

# Gold-Catalyzed Redox Synthesis of Imidazo[1,2-*a*]pyridines using Pyridine *N*-Oxide and Alkynes

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**Abstract:** A mild, catalytic, atom economical synthesis of imidazo[1,2-*a*]pyridines has been developed: catalytic dichloro(2-pyridinecarboxylato)gold [PicAuCl<sub>2</sub>] in the presence of an acid produces a range of imidazo[1,2-*a*]pyridines in good yields starting from alkynes and 2-aminopyridine *N*-oxides. This strategy is mild and foreseen to be of particular use for the installation of stereogenic centers adjacent to the imidazo[1,2-*a*]pyridine ring without loss of enantiomeric excess.

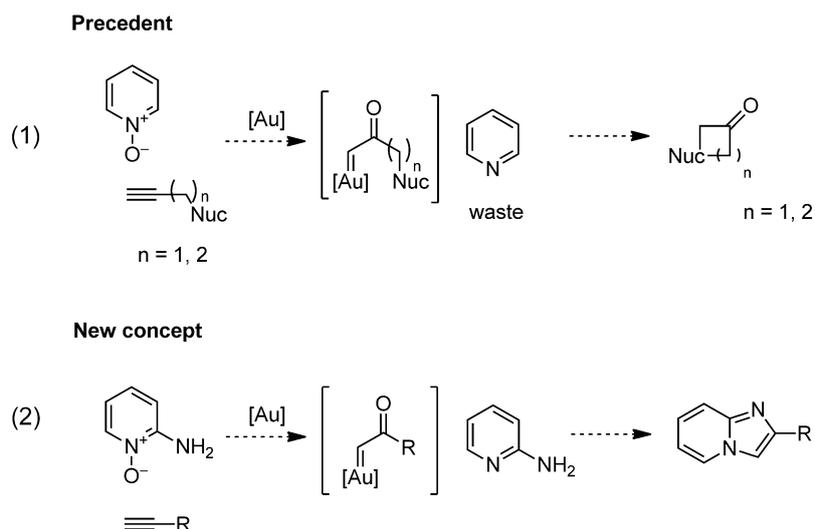
**Keywords:** alkynes; atom economy; gold; imidazo[1,2-*a*]pyridines; pyridine *N*-oxides; redox reaction

The possibility of forming an  $\alpha$ -oxo gold carbenoid species through an oxygen transfer reaction using an alkyne and a nucleophilic oxide (initially a sulfoxide)<sup>[1]</sup> was first exploited in 2007 and this concept has subsequently been expanded: specifically one area in which this redox chemistry has been developed is the accommodation of pyridine *N*-oxides<sup>[2]</sup> which serve as the oxidant in the formation of the  $\alpha$ -oxo gold carbenoid species (Scheme 1).<sup>[3]</sup> This reaction combination has utilized both intra- and intermolecular attack of the *N*-oxide moiety on the alkyne, however, in cases where the *N*-oxide has been utilized in an intermolecular reaction a stoichiometric amount of pyridine waste is produced.<sup>[4]</sup> As an alternative, we envisaged a process in which 2-aminopyridine *N*-oxide would serve as the oxidant and be incorporated in the molecular complexity of the product through trapping the carbenoid species.<sup>[5]</sup> Imidazo[1,2-*a*]pyridines have recently attracted significant interest in the pharmaceutical industry as they exhibit antibacterial,<sup>[6]</sup> antifungal,<sup>[7]</sup> antiviral,<sup>[8]</sup> and anti-inflammatory properties.<sup>[9]</sup> The imidazo[1,2-*a*]pyridine ring system can be

formed in many ways: typically they are formed *via* condensation of aminopyridines and  $\alpha$ -halo ketones<sup>[10]</sup> and can be formed by a one-pot condensation of an aldehydes, isonitrile and a 2-aminopyridine although this approach can require harsh conditions so limiting the scope of functionalities tolerated in this reaction.<sup>[11]</sup> More recently a number of copper-catalyzed methodologies have been developed, namely a three-component reaction of a 2-aminopyridine with an aldehyde and an alkyne,<sup>[12]</sup> a dehydrogenative coupling of a ketone with a 2-aminopyridine conducted at 40 °C,<sup>[13]</sup> an oxidative cyclization of a haloalkyne with an aminopyridine at 60 °C,<sup>[14]</sup> and an oxidative reaction between a ketone and a 2-aminopyridine carried out at 120 °C.<sup>[15]</sup> Two further methods reported recently are worthy of note, the iron(III)-catalyzed reaction between a nitroolefin and an aminopyridine achieved at 80 °C,<sup>[16]</sup> and the silver-mediated oxidative coupling between terminal alkynes and a 2-aminopyridine conducted at 110 °C.<sup>[17]</sup>

The concept reported here offers an atom economic redox<sup>[18]</sup> process to imidazo[1,2-*a*]pyridines by employing the pyridine component both as a nucleophile, directly attacking the gold carbenoid intermediate, and it is involved in the regioselective formation of these *N*-bridgehead heterocycles [Scheme 1, Eq. (2)]. Interestingly this combination of reagents appears to offer more flexibility in the choice of components in the reaction.<sup>[19]</sup> We foresaw that this new methodology might allow access to a range *N*-bridgehead heterocycles with chiral substituents which would otherwise be extremely difficult to obtain using the classical routes. To test our initial hypothesis and delineate reaction parameters, the reaction of 2-aminopyridine *N*-oxide and 1-chloro-3-ethynylbenzene was investigated.

Gratifyingly, our initial efforts identified the use of 1.2 equiv. of pyridine *N*-oxide and 10 mol% of dichloro(2-pyridinecarboxylato)gold [PicAuCl<sub>2</sub>] in di-



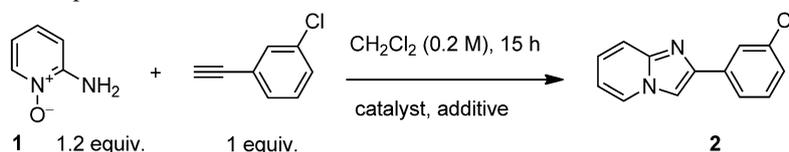
**Scheme 1.** Precedent using an intermolecular pyridine *N*-oxide and the new concept for imidazo[1,2-*a*]pyridine synthesis using a 2-aminopyridine *N*-oxide.

chloromethane at room temperature as suitable conditions for the reaction, giving a 43% conversion to the desired imidazo[1,2-*a*]pyridine **2** (entry 1 in Table 1). Addition of 1 equivalent of MsOH improved the conversion, with 71% of starting alkyne being converted to the desired product. Alternative acids such as TFA, HNTf<sub>2</sub>, acetic acid and *para*-nitrobenzoic acid were then tested and as previously noted, faster reaction was seen on lowering of the *pK<sub>a</sub>* of the acid.<sup>[2]</sup>

The acid appears to play a key role: this we believe increases the reaction rate by promoting the dissolu-

tion of the sparingly insoluble starting pyridine *N*-oxide. This fact was particularly highlighted in the case of *para*-nitrobenzoic acid (entry 5) where the formation of an insoluble salt resulted in no conversion to the product. The best conversion to product was achieved using MsOH or TFA as the acid (entries 2 and 3). On the other hand, no product was formed in the absence of gold catalysts (entry 4).<sup>[20]</sup> Interestingly slow formation of the desired compound was observed when 0.5 equivalent of TFA was used (entry 7), and therefore 1 equivalent of TFA was chosen for further studies. Dichloromethane proved

**Table 1.** Evaluation of reaction parameters.



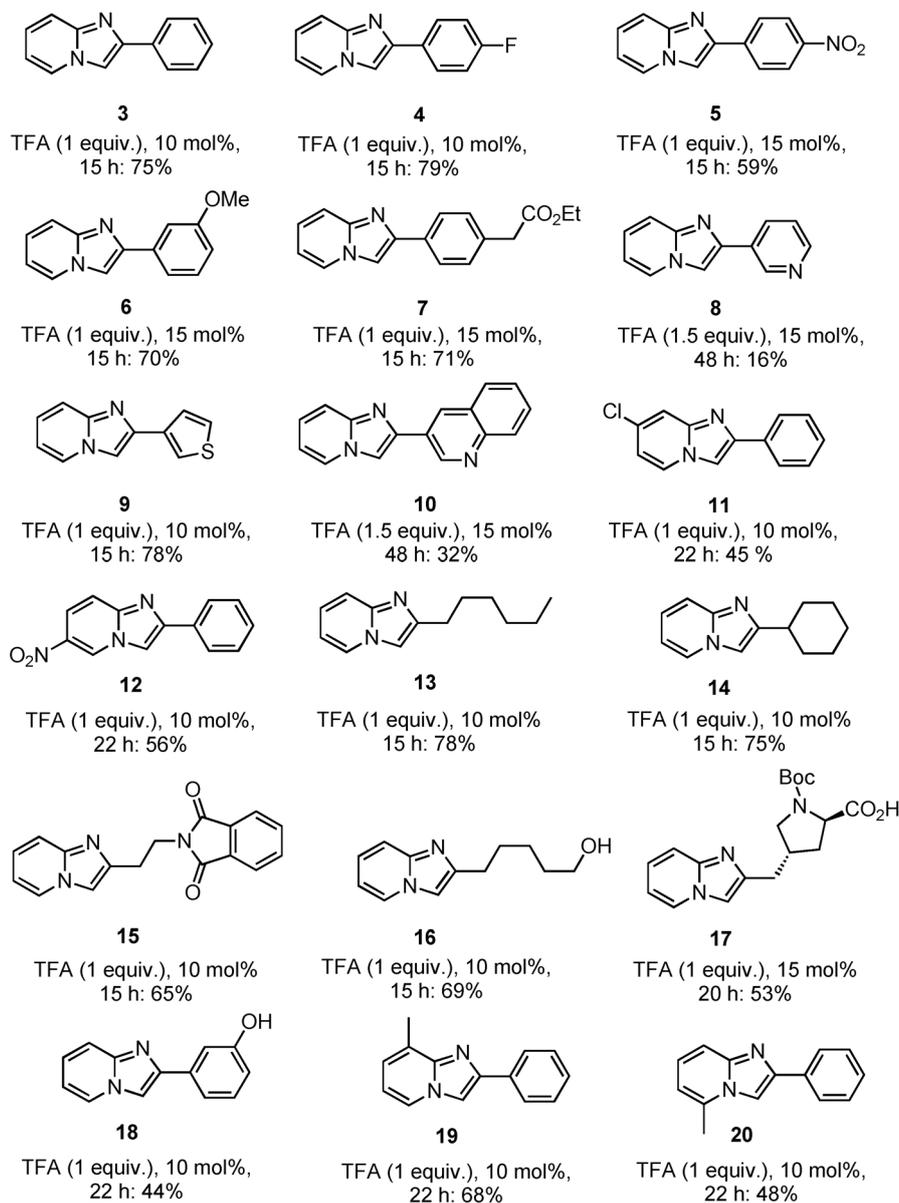
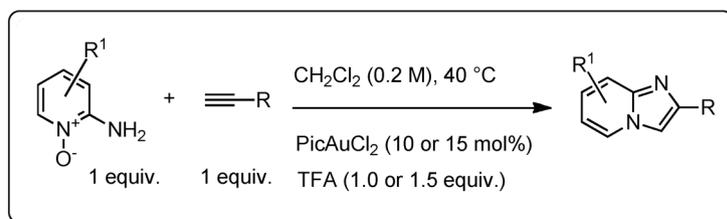
Entry	Catalyst <sup>[a]</sup>	Additive	Conversion <sup>[b]</sup>
1	PicAuCl <sub>2</sub>	None	43
2	PicAuCl <sub>2</sub>	MsOH (1 equiv.)	71
3	PicAuCl <sub>2</sub>	TFA (1 equiv.)	70
4	None	TFA (1 equiv.)	none
5	PicAuCl <sub>2</sub>	<i>p</i> -NO <sub>2</sub> C <sub>6</sub> H <sub>4</sub> CO <sub>2</sub> H (1 equiv.)	none
6	PicAuCl <sub>2</sub>	HNTf <sub>2</sub> (1 equiv.)	72
7	PicAuCl <sub>2</sub>	TFA (0.5 equiv.)	54
8	AuCl	TFA (1 equiv.)	33
9	AuCl <sub>3</sub>	TFA (1 equiv.)	53
10	NHCAuNTf <sub>2</sub>	TFA (1 equiv.)	36
11	PPh <sub>3</sub> AuNTf <sub>2</sub>	TFA (1 equiv.)	36
12	PicAuCl <sub>2</sub>	TFA (1 equiv.) <sup>[c]</sup>	89 (72) <sup>[d]</sup>

<sup>[a]</sup> 10 mol% of catalyst was used.

<sup>[b]</sup> Determined by correlation between HPLC-MS and crude <sup>1</sup>H NMR analysis using 3,5-dinitrobenzoic acid as internal standard.

<sup>[c]</sup> The reaction mixture was heated at 40 °C for 15 h.

<sup>[d]</sup> Isolated yield after column chromatography.



**Scheme 2.** Scope of reaction with substitution possible on all positions of the pyridine *N*-oxide and various terminal alkynes. The yields were determined after column chromatography or preparative HPLC.

to be the solvent of choice; toluene, chlorobenzene and 1,2-dichloroethane did not give any product and other solvents were screened but none produced a better conversion than dichloromethane.<sup>[21]</sup> The concentration of the reaction mixture appeared not to affect the reaction rate. Various alternative metal cat-

alysts were screened during the optimization of the catalyst: platinum and copper catalysts failed to produce any of the desired product<sup>[22]</sup> and gold(I) catalysts, such as AuCl and Ph<sub>3</sub>PAuNTf<sub>2</sub> (entries 8 and 11), generally reacted sluggishly and produced many impurities. Finally, heating the reaction mixture to



alkyne (0.027 mL, 0.22 mmol) and  $\text{PicAuCl}_2$  (8.7 mg, 0.022 mmol) were added. After stirring overnight at 40 °C,  $\text{Et}_3\text{N}$  (20  $\mu\text{L}$ ) was added and the reaction mixture was concentrated under reduced pressure and purified by column chromatography to give pure imidazo[1,2-*a*]pyridine **2**; yield: 36.2 mg (72%).

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