Supporting Information

A New Look at Boron Enolate Chemistry: Aminative C-C Bond Formation Using Diaminoboron enolate with Aldehyde

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1. General

All reactions were performed in drybox or using Schlenk technique under a nitrogen atmosphere with magnetic stirring. ^1H NMR spectra were recorded on a Varian Mercury-400 (400 MHz) or Varian GEMINI-2000 (300 MHz) spectrometer using CDCl_3 as solvent and tetramethylsilane as internal standard or using C_6D_6 as solvent and internal standard. ^{13}C NMR spectra were recorded on a Varian GEMINI-2000 spectrometer at 75.45 MHz with CDCl_3 as solvent. Chemical shifts of the ^{13}C NMR spectra were measured relative to CDCl_3 (77.0 ppm). ^{11}B NMR spectra were recorded on a Varian Mercury-400 spectrometer at 128.48 MHz with C_6D_6 as solvent. Chemical shifts of the ^{11}B NMR spectra were measured relative to $\text{BF}_3\cdot\text{Et}_2\text{O}$ (0 ppm). High resolution mass (FAB) spectra were recorded on a JEOL JMS-700 spectrometer.

Anhydrous solvents were purchased from Kanto Chemical Co. Aldehydes and ketones were dried over CaH_2 and distilled under Ar. Bis(diamino)chloroboranes were

synthesized according to the literature method.¹

2. Preparation of boron enolates 2a–2e

2.1. General procedure.

To a solution of diisopropylamine (10 mmol) in THF (10 mL) was added *n*-butyllithium (1.6 M in hexane, 6.3 mL, 10 mmol) dropwise at 0 °C. Stirring was continued for 30 min. at 0 °C. To the reaction mixture cooled to -78 °C was added dropwise a solution of ketone (10 mmol) in THF (10 mL). After stirring for 15 min., chlorobis(dialkylamino)borane (10 mmol) was added slowly at -78 °C. The reaction mixture was allowed to warm up to room temperature and stirred further for 3 h. Evaporation of the volatile material followed by addition of hexane (20 mL) to the residue resulted in precipitation of LiCl, which was filtered off. Evaporation of hexane gave essentially pure boron enolate, which can be purified by distillation. Obtained yields varied between 82% and 97%.

1-(1-bis(diethylamino)boryloxyvinyl)benzene (2a) (b.p. 90 °C/ 0.3 mmHg)

¹H NMR (C₆D₆): δ 0.97 (t, *J* = 7.2 Hz, 12H), 2.90 (q, *J* = 7.2 Hz, 8H), 4.42 (d, *J* = 1.2 Hz, 1H), 4.85 (d, *J* = 1.2 Hz, 1H), 7.05-7.18 (m, 3H) 7.77 (dd, *J* = 7.2 Hz, *J* = 1.2 Hz, 2H). ¹³C NMR (C₆D₆): δ 15.6, 41.1, 87.8, 125.5, 127.9, 128.5, 137.8, 156.9. ¹¹B NMR (C₆D₆): δ = 24.4.

3. Aminative alkylation of aldehydes

¹Chavant, P. Y.; Vaultier M. *J. Organomet. Chem.* **1993**, 455, 37-46. Gerrard, W.; Lappert, M. F.; Pearce, C.A. *J. Chem Soc.* **1957**, 381-386.

3.1. General procedure.

Boron enolate **2** (0.25 mmol) was dissolved in THF or DMF (0.5 mL). Aldehyde (0.50 mmol) was then added, and the mixture was stirred at 50 °C for 5 h in THF or for 1.5 to 2 h in DMF. To the reaction mixture were added ice water and, subsequently, *tert*-butyl methyl ether (15 mL). Basic components were extracted three times with hydrochloric acid (0.5 M, 5 mL $\times$ 3). The combined acid layers were washed with *tert*-butyl methyl ether (10 mL) and cooled to 0 °C. The pH of the solution was brought to 8 by addition of conc. ammonia solution. The organic material was extracted with *tert*-butyl methyl ether and washed with water (10 mL). Removal of the solvent in vacuo at 0 °C afforded the products as colorless or pale yellow oil.

3-Diethylamino-1,3-diphenyl-propan-1-one (**4aa**)²

¹H NMR (C₆D₆): δ = 0.90 (t, J = 7.2 Hz, 6H), 2.22 (dq, J = 13.2, 6.8 Hz, 2H), 2.42 (dq, J = 13.2, 7.2 Hz, 2H), 3.11 (dd, J = 15.6 Hz, J = 7.6 Hz, 1H), 3.26 (dd, J = 15.6 Hz, J = 6.4 Hz, 1H), 4.70 (t, J = 7.0 Hz, 1H), 6.98-7.24 (m, 8H), 7.78 (dd, J = 6.8, 1.6 Hz, 2H). ¹³C NMR (C₆D₆): δ = 13.9, 41.2, 44.0, 60.5, 127.5, 128.9, 129.0, 130.6, 132.9, 141.8, 199.6.

3-Diethylamino-3-(4-methoxy-phenyl)-1-phenyl-propan-1-one (**4ab**)

¹H NMR (C₆D₆): δ 0.98 (t, J = 7.2 Hz, 6H), 2.31 (dq, J = 13.2, 6.8 Hz, 2H), 2.58 (dq, J =

²Hosomi, A.; Yanagi, T.; Hojo, M.; *Tetrahedron Lett.* **1991**, 32, 2371-2374; Clark, J. H.; Cork, D. G.; Gibbs, H. W.; *Perkin Trans. 1* **1983**, 9, 2253-2258; Clark, J. H.; Cork, D. G.; *Chem. Commun.* **1982**, 11, 935-936.

13.2, 7.2 Hz, 2H), 3.38 – 3.50 (m, 2H), 3.76 (s, 3H), 4.52 (t, $J = 7.0$ Hz, 1H), 6.81 (d, $J = 8.8$ Hz, 2H), 7.21 (d, $J = 8.8$ Hz, 2H), 7.45 (t, $J = 8.0$ Hz, 2H), 7.55 (δ, $J = 6.8$ Hz, 1H), 7.91 (dd, $J = 8.4, 1.6$ Hz, 2H). ^{13}C NMR (C_6D_6): δ 13.0, 41.3, 43.2, 55.1, 59.2, 113.3, 128.1, 128.4, 129.4, 130.3, 132.8, 137.5, 158.5, 199.4. IR (neat): 2970, 2834, 1683, 1609, 1511, 1447, 1246, 1179, 1036, 831, 708 cm^{-1} . MS (FAB): m/z (%) 312 (12) $[\text{M}+\text{H}^+]$, 289 (19), 239 (37), 192 (11), 154 (100), 136 (66), 119 (10), 107 (18), 89 (14), 77 (12), 65 (5). HRMS for $\text{C}_{20}\text{H}_{25}\text{O}_2\text{N}\cdot\text{H}^+$: calcd.: 312.1964, found: 312.1964.

4-(3-Diethylamino-3-phenyl-propionyl)-benzonitrile (4ac)

^1H NMR (CDCl_3): δ 0.89 (t, $J = 7.2$ Hz, 6H), 2.36 (dq, $J = 13.2$ Hz, $J = 6.8$ Hz, 2H), 2.52 (dq, $J = 13.2$ Hz, $J = 6.8$ Hz, 2H), 3.41-3.61 (m, 2H), 4.60 (dd, $J = 8.0, 5.6$ Hz, 1H), 7.41-7.57 (m, 8H), 7.89 (dd, $J = 7.2, 1.6$ Hz, 2H). ^{13}C NMR (CDCl_3): δ 13.0, 39.7, 43.4, 59.3, 110.6, 118.9, 127.9, 128.7, 129.0, 131.9, 133.3, 136.9, 147.2, 198.5. IR (neat): 2970, 2811, 2229, 1683, 1607, 1385, 1206, 1065, 841, 691 cm^{-1} . MS (FAB): m/z (%) 307 (31) $[\text{M}+\text{H}^+]$, 277 (5), 234 (5), 187 (100), 159 (4), 135 (4), 105 (39), 89 (6), 77 (8). HRMS for $\text{C}_{20}\text{H}_{23}\text{ON}_2\cdot\text{H}^+$: calcd.: 307.1810, found: 307.1810.

3-(Diethylamino)-1-phenylpropan-1-one (4ad)³

^1H NMR (C_6D_6): δ 1.05 (t, $J = 7.2$ Hz, 6H), 2.57 (q, $J = 7.2$ Hz, 2H), 2.91 (dd, $J = 8.4$ Hz, $J = 6.4$ Hz, 2H), 3.14 (dd, $J = 8.0, 6.8$ Hz, 2H), 7.45 (dt, $J = 6.8, 1.2$ Hz, 2H), 7.53 (t, $J = 6.0$

³ Rochin, C.; Babot, O.; Dunogues, J.; Duboudin, F. *Synthesis* **1986**, 8, 667-668.

Hz, 1H), 7.96 (dt, $J = 6.8, 1.2$ Hz, 2H). ^{13}C NMR (C_6D_6): δ 11.7, 36.3, 46.9, 47.8, 128.1, 128.6, 133.8, 137.1, 199.9.

3-Diallylamino-1,3-diphenyl-propan-1-one (4ba)

^1H NMR (C_6D_6): δ 2.73 (dd, $J = 14.4$ Hz, $J = 7.6$ Hz, 2H), 3.09 (dd, $J = 15.6$ Hz, $J = 7.2$ Hz, 1H), 3.15 – 3.20 (m, 2H), 3.31 (dd, $J = 15.6$ Hz, $J = 7.6$ Hz, 1H), 4.77 (t, $J = 7.2$ Hz, 1H), 4.93 – 5.10 (m, 4H), 5.67 – 5.76 (m, 2H), 6.99–7.18 (m, 7H), 7.34 (d, $J = 7.6$ Hz, 1H), 7.77 (dd, $J = 6.8$ Hz, $J = 1.8$ Hz, 2H). ^{13}C NMR (C_6D_6): δ = 42.7, 54.7, 61.2, 118.3, 128.9, 129.9, 130.0, 130.1, 130.3, 138.0, 138.9, 141.2, 199.2. IR (film): 3080, 2813, 1686, 1580, 1493, 1449, 1285, 996, 919, 702 cm^{-1} . MS (FAB): m/z (%) 306 (89) $[\text{M}+\text{H}^+]$, 289 (17), 264 (20), 186 (100), 154 (92), 136 (54), 105 (52), 96 (39), 89 (10). HRMS for $\text{C}_{21}\text{H}_{24}\text{ON}\cdot\text{H}^+$: calcd.: 306.1858, found: 306.1856.

1,3-Diphenyl-3-pyrrolidin-1-yl-propan-1-one (4ca)⁴

^1H NMR (C_6D_6): δ 1.47 (brm, 4H), 2.34 (brm, 4H), 3.12 (dd, $J = 16.0, 6.8$ Hz, 1H), 3.35 (dd, $J = 16.0, 6.0$ Hz, 1H), 4.13 (t, $J = 6.4$ Hz, 1H), 6.91–7.12 (m, 6H), 7.41 (d, $J = 8.0$ Hz, 1H), 7.77 (dd, $J = 6.8, 1.8$ Hz, 2H). ^{13}C NMR (C_6D_6): δ 24.0, 46.2, 52.7, 65.9, 127.7, 128.7, 128.9, 132.9, 138.3, 144.2, 197.8.

⁴Kinastowski, S.; Grabarkiewicz-Szczesna, J.; Kostecki, M.; *Pol. J. Chem.* **1980**, 9, 1697-1706.

4da

3-Diethylamino-2,2-dimethyl-1,3-diphenylpropan-1-one (4da)

^1H NMR (CDCl_3): δ 0.82 (t, $J = 7.2$ Hz, 6H), 1.05 (s, 3H), 1.38 (s, 3H), 2.21 (dq, $J = 13.2$, 6.8 Hz, 2H), 2.61 (dq, $J = 13.2$, 7.2 Hz, 2H), 4.33 (s, 1H), 7.17-7.33 (m, 8H), 7.51 (dd, $J = 6.8$, 1.6 Hz, 2H). ^{13}C NMR (CDCl_3): δ 12.5, 22.9, 27.1, 45.2, 52.8, 71.2, 110.9, 118.8, 127.0, 127.7, 127.8, 130.1, 130.6, 138.8, 199.2. IR (neat): 2968, 2931, 2815, 1697, 1493, 1468, 1382, 1057, 756, 700 cm^{-1} . MS (FAB): m/z (%) 310 (43) $[\text{M}+\text{H}^+]$, 289 (17), 188 (6), 163 (48), 154 (100), 136 (58), 105 (18), 89 (10), 77 (9). HRMS for $\text{C}_{21}\text{H}_{28}\text{ON}\cdot\text{H}^+$: calcd.: 310.2171, found: 310.2171.

4ea

4-(diethylamino)-4-phenylbutan-2-one (4ea)⁵

^1H NMR (CDCl_3): δ 1.01 (t, $J = 6.9$ Hz, 6H), 2.10 (s, 3H), 2.26 (dq, $J = 13.2$, 7.2 Hz, 2H), 2.60 (dq, $J = 14.7$, 7.2 Hz, 2H), 2.79 (dd, $J = 15.0$, 7.5 Hz, 1H), 3.01 (dd, $J = 15.0$, 6.9 Hz, 1H), 4.33 (t, $J = 7.5$ Hz, 1H), 7.23 – 7.33 (m, 5H). ^{13}C NMR (CDCl_3): δ 13.1, 30.4, 43.2, 46.5, 59.6, 127.1, 128.1, 128.3, 139.9, 207.9.

⁵ Clark, J. H.; Cork, D. G., *Chem. Commun.* **1982**, 11, 635-636.

Ethyl 2-(diethylamino)-4-oxo-4-phenylbutanoate (4ae)

^1H NMR (C_6D_6): δ 1.05 (t, $J = 7.2$ Hz, 6H), 1.28 (t, $J = 7.2$ Hz, 3H), 2.56 (dq, $J = 12.8$, 6.8 Hz, 2H), 2.67 (dq, $J = 12.8$, 7.2 Hz, 2H), 3.31 (dd, $J = 17.6$, 4.8 Hz, 1H), 3.57 (dd, $J = 17.6$, 8.4 Hz, 1H), 4.15-4.19 (m, 3H), 7.47 (t, $J = 8.0$ Hz, 2H), 7.53-7.59 (m, 1H), 7.97 (dd, $J = 8.8$, 1.6 Hz, 2H). ^{13}C NMR (C_6D_6): δ 13.9, 14.3, 38.7, 45.1, 58.7, 60.4, 128.1, 128.6, 133.1, 137.0, 172.4, 199.6. IR (neat): 2964, 2858, 1698, 1636, 1470, 1397, 1260, 1065, 801, 699 cm^{-1} . MS (FAB): m/z (%) 278 (90) $[\text{M}+\text{H}^+]$, 204 (100), 158 (46), 154 (29), 136 (19), 105 (28), 77 (8), 56 (7). HRMS for $\text{C}_{16}\text{H}_{24}\text{O}_3\text{N}\cdot\text{H}^+$: calcd.: 278.1756, found: 278.1749.

Ethyl 2-(diethylamino)-3,3-dimethyl-4-oxo-4-phenylbutanoate (4de)

^1H NMR (C_6D_6): δ 1.05 (t, $J = 7.2$ Hz, 6H), 1.25 (t, $J = 7.2$ Hz, 3H), 1.34 (s, 6H), 2.57 (dq, $J = 13.2$, 7.2 Hz, 2H), 2.68 (dq, $J = 13.2$, 6.8 Hz, 2H), 4.06 (s, 1H), 4.09-4.20 (m, 2H), 7.37-7.40 (m, 3H), 7.53 (dd, $J = 7.6$ Hz, $J = 1.6$ Hz, 2H). ^{13}C NMR (C_6D_6): δ 14.1, 14.4, 20.8, 26.2, 47.4, 60.1, 69.3, 127.1, 127.9, 129.9, 140.6, 172.4, 197.8. IR (film): 2971, 2933, 1723, 1679, 1466, 1382, 1198, 1069, 963, 758, 700 cm^{-1} . MS (FAB): m/z (%) 306 (20) $[\text{M}+\text{H}^+]$, 289 (9), 232 (12), 158 (100), 154 (48), 136 (37), 120 (6), 105 (18), 89 (7), 73 (34), 56 (5). HRMS for $\text{C}_{18}\text{H}_{28}\text{O}_3\text{N}\cdot\text{H}^+$: calcd.: 306.2069, found: 306.207.

Reaction of boron enolate 5 with benzaldehyde. (Table 2)

Reactions were carried out according to the general procedure. The compounds **7a** and **7b**

were reported in the literature.⁶

Crossover experiment using boron enolate **2b and **2e**. (Scheme 2)**

Boron enolate **2b** (40.0 mg, 0.125 mmol) was dissolved in DMF-*d*⁷ (0.6 mL). Boron enolate **2e** (26.5 mg, 0.125 mmol) was added and the mixture was heated for 2 h at 50 °C. ¹H NMR data showed no formation of boron enolates other than **2b** and **2e**. Benzaldehyde (52 μ l, 0.5 mmol) was added and the mixture was stirred for 2 h at 50 °C. To the yellow solution cooled to room temperature were added ice water (3 ml) and *t*-butyl methyl ether (15 ml). Basic substances were extracted three times with 5 ml 0.5 N hydrochloric acid. The combined acidic aqueous layers were washed with 10 ml *t*-butyl methyl ether, cooled to 0 °C, and adjusted to pH 9 by addition of conc. ammonia solution. Organic material was extracted with *t*-butyl methyl ether and washed with 10 ml water. Removal of the solvent in vacuo at 0 °C yielded 51 mg of a product mixture containing **4aa** and **4ea** in a ratio of 1:1.38. Yield: **4aa**: 69 %, **4ea**: 95 % .

⁶ **7a**: Arend, M.; Nikolaus, R. *Angew. Chem.* **1995**, *107*, 2861. **7b**: Seebach, D.; C. Betschart; M. Schiess, *Helv. Chim. Acta.* **1984**, *67*, 1593.

^1H and ^{13}C NMR spectra of **4ab**

^1H and ^{13}C NMR spectra of **4ac**

^1H and ^{13}C NMR spectra of **4ba**

STANDARD 1H OBSERVE

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SAMPLE					
date	Jun 30 2003	dfrq		IRC, & VV	
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file	400.446.d	sp	dowr	30	
ACQUISITION					
acq		dof		unau	
nt	3.000	daf		200	
up	42604	PROCKESSNAME			
pr	5006.0	u	write		
fb	16	fn		ft	
db	34.00	prc	not used		
pw	6.0	wevr			
gl	1.500	wepr	wft		
ct	0	wev	wft		
cl	16	wnt			
clock	0	ctv			
gain					
in1	FLAME				
in		n			
ch		y			
DISPLAY					
sp	-200.3				
up	44642.7				
vs	250				
sc					
wc	270				
u	2280.37				
rfl	964.3				
isp	0				
th	4				
no	100.000				
scn	calc	ph

13C OBSERVE

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      file      CCG 23 dfrs      36
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      st      18 613      177
      in      0 542      10000
      no      100000 0 in      PROCESSING
      no      100000 0 in      1.00
      DW      2 56 0      not used
      TM      2 56 0      not used
      TO      1 2 000 2      7800
      tot      0 0 0      0
      tot      1884 0      0
      tot      544 0      0
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      LOCK      not used
      11      FLAGE      n
      11      n
      80      n
      DISPLAY  11
      NO      15845 5
      80      11
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      80      600
      nrm      39.52
      hzm      505 20
      hzm      7870 0
      rfs      5810 4
      rfs      18
      END  NO 40

```

^1H and ^{13}C NMR spectra of **4da**

STANDARD IN OBSERVE

exp1 std1h

SAMPLE DEC. & VT
 date Jul 16 2003 dfrq 400.446
 solvent CDCl3 da H1
 file exp dprc 30
 ACQUISITION dof 0
 sfrq 400.446 da mm
 tn H1 dm c
 at 3.500 daf 200
 ap 42042 PROCESSING
 sr 4006.0 vfile
 sb 3400 proc ft
 bs 16 fn not used
 tprc 59
 pw 6.0 werr
 d1 1.500 wexp wft
 tot 9 wde wft
 nt 16 wst
 ct 16
 alock n
 gain not used
 FLAGS
 ll n
 in n
 ap y
 DISPLAY
 sp -200.3
 wp 4404.7
 vs 219
 sc 0
 vc 370
 hzmm 11.91
 ls 1119.43
 rfi 344.3
 rfp 0
 lb 10
 lns 100.000
 nm odc ph

13C OBSERVE

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 solvent CDCl3 gn H1
 file exp dprc 30
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 sfrq 75.459 dm yyy
 tn C13 dm c
 at 0.842 dmf 10000
 no 30000 PROCESSING
 sr 19000.0 lb 1.00
 sb 10400 vfile
 bs 16 proc ft
 tprc 59 fn not used
 pw 6.0
 d1 1.158 werr react
 tot 0 wexp wft
 nt 1024 wos wft
 ct 1024 wst
 alock n
 gain not used
 FLAGS
 ll n
 in n
 ap y
 DISPLAY
 sp -754.9
 wp 15840.5
 vs 150
 sc 0
 vc 400
 hzmm 38.63
 ls 500.00
 rfi 7871.1
 rfp 5810.4
 lb 10
 lns 1.000
 nm no ph

^1H and ^{13}C NMR spectra of **4ae**

STANDARD 1H OBSERVE:

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SAMPLE					
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solvent	CDCl3	da	mm	441	
file	emp	dpr	100	9	
acq	exp	dpr	100	9	
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mp	400.446	da	mm	9	
tn	mm	da	mm	100	
vs	1.500	da	mm	100	
cp	42942	PROCROSSING			
bs	9089.0	wtell			
fb	3400	proc	not	fted	
fw	16	fn	mm	mm	
pr	3400	proc			
pw	6.0	weir			
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d2	1.500	weir	wt		
at	16	wt			
ct	16	wt			
in	lock	8			
gn	not	used			
in	FLAGS				
in	na				
dp	DISPLAY				
wp	-200.3				
zp	404.7				
sc	25.9				
sc	0				
sm	770				
ss	11.85				
is	1764.66				
rfl	364.3				
th	25.9				
th	8				
th	100.000				
end	pr