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## COMMUNICATION

## Synthesis of a Guanidine NHC complex and its Application in Borylation Reactions

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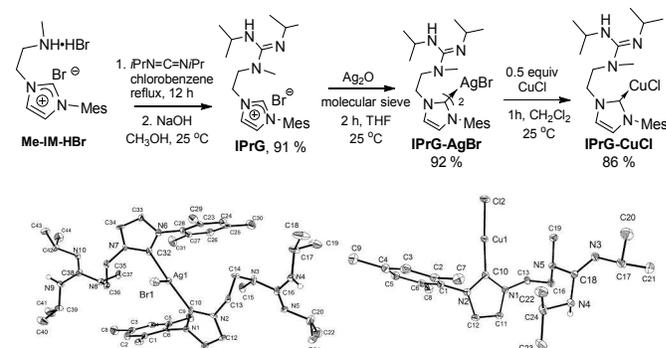
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**Synthesis of guanidine-linked NHC can be achieved easily through reacting amino-NHC with carbodiimide. Subsequently, guanidine-NHC Ag and Cu complexes were isolated and fully characterized. These Cu complexes are found to be versatile catalysts for hydroboration, semihydrogenation and carboboration of alkynes in highly stereo- and regioselective fashion.**

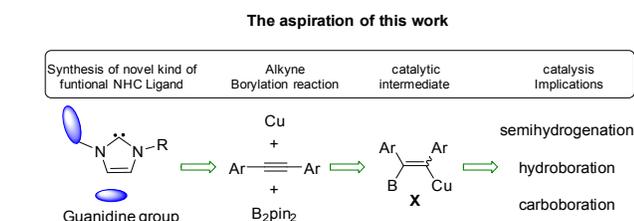
The judicious use of N-heterocyclic carbenes (NHCs) as ligand has resulted in significant advances in catalysis sector,<sup>1</sup> attributed to their strong coordination ability and synthetic simplicity with tunable steric and electronic properties. Obviously, covalently attaching additional functional group on NHC scaffold would provide additional utilities that may be useful in catalysis. Our group always has on-going interest in developing catalytic process based on functional NHC ligands. For example, we have utilized amino-linked NHC to promote Ni-mediated C–H bond activation of pyridine and heteroarenes in selective manner.<sup>2</sup>

communication, we successfully prepared and characterized guanidine-linked NHC and its copper complex. This guanidine-NHC copper complex has been shown to serve as an efficient and versatile catalyst for hydroboration. Furthermore, we anticipated vinyl copper intermediate **X** may be further exploited for subsequent semihydrogenation and carboboration of alkynes using benign synthetic alternatives based on B<sub>2</sub>pin<sub>2</sub> as shown in Scheme 1.



**Scheme 2.** Synthetic routes and molecular structures of **IPrG-AgBr** and **IPrG-CuCl**.

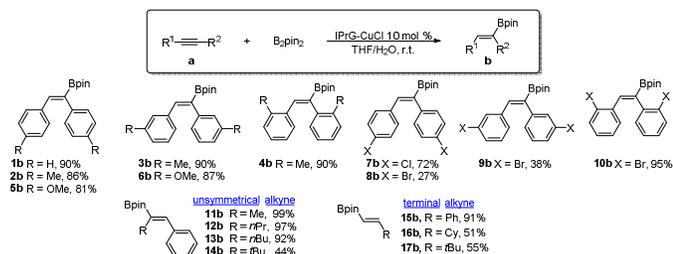
Pursuant to our on-going interest in the development of new catalytic properties based on functional NHC ligands,<sup>4</sup> we have prepared the first ever imidazolium salt bearing a guanidine pendant arm, **IPrG** by refluxing carbodiimide with amino-imidazolium salt **Me-IM-HBr**, followed by treatment of sodium hydroxide as summarized in Scheme 2. Reacting NHC precursor **IPrG** with Ag<sub>2</sub>O afforded the desired silver NHC transfer adduct **IPrG-AgBr**. The crystal structure of **IPrG-AgBr** contains T-shape tri-coordinated silver bromide complex with two guanidine-NHCs orientated in an anti-manner



**Scheme 1.** Strategic plans for developing a versatile copper catalyst based on guanidine-NHC ligand.

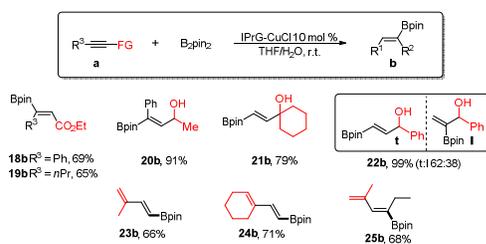
In this context, we would like to further extend the architectural diversity and possible catalytic application beyond the realm of amino functional NHC by attaching guanidine at NHC framework, considering guanidine has rich chemistry in biological function and organic catalysis.<sup>3</sup> In this

(Scheme 2 left). Subsequently, the copper chloride complex **IPrG-CuCl** could be readily obtained via transmetalation reaction with **IPrG-AgBr**. Consistent with the NMR spectroscopic data and mass analysis, the molecular structure of **IPrG-CuCl** consists of the copper centre coordinated in a quasi-linear fashion with the NHC and chloride ligands (176 °) with a Cu-C bond distance of 1.878 Å (Scheme 2, right).



<sup>a</sup> Reaction conditions: **a** (0.25 mmol), B<sub>2</sub>pin<sub>2</sub> (1.3 equiv), **IPrG-CuCl** (10 mol %) in THF (3 mL) and H<sub>2</sub>O (0.1 mL), room temp for 1h. Yield of isolated product.

**Scheme 3.** Hydroboration process with various internal and terminal alkynes<sup>a</sup>



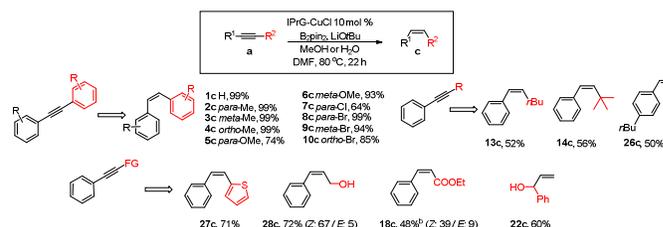
<sup>a</sup> Reaction Conditions: **a** (0.25 mmol), B<sub>2</sub>pin<sub>2</sub> (1.3 equiv), **IPrG-CuCl** (10 mol%), NaBr (3 equiv) in THF (3 mL) and H<sub>2</sub>O (0.1 mL) at room temp for 1h. Yield of isolated product.

**Scheme 4.** Hydroboration process with various functional alkynes<sup>a</sup>

The development of various organoboron compounds via efficient copper-mediated hydroboration of unsaturated substrates would definitely be worthwhile to pursue, particularly the straightforward addition of diboron reagents to carbon-carbon multiple bonds.<sup>5</sup> At this juncture, we have turned our attention to developing catalytic hydroboration process of alkynes. During the course of optimizing the hydroboration reaction of diphenylacetylene **1a**, we found the combination of catalytic amount of copper catalyst **IPrG-CuCl** (10 mol %), bis(pinacolato)diboron (B<sub>2</sub>pin<sub>2</sub>, 1.3 equiv) and 0.1 mL H<sub>2</sub>O (~10 equiv) in THF would afford a high yield of hydroborated product **1b** (90%) with *Z*-stereoselectivity.<sup>6</sup> With the optimization protocol in hand, we investigated the scope of the reaction with various diarylalkynes. Complete *Z*-selectivity of the hydroborated product and excellent yields were observed for diarylalkyne derivatives bearing electron-donating methyl and methoxy substituents at different positions (**2b-6b**). High yields were also witnessed for diarylalkynes carrying substituents like *p*-chloro (**7b**) and *o*-bromo groups (**10b**), except those with *para*- and *meta*-bromo groups, which gave lower yields. The low yield in both reactions is perhaps caused by the strong

electronic effect of bromo substituent at *para* and *meta* position. The unsymmetrically substituted alkyl phenyl alkynes were successfully converted into (*Z*)-olefinic products **11b-13b**. In all cases, borylation occurred perfectly at the β carbon to the aryl group with (*Z*)-configuration (or geometry). Lastly, terminal alkynes are also suitable substrate in this hydroboration protocol, as exemplified by the formation of **15b-17b** products. Unlike other CuX systems,<sup>5</sup> no base was required using **IPrG-CuCl** catalyst, implying that the dangling guanidine pendant arm might serve as an internal base.

To further expand the utility of this catalytic paradigm, we have examined more challenging alkynes bearing reactive functional groups. Our method exhibits excellent *Z*- and regio selectivity in the hydroboration of α,β-unsaturated alkynyl esters to afford products **18b-19b** with boryl group ended up at β position with respect to the carboxy group. The hydroboration of propargyl alcohols is also possible in this method. For example, a *syn*-Hydroboration of (**20a**) and (**21a**) gave only β-regiomer with respect to hydroxy group in high yields. 1-phenylprop-2-yn-1-ol (**22a**) still maintained high regioselectivity (62:38: terminal: internal) with excellent conversion. Finally, we were also delighted to show that such a catalytic hydroboration manifold can be applied to enynes (**23a-25a**) as well, with average yields ~60% without affecting the olefinic functionality of these substrates.

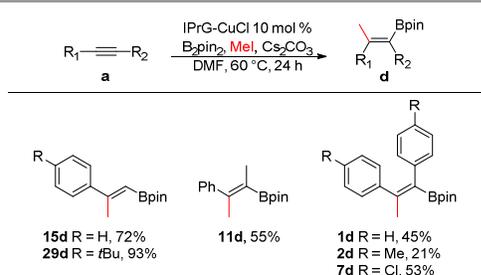


<sup>a</sup> Reaction Conditions: **a** (0.28 mmol), B<sub>2</sub>pin<sub>2</sub> (1 equiv), **IPrG-CuCl** (10 mol %), LiOtBu (1 equiv), MeOH or H<sub>2</sub>O (10 equiv) in DMF (2 mL). <sup>b</sup> LiBr (3 equiv).

**Scheme 5.** Semihydrogenation process with various alkynes<sup>a</sup>

Following the establishment of **IPrG-CuCl** as a successful hydroboration catalyst, we are curious if hydroboration reactions of unsaturated carbon linkages can be further exploited to mimic the semihydrogenation process to generate olefins in a greener manner. A corollary to this hypothesis is that an intermediate such as **X** (Scheme 1) might also enable protonation of the C-B and C-Cu sites by methanol or water under appropriate conditions. Delightfully, the one-step semihydrogenation of diphenylacetylene to (*Z*)-stilbene **1c** (99%) can be achieved in DMF solvent by adding LiOtBu base and maintaining the catalytic conditions similar to those described above for the hydroboration process. With this newly developed protocol in hand, we examined the scope and limitation of the reaction with various diarylalkynes (Scheme 5). Complete *Z*-selectivity of the semihydrogenation products and excellent yields (~95%) were observed for diarylalkyne derivatives bearing electron-donating methyl substituents at all

positions **2c-4c** and methoxy groups at *meta* (**6c**). A good yield was witnessed for the reaction of *para*-methoxy (**5c**) and *para*-bromo (**8c**) while complete selectivity for the *Z*-isomer is still maintained. Gratifyingly, *para*-chloride (**7c**) did not seem to perturb the rate or selectivity of the reaction. It is noted that the semihydrogenation transformation can also proceed smoothly with H<sub>2</sub>O, acting as an alternative hydrogen source. To the best of our knowledge, this is the first case of selective semihydrogenation of alkynes towards (*Z*)-alkenes with no reduction to the alkanes using commercially available boron reagents. Phenylalkynes with alkyl fragments such as linear butyl (**13a**) or hindrance *t*-butyl (**14a**) as well as terminal alkyne (**26a**) are also compatible for this catalytic reaction with complete *syn* stereoselectivity. Similarly, good yield with high *Z* selectivity was observed for 2-(phenylethynyl)thiophene (**27a**) and propargyl alcohol derivatives like (**28a**) and (**22a**) in semihydrogenation reaction. Equally important, the alkyne derivative bearing ester moiety (**18a**) could also be reduced without perturbing the carboethoxy functionality albeit in lower yield of 48%.



<sup>a</sup> Reaction conditions: **a** (0.25 mmol), MeI (4 equiv), B<sub>2</sub>Pin<sub>2</sub> (1.5 equiv), IPrG-CuCl (10 mol%), Cs<sub>2</sub>CO<sub>3</sub> (1.5 equiv) in DMF (2 ml) at 60 °C for 24 h.

#### Scheme 6. Carboborylation process with alkynes<sup>a</sup>

Based on the positive results in semihydrogenation process, we were curious if a new chemical transformation can further be realized by exploiting vinylcopper intermediate **X** with other electrophile like alkyl halide instead of methanol to have *syn*-carboboration of simple alkynes.<sup>7</sup> To our delight, the methylboration of phenylacetylene afforded the desired product **15d** in high yield (72 %) in the presence of B<sub>2</sub>pin<sub>2</sub>, methyl iodide and Cs<sub>2</sub>CO<sub>3</sub> base with a catalytic amounts of IPrG-CuCl (Scheme 6). Similarly, internal alkyne like **11a** and **1a** could be effectively transformed into carboboration adducts **11d** and **1d** with only one regiomer in a moderate yield, respectively. Other aryl alkyne derivatives like **7a** and **29a** are also suitable for this reaction to afford a good yield of final product.

In short, we have successfully prepared and isolated a new kind of functional NHC and its copper complexes IPrG-CuCl, namely guanidine NHC. It is found to be highly active catalyst for hydroboration of various kinds of alkynes bearing active functional group with a good regioselectivity. More important, we have also unraveled a highly efficient catalytic system for the *Z*-selective semihydrogenation of alkynes using commercially available diboron reagents and water or alcohol

as viable hydrogen sources, as opposed to the use of hydrogen gas. The versatility of the IPrG-CuCl is further illustrated by mediating carboboration reaction with alkynes. Further mechanistic investigations of semihydrogenation process and the development of a more effective catalyst with broader scope are now the focus of our ongoing efforts.

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#### Notes and references

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Electronic Supplementary Information (ESI) available: Full experimental and analytical details, including crystallographic data and tables. CCDC 938476 (IPrG-AgBr) and CCDC 938477 (IPrG-CuCl). For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/c000000x/

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