The First Simple Method of Protection of Hydroxy Compounds as their *O*-Boc Derivatives under Lewis Acid Catalysis

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Abstract: The first Lewis acid catalyzed protection of alcohols as Boc derivatives is described. Zinc acetate is a very efficient catalyst for this transformation and the reaction can be applied to primary, secondary and aromatic alcohols, providing the first example of a generally applicable method.

Key words: alcohols, esterification, protecting groups, Lewis acids, zinc acetate

The importance of organic carbonates has been increasing in the past few years both in industry and in laboratories.[1] Organic carbonates, in fact, find employment as fuel additives, lubricating oils, herbicides, pesticides, plastics, solvents and for medicinal and biological applications. In addition, they can act as useful protecting groups of alcohols and phenols since more stable than the corresponding esters under basic conditions.[1a]

Traditional methods for the preparation of organic carbonates required the use of very toxic reagents,[1,2] such as phosgene, pyridine and carbon monoxide, thus many efforts have been recently devoted to develop more environmentally friendly procedures for their synthesis.[3] Moreover, for the synthesis of mixed (unsymmetrical) carbonates, these methods all suffer from many drawbacks, such as low selectivity, limited scope and difficult availability of the substrate.

Among carbonic acid derivatives used as protecting groups, *tert*-butyl carbonates (*O*-Boc alcohols) and carbamates (*N*-Boc amines) are of great importance in organic chemistry. However, whereas *N*-Boc derivatives are extensively used for protecting amino groups,[4] *O*-Boc protection is restricted to aryl alcohols.[5] Introduction of Boc group is generally achieved by using di-*tert*-butyldicarbonate (Boc_2O) in a phase transfer protocol,[6] or by direct acylation with Boc_2O and dimethylaminopyridine (DMAP) as the catalyst,[7] or, finally, by alcoholate nucleophilic cleavage of Boc_2O.[8] Alternatively, reactive Boc species were employed, such as Boc-imidazole[9] or 1-*tert*-butoxy-2-*tert*-butoxycarbonyl-1,2-dihydroisoquinoline (BBDI).[10]

All these methodologies work in basic media[6,8,9] or in the presence of a Lewis base.[7,10] Only recently oxometallic species, such as oxovanadium[11] and oxomolybdenum,[12] were introduced as amphoteric catalysts for nucleophilic acyl substitutions of anhydrides and dicarbonates.

In brief, an efficient and simple protocol for the synthesis of *tert*-butyl carbonates under Lewis acid conditions is still lacking.

In recent years, we were involved in the study of the ability of metal perchlorates to act as powerful Lewis acids, exploiting their attitude to activate bidentate compounds. In particular, metal perchlorates can promote various acylation and esterification reactions[13] and the synthesis of β-enamino esters.[14]

On the other hand, we found a peculiar reactivity of di-*tert*-butyldicarbonate in the presence of metal perchlorates. In fact, if protection of amines as Boc derivatives can be achieved in very good yields with zinc perchlorate as the catalyst,[15] aryl and alkyl *tert*-butyl ethers instead of the corresponding Boc derivative are obtained, when alcohols are allowed to react with magnesium perchlorate as the catalyst.[16]

We screened many common Lewis acids in order to find one able to catalyze *O*-Boc alcohol formation, by using the reaction of octanol with Boc_2O as sample reaction.[17] Perchlorates or triflates gave the exclusive formation of *tert*-butyl ether or a mixture of ether and carbonates, with the prevalence of the former. Other Lewis acids, such as magnesium, zinc or lanthanide halides, led to complex mixture of both compounds or were completely inefficient. We found that only zinc acetate hydrate is a very efficient catalyst for the synthesis of *O*-Boc alcohols.

The methodology here reported represents the first example of protection of alcohols as Boc derivatives under Lewis acid conditions.

Alcohols (**1a**–**m**), di-*tert*-butyldicarbonate and zinc acetate hydrate (10% mol) were dissolved in the minimum amount of dichloromethane and refluxed.[18] Results are reported in Table 1.

The reaction is general and can be applied to primary and secondary alcohols, various substituted phenols and naphthol. The nature of the substituent on the aromatic ring seems to influence the reaction rate, in fact an electron-donating group fastened the reaction with respect to an elec-

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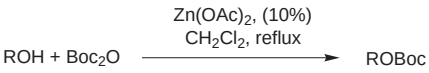
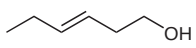
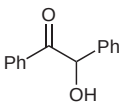
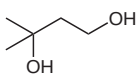
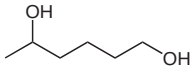
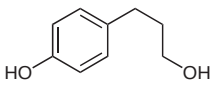
tron-withdrawing one (Table 1, entries 6–8). However, an almost complete conversion was observed in all cases.

Neither isomerization of carbon–carbon double bonds (Table 1, entry 2), nor racemization (Table 1, entries 4, 10) were observed. Various functionalities present in the substrates, such as an ester and a ketone (Table 1, entries 4, 5) as well as a methoxy and a nitro group, (Table 1, entries 6, 8) are tolerated under the adopted reaction conditions. The reaction does not work with tertiary alcohols.

Then we carried out some reaction on diols, in order to test chemoselectivity of the reaction. A selective protection of the primary hydroxy group of diol **1k**, bearing a tertiary and primary function, can be achieved (Table 1, entry 11). In diols bearing primary and secondary or arylic hydroxy groups, a mixture of monoprotected alcohol on the primary function (**2l**,**m**), diprotected diol (**3l**,**m**) and starting material (**1l**,**m**) was recovered (Table 1, entry 12, 13).[19,20] No monoprotected alcohol on the secondary or aromatic framework was detected.

Table 1 Synthesis of Boc Alcohols with 10% $Zn(OAc)_2$ in CH_2Cl_2 at Reflux



Entry	Alcohol	Time (h)	Yield (%)
1	*n*-$C_8H_{17}OH$ (**1a**)	6	98
2	 **1b**	6	98
3	$PhCH_2OH$ (**1c**)	8.25	98
4	(*S*)-MeCH(OH)COOEt (**1d**)	7	98
5	 **1e**	19	90
6	4-MeO-C_6H_4OH (**1f**)	7	98
7	PhOH (**1g**)	13	95
8	4-NO_2-C_6H_4OH (**1h**)	17	98
9	β-Naphthol (**1i**)	18.5	98
10	Cholesterol (**1j**)	15.25	98
11	 **1k**	12.33	98
12	 **1l**	5	96[a]
13	 **1m**	12.33	74[b]

[a] As sum of 80% of primary monoprotected (**2l**) and 16% diprotected diol (**3l**); trace (<3%) of starting material (**1l**) was also recovered.[19,]
[b] As sum of 39% of primary monoprotected (**2m**) and 35% diprotected diol (**3m**); 24% of starting material (**1m**) was also recovered.[20]

In order to increase the environmental friendliness of the reaction, we tested solvent-free conditions in the case of liquid substrates or those that melt below 60 °C. Higher temperatures cause decomposition of Boc_2O.[21]

Alcohols (**1a**–**d**,**f**,**g**,**n**–**z**,**aa**) a slight excess of Boc_2O and zinc acetate hydrate (10 mol%) were melted together and stirred at the appropriate temperature (Table 2).[22,23]

The reaction maintained its chemoselectivity. In fact both the functionalities previously tested and others, such as *Z*-double bonds, amino and fluoride groups, were unaffected.

Conversely from simple alcohols, which are usually unreactive in the absence of the catalyst,[7,24] amino alcohol **1r** can be protected in the absence of any catalyst. Actually, although it is reported that Et_3N is unable to act as catalyst in Boc protection of hydroxy compounds,[7] the very similar dimethylamino group can act as an intramolecular basic catalyst. The conversion was complete in about 6 hours. However, accordingly with literature,[7] a 83:17 mixture of *O*-Boc derivative **2r** and bis[3-(*N*,*N*-dimethylamino)propyl]carbonate (**4r**) was obtained.[25]

It is noteworthy that the ratio of **2r** and **4r** increases to 94:6 when zinc acetate catalysis works, according to the assertion that more acidic media give higher amounts *O*-Boc products and suppress the symmetrical carbonate formation.[7] Reaction with diol **1l** was also attempted, but a messy reaction mixture was obtained.

In order to show the merit of the present work, orthogonality of Boc protection with other classical protective groups was also checked. Acid-cleavable protective groups, such as acetonide, THP and silyl, *N*-Boc functions survive under these reaction conditions (Table 2, entries 17–20), demonstrating that the current catalytic conditions are not harsh.

In conclusion, the first general and efficient protection of hydroxy compounds into their Boc derivatives is described. The reaction can be carried out in solvent-free conditions, and by-products are carbon dioxide and *tert*-butanol, therefore this method is environmentally benign. This is the first example of Boc protection obtained under Lewis acid catalyzed conditions, conversely from all the other methods, which worked under basic conditions. The current conditions are not too harsh and allow acid-sensitive functional groups to survive. Only tertiary hydroxy groups of diols are unaffected. However, some protective groups are demonstrated to be orthogonal with Boc protection, so this drawback can be easily overcome in diol reaction.

Since the intervention of the alcoholate is reported to be essential for the occurrence of the reaction in base-catalyzed reactions, studies are in progress to understand the

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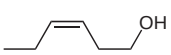
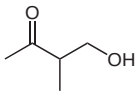
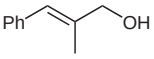
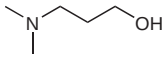
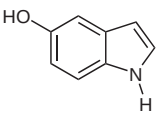
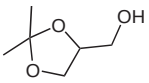
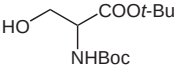
Table 2 Synthesis of Boc Alcohols with 10% $Zn(OAc)_2$ under Solvent-Free Conditions

Entry	Alcohol	Temp (°C)	Time (h)	Yield (%)
1	**1a**	50	12.5	98
2	**1b**	50	6.5	98
3	 **1n**	50	9	98
4	**1c**	50	6	98
5	$PhCH_2CH_2OH$ (**1o**)	50	16	98
6	 **1p**	50	11.75	98
7	 **1q**	50	6	98
8	 **1r**	50	8.25	98[a]
9	**1d**	60	4.5	98
10	(–)-Menthol (**1s**)	50	30	98
11	2-$C_8H_{17}OH$ (**1t**)	50	19	92
12	**1f**	60	7	96
13	3-MeO-C_6H_4OH (**1u**)	50	6.25	98
14	**1g**	50	6	95
15	4-F-C_6H_4OH (**1v**)	50	29.5	97
16	 **1w**	50	17.33	98
17	 **1x**	50	16.33	98
18	$THPO(CH_2)_4OH$ (**1y**)	50	20.5	96
19	*i*-$Pr_3SiO(CH_2)_6OH$ (**1z**)	50	21	97
20	 **1aa**	50	7	87

[a] As a 94:6 mixture of Boc alcohol (**2r**) and bis[3-(*N*,*N*-dimethylamino)propyl]carbonate (**4r**).[25]

mechanism of this reaction. Moreover, it is still under investigation how the change of the catalyst counter ion from perchlorate to acetate shifts the reaction product from *tert*-butyl ether to the *O*-Boc derivative.

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(17) Unpublished results.
(18) In a two-necked flask equipped with a magnetic stirring bar, alcohols **1a**–**m** (1 mmol), di-*tert*-butyl dicarbonate (1.1 mmol), and $Zn(OAc)_2 \cdot 2H_2O$ (0.1 mmol) were dissolved in CH_2Cl_2 (1 mL). The mixture was stirred and refluxed until the GC-MS analysis revealed the presence of **1** or Boc_2O for diols (Table 1). The crude reaction mixture was diluted with

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H_2O and extracted twice with CH_2Cl_2. The organic layer was separated, dried over $MgSO_4$, filtered and the solvent was removed by rotary evaporation. The Boc alcohols **2a**–**m** were purified, when necessary, by flash chromatography on silica gel with a mixture of PE–Et_2O = 8:2.

(19) Product ratio was calculated by integration of the triplet at δ = 3.64 ppm (2 H, *J* = 6.6 Hz, CH_2O of **1l**) and doublets at δ = 1.26 ppm (d, 3 H, MeCH, **3l**) and δ = 1.19 ppm (d, 3 H, MeCH, **2l**) in the ^{1}H NMR spectrum of the crude reaction mixture. Products were then separated by flash chromatography and recovered amounts confirmed the calculated ratio.

(20) Product ratio was calculated by integration of the triplet at δ = 3.68 ppm (2 H, *J* = 6.6 Hz, CH_2O of **1m**) and singlets at δ = 1.49 ppm (9 H, aromatic Boc) and δ = 1.55 ppm (9 H + 9 H, aliphatic Boc) in the ^{1}H NMR spectrum of the crude reaction mixture. Products were then separated by flash-chromatography and recovered amounts confirmed the calculated ratio.

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(22) All the reactions were carried out without solvent. A mixture of alcohols **1a**–**d**,**f**,**g**,**n**–**z**,**aa** (1 mmol), di-*tert*-butyl dicarbonate (1.1 mmol), and $Zn(OAc)_2{\cdot}2H_2O$ (0.1 mmol) were melted (50–60 °C) in a two-necked flask equipped with a magnetic stirring bar. The mixture was stirred until the GC-MS analysis revealed the presence of **1** (Table 2). The crude reaction mixture was diluted with H_2O and extracted twice with CH_2Cl_2. The organic layer was separated, dried over $MgSO_4$, filtered and the solvent was removed by rotary evaporation. The Boc alcohols **2a**–**d**,**f**,**g**,**n**–**z**,**aa** were purified, when necessary, by flash chromatography on silica gel with a mixture of PE–Et_2O = 8:2.

(23) Benzyl *tert*-butyl carbonate (**2c**),[6] (4-methoxyphenyl) *tert*-butyl carbonate (**2f**),[10] phenyl *tert*-butyl carbonate (**2g**),[25] (4-nitrophenyl) *tert*-butyl carbonate (**2h**)[10] and (2-phenylethyl) *tert*-butyl carbonate (**2o**)[12] are known compounds. Physical data for new compounds follow.

Octyl *tert*-butyl carbonate (**2a**): oil. ^{1}H NMR: δ = 0.88 (t, 3 H, *J* = 7.1 Hz, Me), 1.20–1.40 [m, 10 H, $(CH_2)_5$], 1.49 (s, 9 H, *t*-Bu), 1.60–1.70 (m, 2 H, CH_2), 4.05 (t, 2 H, *J* = 6.8 Hz, CH_2O) ppm. ^{13}C NMR: δ = 14.0 (Me), 22.6 (CH_2), 25.7 (CH_2), 27.6 (3 Me), 28.7 (CH_2), 29.1 (CH_2), 29.2 (CH_2), 31.7 (CH_2), 67.2 (CH_2), 81.7 (C), 153.7 (C=O). MS (EI): *m/z* (%) = 113 (5), 112 (8), 84 (19), 83 (19), 71 (16), 70 (24), 69 (24) 57 (100).

[(*E*)-3-Hexenyl] *tert*-butyl carbonate (**2b**): oil. ^{1}H NMR: δ = 0.97 (t, 3 H, *J* = 7.5 Hz, Me), 1.49 (s, 9 H, *t*-Bu), 1.95–2.10 (m, 2 H, CH_2), 2.30–2.40 (m, 2 H, CH_2), 4.06 (t, 2 H, *J* = 6.8 Hz, CH_2O), 5.30–5.45 [dtt, 1 H, *J* = 15.2 (d), 6.8 (t), 1.6 (t)Hz, CH=], 5.50–5.65 [dtt, 1 H, *J* = 15.2 (d), 6.3 (t), 1.4 (t)Hz, CH=] ppm. ^{13}C NMR: δ = 13.7 (Me), 25.7 (CH_2), 27.9 (3 Me), 32.1 (CH_2), 66.7 (CH_2), 81.8 (C), 123.8 (CH=), 135.3 (CH=), 153.7 (C=O) ppm. MS (EI): *m/z* (%) = 144 (1), 82 (100), 67 (74), 57 (64), 55 (44).

Ethyl (*S*)-2-(*tert*-butoxycarbonyloxy)propanoate (**2d**): oil; $[\alpha]_D^{20}$ (solv) –34.3 (*c* 1.02, $CHCl_3$). ^{1}H NMR: δ = 1.28 (t, 3 H, *J* = 7.2 Hz, Me), 1.51 (d, 3 H, *J* = 7.1 Hz, Me) ppm. ^{13}C NMR: δ = 14.0 (Me), 16.9 (Me), 27.6 (3 Me), 61.3 (CH_2), 70.8 (CH), 82.8 (C), 152.7 (C=O), 170.7 (C=O) ppm. MS (EI): *m/z* (%) = 163 (3), 145 (10), 101 (16), 87 (3), 75 (5), 73 (13), 57 (100).

2-(*tert*-Butoxycarbonyloxy)-1,2-diphenylethanone (**2e**): mp 147–148 °C. ^{1}H NMR: δ = 1.49 (s, 9 H, *t*-Bu), 6.70 (s, 1 H, CHO), 7.30–7.50 and 7.92–7.96 (m, 8 H + 2 H, ArH) ppm. ^{13}C NMR: δ = 27.7 (3 Me), 79.7 (CH), 83.2 (CH), 128.6 (2 CH), 128.7 (2 CH), 128.8 (2 CH), 129.1 (2 CH), 129.3 (CH),133.2 (C), 133.4 (CH), 134.6 (C), 152.9 (C=O), 193.9 (C=O) ppm. MS (EI): *m/z* (%) = 256 (1), 195 (3), 167 (2), 165 (3), 105 (100), 79 (17), 77 (44), 57 (14), 51 (13).

(2-Naphthyl) *tert*-butyl carbonate (**2i**): mp 77–78 °C. ^{1}H NMR: δ = 1.58 (s, 9 H, *t*-Bu), 7.31 (dd, 1 H, *J* = 8.9, 2.5 Hz, H-3), 7.40–7.55 (m, 2 H, H-6, H-7), 7.64 (d, 1 H, *J* = 2.4 Hz, H-1), 7.75–7.85 (m, 3 H, H-4, H-5, H-8) ppm. ^{13}C NMR: δ = 27.7 (3 Me), 83.6 (C), 118.1 (CH), 120.8 (CH), 125.6 (CH), 126.5 (CH), 127.6 (CH), 127.7 (CH), 129.3 (CH), 131.3 (C), 133.7 (C), 148.7 (C), 152.0 (C=O) ppm. MS (EI): *m/z* (%) = 244 (1) [M^+], 185 (4), 144 (100), 127 (7), 115 (45), 89 (6), 63 (5), 57 (24).

Cholesteryl *tert*-butyl carbonate (**2j**): mp 141–142 °C; $[\alpha]_D^{20}$ (solv) –30.6 (*c* 0.99, $CHCl_3$). ^{1}H NMR: δ = 0.68 (s, 3 H, H-18), 0.86 (d, 6 H, *J* = 6.2 Hz, H-26, H-27), 0.91 (d, 3 H, *J* = 6.4 Hz, H-21), 1.00 (s, 3 H, H-19), 1.49 (s, 9 H, *t*-Bu), 0.80–2.06 (m, 27 H), 2.33–2.42 (m, 2 H), 4.34–4.49 (m, 1 H, H-3), 5.39 (d, 1 H, *J* = 4.7 Hz, H-6) ppm. ^{13}C NMR: δ = 12.1 (C-18), 18.9 (C-21), 19.4 (C-19), 21.1 (C-11), 22.8 (C-26), 23.0 (C-27), 24.0 (C-23), 24.5 (C-15), 28.0 (C-2, C-25), 28.1 (3 Me), 28.2 (C-16), 32.1 (C-7, C-8), 36.0 (C-20), 36.4 (C-22), 36.8 (C-10), 37.2 (C-4), 38.3 (C-1), 39.7 (C-24), 39.9 (C-12), 42.5 (C-13), 50.2 (C-9), 56.4 (C-17), 56.9 (C-14), 77.6 (C-3), 81.9 (C), 122.9 (C-6), 139.8 (C-5), 153.1 (C=O) ppm. MS (EI): *m/z* (%) = 429 (1), 405 (4), 386 (57), 301 (55), 275 (60), 255 (51), 213 (63), 207 (47), 159 (59), 145 (75), 107 (87), 105 (77), 57 (70), 55 (88), 44 (100).

(3-Hydroxy-3-methylbutyl) *tert*-butyl carbonate (**2k**): oil. ^{1}H NMR: δ = 1.27 (s, 6 H, 2 e), 1.49 (s, 9 H, *t*-Bu), 1.87 (t, 2 H, *J* = 6.8 Hz, CH_2), 4.25 (t, 2 H, *J* = 6.8 Hz, CH_2O) ppm. ^{13}C NMR: δ = 27.7 (3 Me), 29.5 (2 Me), 41.5 (CH_2), 63.9 (CH_2), 69.8 (C), 82.0 (C) ppm. MS (EI): *m/z* (%) = 148 (5), 133 (15), 89 (16), 84 (16), 71 (52), 59 (100), 57 (78).

(5-Hydroxyhexyl) *tert*-butyl carbonate (**2l**): oil. ^{1}H NMR: δ = 1.19 (d, 3 H, *J* = 6.1 Hz, MeCH), 1.61–1.74 (m, 4 H, CH_2CH_2), 1.49 (s, 9 H, *t*-Bu), 1.61–1.74 (m, 2 H, CH_2), 1.79 (br s, 1 H, disappears with D_2O, OH), 3.85–3.74 (m, 1 H, CHO), 4.07 (t, 2 H, *J* = 6.5 Hz, CH_2O) ppm. ^{13}C NMR: δ = 21.9 (Me), 23.4 (CH_2), 27.7 (3 Me), 28.6 (CH_2), 38.7 (CH_2), 66.9 (CH_2), 67.8 (CH), 81.8 (C), 153.6 (C=O) ppm. MS (EI): *m/z* (%) = 162 (2) [M^+ – 56], 145 (3), 119 (8), 100 (7), 85 (20), 83 (28), 57 (100), 56 (61).

Bis(1,5-*tert*-butoxycarbonyloxy)hexane (**3l**): oil. ^{1}H NMR: δ = 1.26 (d, 3 H, *J* = 6.7 Hz, MeCH), 1.49 (s, 18 H, 2 *t*-Bu), 1.50–1.76 (m, 6 H, 3 CH_2), 4.06 (t, 2 H, *J* = 6.4 Hz, CH_2O), 4.64–4.76 (m, 1 H, CHO) ppm. ^{13}C NMR: δ = 19.9 (Me), 21.7 (CH_2), 27.72 (3 Me), 27.74 (3 Me), 28.5 (CH_2), 35.5 (CH_2), 66.7 (CH_2), 73.7 (CH), 81.6 (C), 81.8 (C), 153.2 (C=O), 153.6 (C=O) ppm. MS (EI): *m/z* (%) = 206 (3) [M^+ – (56 × 2)], 145 (11), 119 (9), 101 (7), 83 (35), 57 (100), 56 (38).

3-(4-Hydroxyphenyl)propyl *tert*-butyl carbonate (**2m**): oil. ^{1}H NMR: δ = 1.49 (s, 9 H, *t*-Bu), 1.93 (quint, 2 H, *J* = 7.0 Hz, CH_2), 2.63 (t, 2 H, *J* = 7.1 Hz, CH_2), 4.07 (t, 2 H, *J* = 7.0 Hz, CH_2O), 5.17 (br s, 1 H, disappears with D_2O, OH), 6.70 and 7.04 (A_2B_2 system, 2 H + 2 H, ArH) ppm. ^{13}C NMR: δ = 27.8 (3 Me), 30.4 (CH_2), 31.0 (CH_2), 66.4 (CH_2), 82.1 (C), 115.3 (2 CH), 129.5 (2 CH, C), 133.4 (C), 153.9 (C=O) ppm. MS (EI): *m/z* (%) = 252 (1) [M^+] 196 (7), 152 (25), 133 (50), 107 (100), 77 (18), 57 (14), 56 (14).

3-(4-*tert*-Butoxycarbonyloxyphenyl)propyl *tert*-butyl carbonate (**3m**): oil. ^{1}H NMR: δ = 1.49 (s, 9 H, *t*-Bu), 1.55 (s, 9 H, *t*-Bu), 1.90–2.02 (m, 2 H, CH_2), 2.63–2.73 (m, 2 H, CH_2), 4.08 (t, 2 H, *J* = 6.4 Hz, CH_2O), 7.08 and 7.18 (A_2B_2 system, 2 H + 2 H, ArH) ppm. ^{13}C NMR: δ = 27.6 (3 Me), 27.7 (3 Me), 30.3 (CH_2), 31.4 (CH_2), 66.3 (CH_2), 81.9 (C),

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83.4 (C), 121.2 (2 CH), 129.2 (2 CH,), 138.6 (C), 149.3 (C), 152.2 (C=O), 153.6 (C=O) ppm. MS (EI): *m/z* = (%) 280 (1) [M^+ – 72], 262 (10), 150 (48), 133 (10), 104 (100), 91 (58), 71 (20), 57 (25).

[(*Z*)-3-Hexenyl] *tert*-butyl carbonate (**2n**): oil. ^{1}H NMR: δ = 0.97 (t, 3 H, *J* = 7.5 Hz, Me), 1.48 (s, 9 H, *t*-Bu), 2.06 (quint, 2 H, *J* = 7.5 Hz, CH_2), 2.41 (q, 2 H, *J* = 7.1 Hz, CH_2), 4.05 (t, 2 H, *J* = 7.1 Hz, CH_2O), 5.27–5.38 (m, 1 H, CH=), 5.46–5.57 (m, 1 H, CH=) ppm. ^{13}C NMR: δ = 14.2 (Me), 20.6 (CH_2), 26.8 (CH_2), 27.4 (3 Me), 66.4 (CH_2), 81.8 (C), 123.3 (CH=), 134.8 (CH=), 153.6 (C=O) ppm. MS (EI): *m/z* (%) = 144 (1), 82 (100), 67 (86), 57 (88), 55 (54).

4-(*tert*-Butoxycarbonyloxy)-3-methyl-2-butanone (**2p**): oil. ^{1}H NMR: δ = 1.15 (d, 3 H, *J* = 7.3 Hz, Me), 1.48 (s, 9 H, *t*-Bu), 2.21 (s, 3 H, MeCO), 2.85–2.95 (m, 1 H, CH), 4.07 (dd, 1 H, *J* = 11.0, 5.8 Hz, CHO), 4.27 (dd, 1 H, *J* = 11.0, 7.4 Hz, CHO) ppm. ^{13}C NMR: δ = 13.6 (Me), 27.9 (3 Me), 29.0 (Me), 46.2 (CH), 67.9, (CH_2), 82.5 (C), 153.5 (C=O), 209.5 (C=O) ppm. MS (EI): *m/z* (%) = 146 (2), 105 (11), 85 (30), 69 (11), 57 (100).

3-(*tert*-Butoxycarbonyloxy)-2-methyl-1-phenylpropene (**2q**): oil. ^{1}H NMR: δ = 1.51 (s, 9 H, *t*-Bu), 1.91 (s, 3 H, Me), 4.62 (s, 2 H, CH_2O), 6.55 (s, 1 H, CH=), 7.20–7.35 (m, 5 H, ArH) ppm. ^{13}C NMR: δ = 15.5 (Me), 27.8 (3 Me), 72.7 (CH_2), 82.1 (C), 126.7 (CH), 128.1 (2 CH), 128.6 (CH), 128.9 (2 CH), 132.5 (C), 137.0 (C), 153.5 (C=O) ppm. MS (EI). *m/z* (%) = 192 (47), 148 (26), 131 (61), 130 (100), 129 (67), 115 (60), 91 (58), 57 (23).

[3-(*N*,*N*-Dimethylamino)propyl] *tert*-butyl carbonate (**2r**): oil. ^{1}H NMR: δ = 1.47 (s, 9 H, *t*-Bu), 1.75–1.90 (m, 2 H, CH_2), 2.21 (s, 6 H, NMe_2), 2.34 (t, 2 H, *J* = 7.4 Hz, CH_2N), 4.10 (t, 2 H, *J* = 6.7 Hz, CH_2O) ppm. ^{13}C NMR: δ = 27.1 (CH_2), 27.8 (3 Me), 45.5 (2 Me), 56.2 (CH_2), 65.5 (CH_2), 81.9 (C), 153.6 (C=O). MS (EI): *m/z* (%) = 203(5) [M^+], 130 (5), 86 (12), 58 (100).

Menthyl *tert*-butyl carbonate (**2s**): oil; $[\alpha]_D^{20}$ (solv) –42.5 (*c* 0.97, $CHCl_3$). ^{1}H NMR: δ = 0.79 (d, 3 H, *J* = 6.9 Hz, Me), 0.89 (d, 3 H, *J* = 7.1 Hz, Me), 0.91 (d, 3 H, *J* 6.4 Hz, Me), 0.95–1.10 (m, 2 H), 1.35–1.45 (m, 2 H), 1.48 (s, 9 H, *t*-Bu), 1.60–1.70 (m, 2 H), 1.90–2.10 (m, 2 H), 4.47 [dt, 1 H, *J* = 11.2 (t), 4.4 (d)Hz, CHO] ppm. ^{13}C NMR: δ = 16.1 (Me), 20.7 (Me), 21.9 (Me), 23.2 (CH_2), 26.0 (CH), 27.8 (3 Me), 31.4 (CH), 34.1 (CH_2), 40.9 (CH_2), 46.9 (CH), 77.0 (CH), 81.4 (C), 153.3 (C=O) ppm. MS (EI): *m/z* (%) = 138 (64), 123 (28), 95 (56), 81 (54), 71 (24), 57 (100).

2-Octyl *tert*-butyl carbonate (**2t**): oil. ^{1}H NMR: δ = 0.88 (t, 3 H, *J* = 7.1 Hz, Me), 1.25 (d, 3 H, *J* = 6.2 Hz, Me) 1.25–1.35 [m, 8 H, $(CH_2)_4$], 1.48 (s, 9 H, *t*-Bu), 1.44–1.70 (m, 2 H, CH_2), 4.66–4.74 (m, 1 H, CHO) ppm. ^{13}C NMR: δ = 14.0 (Me), 20.0 (Me), 22.5 (CH_2), 25.4 (CH_2), 27.8 (3 Me), 29.1 (CH_2), 31.7 (CH_2), 36.0 (CH_2), 74.2 (CH), 81.5 (C) 153.3 (C=O). MS (EI): *m/z* (%) = 129 (4), 113 (7), 112 (10), 97 (6), 84 (6), 83 (6), 71(14), 57 (100).

(3-Methoxyphenyl) *tert*-butyl carbonate (**2u**): oil. ^{1}H NMR: δ = 1.56 (s, 9 H, *t*-Bu), 3.79 (s, 3 H, OMe), 6.70–6.80 (m, 3 H, H-2, H-4, H-6), 7.26 (t, 1 H, *J* = 8.4 Hz, H-5) ppm. ^{13}C NMR: δ = 27.7 (3 Me), 55.4 (OMe), 83.5 (C), 107.3 (CH), 111.6 (CH), 113.5 (CH), 129.7 (CH), 151.7 (C), 152.0 (C=O), 160.4 (C) ppm. MS (EI): *m/z* (%) = 165 (10), 124 (100), 95 (17), 94 (25), 81 (13), 57 (34).

(4-Fluorophenyl) *tert*-butyl carbonate (**2v**): oil. ^{1}H NMR: δ = 1.55 (s, 9 H, *t*-Bu), 7.00–7.15 (m, 4 H, ArH) ppm. ^{13}C NMR: δ = 27.7 (3 Me), 83.7 (C), 116.0 (d, J_{C-F} 23.6 Hz, 2 CH), 122.7 (d, J_{C-F} = 9.0 Hz, 2 CH), 147.0 (d, J_{C-F} = 3.3 Hz, C), 151.9 (C=O), 160.1 (d, J_{C-F} = 246.0 Hz, C) ppm. MS (EI): *m/z* (%) = 197 (6), 139 (15), 119 (95), 95 (29), 83 (26), 57 (100).

5-Indolyl *tert*-butyl carbonate (**2w**): mp 111–112 °C. ^{1}H NMR: δ = 1.57 (s, 9 H, *t*-Bu), 6.53 (br s, 1 H, H-3), 6.99 (dd, 1 H, *J* = 8.7, 2.2 Hz, H-6), 7.22 (t, 1 H, *J* = 2.9 Hz, H-2), 7.33 (d, 1 H, *J* = 8.7 Hz, H-7), 7.41, (d, *J* = 2.1 Hz, H-4), 8.17 (br s, 1 H, NH) ppm. ^{13}C NMR: δ = 27.7 (3 Me), 83.1 (C), 102.8 (C-3), 111.3 (C-4), 112.4 (C-7), 115.8 (C-6), 125.6 (C-2), 128.0 (C-3′), 133.6 (C-7′), 144.8 (C), 153.0 (C) ppm. MS (EI): *m/z* (%) = 233 (2) [M^+], 174 (4), 133 (100), 116 (5), 104 (16), 77 (6), 57 (20).

2,2-Dimethyl-4-(*tert*-butoxycarbonyloxymethyl)-1,3-dioxolane (**2x**): oil. ^{1}H NMR: δ = 1.36 (s, 3 H, Me), 1.43 (s, 3 H, Me), 1.49 (s, 9 H, *t*-Bu), 3.78 (dd, 1 H, *J* = 8.5, 5.9 Hz, H-5a), 4.04–4.16 (m, 3 H, CH_2 and H-5b), 4.33 (quint, 1 H, *J* = 5.7 Hz, H-4) ppm. ^{13}C NMR: δ = 25.2 (Me), 26.6 (Me), 27.6 (3 Me), 66.3 (CH_2), 66.9 (CH_2), 73.3 (CH), 82.3 (C), 109.7 (O–C–O), 153.2 (C=O). MS (EI): *m/z* (%) = 217 (5) [M^+ – 15], 161 (67), 117 (100), 101 (64), 57 (64).

4-(Tetrahydropyranyloxy)butyl *tert*-butyl carbonate (**2y**): oil. ^{1}H NMR: δ = 1.49 (s, 9 H, *t*-Bu), 1.45–1.88 (m, 10 H, 5 CH_2), 3.36–3.55 (m, 2 H, CH_2), 3.70–3.90 (m, 2 H, CH_2), 4.10 (t, 2 H, *J* = 6.80 Hz, CH_2-OBoc), 4.58 (t, 1 H, *J* = 3.50 Hz, CH) ppm. ^{13}C NMR: δ = 19.5 (CH_2), 25.4 (CH_2), 25.7 (CH_2), 26.0 (CH_2), 27.7 (3 Me), 30.6 (CH_2), 62.2 (CH_2), 66.8 (CH_2), 66.9 (CH_2), 81.7 (C), 98.7 (O–C–O), 153.6 (C=O) ppm. MS (EI): *m/z* (%) = 217 (1) [M^+ – 57], 160 (1), 117 (18), 101 (31), 85 (100), 73 (35), 57 (57), 55 (67).

6-(Triisopropyloxy)hexyl *tert*-butyl carbonate (**2z**): oil. ^{1}H NMR: δ = 0.97–1.08 (m, 21 H), 1.30–1.41 (m, 4 H, 2 CH_2), 1.48 (s, 9 H, *t*-Bu), 1.43–1.58 (m, 2 H, CH_2), 1.59–1.70 (m, 2 H, CH_2), 3.66 (t, 2 H, *J* = 6.9, CH_2OSi), 4.05 (t, 2 H, *J* = 7.3 Hz, CH_2OBoc) ppm. ^{13}C NMR: δ = 12.0 (3 CH), 18.0 (6 Me), 25.5 (CH_2), 25.6 (CH_2), 27.8 (3 Me), 28.7 (CH_2), 32.8 (CH_2), 63.3 (CH_2), 67.1 (CH_2), 81.7 (C), 153.7 (C=O) ppm. MS (EI): *m/z* (%) = 275 (3) [M^+ – 99], 231 (13), 171 (12), 149 (16) 131 (83), 119 (51), 103 (44), 83 (93), 75 (50), 55 (100).

tert-Butyl 3-(*tert*-butoxycarbonyloxy)-2-(*tert*-butoxycarbonylamino)propanoate (**2aa**): mp 85–87 °C. ^{1}H NMR: δ = 1.45 (s, 9 H, *t*-Bu), 1.47 (s, 18 H, 2 *t*-Bu), 4.23 (dd, 1 H, *J* = 11.0, 3.0 Hz, C*H*H), 4.43 [dt, 1 H, *J* = 8.0 (d), 3.0 (t) Hz, CH], 4.51 (dd, 1 H, *J* = 11.0, 3.0 Hz, CH*H*), 5.34 (br d, 1 H, *J* = 8.0 Hz, NH) ppm. ^{13}C NMR: d = 27.6 (3 Me), 27.8 (3 Me), 28.2 (3 Me), 53.5 (CH), 66.7 (CH_2), 79.9 (C), 82.4 (C), 82.6 (C), 153.0 (C=O), 155.1 (C=O), 168.5 (C=O) ppm. MS (EI): *m/z* (%) = 234 (2) [M^+ – 127], 232 (2), 204 (11), 176 (9), 148 (8), 104 (36), 59 (23), 57 (100).

(24) In a blank run, octanol and Boc_2O were stirred together for 144 h and only 13% conversion to carbonate was detected by NMR.

(25) Product ratio was calculated by integration of the triplets at δ = 4.10 (*J* = 6.7 Hz) and 4.18 (*J* = 6.4 Hz) ppm (typical of **2r** and **4r**, respectively) in the ^{1}H NMR spectrum of the crude reaction mixture.

(26) Nakamura, K.; Nakajima, T.; Kayahara, H.; Nomura, E.; Taniguchi, H. *Tetrahedron Lett.* **2004**, *45*, 495.

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