A novel route to the fluorinated diimines: carbon monoxide-promoted reductive homocoupling of fluorinated imidoyl iodides in the presence of a palladium catalyst†

Hideki Amii, Mitsuhiro Kohda, Motoharu Seo and Kenji Uneyama*

*Department of Applied Chemistry, Faculty of Engineering, Okayama University, Okayama 700-8530, Japan. E-mail: uneyamak@cc.okayama-u.ac.jp; Fax: +81-86-251-8021; Tel: +81-86-251-8075*

A new catalytic access to the fluorinated diimines which involves palladium(0)-catalyzed reductive dimerization of the imidoyl iodides is presented.

In recent years, α-diimines **1** (1,4-diazabutadienes) have received considerable attention due to their widespread applications as catalyst ligands (Scheme 1). The diimine complexes[1] have been utilized as catalysts for a wide repertoire of reactions, such as alkene polymerization,[2a,b] alkene–CO copolymerization,[2c] aziridination,[2d] allylic amination,[2e] Suzuki–Miyaura cross-coupling,[2f] alkyne hydrogenation,[2g] alkyne coupling reactions[2h,i] and many others.
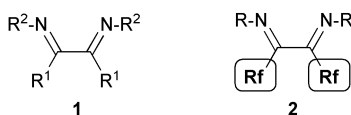
Scheme 1

Fluorinated α-diimines **2** are considered to be a new class of catalyst ligands which would dramatically change the catalytic activities due to the nature of fluorine atom(s). Despite their potential utility as catalyst ligands,[3] to our knowledge, there has been only one report on the synthesis of fluorinated α-diimines which possess fluorine atoms in the main chain. Diels *et al.* reported a new synthesis of 2,3-bis(trifluoromethyl)- and 2,3-bis(pentafluorophenyl)-1,4-diazabutadienes *via* the use of the corresponding fluorinated diketones as a starting material.[4] Furthermore, they demonstrated that fluorinated α-diimines could act as a strong π-acceptor ligand due to their energetically low-lying LUMO.

We envisioned that the dimerization reaction of fluorinated imino compounds might be a general reaction leading to the fluorinated α-diimines. Herein, we report a new access to the fluorinated diimines **2** which involves palladium(0)-catalyzed reductive dimerization of the imidoyl iodides **3** in the presence of carbon monoxide (eqn. 1).
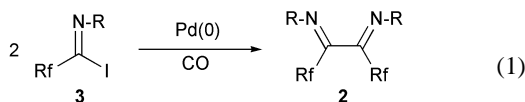
In general, Pd-catalyzed homocoupling reactions of organic halides require electrochemical reduction or chemical reduction *via* the use of Zn, trialkylamines, triphenylphosphine, 2-propanol, hydroquinone, or tetrakis(dimethylamino)ethylene (TDAE), which can regenerate the catalytically active Pd(0) species.[5–7] Contrary to these extensive studies of aryl–aryl[5,6] and vinyl–vinyl[7] homocoupling reactions, very little attention has been devoted to the reductive acyl–acyl and imidoyl–imidoyl homocoupling reactions, which could be catalytic and straightforward entries to the α-diketones and α-diimines.

After several attempts under ordinary homocoupling conditions, carbon monoxide was found to be an effective co-

reductant for Pd-catalyzed homocoupling of fluorinated imidoyl iodides **3**.[8]

When a mixture of **3a** and K_2CO_3 in DMF–toluene was heated at 70 °C for 24 h in the presence of a catalytic amount of a Pd(0) complex under argon atmosphere essentially no reaction was observed, resulting in recovery of the starting material **3a** (entry 1 in Table 1). A dramatic change was observed when the reaction was conducted under CO (1 atm) to provide the homocoupling product **2a** in 64% yield (entry 2).‡ Carbon monoxide would play an important role for regeneration of catalytically active Pd(0) species.

Other examples of the formation of diimines **2** are given in Table 1. The imidoyl iodides **3** possessing either electron-donating (entries 2, 3, 6, 7 and 9) or electron-withdrawing substituents (entry 5)[9] on the *N*-aryl groups provided **2** in good yields. For the practical use of α-diimines as a catalyst ligand, fine tuning of the electronic and steric properties of the *N*-substituent of imine moieties plays a significant role in the selectivity of the catalytic reactions; the selectivities in the catalytic reactions increase occasionally in accord with increasing steric demand of the *N*-substituents of the diimine ligands. The present homocoupling procedure worked well for the preparation of the fluorinated α-diimines with bulky *N*-substituents. The imidoyl iodides **3e–g** endowed with the bulky aromatic groups (Ar = 2,6-$Me_2C_6H_3$, 2,6-$^iPr_2C_6H_3$ and 2-naphthyl) on the nitrogen afforded the corresponding diimines **2e–g** (entries 6–8). Furthermore, the imidoyl iodide **3h** bearing a long perfluoroalkyl chain underwent the reductive homocoupling to give the symmetrical bis(perfluoroalkyl)diimine **2h** in 55% yield (entry 9).

One of the well-established methods for the synthesis of α-diimines is the condensation reaction of α-diketones with primary amines. Compared with available methods, the present methodology merits attention due to the simplicity of the experimental procedure: (i) the use of only a catalytic amount of
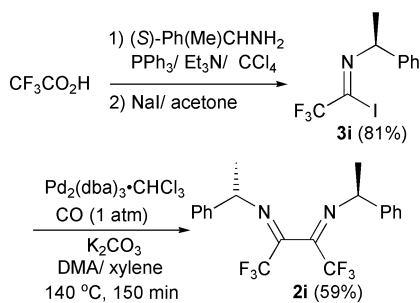
Table 1
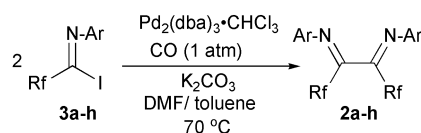
Entry[a]	Rf	Ar	Diimine **2**	Yield[b]
1[c]	CF_3	4-$MeOC_6H_4$	**2a**	0%
2	CF_3	4-$MeOC_6H_4$	**2a**	64%
3	CF_3	4-MeC_6H_4	**2b**	70%
4	CF_3	Ph	**2c**	71%
5	CF_3	4-ClC_6H_4	**2d**	62%
6	CF_3	2,6-$Me_2C_6H_3$	**2e**	82%
7	CF_3	2,6-(^iPr)$_2C_6H_3$	**2f**	34%
8	CF_3	2-Np	**2g**	44%
9	C_3F_7	4-$MeOC_6H_4$	**2h**	55%

[a] Each reaction was carried out in the presence of 5 mol% of $Pd_2(dba)_3 \cdot CHCl_3$ (Pd: 0.10 equiv.). [b] Isolated yield. [c] The reaction was carried out under an argon atmosphere (in the absence of CO).

Scheme 2

a Pd(0) complex allows selective formation of the fluorinated α-diimines **2**; (ii) carbon monoxide as a reducing agent is inexpensive and easy to remove. Moreover, the starting materials **3** are more readily available than fluoroalkyl α-diketones and easily prepared in good yields from commercially available fluorinated carboxylic acids and primary amines.[8b]

Next, a further application of this method to the synthesis of the chiral diimine ligands was explored. The imidoyl iodide **3i** possessing a chiral moiety on the nitrogen atom, which was prepared from trifluoroacetic acid (TFA) and (S)-phenyl-ethylamine, underwent reductive homocoupling to afford the corresponding diimine **2i** without any loss of optical purity (Scheme 2).

In conclusion, we have disclosed a new entry to the synthesis of the fluorinated α-diimines. Also for the reductive homocoupling of imidoyl iodides, we have developed a new catalyst system Pd(0)–CO, which would possess a broad applicability in other reductive couplings of organic halides. Further studies are underway to explore the synthetic applications of the fluorinated α-diimines as a ligand to a wide variety of catalytic transformations including catalytic enantioselective reactions.

Notes and references

‡ A typical procedure for the Pd-catalyzed homocoupling of **3** is as follows: a two-necked flask attached to a CO (1 atm) balloon was charged with Pd$_2$(dba)$_3$·CHCl$_3$ (0.025 g, 0.025 mmol) and K$_2$CO$_3$ (0.138 g, 1 mmol), and toluene (2 mL). Then 0.165 g (0.50 mmol) of trifluoroacetimidoyl iodide **3a** in 2 mL of toluene was added to the catalyst mixture. Subsequently, 0.05 mL of DMF was added. The reaction vessel was wrapped with aluminium foil to minimize exposure to the light. The reaction mixture was stirred at 70 °C for 7 h. The reaction was monitored by TLC. When the imidoyl iodide **3a** was consumed, the resulting suspension was filtered through a short celite column (AcOEt). After evaporation of the solvent, the residue was purified by silica gel column chromatography (hexane : ether (9 : 1) elute) to give a yellow solid of **2a** (0.064 g, 0.16 mmol, 64%): mp 121 °C; IR(KBr) 1598, 1506 cm^{-1}; ^{1}H NMR (CDCl$_3$, 200 MHz) δ 6.78 (s, 8 H), 3.80 (s, 6 H); ^{19}F NMR (CDCl$_3$, 188 MHz, C$_6$F$_6$ as an internal standard) δ 93.9 (s, 6 F); MS m/z 404 (M$^+$ 8), 389 (14), 202 (100), 107 (43), 77 (73). Anal. Calcd for C$_{18}$H$_{14}$F$_6$N$_2$O$_2$: C, 53.47; H, 3.49; N, 6.93. Found: C, 53.28; H, 3.34; N, 7.23%.

1 For a review of metal-diimine complexes, see: G. van Koten and K. Vrieze, *Advances in Organometallic Chemistry*, Academic Press, New York, 1982, vol. 21, pp. 151–239.
2 (a) S. D. Ittel, L. K. Johnson and M. Brookhart, *Chem. Rev.*, 2000, **100**, 1169; (b) D. J. Tempel, L. K. Johnson, R. L. Huff, P. S. White and M. Brookhart, *J. Am. Chem. Soc.*, 2000, **122**, 6686; (c) J. H. Groen, J. G. P. Delis, P. W. N. M. van Leeuwen and K. Vrieze, *Organometallics*, 1997, **16**, 68; (d) D. B. Llewellyn, D. Adamson and B. A. Arndtsen, *Org. Lett.*, 2000, **2**, 4165; (e) S. Cenini, F. Ragaini, S. Tollari and D. Paone, *J. Am. Chem. Soc.*, 1996, **118**, 11964; (f) G. A. Grasa, A. C. Hillier and S. P. Nolan, *Org. Lett.*, 2001, **3**, 1077; (g) M. W. van Laren and C. J. Elsevier, *Angew. Chem., Int. Ed.*, 1999, **38**, 3715; (h) R. van Belzen, H. Hoffmann and C. J. Elsevier, *Angew. Chem., Int. Ed. Engl.*, 1997, **36**, 1743; (i) E. Shirakawa, H. Yoshida, Y. Nakao and T. Hiyama, *J. Am. Chem. Soc.*, 1999, **121**, 4290.
3 M. Gasperini, F. Ragaini and S. Cenini, *Organometallics*, 2002, **21**, 2950.
4 B. N. Diel, P. J. Deardorff and C. M. Zelenski, *Tetrahedron Lett.*, 1999, **40**, 8523.
5 A review on Pd-catalyzed homocoupling: M. Kotora and T. Takahashi, *Handbook of Organopalladium Chemistry for Organic Synthesis*, Wiley-Interscience, New York, 2002, vol. 1, pp. 973–993.
6 Recent reports on Pd-catalyzed reductive homocoupling: (a) A. Jutand and A. Mosleh, *J. Org. Chem.*, 1997, **62**, 261; (b) V. Penalva, J. Hassan, L. Lavenot, C. Gozzi and M. Lemaire, *Tetrahedron Lett.*, 1998, **39**, 2559; (c) F. T. Luo, A. Jeevanandam and M. K. Basu, *Tetrahedron Lett.*, 1998, **39**, 7939; (d) D. D. Hennings, T. Iwama and V. H. Rawal, *Org. Lett.*, 1999, **1**, 1205; (e) D. Albanese, D. Landini, M. Penso and S. Petricci, *Synlett*, 1999, 199; (f) S. Venkatraman and C. J. Li, *Org. Lett.*, 1999, **1**, 1133; (g) S. Mukhopadhyay, G. Rothenberg, D. Gitis and Y. Sasson, *Org. Lett.*, 2000, **2**, 211; (h) M. Kuroboshi, Y. Waki and H. Tanaka, *Synlett*, 2002, 637.
7 R. Grigg, P. Stevenson and T. Worakun, *Tetrahedron*, 1988, **44**, 2049.
8 (a) K. Uneyama, *J. Fluorine Chem.*, 1999, **97**, 11; (b) K. Tamura, H. Mizukami, K. Maeda, H. Watanabe and K. Uneyama, *J. Org. Chem.*, 1993, **58**, 32; (c) H. Amii, Y. Kishikawa, K. Kageyama and K. Uneyama, *J. Org. Chem.*, 2000, **65**, 3404; (d) H. Amii, Y. Kishikawa and K. Uneyama, *Org. Lett.*, 2001, **3**, 1109.
9 Crystal data for **2d** (Ar = 4-ClC$_6$H$_4$): C$_{16}$H$_8$Cl$_2$F$_6$N$_2$, M = 413.15, monoclinic, a = 7.2370(8), b = 9.150(2), c = 13.068(2) Å, β = 100.907(9)°, V = 849.7(2) Å^3, T = 288 K, space group P2/n (no. 13), Z = 2, D = 1.615 g cm^{-3}. The structure was solved by direct methods (SIR 97), yielding R = 0.0702, R$_w$ = 0.1371 for 1371 independent reflections with F^2 > 5σ(F^2). CCDC 206534. See http://www.rsc.org/suppdata/cc/b3/b303040g/ for crystallographic data in .cif or other electronic format.