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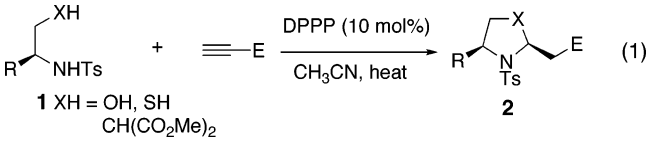
Bisphosphine-Catalyzed Mixed Double-Michael Reactions: Asymmetric Synthesis of Oxazolidines, Thiazolidines, and Pyrrolidines

Vardhineedi Sriramurthy, Gregg A. Barcan, and Ohyun Kwon*

Department of Chemistry and Biochemistry, University of California, Los Angeles, California 90095-1569

Received May 24, 2007; E-mail: ohyun@chem.ucla.edu

Five-membered nitrogen-atom-containing heterocycles are structural components of many natural products and pharmaceuticals;[1] in addition, many of them—for example, enantiopure azolidine derivatives—have been employed as synthetic intermediates, auxiliaries, ligands, and catalysts for asymmetric synthesis.[2] Consequently, there is a high demand for new methods for the efficient construction of optically active azolidine derivatives.[3] As part of a program aimed at developing phosphine-mediated annulation reactions,[4] we sought a novel route toward highly substituted and functionalized five-membered-ring nitrogen-atom-containing heterocycles. In light of recent reports on the phosphine-catalyzed conjugate additions of electron-deficient olefins and acetylenes with alcohols,[5] herein we report a bisphosphine-catalyzed mixed double-Michael process[6] that generates azolidines (**2**; eq 1). Use of amino-acid-derived pronucleophiles (**1**) as Michael donors and electron-deficient acetylenes as Michael acceptors provides efficient access to azolidines containing both diversity and asymmetry.

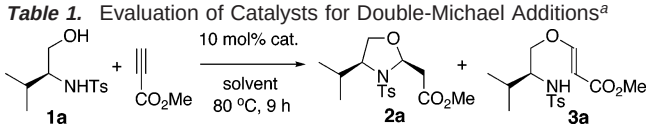


(1)

Our initial evaluation of the proposed double-Michael addition began with the reaction between amino alcohol **1a** and methyl propiolate (Table 1). Employing PPh_3 as the catalyst gave the desired double-Michael adduct **2a** in 35% yield in addition to a 40% yield of the mono-Michael adduct **3a** (entry 1).[7] Use of Ph_2PEt led to a moderate improvement in the yield of the oxazolidine product **2a** (entry 2), but none was formed from the reaction catalyzed by Me_3P (entry 3).[8] In contrast, diphenylphosphinopropane (DPPP) catalysis increased the yield of the desired double-Michael adduct **2a** to 71% (entry 4).[9] Further increases in the yield and reaction rate were achieved when performing the reaction in a more polar solvent, CH_3CN (entry 5). On the basis of the encouraging results we obtained with DPPP as the catalyst, we also tested the applicability of the homologous bisphosphines diphenylphosphinomethane (DPPM), diphenylphosphinoethane (DPPE), diphenylphosphinobutane (DPPB), and diphenylphosphinopentane (DPPPent). The appreciably poorer yield (37%) of the DPPM-mediated reaction, relative to those of the other bisphosphines (entries 6−9), provides a critical clue regarding the reaction mechanism (vide infra).

Scheme 1 presents a plausible mechanism for the dependence of the reaction on both the bidentate nature of the phosphine catalyst and the tether length between the two phosphine moieties. The reaction is triggered by the conjugate addition of the phosphine to the electron-deficient acetylene. The resulting vinyl anion **4** deprotonates the pronucleophile **1**, which facilitates the first conjugate addition to form intermediate **6**.[5b,10] Upon β-elimination of the phosphine, the mono-Michael product **3** is formed. The presence of an additional phosphine moiety at the optimal distance,

Table 1. Evaluation of Catalysts for Double-Michael Additions[a]



			isolated yields (%)	
entry	catalyst	solvent	**2a**	**3a**
1[b]	Ph_3P	toluene	35	40
2[b]	Ph_2PEt	toluene	42	30
3[b]	Me_3P	toluene	0	22
4[b]	DPPP	toluene	71	12
5	DPPP[c]	CH_3CN	92	0
6	DPPM[c]	CH_3CN	37	42
7	DPPE[c]	CH_3CN	84	0
8	DPPB[c]	CH_3CN	82	0
9	DPPPent[c]	CH_3CN	79	6

[a] All reactions were performed using 1 mmol of **1a**, 1.1 mmol of methylpropiolate, and 10 mol % of the catalyst. [b] These reactions were run for 48 h. [c] DPPM, DPPE, DPPP, DPPB, and DPPPent are acronyms for diphenylphosphinomethane, -ethane, -propane, -butane, and -pentane, respectively.

as in DPPP, provides additional stabilization to the intermediate phosphonium ions **6** and **7**. The latter undergoes S_N2 displacement to produce the cyclized product **2**.[11] In the absence of anchimeric assistance, as in the case of the monodentate phosphines, the decreased stability of the phosphonium ion led to an unfavorable equilibrium for the formation of **6** from **3**.[12] The relatively short tether of DPPM prohibits the orbital overlap required for anchimeric assistance because of geometrical constraints. The other phosphines for which intramolecular stabilization was possible, namely, DPPE, DPPB, and DPPPent, gave results similar to those obtained using DPPP. Note that intramolecular stabilization of phosphonium ions by nitrogen atoms has precedent in the literature.[13]

With the optimal reaction conditions in hand, that is, DPPP as catalyst and CH_3CN as solvent, we next explored the scope of the double-Michael reaction using a variety of amino-acid-derived pronucleophiles and electron-deficient acetylenes (Table 2). The formation of oxazolidines from β-amino alcohols and methyl propiolate proceeded smoothly, with high yields and diastereoselectivities (entries 1 and 4). The Michael acceptors acetylacetylene and tosylacetylene also gave good results (entries 2 and 3). This methodology works well for the syntheses of thiazolidines from β-amino thiols (entries 5−7).[14] All of the substrates provided similarly high yields and diastereoselectivities for the formation of thiazolidines.[15]

We further tested the generality of our reaction by using carbonucleophiles (entries 8−10) for the preparation of pyrrolidine derivatives, which are ubiquitous in natural products of pharmacological interest.[16] Under the optimized conditions, we generated the pyrrolidines **2h** and **2i** from the valine-derived γ-amino malonate **1h** (entries 8 and 9, respectively).[17] Employing the cyclic γ-amino diester **1j** furnished the octahydroindole derivative **2j** as a single diastereoisomer in good yield (entry 10). Octahydroindoles, which

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Scheme 1. Proposed Mechanism for the Formation of **2**

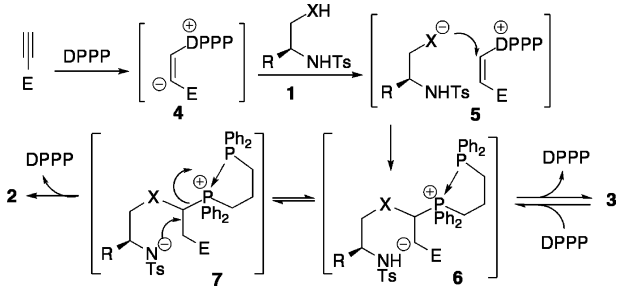
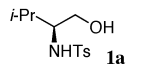
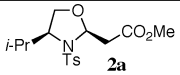
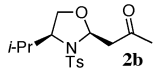
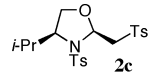
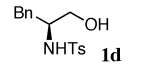
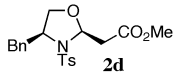
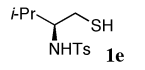
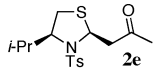
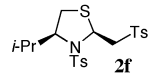
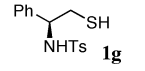
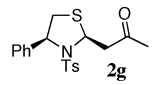
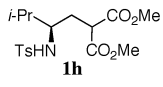
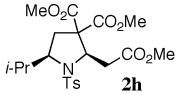
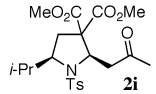
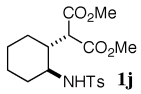
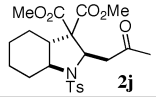


Table 2. Syntheses of Various Azolidines[a]

entry	substrate	product	yield %[b] (cis:trans)[c]
1	 **1a**	 **2a**	92 (96:4)
2	**1a**	 **2b**	92 (94:6)
3	**1a**	 **2c**	87 (97:3)
4	 **1d**	 **2d**	91 (95:5)
5	 **1e**	 **2e**	93 (95:5)
6	**1e**	 **2f**	89 (96:4)
7	 **1g**	 **2g**	88 (96:4)
8	 **1h**	 **2h**	82 (94:6)
9	**1h**	 **2i**	91 (95:5)
10	 **1j**	 **2j**	80 (100:0)

[a] All reactions were performed using 1 mmol of the substrate, 1.1 equiv of the corresponding acetylene, and 10 mol % of DPPP in CH_3CN at 80 °C for 9 h. [b] Isolated yields after chromatographic purification. [c] Determined through ^1H NMR spectroscopic analysis.

are present in a large number of natural products, are often challenging synthetic targets.[18]

In summary, we have developed a remarkably simple protocol for the synthesis of oxazolidines, thiozolidines, pyrrolidines, and octahydroindoles. This mixed double-Michael process operates best under bisphosphine catalysis to provide β-amino carbonyl derivatives of azolidines[19] in excellent yields and with high diastereoselectivities. Presumably, the use of bis(diphenylphosphine) derivatives allows intramolecular stabilization of the phosphonium ion intermediates. We are currently exploring the development of an enantioselective version of this ring-forming process from achiral starting materials and its application to the synthesis of selected drug candidates.

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Supporting Information Available: Representative experimental procedures and spectral data for all new compounds (PDF). Crystallographic data for **2a** and **3a** (CIF). This material is available free of charge via the Internet at http://pubs.acs.org.

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