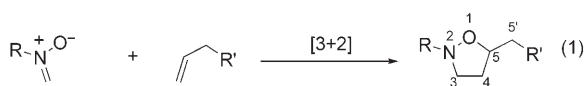


Stereoselective Synthesis of Isoxazolidines through Pd-Catalyzed Carboetherification of *N*-Butenylhydroxylamines**

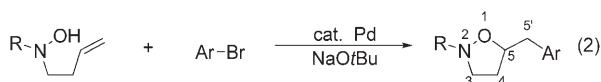
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Isoxazolidines are frequently used as intermediates in the synthesis of complex molecules^[1] and are found in several interesting biologically active compounds.^[2] In addition, the isoxazolidine N–O bond can be easily cleaved under reducing conditions to afford 1,3-amino alcohols, which are also of synthetic utility.^[3] The most commonly employed method for the construction of isoxazolidines involves 1,3-dipolar cycloaddition reactions between nitrones and alkenes,^[4] which generates the O1–C5 bond and the C3–C4 bond in one step [Eq. (1)]. Although these transformations are very useful, many intermolecular cycloadditions of unactivated alkenes



generate mixtures of regioisomers.^[4] Moreover, the major stereoisomers typically result from *endo* addition on the less hindered face of the alkene, and the selective preparation of stereoisomers resulting from *exo* addition and/or addition to the more substituted alkene face cannot be achieved in a straightforward manner.^[4]

Herein, we describe a new approach to the construction of substituted isoxazolidines based on palladium-catalyzed carboetherification reactions of *N*-butenyl hydroxylamine derivatives with aryl bromides [Eq. (2)]. This method represents a new strategy for construction of the isoxazolidine ring, in



which the O1–C5 bond and a C5'–Ar bond are formed in one step.^[5] These transformations also provide access to isoxazolidine stereoisomers that cannot be generated with currently

available methods. The reactions appear to proceed by intramolecular alkene insertion into previously unprecedented palladium alkoxyamine intermediates, which may be of utility in other Pd-catalyzed carbon–heteroatom bond-forming processes.

In preliminary experiments, we examined Pd-catalyzed reactions of *N*-butenyl hydroxylamines **1–3** with 4-bromobiphenyl under conditions that were employed in our prior studies on Pd-catalyzed carboetherification reactions of γ -hydroxyalkenes.^[6–8] As shown in Table 1, attempts to cyclize unprotected hydroxylamine substrate **1** and *N*-tert-

Table 1: Carboetherification of *N*-butenyl hydroxylamines.^[a]

Hydroxylamine	R	Isoxazolidine	Yield [%] ^[b]
1	H	–	0 ^[c]
2	Boc	–	0 ^[c]
3	Bn	4	80

[a] Conditions: 1.0 equiv substrate, 1.2 equiv ArBr, 1.2 equiv NaOtBu, 2 mol% Pd(OAc)₂, 2 mol% DPE-Phos, THF (0.125 M), 65 °C. [b] Yields represent average yields of isolated product for two or more experiments. [c] Heck arylation products were observed.

butyloxycarbonyl(Boc)-protected derivative **2** were unsuccessful.^[9] However, we were gratified to find that treatment of *N*-benzyl-protected substrate **3** with 4-bromobiphenyl and NaOtBu in the presence of catalytic amounts of Pd(OAc)₂ and DPE-Phos^[10] afforded the desired product **4** in 80% yield.

With viable reaction conditions and a suitable nitrogen protecting group identified, we examined Pd-catalyzed carboetherification reactions between several different substituted hydroxylamines and a number of aryl bromides. As shown in Table 2, this method is effective with electron-rich (entry 10), electron-neutral (entries 4, 7, 8, and 12), electron-poor (entries 1, 2, 11, and 13), *o*-substituted (entry 8), and heterocyclic (entries 3, 5, 6, and 9) aryl bromides. In addition to the *N*-benzyl-protected derivatives described above, hydroxylamine substrates bearing *N*-methyl or *N*-tert-butyl groups also undergo cyclization in good yield.

The carboetherification reactions are also effective with substrates bearing substituents along the tether between the hydroxylamine moiety and the alkene. Transformations of these substrates provide access to disubstituted isoxazolidines with moderate to excellent stereocontrol. Importantly, in many cases these cyclizations provide a means to generate isoxazolidines that could not be prepared using 1,3-dipolar

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Table 2: Pd-catalyzed synthesis of substituted isoxazolidines.^[a]

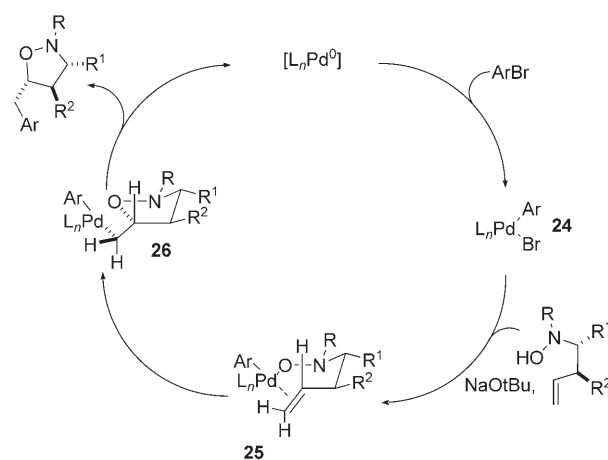
$\text{R}^1\text{-N(OH)-CH=CH-R}^2 + \text{Ar-Br} \xrightarrow[\text{NaOtBu, THF, 65}^\circ\text{C}]{2 \text{ mol \% Pd(OAc)}_2, 2 \text{ mol \% DPE-Phos}} \text{R}^1\text{-N(O)-CH(R}^2\text{)-CH}_2\text{-Ar}$				
Entry	Substrate	Isoxazolidine	d.r. ^[b]	Yield [%] ^[c]
1			—	85
2			> 20:1 (5:1)	56
3			3:1 (3:1)	70
4			> 20:1 (3:1)	57
5			3:1 (3:1)	77
6			3:1 (3:1)	78
7			3:1 (3:1)	61
8			> 20:1 (10:1)	82
9			> 20:1 (10:1)	85
10			19:1 (9:1)	94
11			> 20:1 (9:1)	89
12 ^[d]			> 20:1 (> 20:1)	78
13 ^[d]			> 20:1 (> 20:1)	69

[a] Conditions: 1.0 equiv substrate, 1.2 equiv ArBr, 1.2 equiv NaOtBu, 2 mol % Pd(OAc)₂, 2 mol % DPE-Phos, THF (0.125 M), 65 °C. [b] d.r. = diastereomeric ratio of isolated material. Numbers in parentheses are the observed diastereomeric ratios for the crude reaction mixture. [c] Yields represent average yields of product isolated in two or more experiments. [d] The reaction was conducted at 110 °C in toluene solvent with [Pd₂(dba)₃] (1 mol %) used in place of Pd(OAc)₂ (dba = dibenzylideneacetone).

cycloaddition methods. For example, Pd-catalyzed reactions of **10** with 4-bromobiphenyl and 3-bromobenzotrifluoride provide **22** and **23**, respectively, in 78 % and 69 % yields, with > 20:1 diastereoselectivity and regioselectivity (Table 2, entries 12 and 13). In contrast, a 1,3-dipolar cycloaddition

reaction between a nitron and a 3-arylcyclopentene would be expected to occur on the less hindered face of the alkene to afford a different stereoisomer and would likely generate mixtures of regioisomers.^[4] In addition, reactions of **8** with aryl bromides proceed in 82–85 % yield and 10:1 d.r. to afford the (2*R**,3*aS**)-hexahydropyrrolo[1,2*b*]isoxazole isomers **18** and **19** (Table 2, entries 8 and 9). However, dipolar cycloadditions between 3,4-dihydropyrrole-1-oxide and allylbenzene derivatives instead generate stereoisomeric (2*S**,3*aS**)-hexahydropyrrolo[1,2*b*]isoxazoles.^[11] The hydroxylamine carboetherifications can also be used to prepare *trans*-4,5-disubstituted isoxazolidines **12–14** and *cis*-3,5-disubstituted isoxazolidines **15–17** in good yield with 3:1 to 5:1 diastereoselectivity.

A plausible mechanism for the isoxazolidine-forming reactions is shown in Scheme 1. These transformations appear to be mechanistically related to Pd-catalyzed carbo-


Scheme 1. Catalytic cycle of the Pd-catalyzed carboetherification reaction of *N*-butenylhydroxylamines.

etherification reactions of γ -hydroxy alkenes with aryl bromides^[6] and are likely initiated by oxidative addition of the aryl bromide to Pd⁰ to afford **24**. The [L_nPd(Ar)(Br)] complex can then be transformed to intermediate **25** by reaction with the hydroxylamine substrate and NaOtBu. Intramolecular *syn* oxypalladation^[6,12] of the tethered alkene moiety of **25** would generate **26**, which can undergo C–C bond-forming reductive elimination^[13] to afford the observed isoxazolidine products. The conversion of **10** to *syn*-addition products **22** and **23** is consistent with this hypothesis. Moreover, this model also accounts for the observed stereochemistry of **12–21**, as the *syn* oxypalladation likely occurs from an organized cyclic transition state in which nonbonding interactions are minimized by pseudoequatorial orientation of the substrate R¹ and R² groups. This transition state arrangement would provide *cis*-3,5-disubstituted products (R² = H) and *trans*-4,5-disubstituted compounds (R¹ = H).

Although palladium(aryl)alkoxides have been shown to be important intermediates in a number of catalytic processes,^[6,14,15] the analogous complexes derived from hydroxylamines (e.g. **25**) are unknown. The reactions described in this paper represent the first examples of catalytic transforma-

tions involving $[Pd(Ar)(ONRR')]$ species. These previously unknown intermediates will likely find additional applications in other metal-catalyzed carbon–heteroatom bond-forming reactions.^[15]

In conclusion, we have developed a new stereoselective method for the construction of substituted isoxazolidines through Pd-catalyzed carboetherification reactions of unsaturated hydroxylamine substrates. In many cases the stereochemical outcome of these transformations is complementary to that of nitrene cycloadditions, and this method provides a new strategic disconnection that can be used for retrosynthetic analysis of substituted isoxazolidines.

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