual extractive work-up and flash column chromatography (hexane:EtOAc = 5:1 → 3:1) gave **7aq** (160 mg, 77%). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47–7.51 (m, 3H), 7.42 (m, 2H), 6.18 (s, 1H), 4.18 (m, 1H), 3.65 (m, 2H), 3.50–3.59 (m, 2H), 3.11 (m, 1H), 2.89 (m, 1H), 2.80 (m, 2H), 2.62–2.66 (m, 4H), 1.82–1.86 (m, 4H), 1.65 (m, 2H), 1.04 (s, 9H), 0.16 (s, 3H), 0.00 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 210.9, 183.7, 138.2, 129.6, 128.7, 128.3, 126.8, 74.3, 71.6, 71.4, 41.6, 40.1, 35.5, 33.7, 31.8, 29.7, 29.4, 27.2, 27.1, 26.3, 26.1, −4.5, −5.0. FT-IR (neat) 3422, 3026, 2929, 2859, 1702, 1672, 1611, 1495, 1453, 1435, 1407, 1337, 1283, 1236, 1183, 1117, 1080, 1030, 989, 842, 744, 699, 604, 541, 503 cm^{-1}. ESI MS (*m/z*) 417.3 $[M+1]^+$.

Other compounds were prepared similarly, and the spectroscopic data of selected compounds are shown as follows.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)butoxy]-pentyl}-cyclopent-2-enone (7ap, entry 1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.95 (s, 1H), 3.71 (m, 1H), 3.42 (t, J = 6.6 Hz, 2H), 3.32 (m, 2H), 2.58 (m, 2H), 2.39–2.43 (m, 4H), 1.50–1.70 (m, 5H), 1.38–1.44 (m, 3H), 0.93 (t, J = 6.6 Hz, 3H), 0.89 (s, 9H), 0.06 (s, 6H).). FT-IR (neat) 2932, 2863, 1703, 1672, 1609, 1460, 1435, 1406, 1237, 1184, 1109, 987, 919, 843,

480 cm^{-1}. ESI MS (*m/z*) 355.3 $[M+1]^+$.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-(methoxyphenyl)propoxy]-pentyl}-cyclopent-2-enone (7ar, entry 3). ^1H NMR (500 MHz, $CDCl_3$) δ 7.10 (d, *J* = 6.6 Hz, 2H), 6.80 (d, *J* = 6.6 Hz, 2H), 5.95 (s, 1H), 3.88–3.92 (m, 1H), 3.79 (s, 3H), 3.38–3.42 (m, 2H), 3.23–3.35 (m, 2H), 2.82 (dd, *J* = 13.6, 5.0 Hz, 1H), 2.55–2.65 (m, 3H), 2.38–2.45 (m, 4H), 1.54–1.67 (m, 4H), 1.40–1.45 (m, 2H), 0.83 (s, 9H), −0.08 (s, 3H), −0.18 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 210.5, 183.3, 158.3, 131.1, 131.0, 131.0, 129.7, 113.7, 74.9, 73.1, 71.4, 55.5, 40.6, 35.6, 33.7, 31.8, 29.7, 27.2, 26.3, 18.4, −4.5, −4.8. FT-IR (neat) 2927, 2855, 1707, 1674, 1613, 1511, 1462, 1438, 1299, 1245, 1178, 1107, 1035, 992, 939, 830, 774, 723, 663, 523 cm^{-1}. ESI MS (*m/z*) 447.3 $[M+1]^+$.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-isopropoxypropoxy]-pentyl}-cyclopent-2-enone (7as, entry 4). ^1H NMR (500 MHz, $CDCl_3$) δ 5.89 (s, 1H), 3.83 (m, 1H), 3.52 (m, 1H), 3.37–3.41 (m, 4H), 3.29 (m, 2H), 2.56 (m, 2H), 2.31–2.40 (m, 4H), 1.48–1.62 (m, 4H), 1.35 (m, 2H), 1.04–1.12 (2d, 6H), 0.83 (m, 9H), 0.02 (s, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 206.4, 179.3, 125.8, 69.6, 68.2, 67.7, 67.5, 66.6, 31.6, 29.8, 27.8, 25.8, 23.2, 22.3, 22.2, 22.0, 18.4, 14.6, −8.3, −8.5. FT-IR (neat) 2928, 2856, 1709, 1674, 1616, 1462, 1438, 1409, 1367, 1335, 1249, 1180, 1119, 1004, 938, 833, 811, 776, 666, 573, 476 cm^{-1}. ESI MS (*m/z*) 399.3 $[M+1]^+$.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-cyclohexyloxy]-pentyl}-cyclopent-2-enone (7au, entry 6). ^1H NMR (500 MHz, $CDCl_3$) δ 5.88 (s, 1H), 3.31–3.52 (m, 3H), 2.96 (m, 1H), 2.45–2.57 (m, 2H), 2.28–2.39 (m, 4H), 1.87 (m, 1H), 1.79 (m, 1H), 1.46–1.65 (m, 6H), 1.28–1.42 (m, 2H), 1.20–1.27 (m, 4H), 0.89 (s, 9H), 0.06 (s, 3H), 0.01 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 206.4, 179.3, 125.8, 78.4, 70.2, 65.8, 31.6, 29.9, 27.8, 26.3, 25.7, 23.3, 22.3, 22.2, 22.1, 19.8, 19.6, 14.4, −8.2, −8.4. FT-IR (neat) 2928, 2856, 1708, 1674, 1616, 1471, 1462, 1437, 1408, 1375, 1359, 1248, 1181, 1159, 1095, 1021, 1005, 938, 873, 833, 774, 721, 666, 542, 440 cm^{-1}. ESI MS (*m/z*) 381.3 $[M+1]^+$.

{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-butoxy]-pentyl}-cyclohex-2-enone (7bp, entry 7). ^1H NMR (500 MHz, $CDCl_3$) δ 5.87 (s, 1H), 3.67–3.77 (m, 1H), 3.41 (t, *J* = 6.5 Hz, 2H), 3.20–3.40 (m, 2H), 2.36 (t, *J* = 6.7 Hz, 2H), 2.28 (t, *J* = 6.1 Hz, 2H), 2.21 (t, *J* = 7.7 Hz, 2H), 1.99 (m, 2H), 1.45–1.56 (m, 4H), 1.44 (m, 1H), 1.37 (m, 3H), 0.92 (t, *J* = 7.5 Hz, 3H), 0.90 (s, 9H), 0.10 (s, 3H), 0.06 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.3, 166.9, 125.9, 75.4, 72.9, 71.4, 38.3, 37.6, 29.9, 29.6, 27.7, 27.0, 26.9, 25.9, 23.0, 18.5, 9.88, −4.2, −4.5. FT-IR (neat) 2932, 2861, 1663, 1622, 1455, 1437, 1373, 1347, 1324, 1253, 1190, 1117, 1028, 965, 886, 755, 720, 694, 538, 502 cm^{-1}. ESI MS (*m/z*) 369.3 $[M+1]^+$.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-phenylpropoxy]-pentyl}-cyclohex-2-enone (7bq, entry 8). ^1H NMR (500 MHz, $CDCl_3$) δ 7.25 (m, 2H), 7.19 (m, 3H), 5.88 (s, 1H), 3.95 (m, 1H), 3.42 (td, *J* = 6.5, 2.8 Hz, 2H), 3.24–3.38 (m, 2H), 2.89 (dd, *J* = 13.5, 4.7 Hz, 1H), 2.65 (dd, *J* = 13.4, 7.6 Hz, 1H), 2.36 (t, *J* = 6.7 Hz, 2H), 2.28 (t, *J* = 6.2 Hz, 2H), 2.22 (t, *J* = 7.7 Hz, 2H), 1.99 (m, 2H), 1.47–1.66 (m, 4H), 1.39 (m, 2H), 0.82 (s, 9H), −0.07 (s, 3H), −0.23 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.2, 166.7, 139.1, 130.1, 128.2, 126.3, 126.0, 75.1, 73.1, 71.4, 41.6, 38.3, 37.6, 29.9, 29.8, 27.1, 26.2, 26.1, 23.0, 18.4, −4.5, −5.0. FT-IR (neat) 3027, 2927, 2855, 1669, 1624, 1496, 1471, 1454, 1428, 1360, 1346, 1250, 1191, 1110, 1083, 1047, 992, 939, 887, 830, 809, 775, 749, 598 cm^{-1}. ESI MS (*m/z*) 431.3 $[M+1]^+$.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-isopropoxypropoxy]-pentyl}-cyclohex-2-enone (7bs, entry 9). ^1H NMR (500 MHz, $CDCl_3$) δ 5.78 (s, 1H), 3.73–3.85 (m, 1H), 3.41–3.53 (m, 1H), 3.32–3.36 (m, 4H), 3.20–3.30 (m, 2H), 2.28 (m, 2H), 2.19 (t, *J* = 5.6 Hz, 2H), 2.13 (t, *J* = 7.9 Hz, 2H), 1.90 (m, 2H), 1.36–1.50 (m, 4H), 1.20–1.35 (m, 2H), 1.05 (2d, 6H), 0.80 (s, 9H), −0.08 (s, 3H), 0.01 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 204.8, 171.4, 130.4, 77.9, 76.6, 76.1, 75.9, 75.0, 428, 42.0, 34.4, 34.2, 31.5, 30.6, 30.5, 30.4, 27.4, 26.8, 22.9, 0.1, 0.0. FT-IR (neat) 2928, 2856, 1669, 1624, 1462, 1428, 1368, 1346, 1326, 1250, 1191, 1120, 1004, 938, 886, 833, 811, 776, 665, 572, 500 cm^{-1}. ESI MS (*m/z*) 413.3 $[M+1]^+$.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-phenylpropoxy]-pentyl}-6-benzylcyclohex-2-enone (7cq, entry 10). ^1H NMR (500 MHz, $CDCl_3$) δ 6.98–7.15 (m, 4H), 6.96 (m, 6H), 5.90 (s, 1H), 3.84 (m, 1H), 3.38 (td, *J* = 6.6, 3.0 Hz, 2H), 3.25–3.28 (m, 2H), 2.88 (dd, *J* = 13.4, 4.8 Hz, 1H), 2.62 (dd, *J* = 13.4, 7.5 Hz, 1H), 2.45 (m, 2H), 2.22 (m, 2H), 2.17 (m, 2H), 1.83 (m, 1H), 1.55–1.62 (m, 4H), 1.45–1.54 (m, 2H), 1.32–1.42 (m, 2H), 0.78 (s, 9H), −0.07 (s, 3H), −0.22 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.0, 165.7, 140.4, 139.1, 130.1, 129.5, 128.6 (overlap), 128.3, 126.3, 125.6, 75.1, 73.1, 71.4, 47.9, 41.6, 38.0, 35.7, 29.7, 29.4, 27.3, 27.1, 26.2, 26.1, 18.4, −4.5, −5.0. FT-IR (neat) 3026, 2927, 2855, 1667, 1629, 1602, 1495, 1471, 1453, 1360, 1250, 1210, 1110, 1083, 1030, 992, 939, 887, 831, 809, 775, 740, 698, 665, 556, 510 cm^{-1}. ESI MS (*m/z*) 521.3 $[M+1]^+$.

3-{5-[2-(*tert*-Butyldimethylsilanyloxy)-3-isopropoxypropoxy]-pentyl}-6-benzylcyclohex-2-enone (7cs, entry 11). ^1H NMR (500 MHz, $CDCl_3$) δ 7.22 (m, 2H), 7.13 (m, 3H), 5.84 (s, 1H), 3.83 (m, 1H), 3.58 (m, 2H), 3.30–3.36 (m, 4H), 3.30–3.40 (m, 3H), 2.43–2.53 (m, 2H), 2.23 (m, 2H), 2.20 (t, *J* = 5.2 Hz, 2H), 1.93 (m, 1H), 1.53–1.62 (m, 2H), 1.52 (m, 2H), 1.38 (m, 2H), 1.15–1.19 (2d, 6H), 0.89 (s 9H), 0.05 (s, 3H), –0.05 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 201.0, 165.8, 140.4, 129.5, 128.5, 126.3, 125.5, 73.5, 72.2, 71.7, 71.3, 70.5, 47.9, 38.0, 35.7, 29.7, 29.3, 27.3, 27.1, 26.1, 26.1, 22.3, 22.3, 18.5, −4.4 (overlap). FT-IR (neat) 2927, 2856, 1668, 1453, 1367, 1250, 1211, 1121, 1004, 938, 886, 834, 811, 776, 739, 599, 665, 512 cm^{-1}. ESI MS (*m/z*) 503.4 $[M+1]^+$.

Preparation of 3-(5-(2-Hydroxybutoxy)pentyl)cyclopent-2-enone (8ap, entry 1, General procedure). Similarly to the preparation of 3-{5-[2-(*tert*-butyldimethylsilanyloxy)-butoxy]-pentyl}-cyclopent-2-enone (7ap), except for the use of HF-pyridine in place of triethylamine in the desilylation step, 3-(5-(2-hydroxybutoxy)pentyl)cyclopent-2-enone **8ap** was obtained (69 mg, 58%). ^1H NMR (500 MHz, $CDCl_3$) δ 5.99 (s, 1H), 3.73 (m, 1H), 3.40–3.60 (m, 3H), 3.30 (t, *J* = 8.9 Hz, 1H), 2.59 (m, 2H), 2.51–2.40 (m, 4H), 2.27 (br, 1H), 1.56–1.72 (m, 4H), 1.39–1.56 (m, 4H), 0.98 (t, *J* = 7.4 Hz,

3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 210.4, 183.1, 129.8, 75.0, 71.9, 71.3, 35.6, 33.7, 31.8, 29.6, 27.2, 26.4, 26.2, 10.1. FT-IR (neat) 3379, 2928, 2858, 1702, 1673, 1612, 1461, 1436, 1235, 1181, 1117, 1028, 996, 919, 841, 748, 720, 694, 537, 504 cm^{-1}. ESI MS (*m/z*) 241.2 $[M+1]^+$.

3-(5-(2-Hydroxy-3-phenylpropoxy)pentyl)cyclopent-2-enone (8aq, entry 2). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34–7.28 (m, 2H), 7.23 (m, 3H), 5.95 (s, 1H), 4.02 (m, 1H), 3.42–3.50 (m, 3H), 3.31 (m, 1H), 2.80 (m, 2H), 2.58 (m, 2H), 2.42–2.46 (m, 4H), 2.32–2.25 (br, 1H), 1.70–1.59 (m, 4H), 1.42 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 210.4, 183.1, 138.2, 129.8, 129.6, 128.7, 126.7, 74.3, 71.6, 71.4, 40.2, 35.6, 33.7, 31.8, 29.6, 27.1, 26.2. FT-IR (neat) 3422, 3026, 2929, 2859, 1702, 1672, 1611, 1495, 1453, 1435, 1407, 1337, 1283, 1236, 1183, 1117, 1080, 1030, 989, 842, 744, 699, 604, 541, 503 cm^{-1}. ESI MS (*m/z*) 303.2 $[M+1]^+$.

3-(5-(2-Hydroxy-3-isopropoxypropoxy)pentyl)cyclopent-2-enone (8as, entry 4). ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.95 (s, *J* = 2.4 Hz, 1H), 3.93 (m, 1H), 3.60 (m, 1H), 3.57–3.54 (m, 6H), 2.59 (m, 2H), 2.40–2.44 (m, 4H), 1.51–1.70 (m, 6H), 1.40 (m, 2H), 1.03–1.13 (2d, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 210.5, 183.3, 132.4, 72.4, 71.7, 71.0, 69.9, 69.5, 35.5, 33.7, 31.8, 29.7, 27.1, 26.1, 23.0, 22.2. FT-IR (neat) 2930, 2860, 1705, 1674, 1613, 1437, 1367, 1334, 1179, 1117, 1081, 997, 748, 720, 694, 539 cm^{-1}. ESI MS (*m/z*) 285.2 $[M+1]^+$.

3-(5-(2-Hydroxybutoxy)pentyl)cyclohex-2-enone (8bp, entry 7). ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.85 (s, 1H), 3.72 (m, 1H), 3.40–3.57 (m, 3H), 3.23 (m, 1H), 2.38 (t, 2H), 2.29 (t, 2H), 2.22 (m, 2H), 2.00 (m, 2H), 1.62 (m, 2H), 1.57 (m, 2H), 1.50 (m, 2H), 1.40 (m, 2H), 0.98 (t, *J* = 7.5, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.2, 166.6, 125.9, 75.0, 71.9, 71.3, 38.2, 37.6, 29.9, 29.6, 26.9, 26.4, 26.0, 22.9, 10.1. FT-IR (neat) 3412, 2928, 2859, 1703, 1673, 1612, 1460, 1437, 1407, 1236, 1182, 1116, 1029.66, 978, 919, 842, 748, 721, 595, 540 cm^{-1}. ESI MS (*m/z*) 255.2 $[M+1]^+$.

3-(5-(2-Hydroxy-3-phenylpropoxy)pentyl)cyclohex-2-enone (8bq, entry 8). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.31 (m, 2H), 7.25–7.19 (m, 3H), 5.88 (s, 1H), 4.02 (m, 1H), 3.36–3.54 (m, 3H), 3.31 (dd, *J* = 9.6, 7.2 Hz, 1H), 2.79 (m, 3H), 2.38 (m, 2H), 2.35 (m, 2H), 2.22 (t, *J* = 7.7 Hz, 2H), 1.98 (quintet, *J* = 6.3 Hz, 2H), 1.60 (m, 2H), 1.57 (m, 2H), 1.40 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.2, 166.6, 138.2, 129.6, 128.7, 126.7, 126.0, 74.3, 71.2, 71.4, 40.2, 38.2, 37.6, 29.9, 29.7, 26.95, 26.1, 23.0. FT-IR (neat) 3434, 3026, 2932, 2860, 1662, 1622, 1495, 1453, 1427, 1371, 1347, 1325, 1253, 1191, 1117, 1081, 1030, 965, 886, 744, 699, 604, 501 cm^{-1}. ESI MS (*m/z*) 317.2 $[M+1]^+$.

3-(5-(2-Hydroxy-3-isopropoxypropoxy)pentyl)cyclohex-2-enone (8bs, entry 9). ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.87 (s, 1H), 3.92 (m, 1H), 3.60 (m, 1H), 3.40–3.57 (m, 6H), 2.49 (d, *J* = 4.0 Hz, 1H), 2.38 (t, 2H), 2.28 (t, *J* = 6.1 Hz, 2H), 2.22 (t, *J* = 7.6 Hz, 2H), 1.99 (quintet, *J* = 6.3 Hz, 2H), 1.60 (m, 2H), 1.57 (m, 2H), 1.38 (m 2H), 1.15–1.21 (2d, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.3, 166.9, 125.9, 72.4, 72.2, 71.5, 70.0, 69.5, 38.2, 37.6, 29.9, 29.6, 27.0, 26.0, 23.0, 22.3. FT-IR: 3440, 2931, 2862, 1665, 1623, 1455, 1428, 1368, 1346, 1324, 1253, 1191, 1175, 1118, 1080, 965, 886, 823, 722, 542, 500 cm^{-1}. ESI MS (*m/z*) 299.2 $[M+1]^+$.

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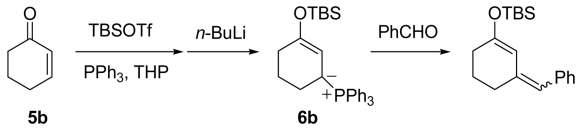
Supporting Information. ^{1}H and ^{13}C NMR spectra of selected compounds are provided.

References and Notes

1. Jung, S. H.; Jang, S. Y. *Bull. Korean Chem. Soc*. **2010**, *31*, 3431.
2. (a) Shim, H. Y.; Jung, S. H. *Bull. Korean Chem. Soc*. **2008**, *29*, 2089. (b) Kim, J. H.; Jung, S. H. *Tetrahedron Lett*. **2007**, *48*, 4243.
3. (a) Kim, J. H.; Jung, S. H. *Bull. Korean Chem. Soc*. **2004**, *25*, 1729. (b) Jung, S. H.; Kim, J. H.; Lee, J. H. *Bull. Korean Chem. Soc*. **2004**, *25*, 1088. (c) Jung, S. H.; Kim, J. H.; Kim, H. J. *Bull. Korean Chem. Soc*. **2004**, *25*, 136. (d) Jung, S. H.; Kim, J. H. *Bull. Korean Chem. Soc*. **2002**, *23*, 1375. (e) Jung, S. H.; Kim, J. H. *Bull. Korean Chem. Soc*. **2002**, *23*, 365.
4. For a review of trialkylsilyl triflates as Lewis acids, see: (a) Emde, H.; Domsch, D.; Feger, H.; Frick, U.; Gotz, A.; Hergott, H. H.; Hofmann, K.; Kober, W.; Krageloh, K.; Osterle, T.; Steppan, W.; West, W.; Simchen, G. *Synthesis* **1982**, 1. (b) Lambert, J. B.; Kania, L.; Zhang, S. *Chem. Rev.* **1995**, *95*, 1191. For recent uses of trialkylsilyl triflates, see: (c) Matsumura, T.; Nakeda, M. *Tetrahedron Lett*. **2014**, *55*, 1412. (d) Berqueiro, J.; Montenegro, J.; Saa, C.; Lopez, S. *RSC Adv.* **2014**, *4*, 14475. (e) Okamoto, K.; Tamura, E.; Ohe, K. *Angew. Chem. Int. Ed*. **2013**, *52*, 10639. (f) Dowrey, C. W.; Dombrowski, G. M.; Maxwell, E. N.; Safran, C. L.; Akomah, O. A. *Eur. J. Org. Chem*. **2013**, 5716. (g) Kobayashi, S.; Kiyohara, H.; Yamaguchi, M. *J. Am. Chem. Soc*. **2011**, *133*, 708.
5. Kozikowski, A. P.; Jung, S. H. *J. Org. Chem.* **1986**, *51*, 3400. Scheme for this transformation is as follows:



5b **6b**

6. For recent reviews of multicomponent reactions, see: (a) Brauch, S. *Chem. Soc. Rev.* **2013**, *42*, 4948. (b) Chebanov, V. A.; Desenko, S. M. *Chem. Heterocycl. Compd.* **2012**, *48*, 566. (c) Eckert, H. *Molecules* **2012**, *17*, 1074. (d) Ruijter, E.; Scheffelaar, R.; Orru, R. V. A. *Angew. Chem. Int. Ed*. **2011**, 50, 6234. (e) Zhu, J.; Bienayme, H. *Multicomponent Reactions*; Wiley-VCH: Weinheim, 2005. (f) Orru, R. V. A.; Greef, M. *Synthesis* **2003**, 1471.
7. For a preparation of **5c**, see: (a) Goto, M.; Akimoto, K.; Aoki, K.; Shindo, M.; Koga, K. *Tetrahedron Lett.* **1999**, *40*, 8129. (b) Dye, J. L.; Lok, M. T.; Tehan, F. J.; Ceraso, J.; Voorhees, K. *J. Org. Soc*. **1973**, *38*, 1775.
8. Tetrahyropyran was purchased from Sigma-Aldrich and distilled over sodium benzophenone ketyl prior to use.