Advanced Synthesis & Catalysis

DOI: 10.1002/adsc.201300910

Nickel-Catalyzed Regio- and Stereoselective Reductive Coupling of Oxa- and Azabicyclic Alkenes with Enones and Electron-Rich Alkynes

Subramaniyan Mannathan[a] and Chien-Hong Cheng[a,*]

[a] Department of Chemistry, National Tsing Hua University, Hsinchu 30013, Taiwan
Fax: (+886)-3572-4698; e-mail: chcheng@mx.nthu.edu.tw

Received: October 11, 2013; Revised: December 8, 2013; Published online: March 11, 2014

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/adsc.201300910.

Abstract: A nickel-catalyzed regio- and stereoselective reductive coupling of oxa- and azabicyclic alkenes with activated alkenes and electron-rich alkynes is described. Thus, 7-oxabenzonorbornadienes underwent reductive coupling with various vinyl ketones such as ethyl, methyl, propyl and α-methyl-substituted vinyl ketones, in the presence of a nickel(II) iodide (NiI_2), zinc (Zn), and water catalyst system in acetonitrile at 50 °C for 14 h to afford 2-alkylnaphthalenes in good to excellent yields. Under similar reaction conditions, 7-azabenzonorbornadiene derivatives provided *cis*-2-alkyl-1,2-dihydronaphthalene derivatives in high yields. On the other hand, the nickel(II) iodide, tris(4-fluorophenyl)-phoshine [$P(4\text{-}FC_6H_4)_3$] and zinc catalyst system successfully catalyzed the reductive coupling reaction of electron-rich alkynes, with 7-aza- and 7-oxabenzonorbornadienes to give *cis*-2-alkenyl-1,2-dihydronaphthalene derivatives in good to excellent yields. In the reaction, a mild reducing agent (zinc) and simple hydrogen source (water) were used.

Keywords: alkynes; bicyclic alkenes; nickel; nickelacyclopentene; reductive coupling

Introduction

The transition metal-catalyzed ring opening addition reaction of oxa- and azabicyclic alkenes is an efficient method for the synthesis of cyclic compounds with multiple stereocenters in a highly stereocontrolled manner.[1] Addition of carbon and heteroatom nucleophiles, organometallic reagents, and electrophilic aryl and alkyl halides, in the presence of metal complexes as the catalyst, was the most commonly employed method.[2] Conversely, such ring-opening addition reactions using π-components have been scarcely studied.[3–7] Notably, few reports have been published on the use of an alkyne as the π component. In 2001, we found an efficient nickel-catalyzed reductive cyclization reaction of oxanorbornadienes with propiolates (electron-deficient alkynes) to synthesize benzocoumarins.[3] Subsequently, we also demonstrated a new method to synthesize *cis*-2-alkenyl-1,2-dihyronaphthalene derivatives.[4] In the meantime, Tam and Burton reported an Ru(II)-catalyzed cyclization of azabenzonorbornadienes with alkynes for the formation of the dihydrobenz[*g*]indole framework.[5a,b] Later, Hayashi and co-workers reported an asymmetric ring opening of oxa- and azabicyclic alkenes with electron-deficient alkynes by the use of a cationic rhodium/(*R*)-BINAP catalyst.[6] Recently, Tenaglia et al. disclosed a ruthenium-catalyzed coupling of oxabenzonorbornadienes with alkynes bearing oxygen atoms at the propargylic position to synthesize benzonorcaradienes.[7] Despite these advances, the reductive ring opening addition reaction of oxa- and azabicyclic alkenes with alkenes has hardly been exploited. Specifically, only the homocyclodimerization of oxabenzonorbornadienes to give naphtho[1,2-*b*]furan ring systems using a rhodium complex as the catalyst was reported.[5c,6]

Our ongoing interest in the regioselective reductive coupling reaction of different π-components[8] and bicyclic chemistry[1b,9] prompted us to extend the reductive coupling reaction of bicyclic alkenes with alkenes. Herein, we report a nickel(II)-catalyzed regio- and stereoselective reductive coupling of oxa- and azanorbornadienes with enones to give functionalized 2-alkyl-1,2-dihydro- and 2-alkylnaphthalene derivatives. In addition, we also demonstrated a nickel-catalyzed reductive coupling of bicyclic alkenes with electron-rich alkynes to prepare *cis*-2-alkenyl-1,2-dihydronaphthalenes in high regio- and stereoselectivity.[10] The reaction is highly step and atom-economical, an important consideration for modern synthetic chemistry.[11]

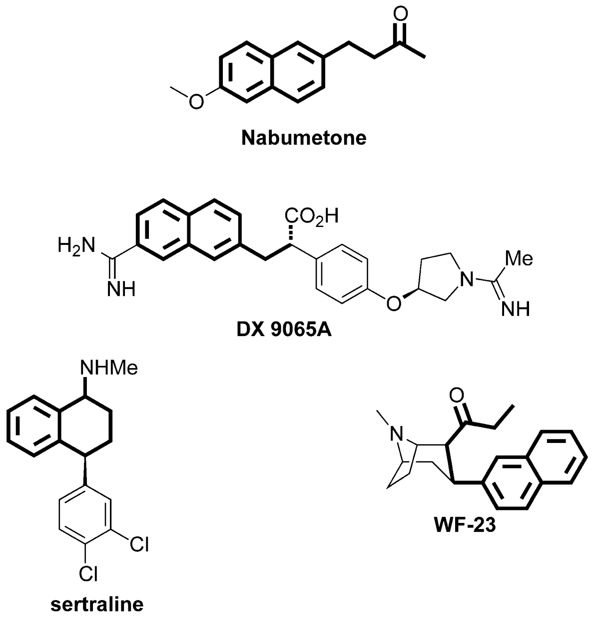


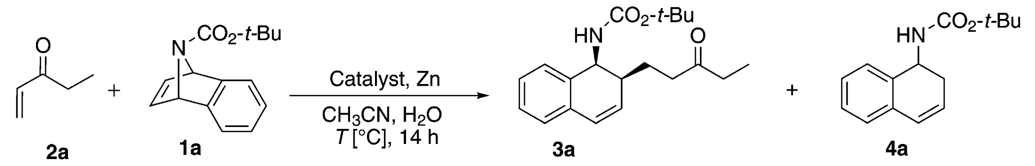
Figure 1. Representative structures involving 1,2-dihydro- and 2-alkylnaphthalenes.

It is noteworthy that the 2-alkyl- and dihydronapthalene skeletons have been found in a wide range of naturally occurring compounds that exhibit diverse biological activities (Figure 1).[12]

Results and Discussion

Our initial investigation began by treating 7-azabenzonorbornadiene (**1a**) with ethyl vinyl ketone (**2a**) in the presence of Ni(dppe)Br_2/Zn/H_2O system using acetonitrile (CH_3CN) as the solvent at 80 °C (Table 1, entry 1).[4] The reaction did not give the expected product **3a**, but afforded only the reductive ring opening product **4a** in high yield. Similarly, Ni(phen)Br_2 (phen = 1,10-phenanthroline) also failed to provide product **3a** (entry 2). We then examined the reaction with simple nickel(II) salts under similar reaction conditions (entries 3–5). Surprisingly, all nickel salts such as $NiCl_2$, $NiBr_2$, and NiI_2 were active affording **3a** in 51, 60 and 64% yields, respectively, (entries 3–5). In all these reactions, **4a** was observed in 24–36% yield. To suppress the formation of **4a** and to increase the product yield of **3a**, the reaction was carried out at

Table 1. Optimization studies[a]



Entry	Catalyst	Temperature [°C]	Solvent	Yield [%][b]	
				3a	**4a**
1	Ni(dppe)Br_2	80	CH_3CN	–	90
2	Ni(Phen)Br_2	80	CH_3CN	–	85
3	$NiBr_2$	80	CH_3CN	60	35
4	$NiCl_2$	80	CH_3CN	51	36
5	NiI_2	80	CH_3CN	64	24
6	NiI_2	50	CH_3CN	75	trace
7	NiI_2	rt	CH_3CN	–	–
8[c]	NiI_2	50	CH_3CN	93	–
9[c]	$NiBr_2$	50	CH_3CN	90	–
10[d]	$NiCl_2$	50	CH_3CN	91	–
11	NiI_2/PPh_3	50	CH_3CN	–	–
12	NiI_2/dppe	50	CH_3CN	–	35
13	none	50	CH_3CN	–	–
14	NiI_2	50	THF	–	–
15	NiI_2	50	DCM	–	–
16	NiI_2	50	1,4-dioxane	–	–
17	NiI_2	50	toluene	–	–

[a] All reactions were carried out using azabenzonorbornadiene (**1a**) (1.00 mmol), ethyl vinyl ketone (**2a**) (1.50 mmol), catalyst (0.050 mmol), Zn (1.50 mmol) and H_2O (2.00 mmol) for 14 h.

[b] Yields were measured from the crude products by the ^{1}H NMR integration method using mesitylene as an internal standard.

[c] 10 mol% nickel salt was used.

[d] 20 mol% $NiCl_2$ was used.

a lower temperature. As expected, the reaction of **1a** and **2a** at 50 °C in the presence of NiI_2 afforded **3a** in 75% yield with **4a** in low yield (entry 6). However, on further lowering the reaction temperature, we did not observe any coupling product (entry 7). Finally, increasing the catalytic loading of nickel salts furnished **3a** in high yields (entries 8–10). Addition of any monodentate and bidentate phosphine ligands completely retarded the present catalytic reaction (entries 11 and 12). The choice of solvent is also crucial to obtain product **3a** in high yield. Acetonitrile appeared to give the highest yield, while other solvents including THF, DCM, toluene and 1,4-dioxane are totally inactive (entries 13–17). This catalytic reaction is highly regio- and stereoselective where the ethyl vinyl ketone (**2a**) is added to **1a** exclusively at the face *cis* to the nitrogen atom and the C–C bond formation occurs specifically at the methylene carbon of vinyl ketone. Control experiments revealed that the reaction did not proceed in the absence of either NiI_2 or Zn and water.

To explore the scope of the reaction, various types of aza- and oxabenzonorbornadienes **1** with ethyl vinyl ketone (**2a**) under the standard reaction conditions were investigated (Table 2, entries 1–9). Thus, azabenzonorbornadienes, **1b–f**, reacted smoothly with **2a** under optimized reaction conditions to give the corresponding *cis*-1-aza-2-alkyldihydronaphthalene derivatives **3b–f** in 77–93% yields (entries 2–6). 7-Oxabenzonorbornadiene derivatives (**1g–i**) also underwent reductive coupling reaction but afforded 2-alkyl-substituted naphthalene derivatives **5** instead of the normal ring opening product, *cis*-2-alkyl-1,2-dihydronaphthols **3**. This was probably due to the fact that *cis*-2-alkyl-1,2-dihydronaphthols formed during the reaction readily underwent dehydration (aromatization) to afford the 2-alkyl-substituted naphthalene derivatives **5**.[15] Thus, the reaction of oxabicyclic alkene **1g** with **2a** provided 2-alkylnaphthalene **5a** in 93% yield (entry 7). Similarly, other oxabenzonorbornadienes, **1h** and **1i**, also afforded **5b** and **5c** in excellent yields (entries 8 and 9).

The present catalytic reaction was also successfully extended to various types of enones (**2b–d**) (Table 2, entries 10–14).[14] The reaction of methyl vinyl ketone (**2b**) with the respective oxa- and azabicyclic alkenes **1g** and **1c** afforded coupling products **5d** and **3g** in high yields (entries 10 and 11). In a similar manner, *n*-propyl vinyl ketone **2c** also underwent coupling to provide **3h** and **5e** in good yields (entries 12 and 13). A substituted vinyl ketone also worked well in the reaction. Thus, treatment of α-substituted vinyl ketone **2d** with **1g** afforded **5f** in 70% yield (entry 14). However, β-substituted vinyl ketone and cyclic enones failed to give the respective reductive coupling products **3** or **5**.

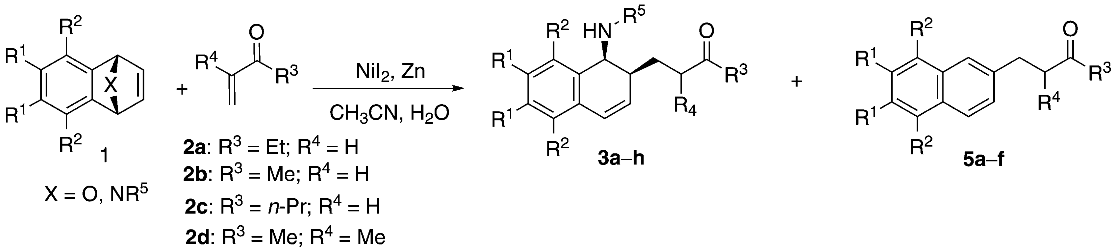
A possible reaction mechanism for the present nickel-catalyzed reductive coupling reaction is proposed in Scheme 1. The catalytic reaction is likely initiated by the reduction of Ni(II) species to Ni(0) by zinc dust.[3,4] Highly chemoselective coordination of an azabenzonorbornadiene (**1a**) and ethyl vinyl ketone (**2a**) to the Ni(0) center followed by regioselective oxidative cyclometallation yields nickelacyclopentane intermediate **9**.[4,13] Subsequent β-heteroatom elimination and protonation afforded product **3a** and the Ni(II) species. Later, the Ni(II) species, is reduced to the active Ni(0) species by Zn.

After successfully achieving the reductive coupling reaction of oxa- and azabicyclic alkenes with enones, we then extended our methodology for the coupling of electron-rich alkynes (**6**) with bicyclic alkenes (**1**). In our previously reported reductive coupling of oxa- and azabicyclic alkenes with alkynes, the reactions were limited to propiolates.[4] The reaction of electron-rich alkynes with oxa- and azabicyclic alkenes under the $Ni(dppe)Br_2/Zn/H_2O$ system in CH_3CN at 80 °C always provided the reductive ring opening product of bicyclic alkene **4** and therefore the coupling reaction of **1** with electron-rich alkynes remains very challenging.

To achieve the reductive coupling reaction of bicyclic alkenes with electron-rich alkynes, we began our optimization studies by treating oxabicyclic alkene (**1g**) with 1-phenyl-1-propyne (**6a**) under the $NiI_2/Zn/H_2O$ system in CH_3CN at 45 °C for 14 h. To our delight, the reductive coupling product **7a** was obtained in 25% yield, along with 1,2-dihydronaphthol and naphthalene as the side products. The reaction is remarkably high regio- and stereoselective in which 1-phenyl-1-propyne (**6a**) was added to **1g** exclusively at the face *cis* to the oxygen atom and the C–C bond formation occurs specifically at the alkyne carbon attached to the methyl substituent. Moreover, the phenyl and methyl groups of **6a** in the product are *cis* to each other. To improve the yield of **6a**, the reaction was examined with various monodentate and bidentate phosphine ligands (see the Supporting Information). After, extensive screening, we found that electron-deficient ligands such as $P(2\text{-furyl})_3$, $P(OMe)_3$, $P(OBu)_3$ and $P(4\text{-}FC_6H_4)_3$ were effective affording the product in 31, 50, 85 and 92% yields, respectively.[16] Similar to the reductive coupling of bicyclic alkenes with enones, the use of CH_3CN as the solvent is also crucial to obtain high product yield. Based on the above studies, we chose 5 mol% NiI_2, 10 mol% $P(4\text{-}FC_6H_4)_3$, Zn, and H_2O in CH_3CN at 45 °C for 14 h as the standard reaction conditions for the reactions in Table 3.

Under the standard reaction conditions, the reactions of various alkynes (**6b–g**) with **1g** were examined. Treatment of 1-phenyl-1-butyne (**6b**) with **1g** gave **7b** in 68% yield. Functionalized alkyne, **6c**, un-

Table 2. Results of the reductive coupling of oxa- and azabenzonorbornadiene **1** with alkenes **2**.[a]



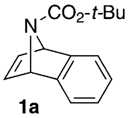
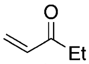
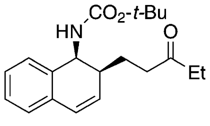
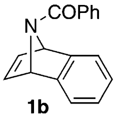
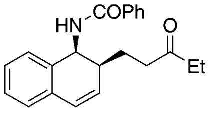
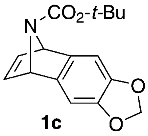
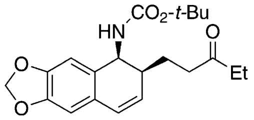
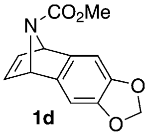
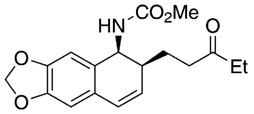
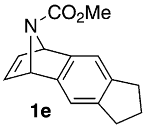
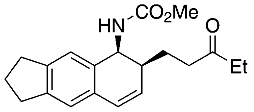
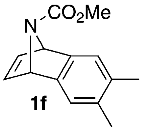
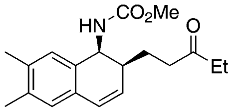
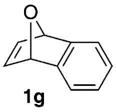
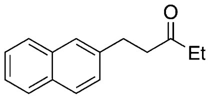
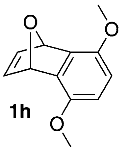
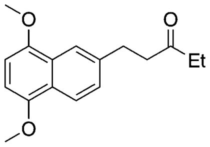
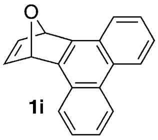
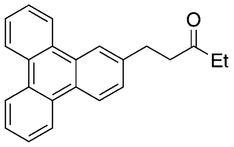
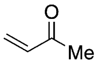
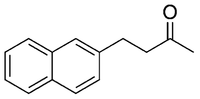
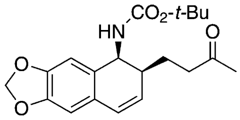
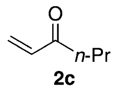
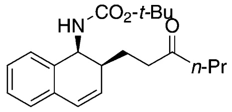
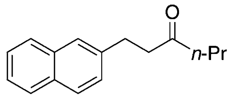
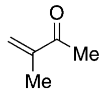
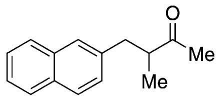
Entry	1	2	Product		Yield [%][b]
1	 **1a**	 **2a**		**3a**	90
2	 **1b**	**2a**		**3b**	81
3	 **1c**	**2a**		**3c**	80
4	 **1d**	**2a**		**3d**	77
5	 **1e**	**2a**		**3e**	93
6	 **1f**	**2a**		**3f**	90
7	 **1g**	**2a**		**5a**	93
8	 **1h**	**2a**		**5b**	80
9	 **1i**	**2a**		**5c**	77
10	**1g**	 **2b**		**5d**	92
11	**1c**	**2b**		**3g**	87

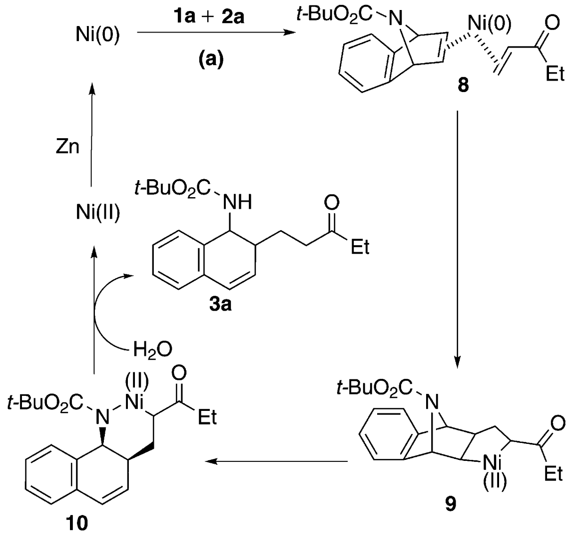
Table 2. (Continued)

Entry	1	2	Product		Yield [%][b]
12	**1a**	 **2c**		**3h**	85
13	**1g**	**2c**		**5e**	88
14	**1g**	 **2d**		**5f**	70[c]

[a] Unless otherwise mentioned, all reactions were carried out with oxa- or azabenzonorbornadienes **1** (1.00 mmol), enones **2** (1.50 mmol), NiI_2 (10.0 mol%), Zn (1.50 mmol), H_2O (2.00 mmol) and CH_3CN (1.50 mL) at 50 °C for 14 h under N_2.

[b] Isolated yield; the stereochemistry of product **3** is a relative configuration and not absolute. [c] 20.0 mol% of ZnI_2 was used.

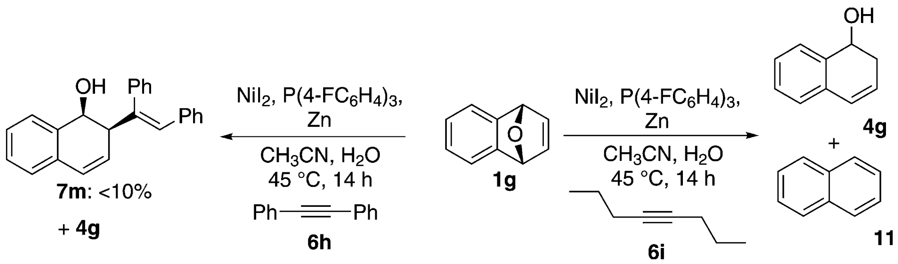
derwent reductive coupling with **1g** to give the expected product **7c** in 82% yield. Terminal alkynes were also compatible for the present reaction.[8b] Thus, phenyl acetylene (**6d**) gave **7d** in high yield. Similarly, *para*-methoxy- (**6e**) and *para*-methyl- (**6f**) substituted phenylacetylenes furnished single regioisomeric products **7e** and **7f** in good to excellent yields.[9a] Gratifyingly, an aliphatic alkyne, 1,4-dimethoxybutyne (**6g**) also gave **7g** in 78% yield. It should be noted that the reaction of diphenylacetylene (**6h**) with **1g** provided the reductive coupling product **7m** only in low yield whereas 4-octyne (**6i**) did not afford any reductive coupling product (Scheme 2).



Scheme 1. Proposed mechanism for reductive coupling of azabicyclic alkene (**1a**) with ethyl vinyl ketone (**2a**).

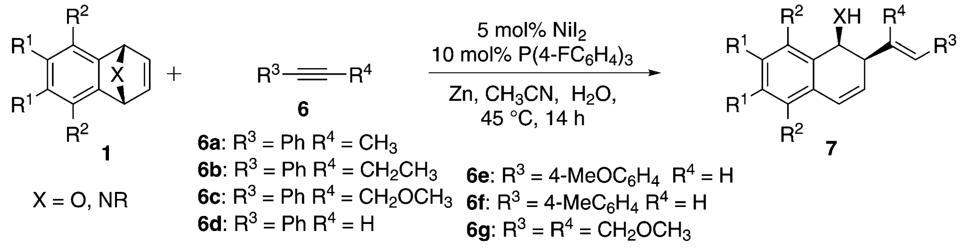
To broaden the scope of the present catalytic reaction, various oxa- and azabicyclic alkenes with **6a** were investigated (Table 3). Thus, 7-oxanorbornadienes, **1h** and **1i**, effectively participated in the reductive coupling reaction to give the corresponding products **7h** and **7i** in good yields. In a similar manner, azabicyclic alkenes **1a–c** also furnished the respective 1,2-dihydronaphthalene derivatives **7j–l** in excellent yields.

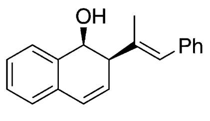
The mechanism for the reductive en-yne coupling is appealing in view of the observed novel regio- and stereoselectivity. On the basis of the above results and known nickel chemistry, the key pathways are proposed as shown in Scheme 3. The catalysis is initiated by the reduction of Ni(II) to Ni(0) by zinc powder. *exo* Coordination of 7-oxabenzonorbornadiene **1g** and alkyne **6a** to the Ni(0) center followed by the regioselective oxidative coupling of the bicyclic alkene and



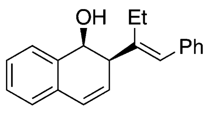
Scheme 2. Nickel-catalyzed reductive coupling of **6h** and **6i** with **1g**.

Table 3. Results of the reductive coupling of oxa- and azabenzonorbornadiene **1** with alkynes **6**.[a,b]

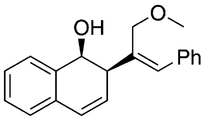




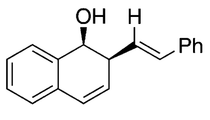
7a: 92%



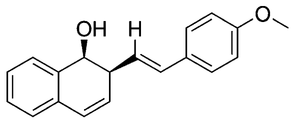
7b: 68%



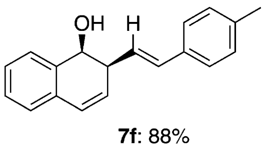
7c: 82%



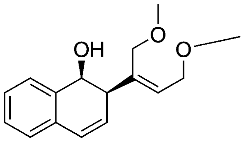
7d: 95%



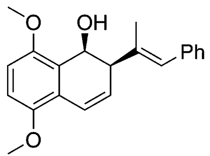
7e: 90%



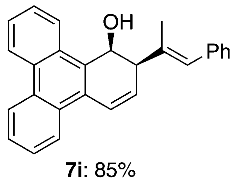
7f: 88%



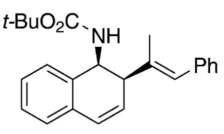
7g: 78%



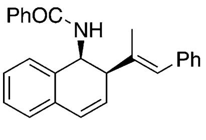
7h: 88%



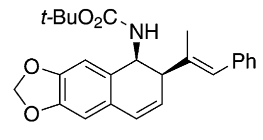
7i: 85%



7j: 97%



7k: 92%

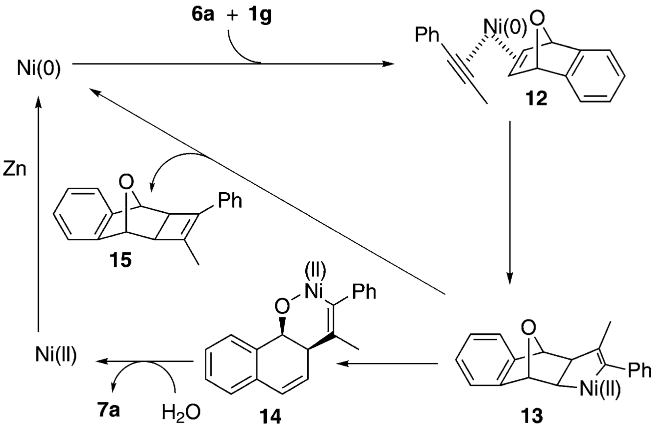


7l: 95%

---

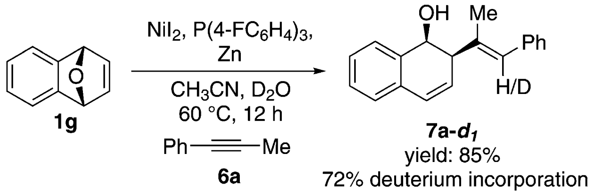
[a] Unless otherwise mentioned, all reactions were carried out with oxa- or azabenzonorbornadiene **1** (1.00 mmol), alkynes **6** (1.50 mmol), NiI$_2$ (5.0 mol%), P(4-FC$_6$H$_4$)$_3$ (10.0 mol%), Zn (2.75 mmol), H$_2$O (2.00 mmol) and CH$_3$CN (1.5 mL) at 45 °C for 14 h under N$_2$.

[b] Isolated yields reported; the stereochemistry of product **7** is a relative configuration and not absolute.



Scheme 3. Proposed mechanism for the reductive coupling of oxabicyclic alkene (**1g**) with 1-phenyl-1-propyne (**6a**).

alkyne leads to the formation of nickelacyclopentene intermediate **13**.[3–6] Subsequent β-oxy elimination of **13** followed by protonation affords the final product **7a** and Ni(II) species. The latter is then reduced by Zn to regenerate the Ni(0) species. It is noteworthy that in the absence of water, intermediate **13** affords [2+2] cycloadduct **15** in 66% yield under the similar reaction conditions. This result clearly reveals that the reaction proceeds *via* nickelacyclopentene intermediate **13**. In addition, an isotope-labeling experiment was carried using D$_2$O instead of H$_2$O (Scheme 4). The reaction proceeded well at 60 °C and afforded the product **7a**-d_1 in 85% yield with 72% deuterium incorporation at the styrene double bond; which strongly supports the requirement of water for the protonation



Scheme 4. Deuterium labeling experiment.

of **14** in the reaction. The isotope abundance was determined by the ^{1}H NMR integration method.

Conclusions

In conclusion, we have demonstrated a new nickel-catalyzed reductive coupling reaction of oxa- and azabicyclic alkenes with enones to prepare 2-alkylnaphthalene and *cis*-2-alkyl-1,2-dihydronaphthalenes in good to excellent yields. In addition, we have also successfully developed suitable reaction conditions for the reductive coupling of oxa- and azabicyclic alkenes with electron-rich alkynes. These reactions are highly regio- and stereoselective, and could be an excellent complement to the ring opening addition reaction- of oxa- and azabicyclic alkenes. Further extension of the reaction with other π components and its related asymmetric version are underway.

Experimental Section

General Procedure for Nickel-Catalyzed Reductive Coupling of Oxa- and Azabicyclic Alkenes (1) with Enones (2)

A sealed tube (20 mL) containing NiI_2 (0.100 mmol, 10.0 mol%), bicyclic alkene **1** (1.0 mmol), and zinc powder (2.75 mmol) was evacuated and purged with nitrogen gas three times. Freshly distilled CH_3CN (1.50 mL) was added and the reaction mixture was stirred for 2 min. Then, alkene **2** (1.50 mmol) and H_2O (2.0 mmol) were added sequentially *via* syringe. The reaction mixture was stirred at 50 °C for 12 h and was diluted with dichloromethane and stirred in the air for 10 min. The mixture was filtered through a Celite and silica gel pad and washed with dichloromethane. The filtrate was concentrated and the residue was purified on a silica gel column using hexane/ethyl acetate as eluent to afford the desired product **3** or **5.**

General Procedure for Nickel-Catalyzed Reductive Coupling of Oxa- and Azabicyclic Alkenes (1) with Alkynes (6)

A sealed tube (20 mL) containing NiI_2 (0.0500 mmol, 5 mol%), $P(4\text{-}FC_6H_4)_3$ (0.2000 mmol, 20 mol%), bicyclic alkene **1** (1.00 mmol), and zinc powder (2.75 mmol) was evacuated and purged with nitrogen gas three times. Freshly distilled CH_3CN (1.50 mL) was added and the reaction mixture was stirred for 2 min. Then, alkyne **6** (1.50 mmol) and H_2O (2.00 mmol) were added sequentially *via* syringe. The reaction mixture was stirred at 45 °C for 14 h and was diluted with dichloromethane and stirred in the air for 10 min. The mixture was filtered through a Celite and silica gel pad and washed with dichloromethane. The filtrate was concentrated and the residue was purified on a silica gel column using hexane/ethyl acetate as eluent to afford the desired product **7**

Acknowledgements

We thank the National Science Council of Republic of China (NSC-102-2628M-007-005) for support of this research.

References

[1] Reviews: a) M. Lautens, K. Fagnou, S. Hiebert, *Acc. Chem. Res.* **2003**, *36*, 48; b) D. K. Rayabarapu, C.-H. Cheng, *Acc. Chem. Res.* **2007**, *40*, 971.
[2] Selected recent references: a) J. Zhu, G. C. Tsui, M. Lautens, *Angew. Chem.* **2012**, *124*, 12519; *Angew. Chem. Int. Ed.* **2012**, *51*, 12353; b) G. C. Tsui, M. Lautens, *Angew. Chem.* **2012**, *124*, 5496; *Angew. Chem. Int. Ed.* **2012**, *51*, 5400; c) G. C. Tsui, N. M. Ninnemann, A. Hosotani, M. Lautens, *Org. Lett.* **2013**, *15*, 1064; d) R. Webster, A. Boyer, M. J. Fleming, M. Lautens, *Org. Lett.* **2010**, *12*, 5418; e) Y. Sawama, Y. Ogata, K. Kawamoto, H. Satake, K. Shibata, Y. Monguchi, H. Sajiki, Y. Kita, *Adv. Synth. Catal.* **2013**, *355*, 517; f) J. Hu, Q. Yang, J. Xu, C. Huang, B. Fan, J. Wang, C. Lin, Z. Bian, A. S. C. Chan, *Org. Biomol. Chem.* **2013**, *11*, 814; g) H. Cheng, D. Yang, *J. Org. Chem.* **2012**, *77*, 9756; h) S. Fang, X. Liang, Y.-H. Long, X. Li, D. Yang, S. Wang, C. Li, *Organometallics* **2012**, *31*, 3113, and references cited therein.
[3] D. K. Rayabarapu, T. Sambaiah, C.-H. Cheng, *Angew. Chem.* **2001**, *113*, 1326; *Angew. Chem. Int. Ed.* **2001**, *40*, 1286.
[4] D. K. Rayabarapu, C.-H. Cheng, *Chem. Eur. J.* **2003**, *9*, 3164.
[5] a) R. R. Burton, W. Tam, *Org. Lett.* **2007**, *9*, 3287; b) A. Tenaglia, S. Marc, *J. Org. Chem.* **2008**, *73*, 1397; c) A. Allen, P. Le Marquand, R. Burton, K. Villeneuve, W. Tam, *J. Org. Chem.* **2007**, *72*, 7849.
[6] T. Nishimura, T. Kawamoto, K. Sasaki, E. Tsurumaki, T. Hayashi, *J. Am. Chem. Soc.* **2007**, *129*, 1492.
[7] A. Tenaglia, S. Marc, L. Giordano, I. De Riggi, *Angew. Chem.* **2011**, *123*, 9228; *Angew. Chem. Int. Ed.* **2011**, *50*, 9062.
[8] a) M. Jeganmohan, C.-H. Cheng, *Chem. Eur. J.* **2008**, *14*, 10876; b) S. Mannathan, C.-H. Cheng, *Chem. Eur. J.* **2012**, *18*, 11771.
[9] a) D. K. Rayabarapu, C.-F. Chiou, C.-H. Cheng, *Org. Lett.* **2002**, *4*, 1679; b) S. Mannathan, C.-H. Cheng, *Chem. Commun.* **2013**, *49*, 1557.
[10] For metal-catalyzed/mediated reductive coupling of alkynes with alkene; Ni: a) W. Li, A. Herath, J. Mont-

gomery, *J. Am. Chem. Soc.* **2009**, *131*, 17024; b) S. K. Chowdhury, K. K. D. Amarasinghe, M. J. Heeg, J. Montgomery, *J. Am. Chem. Soc.* **2000**, *122*, 6775; c) A. Herath, W. Li, J. Montgomery, *J. Am. Chem. Soc.* **2008**, *130*, 469; d) A. Herath, J. Montgomery, *J. Am. Chem. Soc.* **2008**, *130*, 8132; Rh: e) H. Y. Jang, M. J. Krische, *J. Am. Chem. Soc.* **2004**, *126*, 7875; Ti: f) H. A. Reichard, G. C. Micalizio, *Angew. Chem.* **2007**, *119*, 1462; *Angew. Chem. Int. Ed.* **2007**, *46*, 1440.

[11] a) B. M. Trost, *Science* **1991**, *254*, 1471; b) B. M. Trost, *Angew. Chem.* **1995**, *107*, 285; *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 259; c) B. M. Trost, *Acc. Chem. Res.* **2002**, *35*, 695; d) J. Montgomery, *Acc. Chem. Res.* **2000**, *33*, 467; e) S. Ikeda, *Acc. Chem. Res.* **2000**, *33*, 511; f) S. Ikeda, *Angew. Chem.* **2003**, *115*, 5276; *Angew. Chem. Int. Ed.* **2003**, *42*, 5120; g) J. Montgomery, *Angew. Chem.* **2004**, *116*, 3980; *Angew. Chem. Int. Ed.* **2004**, *43*, 3890.

[12] a) B. M. Johnson, P. T. L. Chang, *Anal. Profiles Drug Subst. Excipients* **1996**, *24*, 443; b) S. E. Snyder, F. A. Aviles-Garay, R. Chakraborti, D. E. Nichols, V. J. Watts, R. B. Mailman, *J. Med. Chem.* **1995**, *38*, 2395; c) A. Kamal, L. Gayatri, *Tetrahedron Lett.* **1996**, *37*, 3359; d) K. Kim, Y. Guo, G. A. Sulikowski, *J. Org. Chem.* **1995**, *60*, 6866; e) R. Perrone, F. Berardi, N. A. Colabufo, M. Leopoldo, V. Tortorella, F. Fiorentini, V. Olgiati, A. Ghiglieri, S. Govoni, *J. Med. Chem.* **1995**, *38*, 942.

[13] a) Z. Qiu, Z. Xie, *J. Am. Chem. Soc.* **2009**, *131*, 2084; b) R. J. McKinney, D. L. Thorn, R. Hoffmann, A. Stockis, *J. Am. Chem. Soc.* **1981**, *103*, 2595; c) M. J. Doyle, J. McMeeking, P. Binger, *J. Chem. Soc. Chem. Commun.* **1976**, 376.

[14] Activated alkenes such as acrylates, acrylonitrile, vinyl sulfone, and acrylamides are not suitable substrates for the present reductive coupling reactions under the standard reaction conditions.

[15] NiI_2 could act as Lewis acid and possibly can facilitate the dehydration of *cis*-2-alkyl-1,2-dihydronaphthols.

[16] We did not observe dehydration product of **7a** in the reaction. This is probably due to the presence of $P(4\text{-}FC_6H_4)_3$ ligand which has lowered the acidity of NiI_2 and thus **7** is sustained. This was verified by treating **7a** in the absence of ligand under the standard reaction conditions (Table 3) which afforded the dehydration product of **7a** in 88% yield.