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Reductive Olefination of Aldehydes via Chromium Brook Rearrangement

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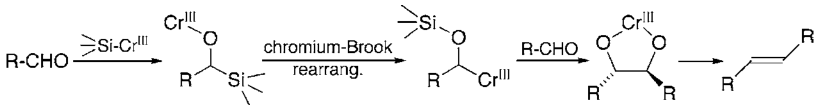
ABSTRACT



The combination of $CrCl_2$ and silyl chlorides converts aryl and conjugated aldehydes into olefinic adducts in good to excellent yields. When constrained by structural features, the intermediate *vic*-diol can be isolated. Available data are consistent with a novel chromium Brook rearrangement.

The inter- and intramolecular reductive coupling of carbonyls to generate olefins is popularly known as the McMurry reaction.[1] It is most often conducted using low-valent titanium, although other metals have been utilized.[2] Mechanistically, the carbonyl forms a transient ketyl that dimerizes on or near the metal surface.[3] The resultant metallopinacolate undergoes stepwise cleavage of the C−O bonds resulting in formation of an alkene. Carbenoid intermediates may also be involved depending upon the reaction conditions and/or structural features.[4] The geometry of the newly formed double bond is controlled principally by thermodynamic factors. Comparable reductions of carbonyls by chromium(II), on the other hand, typically lead to pinacols.[5] In contrast, we have observed that the combination of $CrCl_2$ and silyl chlorides generally converts aryl and conjugated aldehydes into olefinic adducts in good to excellent yields.[6] Consequently, we initiated a study to define the scope of the reaction and the mechanistic reason for the differences in outcomes.

The olefination was optimized using benzaldehyde (**1**) which furnished *trans*-stilbene (**2**) (Table 1).[7] The best yield and fastest reaction time were obtained with trichlorosilane and $CrCl_2$ in THF at reflux (entry 1). EtOAc was also satisfactory (entry 2), whereas THF/DMF (1:1) generated *threo*-dihydrobenzoin (58%) and benzyl alcohol (36%) only.[8] Repetition of the reaction described in entry 1, but utilizing catalytic $CrCl_2$ (10 mol %) regenerated by Mn[9] (4 equiv), also led to a mixture of *threo*-dihydrobenzoin and benzyl alcohol. Control experiments confirmed that both trichlorosilane and $CrCl_2$ were necessary for olefin formation.

[†] Université Louis Pasteur de Strasbourg.

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(1) Reviews: (a) Moser, W. H. *Tetrahedron* **2001**, *57*, 2065. (b) McMurry, J. E. *Chem. Rev.* **1989**, *89*, 1513.

(2) Fürstner, A. In *Transition Metals for Organic Synthesis*, 2nd ed.; Beller, M., Bolm, C., Eds.; Wiley-VCH Verlag: Weinheim, 2004; Vol. 1, p 449.

(3) Hodgson, D. M.; Boulton, L. T. In *Preparation of Alkenes*; Williams, J. M. J., Ed.; Oxford University Press: Oxford, 1996; p 81.

(4) Ephritikhine, M. *Chem. Commun.* **1998**, 2549.

(5) (a) Svatos, A.; Boland, W. *Synlett* **1998**, 549. (b) Fürstner, A.; Shi, N. *J. Am. Chem. Soc.* **1996**, *118*, 12349 and references cited therein.

(6) Contrast with the reductive deoxygenations observed with chlorotrimethylsilane and zinc: Banerjee, A. K.; Sulbaran De Carrasco, M. C.; Frydrych-Houge, C. S. V.; Motherwell, W. B. *J. Chem. Soc., Chem. Commun.* **1986**, 1803.

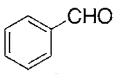
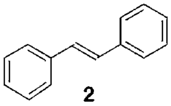
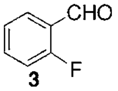
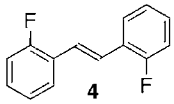
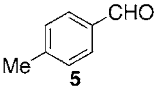
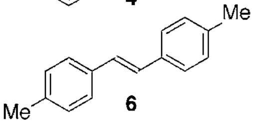
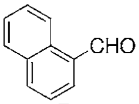
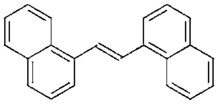
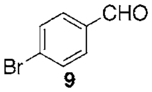
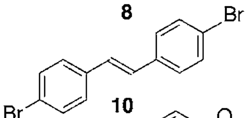
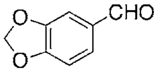
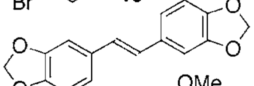
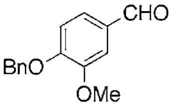
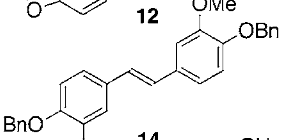
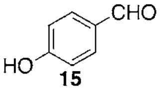
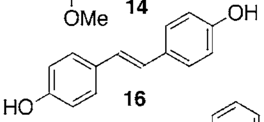
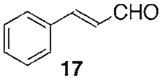
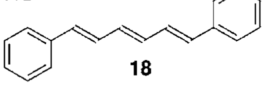
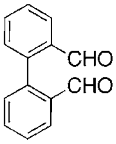
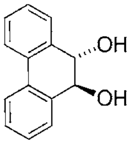
(7) General procedure: The aldehyde (1 mmol) and silyl chloride (5 mmol) were added to a stirring suspension of anhydrous $CrCl_2$ (3−4 mmol) under an argon atmosphere in the solvent (15 mL) (indicated in Table 1). After heating under reflux for the indicated time, the reaction mixture was cooled to room temperature, quenched with water (10 mL), and extracted with ether (3 × 10 mL), and the combined organic extracts were washed with brine, dried, and evaporated. The residue was purified by SiO_2 column chromatography to furnish adducts in the yields stated (Table 1).

(8) Satisfactory spectral data consistent with the literature values or by comparison with commercial samples were obtained for all products using chromatographically homogeneous material.

(9) Alois Fürstner, A.; Shi, N. *J. Am. Chem. Soc.* **1996**, *118*, 1239.

10.1021/ol0607140 CCC: $33.50

Table 1. Reductive Olefination of Aldehydes Using $CrCl_2$/Silyl Chlorides

entry	aldehyde	olefin	silane	solvent, temp (°C)/time (h)	yield (%)
1	 **1**	 **2**	$HSiCl_3$	THF, 67/8	95
2	**1**	**2**	$HSiCl_3$	EtOAc, 76/14	82
3	**1**	**2**	$MeSiCl_3$	THF, 65/24	72
4	**1**	**2**	$EtSiCl_3$	THF, 65/24	65
5	**1**	**2**	$PhSiCl_3$	THF, 65/24	68
6	**1**	**2**	Me_2SiCl_2	THF, 65/12	76
7	**1**	**2**	Me_2SiCl_2	EtOAc, 76/12	74
8	**1**	**2**	Me_3SiCl	THF, 65/12	62
9	**1**	**2**	$[(i\text{Pr})_2ClSiO]_2$	THF, 65/12	45
10	 **3**	 **4**	$HSiCl_3$	THF, 65/12	74[a]
11	 **5**	 **6**	$HSiCl_3$	THF, 65/8	87
12	 **7**	 **8**	$HSiCl_3$	THF, 65/8	90
13	 **9**	 **10**	$HSiCl_3$	THF, 65/12	65
14	 **11**	 **12**	$HSiCl_3$	THF, 65/8	84[b]
15	 **13**	 **14**	$HSiCl_3$	THF, 65/8	92
16	 **15**	 **16**	$HSiCl_3$	THF, 65/8	82
17	 **17**	 **18**	$HSiCl_3$	THF, 65/8	83
18	 **19**	 **20**	$HSiCl_3$	THF, 65/12	95

[a] 8:92 cis/trans by GC analysis. [b] 35:65 cis/trans by GC analysis.

A variety of other chlorosilanes in THF likewise afforded olefinated adducts, inter alia, such as methyl trichlorosilane (entry 3), ethyl trichlorosilane (entry 4), phenyl trichlorosilane (entry 5), dimethyl dichlorosilane (entries 6 and 7), trimethyl chlorosilane (entry 8), and 1,3-dichloro-1,1,3,3-tetraisopropyldisiloxane (entry 9). The outcomes of these reactions broadly followed the overall reactivity of the chlorosilanes toward chromium.

Aldehydes bearing an electron-withdrawing substituent (**3**, entry 10),[10,11] an electron-donating group (**5**, entry 11),[12] and a fused aromatic (**7**, entry 12)[13] gave generally similar results. Importantly, many functional groups were well tolerated, e.g.,

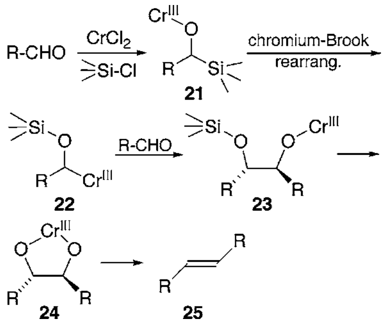


Figure 1. Proposed chromium Brook rearrangement.

bromide (**9**, entry 13),[14] methylenedioxy (**11**, entry 14),[15,16] benzyl/methyl ethers (**13**, entry 15),[17] and, surprisingly, an unprotected phenol (**15**, entry 16).[18] The conjugated aldehyde cinnamaldehyde (**17**) was also well behaved and led to triene **18** (entry 17).[19] However, aliphatic aldehydes and unhindered ketones principally afforded aldol products under the same reaction conditions. The intramolecular condensation of dialdehyde **19** gave rise unexpectedly to *trans*-diol **20** (entry 18),[20] presumably because it could not close to form the cyclic chromium diester necessary for elimination (vide infra).

Although the details must be confirmed, we favor a mechanism whereby the silyl anion, formed via successive one-electron transfers from Cr(II),[21] adds to the aldehyde to give α-hydroxysilane **21** which undergoes chromium Brook rearrangement to organochromium **22** (Figure 1). Numerous other metals and nonmetals are known to undergo similar transformations.[22] Subsequent addition of **22** to a second equivalent of aldehyde furnishes pinacol **23**. The isolation of *trans*-diol **20** as the sole product in entry 18 suggests that cyclic chromate ester **24**, which cannot form in this case, is the obligate intermediate for elimination to olefin **25**. As would be anticipated from this mechanistic hypothesis, heating the aldehyde and $CrCl_2$ or silyl chloride together for several hours prior to addition of the remaining ingredients does not yield olefinic adducts. However, good yields of adduct are obtained when the silyl chloride and $CrCl_2$ are heated together for several hours followed by addition of the aldehyde.

These data reveal a novel entry into an otherwise unattainable class of functionalized chromium anions. Efforts to exploit them as reagents for organic synthesis will be detailed elsewhere.

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Supporting Information Available: Spectra and/or gas chromatograms of **2**, **4**, **6**, **8**, **10**, **12**, **14**, **16**, **18**, and **20**. This material is available free of charge via the Internet at http://pubs.acs.org.

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(10) 2,2′-(*E*)-Difluorostilbene: Dunne, E. C.; Coyne, E. J.; Crowley, P. B.; Gilheany, D. G. *Tetrahedron Lett.* **2002**, *43*, 2449.

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(13) 1,1′-(*E*)-1,2-Ethenediylbisnaphthalene: Satoh, T.; Hanaki, N.; Yamada, N.; Asano, T. *Tetrahedron* **2000**, *56*, 6223.

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(18) 4,4′-(*E*)-Dihydroxystilbene: Ali, M. A.; Kondo, K.; Tsuda, Y. *Chem. Pharm. Bull.* **1992**, *40*, 1130.

(19) 1,6-Diphenyl-(*E*,*E*,*E*)-1,3,5-hexatriene: Doyle, M. P.; Yan, M. *J. Org. Chem.* **2002**, *67*, 602.

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