

Synthesis of polycyclic substituted vinylarenes via a one-pot intramolecular aryl alkylation– *N*-tosylhydrazone insertion reaction†

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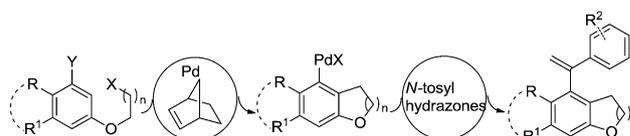
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A novel method of a palladium-catalyzed/norbornene-mediated intramolecular C–H activation/*N*-tosylhydrazones insertion reaction is developed. In this process, various bicyclic or tricyclic substituted vinylarenes are obtained with high efficiency under mild conditions.

Palladium-catalyzed cascades involving direct C–H bond activation have emerged as powerful tools for rapid access to complex highly functionalized structures.¹ The Catellani reaction² offers a unique approach to activate the *ortho* C–H bonds of aryl halides and to provide dual functionalizations at both the ipso- and *ortho*-positions.³ In the past years, many Catellani-type reactions have been reported. Seminal work by Catellani utilizing terminal alkynes⁴ or olefins⁵ as the coupling partners to trap the aryl–Pd complex provided various phenanthrenes and vinylbiphenyl compounds. After Catellani's work, some terminal reagents such as arylboronic acids,⁶ reductants⁷ were reported. In 2006, a palladium-catalyzed tandem intramolecular *ortho* alkylation–cyanation reaction for the synthesis of annulated heterocycles using CN anions in the termination step was further developed by Lautens and co-workers.⁸ But almost all of these transformations involved the types of terminal couplings that are limited to Heck, Suzuki, Cassar–Sonogashira or hydrogenolysis reactions. Therefore, among the various new developments in modified Catellani cross-coupling reactions, the expansion of cross-coupling partners is particularly desirable.

On the other hand, numerous examples of palladium-catalyzed multiple insertion of diazo compounds have been reported.^{9,10} In 2001, Van Vranken reported the catalytic cross-coupling using (trimethylsilyl)diazomethane as the coupling partner in Pd-catalyzed reactions.¹¹ Barluenga and co-workers demonstrated the application of *N*-tosylhydrazones in the



Scheme 1 One pot Pd-catalyzed coupling of *N*-tosylhydrazones and aryl halides with tethered alkyl halides for the synthesis of polycyclic substituted vinylarenes. X, Y = I, Br. *n* = 1, 2, 3.

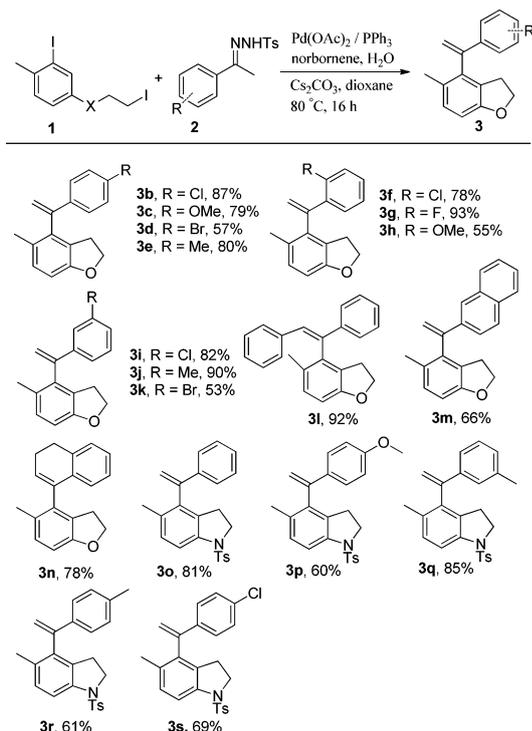
Pd-catalyzed cross-coupling with aryl halides affording the desired alkene products.¹² However, to our knowledge, applying diazo compounds to the palladium-catalyzed Catellani reaction has not been explored in the literature to date. In this context, we report a coupling of *N*-tosylhydrazones and aryl halides with tethered alkyl halides. This strategy allows rapid assembly of oxygen or nitrogen containing heterocyclic systems from alkyl halides under palladium and norbornene-mediated conditions, which then react with *N*-tosylhydrazones through an efficient sequence of Pd carbene migratory insertion and β -H elimination leading to the formation of two separate C–C bonds (Scheme 1).

After optimizing the reaction conditions, we employed aryl iodide (**1a**) (1.0 equiv.), *N*-tosylhydrazone (**2a**) (2.0 equiv.), Pd(OAc)₂ (10 mol%), PPh₃ (20 mol%), Cs₂CO₃ (5.0 equiv.), H₂O (5.0 equiv.), and norbornene (1.0 equiv.) in dioxane (0.1 M) at 80 °C (for details, see the ESI†).

We examined the scope of the reaction with a number of *N*-tosylhydrazones with different substitution patterns (Scheme 2). The reaction system displayed good tolerance toward a range of functional groups. Aromatic groups bearing electron-donating (products **3c**, **3e**, **3h**, **3j**) or electron-withdrawing substituents (products **3b**, **3d**, **3f**, **3g**, **3i**, **3k**) were all tolerated. Steric hindrance had little effect on this transformation, both *ortho*- and *meta*-substituted *N*-tosylhydrazones exhibited good reactivity. 1,2-Diphenylethanyl and 1-(naphthalen-2-yl)ethanyl substituted *N*-tosylhydrazones were good substrates for this transformation, which smoothly afforded the desired products **3l** and **3m** in 92% and 66% yields, respectively. Additionally, the corresponding 3,4-dihydronaphthalenyl substituted *N*-tosylhydrazone

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was compatible with the reaction conditions and was converted into **3n** in 78% yield. Notably, the synthesis of nitrogen-containing heterocyclic products also proved to be very efficient which were obtained in moderate to good yields (products **3o-s**).

The scope of the aryl halides was investigated next (Table 1). We also investigated the feasibility of using aryl bromides under the optimized reaction conditions. To our delight, substrate **1a** and **1b** were transformed into the five-membered ring oxacycle **3a** in 89% and 61% yields, respectively. Considering the reaction, maybe **1b** is less competitive toward Pd(0) oxidative addition than aryl iodide **1a**. Extension to larger ring systems was also possible under these conditions affording the desired six- and seven-membered rings in moderate to good yields. Interestingly, the methyl containing aryl iodides exhibited higher reactivity than aryl bromides except in the case of entry 3. However, the methoxy containing aryl iodides with tethered alkyl iodide were less reactive than tethered alkyl bromide (entries 4–6).

Following the success of the formation of the bicyclic substrates, we explored the possibility of tricyclic products through a double *ortho*-alkylation–carbene migratory insertion and β -H elimination sequence (Table 2). Gratefully, the 5, 6, 5-ring system product **5a** was prepared in 81% yield (entry 1), While the larger 6, 6, 6- and 7, 6, 7-ring systems were only generated in 46% and 42% yields, respectively (entries 2 and 3). In addition, tricyclic compound **5d** was prepared in 79% yield from the corresponding *p*-methoxy *N*-tosylhydrazone (entry 4).

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Table 1 Synthesis of bicyclic vinylarenes via a palladium-catalyzed/norbornene-mediated tandem reaction^a

Entry	Substrates	Products	Yield ^b (%)
1	1a , Y = I 1b , Y = Br	3a	89 61
2	1c , Y = I 1d , Y = Br	3t	60 49
3	1e , Y = I 1f , Y = Br	3u	55 60
4	1g , X = Br 1h , X = I	3v	87 82
5	1i , X = Br 1j , X = I	3w	76 48
6	1k , X = Br 1l , X = I	3x	59 38

^a Conditions: **1** (0.2 mmol), **2a** (0.4 mmol), Pd(OAc)₂ (10% mmol), PPh₃ (20% mmol), Cs₂CO₃ (5.0 equiv.), norbornene (1.0 equiv.), dioxane (2 ml), H₂O (5.0 equiv.), 80 °C, 16 h. ^b Yield of the isolated product.

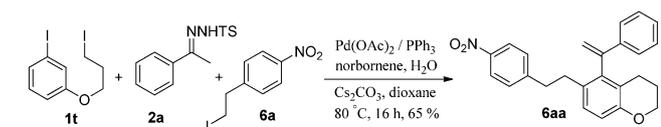
To fully demonstrate the applicability of this methodology, we attempted using a substrate lacking an *ortho* substituent **1t**, tosylhydrazone **2a** and alkyl iodide **6a** for the multicomponent reaction. We were able to obtain the product in satisfactory yield (Scheme 3).

In summary, we have developed a distinct strategy to synthesize polycyclic substituted vinylarenes using a palladium-catalyzed/norbornene-mediated tandem *ortho* alkylation–metal carbene insertion reaction system. This method has been applied toward the synthesis of a variety of synthetically useful bicyclic and tricyclic vinylarenes products. The reaction features good yields, excellent functional-group tolerance, and a wide compatibility of structurally and electronically varied substrates, making it applicable to structurally complex compounds. In addition, this modified Catellani-type C–H activation provides

Table 2 Synthesis of tricyclic vinylarenes via a palladium-catalyzed/norbornene-mediated tandem reaction^a

Entry	Substrates	Products	Yield ^b (%)
1			81
2			46
3			42
4			79

^a Conditions: **4** (0.2 mmol), **2** (0.4 mmol), Pd(OAc)₂ (10% mmol), PPh₃ (20% mmol), Cs₂CO₃ (5.0 equiv.), norbornene (2.0 equiv.), dioxane (4 ml), H₂O (5.0 equiv.), 80 °C, 16 h. ^b Yield of the isolated product.



Scheme 3 Three component reaction. Conditions: **1t** (0.2 mmol), **2a** (0.4 mmol), **6a** (0.6 mmol), Pd(OAc)₂ (10% mmol), PPh₃ (20% mmol), Cs₂CO₃ (5.0 equiv.), norbornene (2.0 equiv.), dioxane (4 ml), H₂O (5.0 equiv.), 80 °C, 16 h.

broad implications for developing various dual functionalizations of aryl halides.

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