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Palladium-Catalyzed Nitration of Meyer−Schuster Intermediates with *t*BuONO as Nitrogen Source at Ambient Temperature

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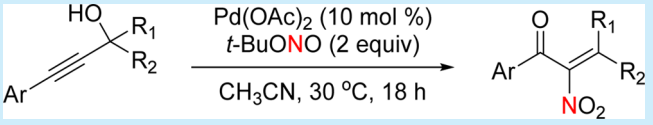
Supporting Information

ABSTRACT: A novel domino palladium-catalyzed nitration of Meyer−Schuster intermediates which were generated in situ from propargylic alcohols was developed, by the use of *t*-BuONO, leading to α-nitro enones in good to excellent yields at room temperature with a broad functional group tolerance.



Nitro compounds are widely used as building blocks[1] and key intermediates in synthetic chemistry, the pharmaceutical industry, and material sciences.[2] The conventional nitration, which proceeds via an electrophilic substitution pathway, usually requires nitric acid as the nitrating reagent with another strong acid as the catalyst at high temperature, causing poor selectivities and severe strong acid waste.[2] Therefore, the development of new nitrating reagents and new approaches to synthesize nitro compounds under mild conditions with high selectivities is highly desirable. Radical chemistry has boomed in the past decade. Synthesis of nitro compounds through the radical process attracted great attention, and great effort has been devoted to this topic. In 2011, Beller and his co-workers reported a metal-free nitration of arylboronic acids under mild conditions, by the use of *tert*-butyl nitrite as a nitro reagent.[3] Recently, Maiti discovered that $AgNO_2$ along with TEMPO can serve a nitrating reagent to lead to nitro olefins with good regio- and stereoselectivities.[4a,b] And later on, the same group reported a pretty similar reaction with $Fe(NO_3)_2$ as the NO_2 source.[4c] In 2014, Li reported a cascade nitration/cyclization reaction to synthesize pyrrolo-[4,3,2-*de*]quinolinones.[5] In 2015, Liang developed a metal-free nitro-carbocyclization of 1,6-enynes.[6] However, all of the above-mentioned nitration reactions were limited to alkynes and alkenes, and the addition of nitro radicals to allenes has not yet been reported.

It is well documented that the propargylic alcohols or propargyl esters could generate allenols via Meyer−Schuster rearrangement.[7] As part of our continuous interest in radical chemistry, we envisioned that nitro radicals, which could be generated from a NO source under oxidative conditions, might attack the allene intermediate A which comes from the rearrangement of propargylic alcohols, rendering α-NO_2 enones via a cascade reaction (Figure 1). To the best of our knowledge, the efficient methods for preparation of complex polysubstituted α-NO_2 enones have not yet been explored despite the fact that enones are valuable building blocks in many reactions.[8] Herein, we reported a radical involved Pd-catalyzed nitration of allene intermediates which were generated via Meyer−Schuster rearrangement, leading to α-nitro enones in good to excellent yields at ambient temperature.

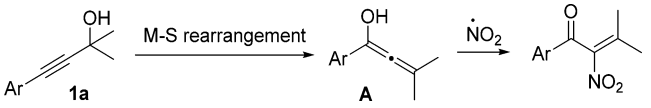
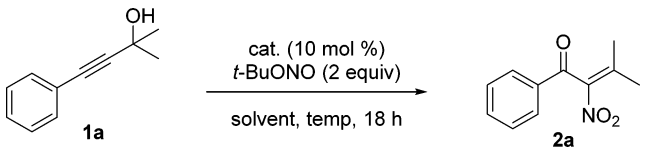


Figure 1. Proposed nitration of propargylic alcohols.

To verify our hypothesis, we chose 2-methyl-4-phenylbut-3-yn-2-ol (**1a**) as model substrates (Table 1). To our delight, when 10 mol % of $Pd(OAc)_2$ was employed, the nitration

Table 1. Optimization of Reaction Conditions[a]



entry	cat. (10 mol %)	solvent (1 mL)	temp (°C)	yield[b] (%)
1	$Pd(OAc)_2$	THF	60	73
2	–	THF	60	0
3	$PdCl_2$	THF	60	49
4	$Pd(PPh_3)_2Cl_2$	THF	60	0
5	$Pd(PPh_3)_4$	THF	60	15
6	$Pd(OAc)_2$	1,4-dioxane	60	74
7	$Pd(OAc)_2$	CH_3CN	60	84
8	$Pd(OAc)_2$	CH_3CN	50	89
9	$Pd(OAc)_2$	CH_3CN	40	84
10	$Pd(OAc)_2$	CH_3CN	30	92(86)[c]

[a]Reaction conditions (unless otherwise mentioned): **1a** (0.25 mmol), *t*-BuONO (2 equiv), catalyst (10 mol %), solvent (1 mL), 18 h, under air. [b]Determined by GC yield. [c]Isolated yield (THF = tetrahydrofuran, CH_3CN = acetonitrile).

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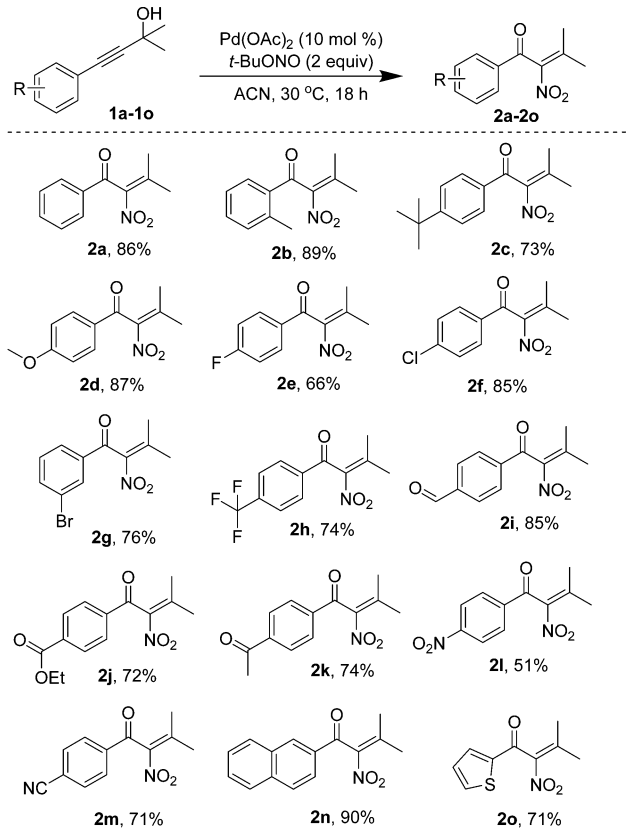
product **2a** was obtained in 73% yield by GC (entry 1); however, the desired product could not be obtained without a metal catalyst (entry 2). We next investigated other palladium catalysts, such as $PdCl_2$, $Pd(PPh_3)_2Cl_2$, and $Pd(PPh_3)_4$, and no better results were obtained (entries 3−5). Subsequent solvent optimization suggested that CH_3CN was the best choice (entries 6−7). In addition, we found that decreasing the reaction temperature to 30 °C could increase the yield from 84% to 92% (entries 8−10). Thus, based on the above experiments, we determined the optimized conditions to be *t*-BuONO (2 equiv), $Pd(OAc)_2$ (10 mol %), and CH_3CN (1 mL) at 30 °C under air for 18 h.

Under the optimal reaction conditions, the nitration of propargylic alcohols via Meyer−Schuster rearrangement to generate α-nitro enones was performed. We first applied the reaction to a range of propargylic alcohols which were prepared from corresponding aryl bromides and 2-methylbut-3-yn-2-ol (Scheme 1). Electron-donating substituents such as 2-methyl,

Scheme 1. Nitration of γ,γ-Dimethyl Propargylic Alcohols[a]

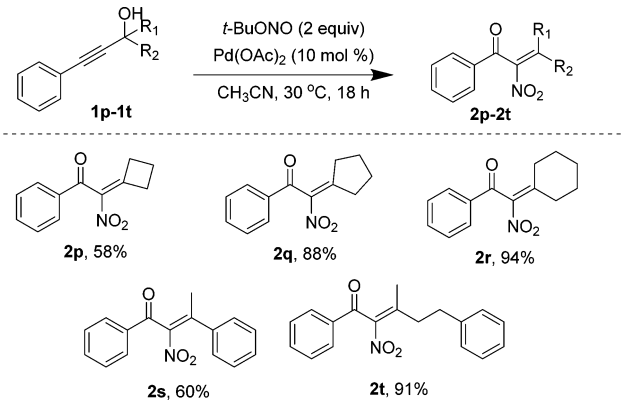


[a]Reaction conditions: **1** (0.25 mmol), *t*-BuONO (0.5 mmol), 10 mol % of $Pd(OAc)_2$, CH_3CN (1 mL), strried at 30 °C under air for 18 h. Isolated yield.

4-*tert*-butyl, 4-methoxy gave the expected products in 89%, 73%, 87% yields respectively (**2b**, **2c**, **2d**). Halo substituents were also well tolerable under the standard conditions, giving corresponding desired products which could be employed for further structural manipulations in good yields (**2e**−**2g**). Moreover, various electron-deficient groups, including trifluoromethyl, aldehyde, esters, ketone, nitro and cyano were compatible in the method as well (**2h**−**2m**). Polyphenylene compound 2-ethynylnaphthalene and a heteroaromatic one, such as thiophene, were also good substrates for this transformation, and corresponding desired products were formed in 90% and 71% yields respectively (**2n**−**2o**).

To further investigate the scope and limitations of this reaction, we next turned our attention toward the propargylic alcohols prepared from phenylacetylene and various ketones (Scheme 2). The desired products were obtained in good to

Scheme 2. Propargylic Alcohols Scope with Various γ-Substituents[a]

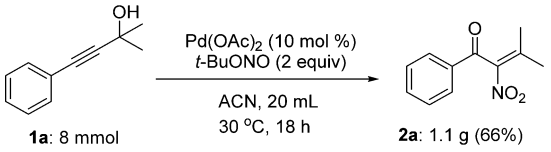


[a]Reaction conditions: **1** (0.25 mmol), *t*-BuONO (0.5 mmol), $Pd(OAc)_2$ (10 mol %), CH_3CN (1 mL), strried at 30 °C under air for 18 h. Isolated yield.

excellent yields from the substrates started from different cyclic ketones (**2p**−**2r**). Other propargylic alcohols prepared from aryl aliphatic ketones or aliphatic aliphatic ketones also gave excellent outcomes (**2s**−**2t**). It should be pointed out that the desired product was obtained in low yields when we employed the present reaction conditions with propargylic alcohols with only one substituent on the γ-position.

Gratifyingly, the reaction could be readily scaled up without loss of its efficiency: 1.1 g (66%) of α-nitro enone **2a** was obtained in 8 mmol scale (Scheme 3), implying its potential synthetic utility in industry.

Scheme 3. Scaled-up Reaction



In order to understand the reaction mechanism, various control experiments were carried out as described in Scheme 4. In the presence of radical quencher 2,6-di-*tert*-butyl-4-methylphenol (BHT) or 1,1-diphenylethylene, the reaction were completely suppressed (eq 1). It also showed that, in the absence of oxygen, the reaction did not perform at all (eq 2). Moreover, when enones **3** and **4** were subjected to the standard conditions, no corresponding desired α-nitro enones were ever detected by GC, which implied that the reaction should not proceed through direct nitration of enones.

On the basis of the above-mentioned control experiments, a tentative reaction mechanism was proposed in Scheme 5: Initially, the combination of *t*-BuONO and H_2O leads to the formation of HNO_2, which promotes the M-S rearrangement to

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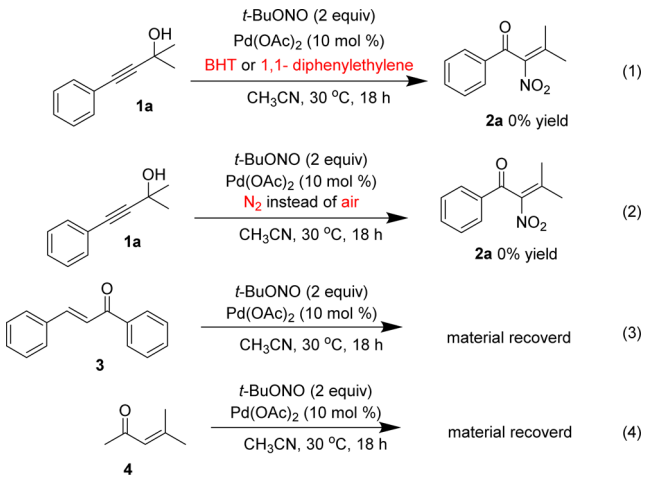
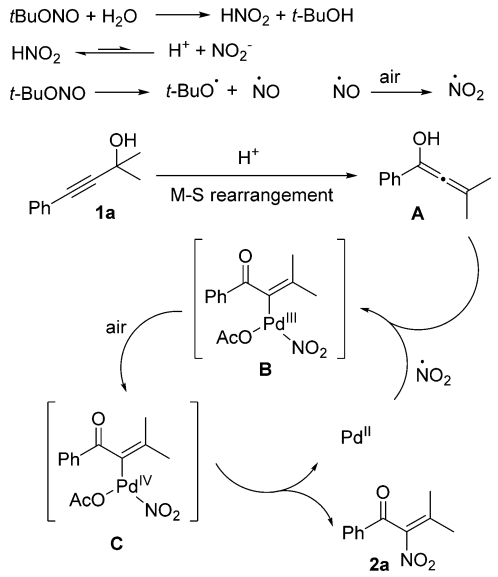
Scheme 4. Experiments for Mechanistic Studies



Scheme 5. Plausible Mechanism



generate intermediate **A**. Subsequently, the NO_2 radical is formed from the NO radical which is directly generated from *t*-BuONO under aerobic conditions.[9] In the presence of a Pd catalyst and NO_2 radical, intermediate **A** is converted into intermediate **B**, which is further oxidized into intermediate **C**.[10] The desired product **2a** is formed with reductive elimination along with the recovery of the Pd catalyst, thus completing the catalytic cycle.

In conclusion, we have developed an efficient protocol for Meyer−Schuster/nitration of propargylic alcohols into α-nitro enones with a Pd-catalyzed aerobic oxidative system. The α-nitro enones have been widely used as synthetic building blocks in organic chemistry and material sciences. The significant features of this method are (1) mild reaction conditions avoiding use of any ligand; (2) very good functional group tolerance; (3) high efficiency with good to excellent isolated yields. We think this method will merit the synthetic organic field, and further studies on its scope, mechanism, and application will be reported in due course in our laboratory.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.6b01740.

Information regarding materials and methods, and all characterization data of compounds from this study (PDF)

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Notes

The authors declare no competing financial interest.

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