Accepted Manuscript

Palladium-catalyzed regio- and chemoselective direct desulfitative arylation of anilides with arylsulfonyl chlorides

Ebrahim Kianmehr, Arezoo Tanbakouchian

PII: S0040-4020(17)30746-9

DOI: 10.1016/j.tet.2017.07.022

Reference: TET 28854

To appear in: *Tetrahedron*

Received Date: 1 April 2017

Revised Date: 16 June 2017

Accepted Date: 11 July 2017

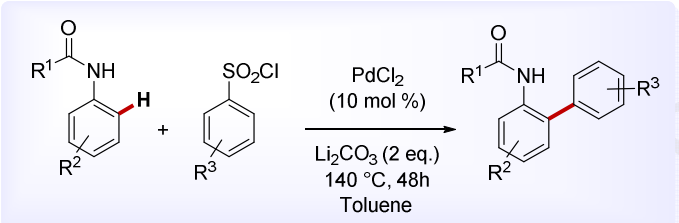
Please cite this article as: Kianmehr E, Tanbakouchian A, Palladium-catalyzed regio- and chemoselective direct desulfitative arylation of anilides with arylsulfonyl chlorides, *Tetrahedron* (2017), doi: 10.1016/j.tet.2017.07.022.

Graphical Abstract

Palladium-catalyzed regio- and chemoselective direct desulfitative arylation of anilides with arylsulfonyl chlorides

Leave this area blank for abstract info.

Ebrahim Kianmehr* and Arezoo Tanbakouchian
School of Chemistry, College of Science, University of Tehran, Tehran 1417614411, Iran



ELSEVIER

Tetrahedron
journal homepage: www.elsevier.com

Palladium-catalyzed regio- and chemoselective direct desulfitative arylation of anilides with arylsulfonyl chlorides

Ebrahim Kianmehr* and Arezoo Tanbakouchian

School of Chemistry, College of Science, University of Tehran, Tehran 1417614411, Iran
kianmehr@khayam.ut.ac.ir

ARTICLE INFO

Article history:
Received
Received in revised form
Accepted
Available online

Keywords:
C-H bond activation
Arylation
Cross-coupling
Palladium
Arylsulfonyl chlorides

ABSTRACT

A straightforward and practical palladium-catalyzed regioselective arylation of anilides is described. This method provides a new approach to prepare 2-aminobiaryls, which are valuable precursors for the synthesis of various *N*-containing heterocyles, using arylsulfonyl chlorides as readily available arylating agents.

1. Introduction

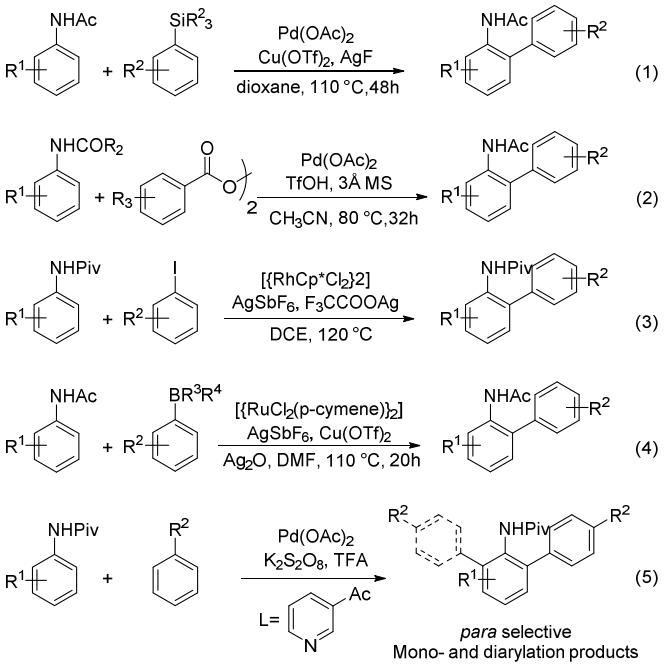
The prevalence of biaryl moiety in natural and biologically active compounds as well as advanced organic materials is motive for finding efficient methods for the construction of this structural motif.[1] Direct transition metal-catalyzed functionalization of unreactive C-H bonds serves as a powerful tool in organic synthesis.[2] Direct C-H bond arylation through transition metal-catalyzed reactions using various coupling reagents such as arylboronic acids,[3] organometallic reagents,[4] aryl halides, aryl tosylates,[5] (di)aryliodonium salts,[6] benzoic acids[7] and arenes[8] have been reported. In most cases, the presence of a directing group to activate the target C-H bond selectively is crucial and choosing the most beneficial directing group is still the challenging part of a synthetic approach.[9] Among the enormous number of directing groups introduced in the last decades, carbonyl containing groups have received special consideration. For example, acylamino groups are beneficial directing groups to activate *ortho* C-H bonds of arenes and are easily removed to attain anilines which are omnipresent structural motifs found in many bioactive compounds.[9a]

2-Aminobiaryls have received particular attention due to their applications in organic synthesis. They can be used as precursors for synthetically important heterocycles such as carbazoles.[10] In addition to well-known coupling reactions such as Suzuki-Miyaura,[11a,b] Kumada[11c-e] and Negishi reactions,[11f] the direct regioselective coupling of anilides with various coupling partners have been reported for the synthesis of this structural motif.[12] As shown in Scheme 1, in 2007, Shi and co-workers described direct palladium catalyzed arylation of acetanilides with silyl reagents (eq 1.).[12a] Palladium-catalyzed decarboxylative arylation of anilides with acylperoxides was reported by Wang and co-workers in 2014 (eq 2.).[12b] *Ortho*-arylation of pivanilide derivatives with aryl iodides as coupling reagents was reported by Cheng et al. in 2015 (eq. 3).[12c] A ruthenium catalyzed arylation of acetanilides using bronic acid derivatives as coupling partners was reported independently by Jeganmohan's and Ackermann's groups in 2014 and 2015, respectively (eq 4.).[12d,e]

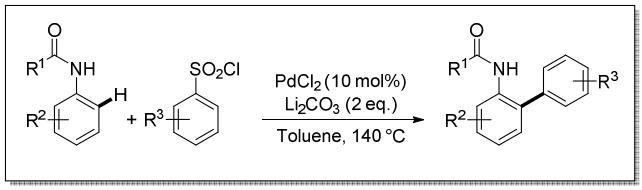
Direct arylation of anilides with arenes has also been reported.[12f-i] Yu and coworkers described Pd-catalyzed arylation of pivanilides using arenes as both solvent and coupling reagent (eq 5.).[12h,i] As part of our ongoing research program on the development of efficient methods for direct functionalization of C-H bonds, we turned our attention to the synthesis of 2-arylanilides via a palladium catalyzed C-H bond activation reaction. In comparison with the above-mentioned methods, an appropriate economically favorable coupling partner is obviously required. Among the coupling candidates, arylsulfonyl chlorides could be the best choice because of their indisputable advantages.

Palladium-catalyzed C-H bond functionalization with arylsulfonyl chlorides has been reported, recently.[13] To the best of our knowledge palladium-catalyzed desulfitative direct arylation of arenes using arylsulfonyl chlorides as the coupling partners has not received more attention. Towards addressing these reports and in continuation of our interest in this area,[14] we wish to report the palladium-catalyzed regioselective direct arylation of anilides with arylsulfonyl chlorides as the arylation agent through C-H bond activation for the first time (Scheme 1).

Previous works:



This work:



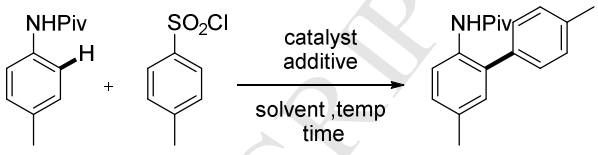
Scheme 1. Examples of anilide arylation

2. Results and discussion

Our initial attempt toward this aim was started by an investigation of the reaction between 4-methyl pivanilide (**1a**) and *p*-toluenesulfonyl chloride (**2a**) as the model reaction (Table 1). To optimize the reaction parameters, the effects of different catalysts, additives, solvents and temperature were examined. To begin our initial trial the reaction between **1a** and **2a** in the present of 10 mol% of $PdCl_2$ as catalyst and 2 equivalents of Li_2CO_3 as additive in 1,4-dioxane was considered and to our delight, the desired product **3a** was formed in 51% yield (Table 1, entry 1). Various solvents were screened to optimize the reaction conditions (Table 1, entries 2-7, see also Table S1, entries 8-10 in the Supporting Information). When the reaction was carried out in DCE the yield slightly increased but the best result was obtained in toluene with 81% yield (Table 1, entry 7). The reaction was performed in the presence of different additives and it was revealed that the role of the additive is crucial for this transformation, and the formation of the desired product **3** is strongly depended on the presence of lithium salts. As shown in Table 1, the best results were obtained with Li_2CO_3 and LiCl whereas Na_2CO_3, K_2CO_3 and Cs_2CO_3 were found to be inferior (entries 7-11, see also Table S1, entries 6 and 7 in the Supporting Information), and finally, no desired product was obtained in the absence of additive (Table 1, entry 12). Other common palladium catalysts such as $Pd(OAc)_2$, $PdCl_2(CH_3CN)_2$, $PdCl_2(COD)_2$ and $PdCl_2(PPh_3)_2$ were examined and no improvement in yields was observed (Table 1, entries 13-16). Decreasing the amount of catalyst from 10 to 5 mol% led to insufficient outcomes (Table 1, entry 17) and control experiments showed that no reaction occurred in the absence of catalyst (Table 1, entry 18). The effect of ligand was also investigated and no improvement in yields was observed in the presence of Ph_3P, bipyridine, phenanthroline or Et_3N (Table S1, entries 1-4). Finally, upon decreasing the reaction temperature from 140 to 120 °C, the yield of the reaction decreased from 81 to 36 % (Table 1, entry 19).

Once the optimized conditions for the desired arylation reaction were established, the scope of the reaction was investigated (Scheme 2). Anilides with halo substituents (F, Cl, Br) smoothly led to the corresponding arylated products in good yields.

Table 1. Optimization of the Reaction Conditions[a]



1a **2a** **3a**

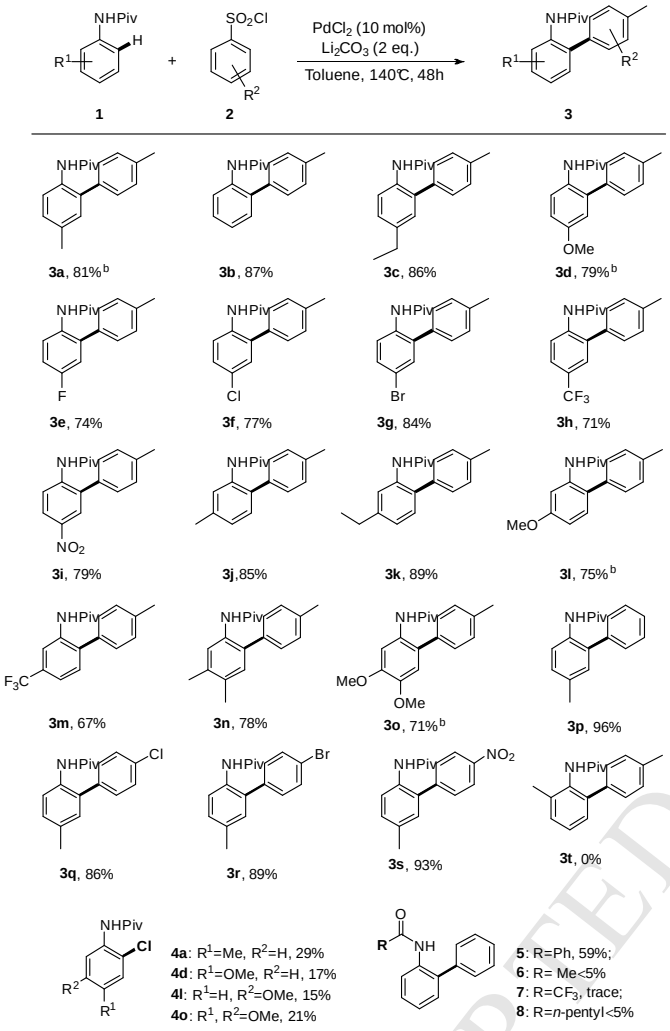
entry	Catalyst (mol %)	additive (equiv)	Solvent	Yield[a] (%)
1	$PdCl_2$ (10)	Li_2CO_3 (2)	1,4-dioxane	51
2	$PdCl_2$ (10)	Li_2CO_3 (2)	DCE	59[b]
3	$PdCl_2$ (10)	Li_2CO_3 (2)	DME	43
4	$PdCl_2$ (10)	Li_2CO_3 (2)	DMF	-
5	$PdCl_2$ (10)	Li_2CO_3 (2)	CH_3CN	-
6	$PdCl_2$ (10)	Li_2CO_3 (2)	PhCl	63
7	**$PdCl_2$ (10)**	**Li_2CO_3 (2)**	**toluene**	**81**
8	$PdCl_2$ (10)	Na_2CO_3(2)	toluene	35
9	$PdCl_2$ (10)	K_2CO_3 (2)	toluene	trace
10	$PdCl_2$ (10)	Cs_2CO_3 (2)	toluene	trace
11	$PdCl_2$ (10)	LiCl (2)	toluene	80
12	$PdCl_2$ (10)	-	toluene	-
13	-	Li_2CO_3 (2)	toluene	-
14	$PdCl_2(MeCN)_2$ (10)	LiCl (2)	toluene	43
15	$Pd(OAc)_2$ (10)	LiCl (2)	toluene	47
16	$PdCl_2(COD)_2$ (10)	LiCl (2)	toluene	54
17	$PdCl_2(PPh_3)_2$(10)	LiCl (2)	toluene	31
18	$PdCl_2$ (5)	LiCl (2)	toluene	69
19	$PdCl_2$ (10)	LiCl (2)	toluene	36[c]

[a] Reaction conditions: **1a** (0.5 mmol), **2a** (1.5 eq), additive (2 eq.) in solvent (2.0 mL) were stirred at 140 ℃ for 48 h. [b] The *ortho* chlorinated pivanilide was detected in 29% yield as the side product. [c] The reaction was carried out at 120 ℃.

Given that these halogen substituents remained intact during the reaction, they can enable additional functionalization at these positions (**3e**, **3f**, **3g** and **3m)**. No remarkable electronic effect of substituents at *para* or *meta* position of pivanilides was observed but in general the presence of alkyl groups slightly enhanced the yields. The presence of CF_3 group on *meta* or *para* position of anilide ring resulted in lower yields (**3h** and **3n**). It is worth noting that with pivanalides bearing strong electron-donating groups, such as OMe, the corresponding chlorinated products were obtained as the side products. Using *meta*-substituted pivanilides, arylation occurred exclusively at the C-*6* position of the substrate with less steric hindrance (**3j**-**3m**). Unfortunately, 2-substituted pivanalides did not afford the corresponding products (**3t**). A series of functional groups on the phenyl ring of arylsulfonyl chlorides, such as bromo, chloro, nitro, methyl were compatible under this procedure, and the products were isolated in good to high yields (**3p**-**3s**). High yields of **3** were obtained from benzenesulfonyl chloride and arylsulfonyl chlorides

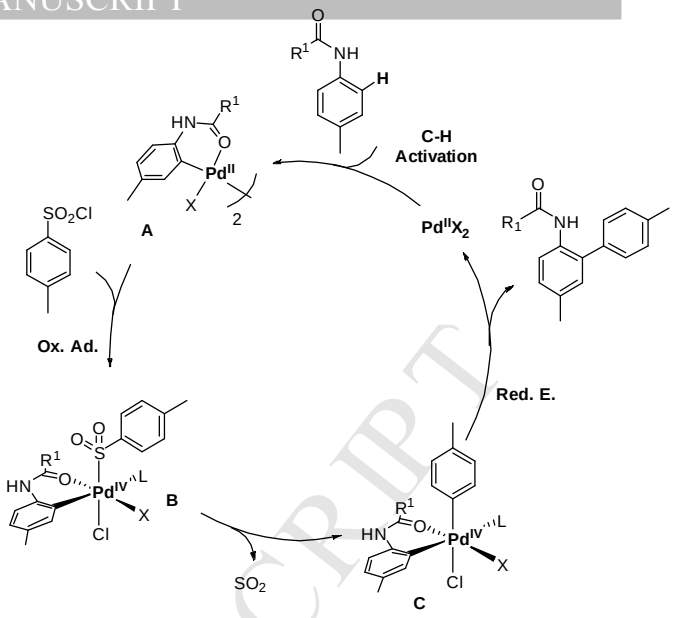
containing electron-withdrawing groups such as NO_2 and Br. In addition to the acetamido group, other directing amido moieties were tested in this *ortho*-arylation reaction. Phenyl moieties gave slightly lower yield while other amido derivatives substituted with Me, *n*-pentyl or CF_3 had disappointing yields.

Scheme 2. Substrate Scope[a]



[a]Reaction conditions: Pivanilide (0.5 mmol), *p*-toluenesulfonyl chloride (1.5 equiv), Li_2CO_3 (2 equiv) in toluene (2.0 mL) were stirred at 140 °C for 48 h.[b]The *ortho*-chlorinated product **4** was obtained as the side product.

Although the mechanism of this reaction has not been established experimentally, on the basis of previous chemistry[13,15] the catalytic cycle shown on Scheme 3 is proposed. Initially, palladation occurs preferentially at the *ortho* position of the anilide, likely via a concerted metallation-deprotonation step which leads to the formation of palladacycle A. In the next step, the oxidative addition of arenesulfonyl chloride to the intermediate A forms the Pd(IV) intermediate B. The intermediate B produces intermediate C with concomitant loss of SO_2 at a higher temperature, and in the next step, the reductive elimination from the Pd(IV) complex affords the 2-aryl anilide and regenerates Pd(II).



Scheme 3. Plausible mechanisms

3. Conclusion

In conclusion, we have developed the palladium-catalyzed *ortho* arylation of anilide derivatives with arylsulfonyl chlorides as the arylating source for the synthesis of 2-arylanilides. The reaction is chemoselective and no over arylation was detected. This method is well tolerated with both EDGs and EWGs substituents on the both coupling partners. Moreover, the directing group can easily removed[16] and provides a simple and practical route for producing the titled products, which could be used as precursors in synthesis of valuable hetrocycles found in pharmaceuticals, electronics industries and bioactive compounds.

4. Experimental section

4.1. General

Solvents, palladium chloride (98%), aniline derivatives were purchased from Merck. Other reagents were purchased from commercial distributors and used without further purification. Anilide derivatives were synthesized according to literature procedures.[11a] Analytical thin layer chromatography (TLC) was performed on precoated silica gel 60 F254 plates. The products were purified by preparative column chromatography on silica gel (0.063-0.200 mm; Merck). ^{1}H and ^{13}C-NMR Spectra: were recorded on Bruker DRX 500 and 400 Advance instruments in $CDCl_3$ and DMSO-d_6; δ in ppm, *J* in Hz. Mass spectrometry was obtained on Agilent 5975C VL MSD (Ion source: EI+, 70eV, 230 °C).

4.2. General Procedure for the Synthesis of 2-aryl anilides

A 10 mL microwave vial was charged with the anilide derivatives (1 equiv, 0.5 mmol), the arenesulfonyl chloride (1.5 equiv), $PdCl_2$ (10 mol%), Li_2CO_3 (2 equiv) and toluene (2 mL). The vial was then sealed and immersed in an oil bath, which was preheated at 140 °C, for 48 h. After this time the reaction mixture was cooled to room temperature and then diluted with DCM and filtered. The residue was purified by using column chromatography (n-hexane) to yield the desired products.

*4.2.1. 1- N-(4',5-dimethyl-[1,1'-biphenyl]-2-yl) pivalamide (**3a**)*[11a, 12h]

The general procedure was followed using 4-methyl pivanilide (95 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3a** (114 mg, 81% yield) as white needle (m.p.= 101–103 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.25 (1H, d, *J* 8.5 Hz, =CH), 7.49 (1H, br, CONH), 7.33–7.26 (4H, m, =CH), 7.19 (1H, dd, *J* 8.5, 2.0 Hz, =CH), 7.08 (1H, d, *J* 2.0 Hz, =CH), 2.46 (3H, s, Me), 2.37 (3H, s, Me), 1.15 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.2, 137.7, 135.2, 133.4, 132.6, 132.2, 130.4, 129.6, 129.1, 128.7, 121, 39.7, 27.4, 21.2, 20.8; MS (IE) m/z (relative intensity %) 281 (M^+, 29), 233 (57), 197 (30), 119 (17), 105 (100), 57 (43). Anal. Calcd for $C_{19}H_{23}NO$: C, 81.10; H, 8.24; N, 4.98; found: C, 81.27; H, 8.29; N, 4.95.

*4.2.2. N-(4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3b**)*[12c]

The general procedure was followed using phenyl pivanilide (88 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (42 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3b** (116 mg, 87% yield) as a yellow oil; δ_H (400 MHz, $CDCl_3$) 8.42 (1H, dd, *J* 8.0, 1.0 Hz, =CH), 7.57 (1H, br, CONH), 7.40–7.25 (6H, m, =CH), 7.18 (1H, td, *J* 7.5, 1.0 Hz, =CH), 2.47 (3H, s, Me), 1.16 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.3, 137.8, 135.2, 135, 132, 129.8, 129.7, 129.2, 128.3, 123.8, 120.79, 39.8, 27.4, 21.2; MS (IE) m/z (relative intensity %) 268 (M+1, 92), 267 (M^+, 93), 183 (49), 167 (23), 149 (20), 57 (100), 41 (37). Anal. Calcd for $C_{18}H_{21}NO$: C, 80.86; H, 7.92; N, 5.24; found: C, 80.65; H, 7.88; N, 5.28.

*N-(5-ethyl-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3c**)*

The general procedure was followed using 4-ethyl pivanilide (102 mg , 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3c** (127 mg, 86% yield) as off-white needle (m.p.= 77–79 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) δ 8.28 (1H, d, *J* 8.5 Hz, =CH), 7.50 (1H, br, CONH), 7.34–7.28 (4H, m, =CH), 7.23 (1H, dd, *J* 8.5, 2.0 Hz, =CH), 7.11 (1H, d, *J* = 2.0 Hz, =CH), 2.68 (2H, q, *J* = 7.5 Hz, CH_2Me), 2.46 (3H, s, Me), 1.28 (3H, t, *J* = 7.5 Hz, CH_2Me), 1.15 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.1, 139.9, 137.7, 135.3, 132.8, 132.2, 129.67, 129.2, 129.2, 127.6, 121, 39.7, 28.3, 27.4, 21.2, 15.7; MS (IE) m/z (relative intensity %) 296 (M^+, 17), 295 (55), 238 (16), 211 (24), 196 (41), 180 (15), 167 (19), 149 (34), 57 (100), 41 (54). Anal. Calcd for $C_{20}H_{25}NO$: C, 81.31; H, 8.53; N, 4.74; found: C, 81.44; H, 8.50; N, 4.72.

*4.2.3. N-(5-methoxy-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3d**)*

The general procedure was followed using 4-methoxy pivanilide (103 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (42 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3d** (117 mg, 79% yield) as off-white needle (m.p.= 109-111 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.18 (1H, d, *J* 9.0 Hz, =CH), 7.36 (1H, br, CONH), 7.33–7.26 (4H, m, =CH), 6.92 (1H, dd, *J* 9.0, 3.0 Hz, =CH), 6.82 (1H, d, *J* 3.0 Hz, =CH), 3.82 (3H s, OMe), 2.45 (3H, s, Me), 1.14 (9H, s, 3Me); δ_C (125 MHz, $CDCl_3$) 176, 155.9, 137.8, 135.1, 134.1, 129.5, 129, 128.3, 122.9, 115.3, 113.1, 55.4, 39.5, 27.3, 21.1; MS (IE) m/z (relative intensity %) 297 (M^+, 100), 240 (18), 213 (59), 198 (57), 168 (15), 57 (34). Anal. Calcd for $C_{19}H_{23}NO_2$: C, 76.74; H, 7.80; N, 4.71; found: C, 76.97; H, 7.85; N, 4.74.

*4.2.4. 2- N-(5-fluoro-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3e**)*

The general procedure was followed using 4-fluoro pivanilide (97 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3e** (105 mg, 74% yield) as colorless prism (m.p.= 75–77 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.30 (1H, dd, *J* 9.0, 5.5 Hz, =CH), 7.44 (1H, br, CONH), 7.32–7.34 (2H, m, =CH), 7.28–7.25 (2H, m, =CH), 7.10–7.04 (1H, m, =CH), 6.98 (1H, dd, *J* 9.0, 3.0 Hz, =CH), 2.46 (3H, s, Me), 1.14 (9H, s, 3Me); δ_F (375 MHz, $CDCl_3$) -118.71; δ_C (100 MHz, $CDCl_3$) 176.3, 158.9 (d, *J* 244.0 Hz), 138.3, 134.2 (d, *J* 7.5 Hz), 134, 131.2 (d, *J* 2.0 Hz), 129.8, 128.9, 122.8 (d, *J* 8.5 Hz), 116.4 (d, *J* 22.5 Hz), 114.6 (d, *J* 22.0 Hz), 39.7, 27.4, 21.2; MS (IE) m/z (relative intensity %) 285 (M^+, 27), 201 (26), 167 (31), 149 (72), 71 (22), 57 (100), 43 (32), 41 (54). Anal. Calcd for $C_{18}H_{20}FNO$: C, 75.76; H, 7.06; N, 4.91; found: C, 75.57; H, 7.10; N, 4.88.

*4.2.5. N-(5-chloro-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3f**)*[12h]

The general procedure was followed using 4-chloro pivanilide (106 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (42 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3f** (116 mg, 77% yield) as off-white needle (m.p.= 102–104 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.36 (1H, d, *J* 9.0 Hz, =CH), 7.53 (1H, br, CONH), 7.37–7.28 (3H, m, =CH), 7.25–7.22 (3H, m, =CH), 2.45 (3H, s, Me), 1.13 (9H, s, 3Me); δ_C (125 MHz, $CDCl_3$) 176.2, 138.4, 133.8, 133.7, 133.5, 129.8, 129.5, 128.9, 128.6, 128, 121.9, 39.7, 27.3, 21.1; MS (IE) m/z (relative intensity %) 303 (M+2, 45), 301 (M^+, 100), 217 (81), 180 (26), 57 (72). Anal. Calcd for $C_{18}H_{20}ClNO$: C, 71.63; H, 6.68; N, 4.64; found: C, 71.91; H, 6.63; N, 4.61.

*4.2.6. N-(5-bromo-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3g**)*[12h]

The general procedure was followed using 4-bromo pivanilide (128 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3g** (145 mg, 84% yield) as yellow needle (m.p.= 98–100 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.33 (1H, d, *J* 9.0 Hz, =CH), 7.51 (1H, br, CONH), 7.48 (1H, dd, *J* 9.0, 2.5 Hz, =CH), 7.39 (1H, d, *J* 2.5 Hz, =CH), 7.33 (2H, d, *J* 8.0 Hz, =CH), 7.27–7.23 (2H, m, =CH), 2.46 (3H, s, Me), 1.13 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.3, 138.5, 134.4, 133.8, 133.6, 132.4, 131, 129.9, 129, 122.2, 116.3, 39.8, 27.3, 21.2; MS (IE) m/z (relative intensity %) 347 (M+2, 61), 345 (M^+, 62), 263 (38), 261 (43), 180 (33), 167 (29), 149 (32), 57 (100), 41 (22). Anal. Calcd for $C_{18}H_{20}BrNO$: C, 62.44; H, 5.82; N, 4.05; found: C, 62.68; H, 5.78; N, 4.09.

*4.2.7. N-(4'-methyl-5-(trifluoromethyl)-[1,1'-biphenyl]-2-yl) pivalamide (**3h**)*[12h]

The general procedure was followed using 4- trifluoromethyl pivanilide (122.5 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (42 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3h** (119 mg, 71% yield) as off-white needle (m.p.= 83–85 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.61 (1H, d, *J* 8.5 Hz, =CH), 7.71 (1H, br, CONH), 7.63 (1H, dd,

J 8.5, 2.0 Hz, =CH), 7.50 (1H, d, *J* 2.0 Hz, =CH), 7.40–7.27 (4H, m, =CH), 2.48 (3H, s, Me), 1.14 (9H, s, 3Me); δ_F (375 MHz, $CDCl_3$) δ -62.01; δ_C (100 MHz, $CDCl_3$) 176.5, 138.7, 138.4, 133.5, 131.8, 130, 129, 126.7 (q, *J* 4.0 Hz), 125.4 (q, *J* 32.5 Hz), 125.4 (q, *J* 4.0 Hz), 123.4 (q, *J* 269.5 Hz), 120.1, 40, 27.3, 21.2; MS (IE) m/z (relative intensity %) 335 (M^+, 63), 251 (68), 248 (25), 235 (14), 85 (24), 57 (100), 41 (37). Anal. Calcd for $C_{19}H_{20}F_3NO$: C, 68.05; H, 6.01; N, 4.18; found: C, 67.88; H, 6.05; N, 4.16.

*4.2.8. N-(4'-methyl-5-nitro-[1,1'-biphenyl]-2-yl) pivalamide (**3i**)*

The general procedure was followed using 4-nitro pivanilide (111 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3i** (123 mg, 79% yield) as light brown needle (m.p.= 82–84 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.69 (1H, d, *J* 9 Hz, =CH), 8.22 (1H, dd, *J* 9, 2.5 Hz, =CH), 8.12 (1H, d, *J* 2.5 Hz, =CH), 7.86 (1H, br, CONH), 7.39 (2H, d, *J* 8.0 Hz, =CH), 7.28 (2H, d, *J* 8.0 Hz, =CH), 2.47 (3H, s, Me), 1.13 (9H, s, 3Me); δ_C (125 MHz, $CDCl_3$) 176.6, 142.9, 141.2, 139.2, 132.5, 131.9, 130.2, 129, 125.1, 124, 119.5, 40.1, 27.1, 21.2; MS (IE) m/z (relative intensity %) 312 (M^+, 64), 228 (18), 211 (26), 180 (24), 85 (35), 57 (100), 41 (61). Anal. Calcd for $C_{18}H_{20}N_2O_3$: C, 69.21; H, 6.45; N, 8.97; found: C, 69.39; H, 6.49; N, 8.92.

*4.2.9. N-(4,4'-dimethyl-[1,1'-biphenyl]-2-yl) pivalamide (**3j**)*[12b, h]

The general procedure was followed using 3-methyl pivanilide (95 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (42 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3j** (119 mg, 85% yield) as a yellow oil; δ_H (400 MHz, $CDCl_3$) 8.28 (1H, d, *J* 1.0 Hz, =CH), 7.55 (1H, br, CONH), 7.33-7.26 (4H, m, =CH), 7.15 (1H, d, *J* 7.5 Hz, =CH), 7.00 (1H, ddd, *J* 8.0, 1.5, 0.5 Hz, =CH), 2.46 (3H, s, Me), 2.43 (3H, s, Me), 1.16 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.3, 138.2, 137.6, 135, 134.9, 129.7, 129.6, 129.3, 124.6, 121.3, 39.8, 27.4, 21.5, 21.2; MS (IE) m/z (relative intensity %) 281 (M^+, 53), 224 (16), 197 (42), 180 (15), 167 (15), 149 (26), 57 (100), 41 (50). Anal. Calcd for $C_{19}H_{23}NO$: C, 81.10; H, 8.24; N, 4.98; found: C, 81.41; H, 8.28; N, 4.95.

*4.2.10. N-(4-ethyl-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3k**)*

The general procedure was followed using 3-ethyl pivanilide (102 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3k** (131 mg, 89% yield) as pale yellow needle (m.p.= 75–77, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.35 (1H, d, *J* 1.5 Hz, =CH), 7.60 (1H, br, CONH), 7.33-7.27 (4H, m, =CH), 7.19 (1H, d, *J* 7.5 Hz, =CH), 7.03 (1H, dd, *J* 8.0, 1.5 Hz, =CH), 2.74 (2H, q, *J* 7.5 Hz, CH_2Me), 2.46 (3H, s, Me), 1.34 (4H, t, *J* 7.5 Hz, CH_2Me), 1.17 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.3, 144.6, 137.6, 135.1, 129.7, 129.7, 129.5, 129.3, 123.4, 120.2, 39.8, 28.9, 27.4, 21.2, 15.6; MS (IE) m/z (relative intensity %) 295 (M^+, 100), 238 (48), 211 (75), 196 (24), 180 (23), 57 (57). Anal. Calcd for $C_{20}H_{25}NO$: C, 81.31; H, 8.53; N, 4.74; found: C, 81.18; H, 8.49; N, 4.76.

*4.2.11. N-(4-methoxy-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3l**)*

The general procedure was followed using 3-methoxy pivanilide (103 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3l** (123 mg, 75% yield) as off-white needle (m.p.= 101–103 ºC, n-hexane) δ_H (400 MHz, $CDCl_3$) 8.19 (1H, d, *J* 2.5 Hz, =CH), 7.64 (1H, br, CONH), 7.32–7.25 (4H, m, =CH), 7.15 (1H, d, *J* 8.5 Hz, =CH), 6.74 (1H, dd, *J* 8.5, 2.5 Hz, =CH), 3.89 (3H, s, OMe), 2.45 (3H, s, Me), 1.15 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.4, 159.5, 137.5, 136.2, 134.8, 130.4, 129.7, 129.4, 124.1, 110.5, 105, 55.4, 39.9, 27.4, 21.2; MS (IE) m/z (relative intensity %) 297 (M^+, 100), 240 (22), 213 (63), 57 (85), 41 (24). Anal. Calcd for $C_{19}H_{23}NO_2$: C, 76.74; H, 7.80; N, 4.71; found: C, 76.50; H, 7.83; N, 4.73.

*4.2.12. N-(4'-methyl-4-(trifluoromethyl)-[1,1'-biphenyl]-2-yl) pivalamide (**3m**)*[12h]

The general procedure was followed using 3-trifluoromethyl pivanilide (122.5 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3m** (112 mg, 67% yield) as colorless needle (m.p.= 117–119 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.82 (1H, d, *J* 1.0 Hz, =CH), 7.66 (1H, br, CONH), 7.43-7.41 (1H, m, =CH), 7.38–7.34 (3H, m, =CH), 7.31–7.26 (2H, m, =CH), 2.48 (3H, s, Me), 1.15 (9H, s, 3Me); δ_F (375 MHz, $CDCl_3$) δ -62.57; δ_C (100 MHz, $CDCl_3$) 176.5, 138.7, 135.8, 134.9, 133.7, 130.5 (q, *J* 32.0 Hz), 130.1, 130, 128.9, 124 (q, *J* 270.5 Hz), 120.2 (q, *J* 4.0 Hz), 117.4 (q, *J* 4.0 Hz), 39.9, 27.3, 21.2; MS (IE) m/z (relative intensity %) 335 (M^+, 67), 278 (11), 251 (83), 250 (36), 248 (26), 235 (17), 18 (13), 85 (19), 57 (100), 41 (33). Anal. Calcd for $C_{19}H_{20}F_3NO$: C, 68.05; H, 6.01; N, 4.18; found: C, 68.26; H, 6.05; N, 4.20.

*4.2.13. N-(4,4',5-trimethyl-[1,1'-biphenyl]-2-yl) pivalamide (**3n**)*

The general procedure was followed using 3, 4-dimethyl pivanilide (102 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3n** (115 mg, 78% yield) as a yellow oil; δ_H (400 MHz, $CDCl_3$) 8.20 (1H, s, =CH), 7.49 (1H, br, CONH), 7.35–7.25 (4H, m, =CH), 7.05 (1H, s, =CH), 2.46 (3H, s, Me), 2.35 (3H, s, Me), 2.29 (3H, s, Me), 1.17 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.2, 137.5, 136.6, 135.2, 132.7, 132.2, 130.9, 129.8, 129.6, 129.2, 122.2, 39.7, 27.4, 21.2, 19.8, 19.2; MS (IE) m/z (relative intensity %) 295 (M, 67), 238 (27), 212 (21), 211 (66), 194 (18), 57 (100), 41 (39). Anal. Calcd for $C_{20}H_{25}NO$: C, 81.31; H, 8.53; N, 4.74; found: C, 81.42; H, 8.50; N, 4.72.

*4.2.14. N-(4,5-dimethoxy-4'-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3o**)*

The general procedure was followed using 3,4-dimethoxy pivanilide (118.5 mg, 0.5 mmol), p-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3o** (116 mg, 71% yield) as a brown oil; δ_H (400 MHz, $CDCl_3$) 8.12 (1H, s, =CH), 7.48 (1H, br, CONH), 7.32–7.25 (4H, m, =CH), 6.77 (1H, s, =CH), 3.97 (3H, s, OMe), 3.88 (3H, s, OMe), 2.44 (3H, s, Me), 1.15 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 176.2, 148.3, 145.1, 137.6, 134.9, 129.7, 129.3, 128.7, 127.1, 112.8, 105, 56.1, 56, 39.7, 27.4, 21.2; MS (IE) m/z (relative intensity %) 327 (M+, 100), 228 (35), 211 (20), 196 (19), 57 (55). Anal. Calcd for $C_{20}H_{25}NO_3$: C, 73.37; H, 7.70; N, 4.28; found: C, 73.60; H, 7.76; N, 4.32.

*4.2.15. N-(5-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3p**)*[11a,12b,c]

The general procedure was followed using 4-methyl pivanilide (95 mg, 0.5 mmol), benzenesulfonyl chloride (133 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3ab** (128 mg, 96% yield) as white needle (m.p.= 94–96 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.24 (1H, d, *J* 8.5 Hz, =C<u>H</u>), 7.54–7.49 (2H, m, =C<u>H</u>), 7.47–7.37 (4H, m, =C<u>H</u>), 7.21 (1H, dd, *J* 8.5, 2 Hz, =C<u>H</u>), 7.11–7.09 (1H, m, =C<u>H</u>), 2.38 (3H, s, <u>Me</u>), 1.13 (9H, s, 3<u>Me</u>); δ_C (125 MHz, $CDCl_3$) 176.1, 138.2, 133.4, 132.5, 132.3, 130.2, 129.2, 128.9, 127.8, 121.1, 121, 39.6, 27.3, 20.7; MS (IE) m/z (relative intensity %) 267 (M+, 67), 210 (16), 183 (77), 182 (37), 57 (100), 41 (28). Anal. Calcd for $C_{18}H_{21}NO$: C, 80.86; H, 7.92; N, 5.24; found: C, 80.62; H, 7.96; N, 5.21.

*4.2.16. N-(4'-chloro-5-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3q**)*

The general procedure was followed using 4-methyl pivanilide (95 mg, 0.5 mmol), 4-chloro benzenesulfonyl chloride (158 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3q** (129 mg, 86% yield) as off-white needle (m.p.= 105–107 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.11 (1H, d, *J* 8.5 Hz, =C<u>H</u>), 7.47–7.44 (2H, m, =C<u>H</u>), 7.32–7.29 (3H, m, =C<u>H</u>), 7.20 (1H, d, *J* 8.5 Hz, =C<u>H</u>), 7.05 (1H, d, *J* 2.0 Hz, =C<u>H</u>), 2.37 (3H, s, <u>Me</u>), 1.15 (9H, s, 3<u>Me</u>); δ_C (100 MHz, $CDCl_3$) 176.3, 136.9, 134, 133.9, 132.3, 131.7, 130.6, 129.3, 129, 122.2, 120.2, 39.6, 27.4, 20.8; MS (IE) m/z (relative intensity %) 301 (M+, 5), 225 (28), 190 (85), 141 (66), 106 (28), 77 (24), 57 (100), 41 (25). Anal. Calcd for $C_{18}H_{20}ClNO$: C, 71.63; H, 6.68; N, 4.64; found: C, 71.91; H, 6.71; N, 4.66.

*4.2.17. N-(4'-bromo-5-methyl-[1,1'-biphenyl]-2-yl) pivalamide (**3r**)*

The general procedure was followed using 4-methyl pivanilide (95 mg, 0.5 mmol), 4-bromo benzenesulfonyl chloride (192 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3r** (153 mg, 89% yield) as off-white needle (m.p.= 122–124 ºC, n-hexane). δ_H (400 MHz, $CDCl_3$) 8.10 (1H, d, *J* 8.5 Hz, =C<u>H</u>), 7.62–7.6 (2H, m, =C<u>H</u>), 7.33 (1H, br, CON<u>H</u>), 7.26–7.23 (2H, m, =C<u>H</u>), 7.20 (1H, dd, *J* 8.5, 2.0 Hz, =C<u>H</u>), 7.04 (1H, d, *J* 2.0 Hz, =C<u>H</u>), 2.36 (3H, s, <u>Me</u>), 1.15 (9H, s, 3<u>Me</u>); δ_C (100 MHz, $CDCl_3$) 176.3, 137.3, 134.1, 132.2, 132, 131.7, 131, 130.3, 129.3, 122.2, 122.1, 39.6, 27.4, 20.8; MS (IE) m/z (relative intensity %) 347 (M+2, 34), 345 (M+, 35), 263 (49), 261 (51), 209 (23), 191 (25), 180 (48), 107 (23), 57 (100), 41 (28). Anal. Calcd for $C_{18}H_{20}BrNO$: C, 62.44; H, 5.82; N, 4.05; found: C, 62.71; H, 5.87; N, 4.09.

*4.2.18. N-(5-methyl-4'-nitro-[1,1'-biphenyl]-2-yl) pivalamide (**3s**)*

The general procedure was followed using 4-methyl pivanilide (95 mg, 0.5 mmol), 4-nitro benzenesulfonyl chloride (166 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the final product **3s** (145 mg, 93% yield) as yellow powder (m.p.= 133–135 ºC, n-hexane/EtOAc). δ_H (400 MHz, $CDCl_3$) 8.34 (d, *J* = 9.0 Hz, 2H =C<u>H</u>), 7.95 (1H, d, *J* = 8.5 Hz, =C<u>H</u>), 7.60–7.56 (2H, m, =C<u>H</u>), 7.26 (1H, dd, *J* 8.5, 2 Hz, =C<u>H</u>), 7.19 (1H, br, CON<u>H</u>), 7.10 (1H, d, *J* 2 Hz, =C<u>H</u>), 2.40 (3H, s, <u>Me</u>), 1.15 (9H, s, 3<u>Me</u>); δ_C (100 MHz, $CDCl_3$) 176.5, 147.3, 145.7, 135, 131.9, 131.8, 130.2, 130.2, 130.2, 123.9, 123.7, 39.5, 27.4, 20.8; MS (IE) m/z (relative intensity %) 312 (M+, 100), 262 (31), 228 (72), 211 (33), 180 (40), 57 (83). Anal. Calcd for $C_{18}H_{20}N_2O_3$: C, 69.21; H, 6.45; N, 8.97; found: C, 69.07; H, 6.48; N, 8.94.

*4.2.19. N-(2-chloro-4-methylphenyl)pivalamide(**4a**)*[17]

The general procedure was followed using 4-methyl pivanilide (95 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the side product **4a** (32 mg, 29% yield) as white needle (m.p.= 65–67 ºC, n-hexane); δ_H (500 MHz, $CDCl_3$) 8.25 (1H, d, *J* 8.5 Hz, =C<u>H</u>), 7.91 (1H, br, CON<u>H</u>), 7.17 (1H, s, =C<u>H</u>), 7.06 (1H, d, *J* 8.5 Hz, =C<u>H</u>), 2.28 (3H, s, <u>Me</u>), 1.33 (9H, s, 3<u>Me</u>); δ_C (125 MHz, $CDCl_3$) 176.4, 134.4, 132.1, 129.1, 128.2, 122.8, 121.3, 40.0, 28.4, 20.5; MS (IE) m/z (relative intensity %) 227 (M+2, 3) 225 (M^+, 11), 190 (20), 141 (73), 106 (13), 57 (100). Anal. Calcd for $C_{12}H_{16}ClNO$: C, 63.85; H, 7.14; N, 6.21; found: C, 63.63; H, 7.17; N, 6.24.

*4.2.20. N-(2-chloro-4-methoxyphenyl)pivalamide (**4d**)*

The general procedure was followed using 4-methoxy pivanilide (103 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (42 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the side product **4d** (20 mg, 17% yield) as yellow oil; δ_H (400 MHz, $CDCl_3$) 8.25 (1H, d, *J* 9.0 Hz, =C<u>H</u>), 7.81 (1H, br, CON<u>H</u>), 6.96 (1H, d, *J* 3.0 Hz, =C<u>H</u>), 6.85 (1H, dd, *J* 9.0, 3.0 Hz, =C<u>H</u>), 3.81 (3H s, O<u>Me</u>), 1.37 (9H, s, 3<u>Me</u>); δ_C (100 MHz, $CDCl_3$) 176.4, 156.0, 128.1, 124.1, 122.8, 114.4, 113.1, 55.7, 39.9, 27.6; MS (IE) m/z (relative intensity %) 243 (M+2, 9), 241 (M^+, 28), 206 (74), 157 (40), 142 (48) 57 (100). Anal. Calcd for $C_{12}H_{16}ClNO_2$: C, 59.63; H, 6.67; N, 5.79; found: C, 59.79; H, 6.62; N, 5.82.

*4.2.21. N-(2-chloro-5-methoxyphenyl)pivalamide (**4l**)*

The general procedure was followed using 3-methoxy pivanilide (103 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the side product **4l** (18 mg, 15% yield) as a colorless oil; δ_H (400 MHz, $CDCl_3$)) 8.19 (1H, d, *J* 3.0 Hz, =C<u>H</u>), 8.07 (1H, br, CON<u>H</u>), 7.25 (1H, d, *J* 9.0 Hz, =C<u>H</u>), 6.62 (1H, dd, *J* 9.0, 3.0 Hz, =C<u>H</u>), 3.83 (3H s, O<u>Me</u>), 1.38 (9H, s, 3<u>Me</u>); δ_C (100 MHz, $CDCl_3$) 176.8, 159.0, 135.4, 129.0, 113.8, 111.2, 106.7, 55.6, 40.3, 27.5; MS (IE) m/z (relative intensity %) 243 (M+2, 3), 241 (M^+, 11), 206 (100), 157 (28), 57 (88). Anal. Calcd for $C_{12}H_{16}ClNO_2$: C, 59.63; H, 6.67; N, 5.79; found: C, 59.40; H, 6.64; N, 5.84.

*4.2.22. N-(2-chloro-4,5dimethoxyphenyl) pivalamide (**4o**)*

The general procedure was followed using 3, 4-dimethoxy pivanilide (118.5 mg, 0.5 mmol), p-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane) gave the side product **4o** (28 mg, 21% yield) as as off-white powder (m.p.= 107–109 ºC, n-hexane); δ_H (400 MHz, $CDCl_3$) 8.11 (1H, s, =C<u>H</u>), 7.48 (1H, br, CON<u>H</u>), 6.73 (1H, s, =C<u>H</u>), 3.88 (3H, s, O<u>Me</u>), 3.83 (3H, s, O<u>Me</u>), 1.33 (9H, s, 3<u>Me</u>); δ_C (100 MHz, $CDCl_3$) 176.5, 148.0, 145.3, 128.3, 113.4, 111.6,

105.2, 56.2, 56.0, 40.0, 27.5; MS (IE) m/z (relative intensity %) 273 (M+2, 17), 271 (M^+, 49), 263 (100), 172 (59), 57 (87). Anal. Calcd for $C_{13}H_{18}ClNO_3$: C, 57.46; H, 6.68; N, 5.15; found: C, 57.59; H, 6.70; N, 5.18.

4.2.23. N-([1,1'-biphenyl]-2-yl)benzamide (5)[12a]

The general procedure was followed using *N*-phenyl benzamide (98.5 mg, 0.5 mmol), *p*-toluenesulfonyl chloride (143 mg, 0.75 mmol), Li_2CO_3 (74 mg, 1 mmol), $PdCl_2$ (9 mg, 10 mol%). Purification by column chromatography (silica gel, n-hexane/EtOAc 10:1), gave the final product **5** (80 mg, 59% yield) as colorless needle (m.p.= 90–92 ºC, n-hexane/EtOAc); δ_H (400 MHz, d_6-DMSO) 9.84 (1H, br, CONH), 7.81 (2H, d, *J* 7.5 Hz, =CH), 7.52 (2H, t, *J* 8.5, =CH), 7.48–7.37 (9H, m, =CH), 7.30 (1H, t, *J* 7.5 Hz, =CH). Anal. Calcd for $C_{19}H_{15}NO$: C, 83.49; H, 5.53; N, 5.12; found: C, 83.59; H, 5.57; N, 5.18.

Acknowledgements

We gratefully acknowledge the financial support from the Research Council of the University of Tehran.

References and notes

1. (a) Hassan, J.; Sévignon, M.; Gozzi, C.; Schulz, E.; Lemaire, M. *Chem. Rev.* **2002**, *102*, 1359–1470; (b) Corbet, J.-P.; Mignani, G. *Chem. Rev.* **2006**, *106*, 2651–2710; (c) Bringmann, G.; Gulder, T.; Gulder, T. A. M.; Breuning, M. *Chem. Rev.* **2011**, *111*, 563–639.
2. (a) Liu, C.; Zhang, H.; Shi, W.; Lei, A. *Chem. Rev.* **2011**, *111*, 1780–1824; (b) Liu, C.; Yuan, J.; Gao, M.; Tang, S.; Li, W.; Shi, R.; Lei, A. *Chem. Rev.* **2015**, *115*, 12138–12204; (c) Davies, H. M. L.; Morton, D. *J. Org. Chem.* **2016**, *81*, 343–350.
3. (a) Yang, Y.; Qiu, X.; Zhao, Y.; Mu, Y.; Shi, Z. *J. Am. Chem. Soc.* **2016**, *138*, 495–498; (b) Yang, Y.; Li, R.; Zhao, Y.; Zhao, D.; Shi, Z. *J. Am. Chem. Soc.* **2016**, *138*, 8734–8737; (c) Yang, S.-D.; Sun, C.-L.; Fang, Z.; Li, B.-J.; Li, Y.-Z.; Shi, Z.-J. *Angew. Chem. Int. Ed.* **2008**, *47*, 1473–1476; (d) Sun, C.-L.; Li, B.-J.; Shi, Z.-J. *Chem. Commun.* **2010**, *46*, 677–685; (e) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457–2483; (f) Lennox, A. J. J.; Lloyd-Jones, G. C. *Chem. Soc. Rev.* **2014**, *43*, 412–443; (g) Lam, P. Y.; Clark, C. G.; Saubern, S.; Adams, J.; Winters, M. P.; Chan, D. M.; Combs, A. *Tetrahedron Lett.* **1998**, *39*, 2941–2944.
4. (a) Johansson Seechurn, Carin C. C.; Kitching, M. O.; Colacot, T. J.; Snieckus, V. *Angew. Chem. Int. Ed.* **2012**, *51*, 5062–5085; (b) Cordovilla, C.; Bartolomé, C.; Martínez-Ilarduya, J. M.; Espinet, P. *ACS Catal.* **2015**, *5*, 3040–3053; (c) Diana Haas; Jeffrey M. Hammann; Robert Greiner; Paul Knochel. *ACS Catal.* **2016**, *6*, 1540–1552; (d) Phapale, V. B.; Cardenas, D. J. *Chem. Soc. Rev.* **2009**, *38*, 1598–1607;(e) Lu, G.-p.; Cai, C.; Lipshutz, B. H. *Green Chem.* **2013**, *15*, 105–109; (f) Gao, H.; Ess, D. H.; Yousufuddin, M.; Kürti, L. *J. Am. Chem. Soc.* **2013**, *135*, 7086–7089;
5. (a) Aihara, Y.; Chatani, N. *Chem. Sci.* **2013**, *4*, 664–670; (b) Adrio, L. A.; Gimeno, J.; Vicent, C. *Chem. Commun.* **2013**, *49*, 8320–8322; (c) Aidene, M.; Belkessam, F.; Soulé, J.-F.; Doucet, H. *ChemCatChem* **2016**, *8*, 1583–1590; (d) Abdellaoui, F.; Ammar, H. B.; Soulé, J.-F.; Doucet, H. *Catal. Commun.* **2015**, *71*, 13–16; (e) Kozhushkov, S. I.; Potukuchi, H. K.; Ackermann, L. *Catal. Sci. Technol.* **2013**, *3*, 562–571;(f) Laidaoui, N.; He, M.; El Abed, D.; Soule, J.-F.; Doucet, H. *RSC Adv.* **2016**, *6*, 62866–62875; (g) Oi, S.; Ogino, Y.; Fukita, S.; Inoue, Y. *Org. Lett.* **2002**, *4*, 1783–1785; (h) So, C. M.; Lau, C. P.; Chan, A. S. C.; Kwong, F. Y. *J. Org. Chem.* **2008**, *73*, 7731–7734; (i) So, C. M.; Kwong, F. Y. *Chem. Soc. Rev.* **2011**, *40*, 4963–4972; (j) Yeung, P. Y.; Chung, K. H.; Kwong, F. Y. *Org. Lett.* **2011**, *13*, 2912–2915.
6. (a) Wu, X.; Yang, Y.; Han, J.; Wang, L. *Org. Lett.* **2015**, *17*, 5654–5657; (b) Williams, T. J.; Fairlamb, I. J. *Tetrahedron Lett.* **2013**, *54*, 2906–2908; (c) Yu, P.; Zhang, G.; Chen, F.; Cheng, J. *Tetrahedron Lett.* **2012**, *53*, 4588–4590.
7. (a) Goossen, L. J.; Rodriguez, N.; Goossen, K. *Angew. Chem. Int. Ed.* **2008**, *47*, 3100–3120; (b) Goossen, L. J.; Collet, F.; Goossen, K. *Isr. J. Chem.* **2010**, *50*, 617–629; (c) Bonesi, S. M.; Fagnoni, M. *Chemistry* **2010**, *16*, 13572–13589; (d) Patra, T.; Nandi, S.; Sahoo, S. K.; Maiti, D. *Chem. Commun.* **2016**, *52*, 1432–1435.
8. (a) Hull, K. L.; Sanford, M. S. *J. Am. Chem. Soc.* **2007**, *129*, 11904–11905; (b) Cho, S. H.; Hwang, S. J.; Chang, S. *J. Am. Chem. Soc.* **2008**, *130*, 9254–9256; (c) Hull, K. L.; Sanford, M. S. *J. Am. Chem. Soc.* **2009**, *131*, 9651–9653; (d) Zhao, X.; Yeung, C. S.; Dong, V. M. *J. Am. Chem. Soc.* **2010**, *132*, 5837–5844; (e) Lyons, T. W.; Hull, K. L.; Sanford, M. S. *J. Am. Chem. Soc.* **2011**, *133*, 4455–4464; (f) Bonin, H.; Sauthier, M.; Felpin, F.-X. *Adv. Synth. Catal.* **2014**, *356*, 645–671;(g) Jiao, L.-Y.; Smirnov, P.; Oestreich, M. *Org. Lett.* **2014**, *16*, 6020–6023; (h) Lou, S.-J.; Mao, Y.-J.; Xu, D.-Q.; He, J.-Q.; Chen, Q.; Xu, Z.-Y. *ACS Catal.* **2016**, *6*, 3890–3894; (i) Sun, D.; Li, B.; Lan, J.; Huang, Q.; You, J. *Chem. Commun.* **2016**, *52*, 3635–3638.
9. (a) Li, B.-J.; Yang, S.-D.; Shi, Z.-J. *Synlett* **2008**, *2008*, 949–957; (b) Zhang, M.; Zhang, Y.; Jie, X.; Zhao, H.; Li, G.; Su, W. *Org. Chem. Front.* **2014**, *1*, 843–895;(c) Chen, Z.; Wang, B.; Zhang, J.; Yu, W.; Liu, Z.; Zhang, Y. *Org. Chem. Front.* **2015**, *2*, 1107–1295; (d) Rouquet, G.; Chatani, N. *Angew. Chem. Int. Ed.* **2013**, *52*, 11726–11743; (e) Hao Tang; Xu-Ri Huang; Jiannian Yao; Hui Chen. *J. Org. Chem.* **2015**, *80*, 4672–4682.
10. (a) Choi, S.; Chatterjee, T.; Choi, W. J.; You, Y.; Cho, E. J. *ACS Catal.* **2015**, *5*, 4796–4802; (b) Tsang, W. C. P.; Zheng, N.; Buchwald, S. L. *J. Am. Chem. Soc.* **2005**, *127*, 14560–14561; (c) Jordan-Hore, J. A.; Johansson, C. C.; Beck, E. M.; Gaunt, M. J. *J. Am. Chem. Soc.* **2008**, *130*, 16184–16186; (d) Cho, S. H.; Yoon, J.; Chang, S. *J. Am. Chem. Soc.* **2011**, *133*, 5996–6005; (e) Youn, S. W.; Bihn, J. H.; Kim, B. S. *Org. Lett.* **2011**, *13*, 3738–3741; (f) Takamatsu, K.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2014**, *16*, 2892–2895; (g) Chng, L. L.; Yang, J.; Wei, Y.; Ying, J. Y. *Chem. Commun.* **2014**, *50*, 9049–9052; (h) Suzuki, C.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2015**, *17*, 1597–1600;(i) Antonchick, A. P.; Samanta, R.; Kulikov, K.; Lategahn, J. *Angew. Chem. Int. Ed.* **2011**, *50*, 8605–8608;
11. (a) Xiong, T.; Li, Y.; Lv, Y.; Zhang, Q. *Chem. Commun.* **2010**, *46*, 6831–6833; (b) Xiong, T.; Li, Y.; Bi, X.; Lv, Y.; Zhang, Q. *Angew. Chem. Int. Ed.* **2011**, *50*, 7140–7143; (c) Ishikawa, S.; Manabe, K. *Org. Lett.* **2007**, *9*, 5593–5595; (d) Ishikawa, S.; Manabe, K. *Synthesis* **2008**, *2008*, 3180–3182; (e) Kofink, C. C.; Blank, B.; Pagano, S.; Götz, N.; Knochel, P. *Chem. Commun.* **2007**, 1954–1956; (f) Bolliger, J. L.; Frech, C. M. *Acc.Chem. Res.* **2010**, *16*, 11072–11081.
12. (a) Yang, S.; Li, B.; Wan, X.; Shi, Z. *J. Am. Chem. Soc.* **2007**, *129*, 6066–6067; (b) Li, D.; Xu, N.; Zhang, Y.; Wang, L. *Chem. Commun.* **2014**, *50*, 14862–14865; (c) Haridharan, R.; Muralirajan, K.; Cheng, C.-H. *Adv. Synth. Catal.* **2015**, *357*, 366–370; (d) Chinnagolla, R. K.; Jeganmohan, M. *Chem. Commun.* **2014**, *50*, 2442–2444; (e) Hubrich, J.; Himmler, T.; Rodefeld, L.; Ackermann, L. *Adv. Synth. Catal.* **2015**, *357*, 474–480; (f) Brasche, G.; Garcia-Fortanet, J.; Buchwald, S. L. *Org. Lett.* **2008**, *10*, 2207–2210; (g) Yang, F.; Song, F.; Li, W.; Lan, J.; You, J. *RSC Adv.* **2013**, *3*, 9649; (h) Hui Xu; Ming Shang; Hui-Xiong Dai; Jin-Quan Yu. *Org. Lett.* **2015**, *17*, 3830–3833; (i) Wang, X.; Leow, D.; Yu, J.-Q. *J. Am. Chem. Soc.* **2011**, *133*, 13864–13867.
13. (a) Yuan, K.; Soulé, J.-F.; Doucet, H. *ACS Catal.* **2015**, *5*, 978–991; (b) Wei, Z.; Xue, D.; Zhang, H.; Guan, J. *Appl. Organomet. Chem.* **2016**, *30*, 767–771; (c) Hfaiedh, A.; Ben Ammar, H.; Soule, J.-F.; Doucet, H. *Org. Biomol. Chem.* **2016**, *14*, 4947–4956; (d) Hfaiedh, A.; Yuan, K.; Ben Ammar, H.; Ben Hassine, B.; Soulé, J.-F.; Doucet, H. *ChemSusChem* **2015**, *8*, 1794–1804; (e) Wang, C.; Jia, H.; Li, Z.; Zhang, H.; Zhao, B. *RSC Adv.* **2016**, *6*, 21814–21821; (f) Yuan, K.; Sang, R.; Soule, J.-F.; Doucet, H. *Catal. Sci. Technol.* **2015**, *5*, 2904–2912; (g) Zhang, W.; Liu, F.; Zhao, B. *Appl. Organomet. Chem.* **2015**, *29*, 524–527; (h) Zhao, X.; Dimitrijević, E.; Dong, V.M. *J. Am. Chem. Soc.*, **2009**, *131*, 3466–3467; (i) Zhao, X.; Dimitrijević, E.; Dong, *Angew. Chem. Int. Ed.* **2011**, 50, 932-934.
14. (a) Kianmehr, E.; Faghih, N.; Khan, K. M. *Org. Lett.* **2015**, *17*, 414–417; (b) Kianmehr, E.; Faghih, N.; Karaji, S.; Amiri Lomedasht, Y.; Khan, K. M. *J. Org. Chem.* **2016**, *801*, 10–13; (c) Kianmehr, E.; Faghih, N.; Tanbakouchian, A.; Mahdavi, M. *Eur. J. Org. Chem.* **2016**, *2016*, 4269–4274; (d) Kianmehr, E.; Kazemi, S.; Foroumadi, A. *Tetrahedron* **2014**, *70*, 349–354; (e) Kianmehr, E.; Khalkhali, M. R.; Rezaeefard, M.; Khan, K. M.; Ng, S. W. *Aust. J. Chem.* **2015**, *68*, 165; (f) Kianmehr, E.; Rezaeefard, M.; Rezazadeh Khalkhali, M.; Khan, K. M. *RSC Adv.* **2014**, *4*, 13764; (g) Kianmehr, E.; Torabi, M.; Rezazadeh Khalkhali, M.; Faghih, N.; Khan, K. M. *Eur. J. Org. Chem.* **2015**, *2015*, 2796–2800;

15. Topczewski, J. J.; Sanford, M. S. *Chem. Sci.* **2015**, 6, 70–76.
16. (a) Sultane, P. R.; Mete, T. B.; Bhat, R. G. *Org. Biomol. Chem.*, **2014**, 12, 261; (b)Taffarel E.; Chirayil S.; Thummel R. P., *J. Org. Chem*. **1994**,59,823-828; (c) Shabashov D.; Daugulis O., *J. Org. Chem*. **2007**, 72, 7720–7725; (d) McClintock S. P.; Zakharov L. N.; Herges R.; Haley M. M. *Chem. Eur. J*. **2011**, 17, 6798 – 6806
17. (a) Bedford R. B.; Engelhart, J. U.; Haddow M. F.; Mitchell C. J.; Webster R. L., *Dalton Trans*., **2010**, 39, 10464–10472; (b) Bedford R. B.; Haddow M. F.; Mitchell C. J.; and Webster R. L. *Angew*. *Chem. Int. Ed*. **2011**, 50, 5524 –5527.