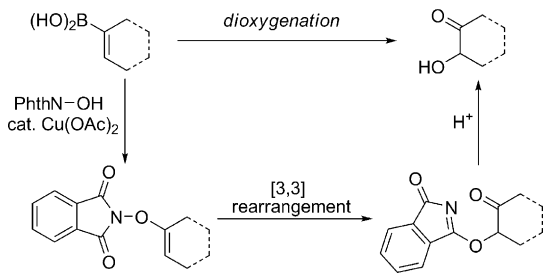
Pericyclic Rearrangement

DOI: 10.1002/anie.201202704

Preparation of α-Oxygenated Ketones by the Dioxygenation of Alkenyl Boronic Acids**

*Aditi S. Patil, Dong-Liang Mo, Heng-Yen Wang, Daniel S. Mueller, and Laura L. Anderson**

The ubiquitous use of aryl, alkenyl, and alkyl boronic acids for the formation of new C–C, C–N, and C–O bonds in cross-coupling reactions is indicative of the importance of these compounds in organic synthesis.[1] Although the use of boronic acids for the preparation of a variety of new bonds is well established, we were interested in testing if the reactivity of alkenyl boronic acids could be further diversified to include dioxygenation and the synthesis of α-oxygenated ketones. The conversion of alkenyl boronic acids to α-oxygenated ketones would provide a unique retrosynthetic disconnection for the preparation of complicated targets containing these challenging motifs.[2–8] Towards the goal of alkenyl boronic acid dioxygenation, we hypothesized that etherification of an alkenyl boronic acid with *N*-hydroxyphthalimide would form an *N*-enoxyphthalimide poised to undergo a [3,3] rearrangement to give an α-oxygenated ketone (Scheme 1). This method would avoid the use of

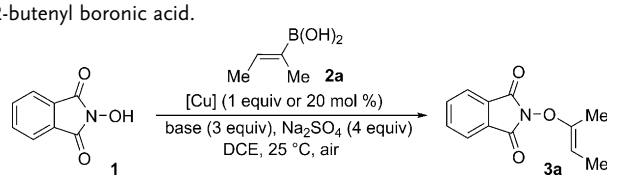


Scheme 1. Dioxygenation of alkenyl boronic acids. OAc = acetate, PhthN = phthalimide.

highly reactive electrophilic oxygenation reagents, not require the preparation of α-halogenated precursors, and allow access to linear α-oxygenated ketones from internal alkynes.[4,5d,7–9] Moreover, the nature of the transition state of the pericyclic reaction would allow for potential diastereoselective construction of the α-oxygenated stereocenter. Herein, we describe the development of a new method for the dioxygenation of alkenyl boronic acids through a copper-mediated etherification of *N*-hydroxyphthalimide followed by a [3,3] rearrangement to provide α-hydroxy or α-benzoyloxy ketones in two high-yielding steps from simple starting materials.

Our efforts towards achieving the dioxygenation of alkenyl boronic acids began with the optimization of conditions for the cross-coupling of alkenyl boronic acids and *N*-hydroxyphthalimide to form *N*-enoxyphthalimides. Although the copper-mediated arylation of *N*-hydroxyphthalimide with aryl boronic acids is known, to the best of our knowledge, the corresponding process for vinylation has not yet been reported.[10–12] Mixtures of copper salts, bases, and dessicants, as well as equivalents of reagents, were screened for their effectiveness in promoting the desired coupling of **1** and **2a**. As shown in entries 1–4 of Table 1, the use of 2 equiv of boronic acid **2a** provided a higher yield of **3a** for both copper-mediated and copper-catalyzed transformations, although the difference in reaction efficiency was more striking for the catalytic process.[13] The greater sensitivity of the catalytic reaction to changes in reaction conditions was consistent throughout the optimization process and guided our inquiry. $Cu(OAc)_2$ (OAc = acetate) was shown to be the

Table 1: Optimization of the etherification of *N*-hydroxyphthalimide with 2-butenyl boronic acid.



Entry	[Cu]	[**2a**]	Base	Yield [%] of **3a**[a]
1	$Cu(OAc)_2$ (1 equiv)	1 equiv	pyridine	71
2	$Cu(OAc)_2$ (1 equiv)	2 equiv	pyridine	96
3	$Cu(OAc)_2$ (20 mol%)	1 equiv	pyridine	6
4	$Cu(OAc)_2$ (20 mol%)	2 equiv	pyridine	87
5	CuCl (20 mol%)	2 equiv	pyridine	7
6	CuI (20 mol%)	2 equiv	pyridine	78
7	$Cu(TFA)_2$ (20 mol%)	2 equiv	pyridine	61
8	$Cu(OTf)_2$ (20 mol%)	2 equiv	pyridine	8
9	CuTC (20 mol%)	2 equiv	pyridine	81
10	$Cu(OAc)_2$ (20 mol%)	2 equiv	NEt_3	68
11	$Cu(OAc)_2$ (20 mol%)	2 equiv	DABCO	NR
12	$Cu(OAc)_2$ (20 mol%)	2 equiv	imidazole	NR
13	$Cu(OAc)_2$ (20 mol%)	2 equiv	KO*t*Bu	NR

[a] Yields were determined by ^{1}H NMR spectroscopy using 1,3,5-trimethoxybenzene as an internal standard; NR = no reaction. DABCO = 1,4-diazabicyclo[2.2.2]octane, DCE = 1,2-dichloroethane, OAc = acetate, TC = 2-thiophenecarboxylate, Tf = trifluoromethanesulfonate, TFA = trifluoroacetate.

[*] A. S. Patil, Dr. D.-L. Mo, H.-Y. Wang, D. S. Mueller, Prof. L. L. Anderson
Department of Chemistry, University of Illinois at Chicago
845 W. Taylor St. MC 111, Chicago, IL 60613 (USA)
E-mail: lauralin@uic.edu

[**] We acknowledge generous funding from ACS-PRF (50491-DNI) and the University of Illinois at Chicago. We also thank Prof. T. Driver and group for insightful discussions.

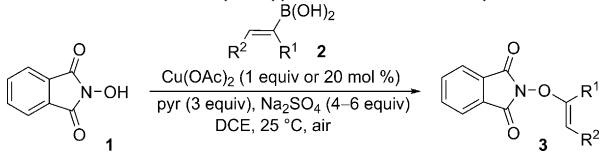
Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/anie.201202704.

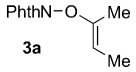
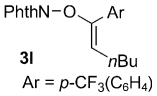
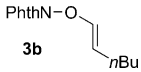
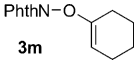
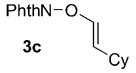
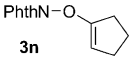
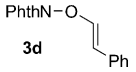
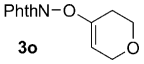
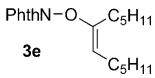
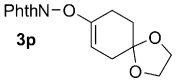
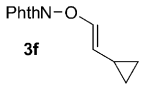
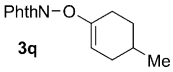
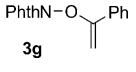
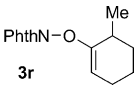
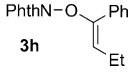
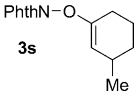
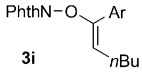
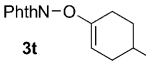
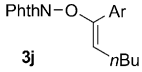
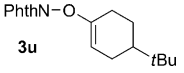
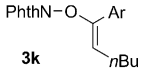
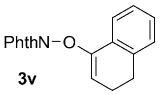
optimal catalyst when compared to other Cu^{I} and Cu^{II} salts (entries 5–9) and pyridine was shown to be the optimal base when compared to other amines and inorganic bases (entries 10–13). Neither the copper-mediated nor the copper-catalyzed coupling reaction showed any conversion to the desired product when run in the absence of air, and both transformations required the use of a halogenated solvent. The cross-coupling process was fairly insensitive to the choice of desiccant; 4 Å molecular sieves and $MgSO_4$ gave the desired product in only slightly attenuated yields.[14] The optimization study concluded that treatment of a 1:2 mixture of **1**/**2a** in 1,2-dichloroethane (DCE) with $Cu(OAc)_2$ (1 equiv or 20 mol%), pyridine (3 equiv), and Na_2SO_4 (4 equiv) in air provided optimal conversion of **2a** to **3a**.

With the optimal conditions for the cross-coupling of **1** and **2a** in hand, the scope of the transformation was evaluated with a variety of alkenyl boronic acids to determine the tolerance for boronic acid substitution patterns. As shown in Table 2, both copper-mediated and copper-catalyzed conditions converted 1- and 2-*trans*-substituted vinyl boronic acids, *Z*-disubstituted alkenyl boronic acids, and cyclic alkenyl boronic acids to the desired *N*-enoxyphthalimides **3** with retention of alkene geometry.[15] Both alkyl- and aryl substituents were tolerated for the boronic acid coupling partner, as were common aryl electron-withdrawing functional groups such as nitro, fluoro, and trifluoromethyl, as well as common protecting groups such as ketals. Trisubstituted alkenyl boronic acids and alkenyl boronic acids with *ortho*-substituted aryl groups currently represent a limitation of this method. Unfavorable steric interactions also hinder the etherification of 6-methyl cyclohexenyl boronic acid **2r**; however, no similar inhibition was observed for the fused system **2v**. The broad scope of the copper-mediated cross-coupling of *N*-hydroxyphthalimide **1** and alkenyl boronic acids **2** ultimately provided an array of *N*-enoxyphthalimides **3** to screen for the [3,3] rearrangement.

Solutions of *N*-enoxyphthalimides **3** in C_6D_6 or toluene were heated at 80–90 °C for 10–16 h to promote a [3,3] rearrangement and afford dioxygenated alkenyl boronic acids as imidates **4**. These rearrangements occurred in almost quantitative yields, as determined by comparison to an internal standard by ^{1}H NMR spectroscopy; however, imidates **4** were unstable when subjected to silica gel chromatography.[16] Isolation and purification of α-hydroxy ketones **5** was achieved in high yield after the hydrolysis of crude samples of **4** (Table 3). An ion-exchange resin provided optimal yields for the cleavage of phthalimide from **4**, but silica gel was similarly effective with longer reaction times. α-Hydroxyketones **5** that were too volatile or hydrophilic to be separated from phthalimide by extraction were protected in solution and isolated as the corresponding α-benzoyloxy ketones **6** (Table 3). The *N*-enoxyphthalimides **3b**–**3d**, underwent rearrangements to form α-oxygenated aldehydes **4b**–**4d**, which were isolated without further purification as the

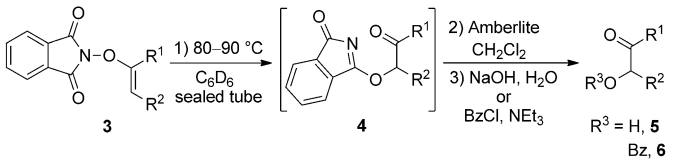
Table 2: Scope of the etherification of *N*-hydroxyphthalimide with alkenyl boronic acids.

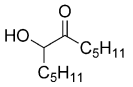
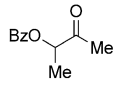
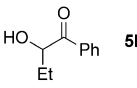
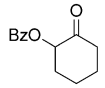
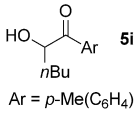
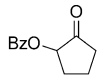
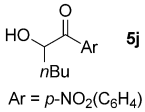
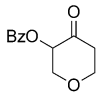
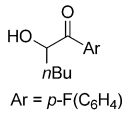
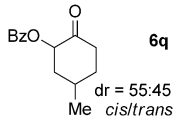
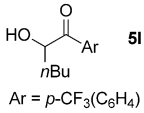
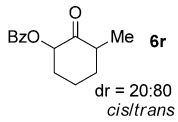
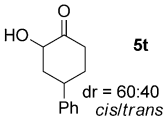
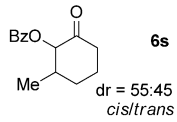
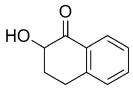
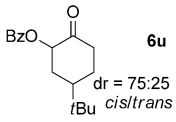


Entry	Product	Yield [%] of **3**[a]	Entry	Product	Yield [%] of **3**[a]
1	 **3a**	98[b] (76)	12	 **3l** Ar = *p*-$CF_3(C_6H_4)$	82 (73)
2	 **3b**	81 (70)	13	 **3m**	83 (76)
3	 **3c**	87 (74)	14	 **3n**	73 (68)
4	 **3d**	88 (78)	15	 **3o**	91 (89)
5	 **3e**	81 (77)	16	 **3p**	86 (82)
6	 **3f**	47	17	 **3q**	84 (78)
7	 **3g**	86 (77)	18	 **3r**	41
8	 **3h**	76 (67)	19	 **3s**	86 (80)
9	 **3i** Ar = *p*-$Me(C_6H_4)$	63 (66)	20	 **3t**	64
10	 **3j** Ar = *p*-$NO_2(C_6H_4)$	67 (55)	21	 **3u**	83
11	 **3k** Ar = *p*-$F(C_6H_4)$	70 (71)	22	 **3v**	76 (52)

[a] Yield of isolated product using 1 equiv $Cu(OAc)_2$ and (yield of isolated product using 20 mol% $Cu(OAc)_2$). [b] When run on a 1 mmol scale, the yield of isolated product using 1 equiv of $Cu(OAc)_2$ was 74%. Cy = cyclohexyl, DCE = 1,2-dichloroethane, PhthN = phthalimide, OAc = acetate, pyr = pyridine.

Table 3: Preparation of α-hydroxy- and α-benzoyloxyketones by rearrangement and hydrolysis of *N*-enoxyphthalimides **3**.

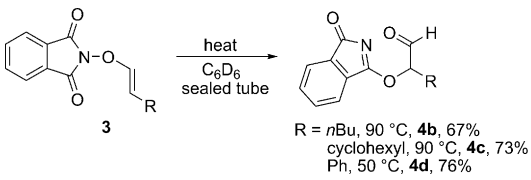


Entry	Product	Yield [%] of **5**[a]	Entry	Product	Yield [%] of **6**[a]
1	 **5e**	78[b]	9	 **6a**	86
2	 **5h**	90[b]	10	 **6m**	67
3	 **5i** Ar = *p*-Me(C_6H_4)	82	11	 **6n**	66
4	 **5j** Ar = *p*-NO_2(C_6H_4)	75	12	 **6o**	69
5	 **5k** Ar = *p*-F(C_6H_4)	88	13	 **6q** dr = 55:45 *cis*/*trans*	65
6	 **5l** Ar = *p*-CF_3(C_6H_4)	86	14	 **6r** dr = 20:80 *cis*/*trans*	66
7	 **5t** dr = 60:40 *cis*/*trans*	82	15	 **6s** dr = 55:45 *cis*/*trans*	69
8	 **5v**	87	16	 **6u** dr = 75:25 *cis*/*trans*	66

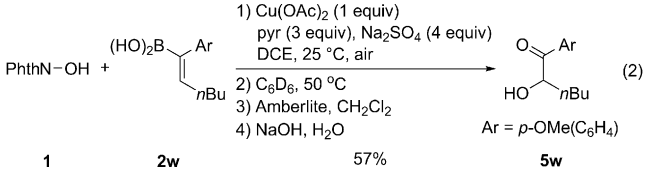
[a] Yield of isolated product. [b] Hydrolysis promoted with SiO_2. Bz = benzoyl, Amberlite = Amberlite IR120H, ion-exchange resin.

corresponding imidates to avoid polymerization of the corresponding α-hydroxy aldehydes [Eq. (1)]. The products shown in Table 3 and equation 1 describe the broad scope of α-oxygenated carbonyl compounds that can be prepared from the dioxygenation of alkenyl boronic acids with *N*-hydroxyphthalimide **1** through the rearrangement of *N*-enoxyphthalimides **3**. This method provides a valuable alternative to known procedures, which originate from ketone or aldehyde starting materials and employ electrophilic sources of oxygen.

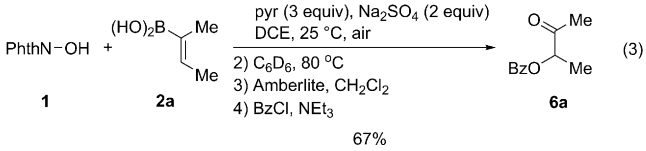
Several aryl-substituted *N*-enoxyphthalimides exhibited exceptions to the general thermal reactivity patterns depicted in Table 3 and equation 1 that suggested trends in the [3,3] rearrangement activity of these compounds. *N*-Enoxyphthalimide **3d** readily formed **4d** when heated to only 50 °C [Eq. (1)]. This transformation is in contrast to **3b** and **3c**, which rearranged at 90 °C, and **3g**, which exhibited no rearrangement reactivity even when heated to 130 °C. The combination of an aryl group at the 1-position of *N*-enoxyphthalimides **3h–3l**, and an alkyl group at the 2-position attenuated the opposing affects observed for **3d** and **3g**, and the rearrangements to afford **4h–4l** occurred at 80 °C (Table 3); however, the addition of an electron-donating group to the aryl ring once again reduced the rearrangement temperature to 25–50 °C to give **5w** [Eq. (2)]. *N*-Enoxyphthalimide **3w** could not be isolated, as the copper-mediated coupling provided a 2:1 mixture of **3w**/**5w**. Filtration of this mixture through silica gel to remove $Cu(OAc)_2$, followed by warming to 50 °C for 10 h and hydrolysis, gave **5w** in 57 % yield over three steps. A similarly efficient process was also observed for the transformation of **2a** to **6a** in 67 % yield with no formal purification of intermediates, only the removal of $Cu(OAc)_2$ prior to rearrangement [Eq. (3)].



(1)



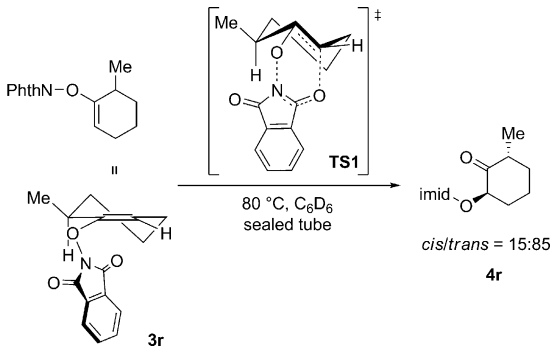
(2)



(3)

$Cu(OAc)_2$ can be present in substoichiometric amounts during the rearrangement of **3a**, but attenuated yields of **4a** are obtained. These results show that the [3,3] rearrangement of **3** is inhibited by the presence of copper salts and facilitated by electron-donating aryl groups at the 1-position and phenyl substituents at the 2-position of the enol ether.

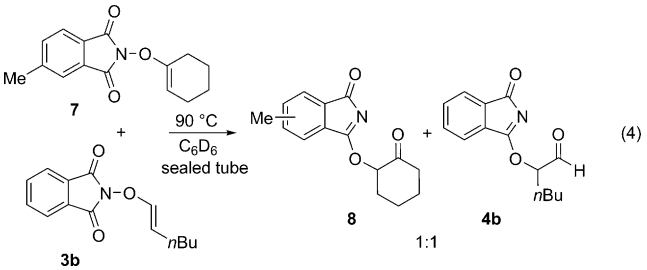
The diastereoselectivity of the [3,3] rearrangement of *N*-enoxyphthalimides was tested using *N*-enoxyphthalimides **3q**–**3u**, which are derived from substituted cyclohexenyl boronic acids. Compounds **3q**, **3s**, **3t**, and **3u** underwent [3,3] rearrangements to give 50:50 to 60:40, *cis*/*trans* diastereomeric mixtures of **4** and subsequent hydrolysis to give **6q**, **6s**, and **5t** with no significant change in the diastereomeric ratio (Table 3). Hydrolysis and protection of **4u** epimerized the α-benzoyl group, resulting in a 75:25 mixture of *cis*/*trans* **6u** (Table 3). Surprisingly, the rearrangement of **3r** strongly favors formation of the *trans* diastereomer (Scheme 2). We



Scheme 2. Diastereoselective rearrangement of **3r** to **4r**.

assume that this result is due to minimization of steric interactions as the rearrangement occurs via a chair transition state (**TS1**). In contrast to 4-substituted cyclohexenyl substrates **3q**, **3s**, and **3u**, rotation to give an approach of the carbonyl oxygen from the higher energy twist conformation and provide the *cis* diastereomer is inaccessible for **3r** because of the 6-methyl substituent, which inhibits rotation of the *N*-enoxyphthalimide around the C–O bond. A moderate increase in the *cis*/*trans* ratio from 15:85 to 20:80 was observed upon hydrolysis and protection of **4r**. To the best of our knowledge, the diastereomeric ratio observed for **4r** represents the highest observed in favor of the *trans* isomer for 2-methylcyclohexanone α-oxygenation.[4d,17] This implies that the dioxygenation of alkenyl boronic acids may not only provide a new retrosynthetic disconnection for the preparation of α-oxygenated carbonyl compounds, but also access to relative stereochemical patterns not readily available through enolate oxidation procedures.

The diastereoselectivity observed for the rearrangement of **3r** suggested that the [3,3] rearrangements of *N*-enoxyphthalimides proceed by a unimolecular pericyclic reaction. The intramolecular nature of the transition state was further supported by a crossover experiment using *N*-enoxyphthalimides **3b** and **7** [Eq. (4)]. When a 1:1 mixture of these compounds was heated in C_6D_6 at 90 °C for 18 h, only **4b** and **7** were observed and there was no evidence of crossover by ^1H or ^{13}C NMR spectroscopy. To investigate the possibility of a radical reaction pathway, a radical clock experiment was tested with *N*-enoxyphthalimide **3f**. Upon heating **3f** in either the presence or the absence of Bu_3SnH, no indication of the formation of an α,β-unsaturated aldehyde was observed, suggesting that the [3,3] rearrangement occurs through a two-electron pathway.



(4)

In summary, we have shown that dioxygenation of alkenyl boronic acids **2** with *N*-hydroxyphthalimide **1** can be achieved by a two-step process involving copper-mediated etherification to form an *N*-enoxyphthalimide **3** and a subsequent [3,3] rearrangement to provide α-hydroxy ketones **5** or α-benzoyloxy ketones **6**, after hydrolysis of the phthalimide imidate. This transformation provides a new retrosynthetic disconnection for the preparation of α-oxygenated carbonyl compounds that does not require the use of a highly reactive electrophilic oxygen source or a carbonyl compound as a starting material. Ongoing work in our laboratory is focused on further exploring the synthetic utility of this transformation and exploiting the observed diastereoselectivity.

Received: April 7, 2012
Published online: June 28, 2012

Keywords: boronic acids · ketones · oxygenation · phthalimides · rearrangement

[1] a) *Boronic Acids*, *Vol. 2* (Ed.: D. G. Hall), Wiley-VCH, Weinheim, **2011**, pp. 1–677; b) N. Miyaura, A. Suzuki, *Chem. Rev.* **1995**, *95*, 2457; c) A. Suzuki, *Angew. Chem.* **2011**, *123*, 6854; *Angew. Chem. Int. Ed.* **2011**, *50*, 6722; d) S. Kotha, K. Lahiri, D. Kashinath, *Tetrahedron* **2002**, *58*, 9633; e) J. X. Qiao, P. Y. S. Lam, *Synthesis* **2011**, 829; f) D. G. Hall, *Synlett* **2007**, 1644; g) H. Prokopcová, C. O. Kappe, *Angew. Chem.* **2009**, *121*, 2312; *Angew. Chem. Int. Ed.* **2009**, *48*, 2276; h) K. Severin, *Dalton Trans.* **2009**, 5254.

[2] For reviews on α-oxygenation reactions, see: a) A. M. R. Smith, K. K. Hii, *Chem. Rev.* **2011**, *111*, 1637; b) J. M. Janey, *Angew. Chem.* **2005**, *117*, 4364; *Angew. Chem. Int. Ed.* **2005**, *44*, 4292; c) W. Adam, R. T. Fell, V. R. Stegmann, C. R. Saha-Moller, *J. Am. Chem. Soc.* **1998**, *120*, 708; d) F. A. Davis, B.-C. Chen, *Chem. Rev.* **1992**, *92*, 919.

[3] For examples of the *O*-nitroso aldol reaction catalyzed by Lewis acids, see: a) N. Momiyama, H. Yamamoto, *Angew. Chem.* **2002**, *114*, 3112; *Angew. Chem. Int. Ed.* **2002**, *41*, 2986; b) N. Momiyama, H. Yamamoto, *Org. Lett.* **2002**, *4*, 3579; c) N. Momiyama, H. Yamamoto, *J. Am. Chem. Soc.* **2004**, *126*, 5360; d) M. Kawasaki, P. Li, H. Yamamoto, *Angew. Chem.* **2008**, *120*, 3855; *Angew. Chem. Int. Ed.* **2008**, *47*, 3795.

[4] For examples of the *O*-nitroso aldol reaction promoted by enamine catalysis, see: a) S. P. Brown, M. P. Brochu, C. J. Sinz, D. W. C. MacMillan, *J. Am. Chem. Soc.* **2003**, *125*, 10808; b) Y. Hayashi, J. Yamaguchi, K. Hibino, M. Shoji, *Tetrahedron Lett.* **2003**, *44*, 8293; c) G. Zhong, *Angew. Chem.* **2003**, *115*, 4379; *Angew. Chem. Int. Ed.* **2003**, *42*, 4247; d) A. Bøgevig, H. Sundén, A. Córdova, *Angew. Chem.* **2004**, *116*, 1129; *Angew. Chem. Int. Ed.* **2004**, *43*, 1109; e) Y. Hayashi, J. Yamaguchi, T. Sumiya, M. Shoji, *Angew. Chem.* **2004**, *116*, 1132; *Angew. Chem. Int. Ed.* **2004**, *43*, 1112; f) N. Momiyama, H. Torii, S. Saito, H. Yamamoto, *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 5374; g) P. Jiao, H. Yamamoto, *Synlett* **2009**, 2685; h) P. Jiao, M. Kawasaki, H. Yamamoto, *Angew. Chem.* **2009**, *121*, 3383; *Angew. Chem. Int. Ed.* **2009**, *48*, 3333.

[5] For examples of the *O*-benzoylation of aldehydes and ketones with benzoyl peroxide using enamine catalysis, see: a) T. Kano, H. Mii, K. Maruoka, *J. Am. Chem. Soc.* **2009**, *131*, 3450; b) H. Gotoh, Y. Hayashi, *Chem. Commun.* **2009**, 3083; c) M. J. P. Vaismaa, S. C. Y. Yau, N. C. O. Tomkinson, *Tetrahedron Lett.* **2009**, *50*, 3625; d) O. Lifchits, N. Demoulin, B. List, *Angew. Chem.* **2011**, *123*, 9854; *Angew. Chem. Int. Ed.* **2011**, *50*, 9680.

[6] For examples of enolate oxidation, see: a) G. M. Rubottom, M. A. Vazquez, D. R. Pelegrina, *Tetrahedron Lett.* **1974**, *15*, 4319; b) T. Hashiyama, K. Morikawa, K. B. Sharpless, *J. Org. Chem.* **1992**, *57*, 5067; c) D. R. Reddy, E. R. Thornton, *J. Chem. Soc. Chem. Commun.* **1992**, 172; d) W. Adam, R. T. Fell, C. Mock-Knoblauch, C. R. Saha-Möller, *Tetrahedron Lett.* **1996**, *37*, 6531; e) R. M. Moriarty, K.-C. Hou, *Tetrahedron Lett.* **1984**, *25*, 691.

[7] For examples of α-oxygenation using oxime rearrangements, see: a) H. O. House, F. A. Richey, Jr., *J. Org. Chem.* **1969**, *34*, 1430; b) C. S. Beshara, A. Hall, R. L. Jenkins, K. L. Jones, T. C. Jones, N. M. Killeen, P. H. Taylor, S. P. Thomas, N. C. O. Tomkinson, *Org. Lett.* **2005**, *7*, 5729; c) O. R. S. John, N. M. Killeen, D. A. Knowles, S. C. Yau, M. C. Bagley, N. C. O. Tomkinson, *Org. Lett.* **2007**, *9*, 4009.

[8] For examples of nucleophilic displacements of α-halogenated ketones, see: a) K. A. Parker, A. Dermatakis, *J. Org. Chem.* **1997**, *62*, 6692; b) A. R. Daniewski, W. Liu, *J. Org. Chem.* **2001**, *66*, 626; c) W. Chai, A. Takeda, M. Hara, S.-J. Ji, C. A. Horiuchi, *Tetrahedron* **2005**, *61*, 2453.

[9] For examples of the preparation of boronic acids from alkynes, see: H. C. Brown, J. B. Campbell, *J. Org. Chem.* **1980**, *45*, 389; see also Ref. [1].

[10] H. M. Petrassi, K. B. Sharpless, J. W. Kelly, *Org. Lett.* **2001**, *3*, 139.

[11] For reviews on copper-mediated etherification reactions, see: a) G. Evano, N. Blanchard, M. Toumi, *Chem. Rev.* **2008**, *108*, 3054; b) S. V. Ley, A. W. Thomas, *Angew. Chem.* **2003**, *115*, 5558; *Angew. Chem. Int. Ed.* **2003**, *42*, 5400.

[12] For seminal and recent examples of the copper-mediated etherification of alcohols with boron reagents, see: a) D. M. T. Chan, K. L. Monaco, R.-P. Wang, M. P. Winters, *Tetrahedron Lett.* **1998**, *39*, 2933; b) D. A. Evans, J. L. Katz, T. R. West, *Tetrahedron Lett.* **1998**, *39*, 2937; c) P. Y. S. Lam, G. Vincent, C. G. Clark, S. Deudon, P. K. Jadhav, *Tetrahedron Lett.* **2001**, *42*, 3415; d) T. D. Quach, R. A. Batey, *Org. Lett.* **2003**, *5*, 1381; e) N. F. McKinley, D. F. O'Shea, *J. Org. Chem.* **2004**, *69*, 5087; f) R. E. Shade, A. M. Hyde, J.-C. Olsen, C. A. Merlic, *J. Am. Chem. Soc.* **2010**, *132*, 1202; g) D. J. Winternheimer, C. A. Merlic, *Org. Lett.* **2010**, *12*, 2508.

[13] Homocoupling of boronic acids is known to be a competing process in these types of transformations. See Ref. [12f] and references therein.

[14] For an expanded optimization table, see the Supporting Information.

[15] Alkene geometry was retained and products **3** were isolated as *E* alkenes within the limits of detection by ^{1}H NMR spectroscopy.

[16] For full characterization and ^{1}H NMR spectroscopy yields of **4** see the Supporting Information.

[17] a) G. M. Rubottom, J. M. Gruber, G. M. Mong, *J. Org. Chem.* **1976**, *41*, 1673; b) G. M. Rubottom, R. C. Mott, H. D. Juve, Jr., *J. Org. Chem.* **1981**, *46*, 2717.

