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A mild inter- and intramolecular amination of aryl halides with a combination of CuI and CsOAc

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ABSTRACT

A unique combination of CuI and CsOAc was found to catalyze aryl amination under mild conditions. The reaction takes place at room temperature or at 90 °C with broad functional group compatibility. The intramolecular reaction was able to form five-, six-, and seven-membered rings with various protecting groups on the nitrogen atom. The scope of the intermolecular amination, as well as its applications to unsymmetrical *N*,*N*′-dialkylated phenylenediamines, was investigated.

1. Introduction

Since various pharmacologically important compounds contain aromatic C(sp^2)–N bonds, the introduction of nitrogen functionalities on aromatic rings has been one of the main topics in organic synthesis. The Ullmann–Goldberg reaction[1] is widely known as a classical method for aryl amination. However, due to its harsh reaction conditions, such as heating in the presence of copper salt at high temperature without solvent, the reaction lacks broad functional group compatibility, thereby limiting its utility for the synthesis of complex molecules. During the past 15 years, Buchwald[2] and Hartwig[3] have developed a palladium-catalyzed aryl amination, which proceeds even at room temperature with a combination of a palladium catalyst and phosphine ligand. Thereafter, Buchwald[4] and Ma[5] reported that the combination of copper iodide and salicylic amide derivatives or proline was quite effective for the same transformation. In an independent study, we developed a novel aryl amination catalyzed by CuI and CsOAc[6a,b] during the synthetic studies of duocarmycins,[6c] which was successfully applied to the gram-scale total synthesis of (+)-yatakemycin[6d,e] (Fig. 1). These copper-mediated reactions are significantly superior to the conventional palladium-mediated reactions, since the reaction takes place with inexpensive copper(I) salt under mild conditions in good compatibility with a range of functional groups. Hence, copper-catalyzed amination chemistry has received considerable attention, and a variety efficient protocols have been reported for the arylation of anilines,[5d,h,7] amides,[4b,d,8] nitrogen heterocycles,[4a,d,i,5h,8c,9] hydrazides,[4b,c,10] and α- or β-amino acids.[5a–c,e,g] In this paper we describe in full detail the development of our aryl amination protocol using a unique combination of CuI and CsOAc and their synthetic scope.

2. Results and discussion

2.1. Optimization process

During the course of synthetic studies toward the duocarmycins, we planned to synthesize the key intermediate **2** by the palladium-catalyzed Buchwald amination. However, typical reaction conditions using a combination of $Pd_2(dba)_3$, P(*o*-tolyl)$_3$ and a base, such as NaO*t*-Bu in toluene, provided bromoindoline **2** in modest yield and were accompanied by a substantial amount of debrominated product **3** (Table 1, entry 1). While debromination was suppressed by using CsOAc instead of KO*t*-Bu, the yield of the desired product **2** remained low (entry 2). Surprisingly, the addition of stoichiometric CuI dramatically facilitated the amination reaction, and the desired product was obtained in 66% yield within 5 min at room temperature without observation of debromination (entry 3). Finally, we found that the amination reaction proceeded without a palladium catalyst, indicating that copper species mediate the intramolecular amination (entry 4).

In order to gain information on the identity of the copper species, which are responsible for promoting the amination reaction, we chose compound **4a** as the model substrate and carried out the reaction using various copper species (Table 2). Copper(I) species, such as CuI, CuBr, CuOAc, and Cu(2-thienylcarboxylate), proved to be effective for the transformation (entries 1–4).[11] On the other

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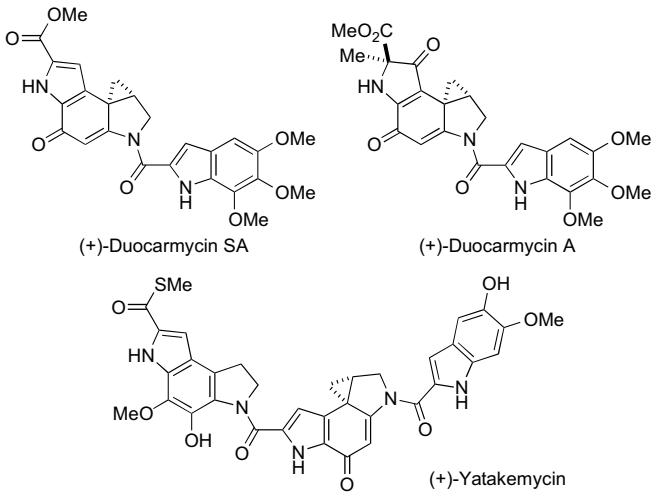


Figure 1. Naturally occurring antitumor antibiotics synthesized by application of our amination reaction.

hand, no desired product was obtained when either Cu(0) or $Cu(OAc)_2$ was used (entries 5 and 6).

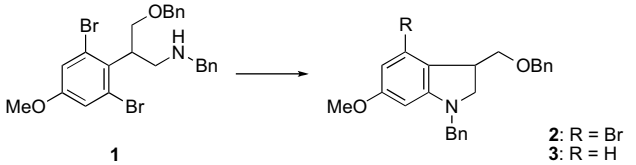
It was found that the appropriate choice of base is also quite important for the reaction (Table 3). Among the series of alkali metal acetates, cesium salt gave the best results. Yields of the desired indoline **5a** after 6 h were substantially decreased when using potassium, sodium, and lithium salts (entries 1–4). Acetate anion was also found to be essential; the yield decreased with cesium benzoate (entry 5), and no reaction was observed with Cs_2CO_3 (entry 12). It is notable that cesium-free conditions, namely, a 1:1 mixture of AcOH and amine bases, promoted the reaction (entries 6–8). Conditions using other bases, such as NaO*t*-Bu or various amines, or without bases resulted in only recovery of the starting material **4a** (entries 9–14).

Next, we examined solvent effects and found that the reaction rates depended on the polarity of the solvents. Thus, the reaction in aprotic highly polar solvents, such as DMF or DMSO, provided the desired indoline in good yield (Table 4, entries 1 and 2). While the polar solvents, including acetonitrile and DME, gave the corresponding indoline in low to modest yields, other solvents afforded only a trace amount of the product **5a** with recovery of the starting material **4a** (entries 3–10).

As shown in Tables 2 and 3, the reaction proceeded in the presence of both Cu(I) and carboxylate ions or commercially available CuOAc. These results and our observations that the addition of CsOAc spontaneously turned the suspension of CuI in DMF to a clear solution at the onset of the reaction strongly indicate that the active species is likely to be CuOAc generated by exchange between CuI and CsOAc. Subsequently, CuOAc would bind on the nitrogen, oxidatively add to C–X bond to give Cu(III) species and finally undergo reductive elimination to give the cyclized product with regeneration of the Cu(I) species (Scheme 1).

Among various alkali metal acetates tested, CsOAc was found to be the best base presumably due to the highest solubility. Use of the combination of CuI–CsOAc is more practical than CuOAc, since one can avoid handling highly hygroscopic CuOAc in air. Based on these optimizations, we finally decided to use the combination of CuI and CsOAc in DMSO or DMF as the standard conditions.

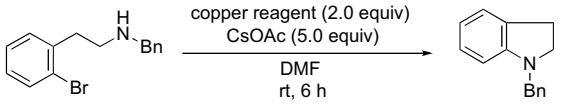
Table 1
Initial key findings on synthetic studies toward duocarmycins



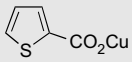
Entry	Conditions	**2**[a] (%)	**3**[a] (%)
1	$Pd_2(dba)_3$,[b] P(*o*-tolyl)$_3$, NaO*t*-Bu, toluene, 110 °C, 2 h	47	11
2	$Pd_2(dba)_3$,[b] P(*o*-tolyl)$_3$, CsOAc, DMF, 120 °C, 4 h	34	Trace
3	$Pd_2(dba)_3$,[b] P(*o*-tolyl)$_3$, CsOAc, CuI,[c] DMF, rt, 5 min	66	0
4	CuI,[c] CsOAc, DMF, rt, 20 min	60	0

[a] Isolated yields.
[b] 10 mol %.
[c] 2 equiv.

Table 2
Choice of copper species



4a **5a**

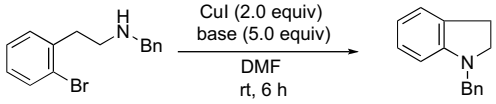
Entry	Copper reagent	**4a**[a] (%)	**5a**[a] (%)
1	CuI	6	83
2	CuBr	2	82
3	CuOAc	8	80
4		5	82
5	Cu(0)	91	0
6	$Cu(OAc)_2$	97	0

[a] Isolated yields.

2.2. Intramolecular amination

Having established the optimal conditions, the scope and limitation of the intramolecular amination was next investigated. First, a variety of protecting groups of the amine were examined using a series of *o*-bromo- and *o*-iodophenethylamine derivatives (Table 5). A smooth amination proceeded at room temperature with *N*-benzyl derivatives (**4a** and **6a**) to afford the corresponding indoline **5a** in excellent yields (entries 1 and 8). Primary amines (R=H) also reacted at room temperature with rapid consumption of the substrate, although the yield was moderate due to the

Table 3
Choice of bases

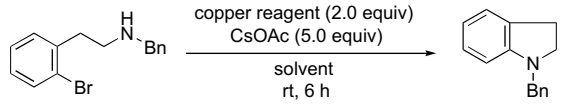


4a **5a**

Entry	Base	**4a**[a] (%)	**5a**[a] (%)
1	CsOAc	6	83
2	KOAc	62	38
3	NaOAc	55	38
4	LiOAc	69	26
5	CsOBz	39	53
6	AcOH (5 equiv)+Et_3N (5 equiv)	49	44
7	AcOH (5 equiv)+*i*-Pr_2NEt (5 equiv)	45	48
8	AcOH (5 equiv)+DBU (5 equiv)	18	78
9	Et_3N	96	0
10	*i*-Pr_2NEt	98	0
11	DBU	86	0
12	Cs_2CO_3	97	0
13	NaO*t*-Bu	96	0
14	None	94	0

[a] Isolated yields.

Table 4
Solvent effect



4a **5a**

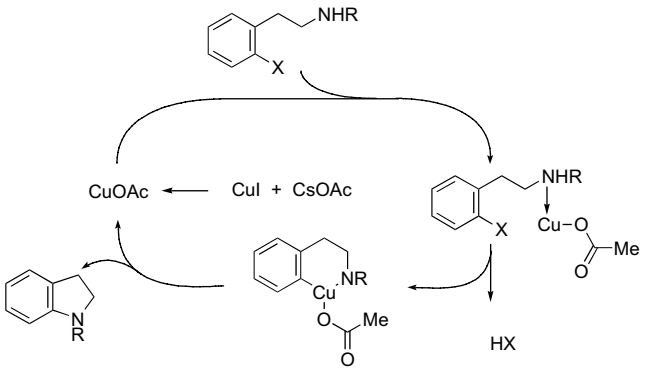
Entry	Solvent	**4a**[a] (%)	**5a**[a] (%)
1	DMF	6	83
2	DMSO	1	84
3	MeCN	41	42
4	DME	84	15
5	THF	84	1
6	1,4-Dioxane	94	4
7	CH_2Cl_2	97	1
8	Toluene	94	2
9	MeOH	92	6
10	DMF–H_2O (1:1)	89	2

[a] Isolated yields.

formation of unidentified byproducts (entries 2 and 9). Compounds having a variety of electron-withdrawing protecting groups on the nitrogen serve as suitable substrate (entries 3–7 and 10–14), although heating at 90 °C was required for the smooth conversion. Among them, the Ns (*o*-nitrobenzenesulfonyl) group[12] proved to be quite effective, and the reaction completed after only an hour (entries 3 and 10). Comparison of the results of aryl iodides and aryl bromides revealed that aryl iodides were in general slightly superior to aryl bromides (entries 4–7 and 11–14). In some cases, reaction of aryl bromides was incomplete even after 24 h (entries 5 and 7). Remarkably, the Alloc group, which is not compatible with palladium-mediated conditions, completely survived the amination reaction (entries 7 and 14).

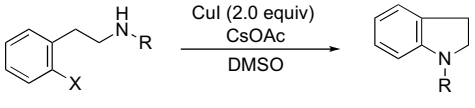
We then examined the formation of a six-membered ring with *o*-bromo and *o*-iodophenylpropylamine (Table 6). *N*-Benzyl derivatives (**7a** and **8a**) underwent smooth cyclization at 90 °C (entries 1 and 4). While primary amines (**7b** and **8b**) decomposed under the heating conditions, reaction at room temperature provided the desired product **9b** albeit in modest yields and was associated with recovery of the minute amount of the starting compound **7b** after 24 h (entries 2 and 5). *N*-Nosyl derivatives (**7c** and **8c**) served as the best substrate and gave the cyclization product **9c** in near quantitative yields in less than 5 h (entries 3 and 6).

The reaction conditions were feasible for forming not only five- (Table 5) and six-membered ring (Table 6), but also for forming seven-membered tetrahydrobenzoazepine **11** (Scheme 2). The reaction proceeded nicely by heating at 120 °C. Despite extensive efforts, however, all attempts to form eight-membered



Scheme 1. Proposed reaction mechanism of the aryl amination.

Table 5
Intramolecular amination with phenylethylamine derivatives



4 or **6** **5**

Entry	Subtrate	R	X	CsOAc (equiv)	Temp (°C)	Time (h)	Yield[a] (%)
1	**4a**	Bn	Br	5	rt	5	87
2	**4b**	H	Br	5	rt	1	47
3	**4c**	Ns	Br	5	90	1	92
4	**4d**	Ac	Br	10	90	24	82
5	**4e**	Boc	Br	10	90	24	82[b]
6	**4f**	Cbz	Br	10	90	24	77
7	**4g**	Alloc	Br	10	90	24	75[c]
8	**6a**	Bn	I	5	rt	4	87
9	**6b**	H	I	5	rt	1	44
10	**6c**	Ns	I	5	90	1	87
11	**6d**	Ac	I	5	90	24	96
12	**6e**	Boc	I	5	90	24	93
13	**6f**	Cbz	I	5	90	24	95
14	**6g**	Alloc	I	5	90	24	81

[a] Isolated yields.
[b] With 5% substrate recovery.
[c] With 9% substrate recovery.

hexahydrobenzoazocine **13** resulted only in recovery of the starting material **12**.

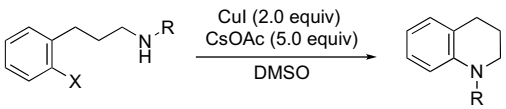
2.3. Catalytic intramolecular amination

Since benzylamine and Ns-amide have proven to be particularly suitable substrates for the intramolecular amination reaction, improvement to the catalytic process was thoroughly investigated using these compounds (Table 7). To this end, we successfully reduced the amount of CuI to 10 mol %, which is sufficient to complete the reaction to obtain the desired indolines or tetrahydroquinolines in good to excellent yields (entries 1, 2, 4, and 5). Remarkably, reaction of Ns-amide **4c** gave the corresponding indoline **5c** in almost quantitative yield with only 1 mol % of CuI (entry 2). In contrast, acetamide **4d** was a poor substrate under the catalytic conditions, and only 18% of the desired product along with 68% of **4d** was isolated even after a day of heating (entry 3).

2.4. Intermolecular amination

After demonstrating the utility of the CuI–CsOAc system for intramolecular aminations, our attention was focused on the

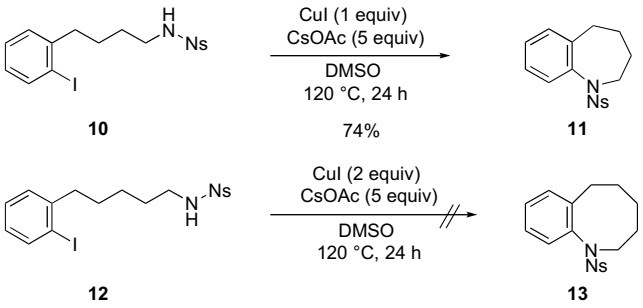
Table 6
Intramolecular amination with phenylpropylamine derivatives



7 or **8** **9**

Entry	Subtrate	R	X	Temp (°C)	Time (h)	Yield[a] (%)
1	**7a**	Bn	Br	90	9	71[b]
2	**7b**	H	Br	rt	24	54[c]
3	**7c**	Ns	Br	90	5	98
4	**8a**	Bn	I	90	9	54
5	**8b**	H	I	rt	24	56
6	**8c**	Ns	I	90	4	99

[a] Isolated yields.
[b] With 4% substrate recovery.
[c] With 3% substrate recovery.



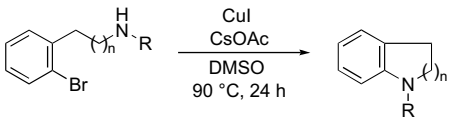
Scheme 2. Formation of seven- or eight-membered rings.

intermolecular process. Initial trials to couple iodobenzene and *n*-$BuNH_2$ under the general conditions established for the intramolecular reaction (1.0 equiv of CuI and 2.5 equiv of CsOAc in DMSO) resulted in the generation of only a minute amount of the desired product **14**. After extensive investigation, we found that a relatively high concentration (ca. 1.0 M in DMSO or DMF) was necessary for satisfactory yields; furthermore, catalyst loading could be decreased to 10 mol % without affecting the yields of the desired indoline product (Table 8, entries 1 and 2) although the yield was dramatically reduced with 5 mol % of CuI (entry 3). Finally, on the basis of the optimization studies (entries 4–8), we set 1.5 equiv of amine, 10 mol % of CuI, and 2.0 equiv of CsOAc as the optimal conditions for the intermolecular aryl amination.

It became apparent that the reaction was sensitive to the substitution pattern of the aryl iodides (Table 9). While *m*- or *p*-iodobenzenes bearing both electron-withdrawing and donating substituents served as suitable substrates to give the corresponding disubstituted anilines in good to excellent yields (entries 2, 3, 5, 6, 8, and 9), *o*-substituted iodobenzene provided low to moderate yields of products, except for the case of *o*-iodonitrobenzene (entries 1, 4, 7, and 12). Since a control experiment using *o*-iodonitrobenzene in the absence of CuI gave the aniline in 95% yield, the amination reaction of *o*-iodonitrobenzene and possibly *p*-iodonitrobenzene proceeded by the conventional S_NAr mechanism. It is notable that selective monoamination reactions could be possible if we used *m*- or *p*-diiodobenzene or *p*-bromoiodobenzene (entries 10, 11, and 13).

By taking advantage of the selective monoamination of diiodobenzenes, we executed a successive diamination to construct an unsymmetrical *N*,*N*′-dialkylated phenylenediamine (Scheme 3). Following the preparation of *N*-butyl-3-iodoaniline **15j** by selective monoamination at room temperature,[6b,13] the second amination was carried out at 90 °C, giving smoothly the phenylenediamine derivative **16** in good yield. This protocol would be quite useful for the synthesis of unsymmetrical *N*,*N*′-dialkylated phenylenediamine,

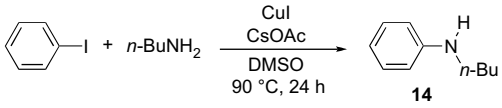
Table 7
Catalytic intramolecular aryl amination



Entry	Substrate	*n*	R	CuI (mol %)	CsOAc (equiv)	Product	Yield[a] (%)
1	**4a**	1	Bn	10	5.0	**5a**	83[b]
2	**4c**	1	Na	1	2.5	**5c**	97
3	**4d**	1	Ac	10	5.0	**5d**	18[c]
4	**7a**	2	Bn	10	5.0	**9a**	69
5	**7c**	2	Ns	10	5.0	**9c**	96

[a] Isolated yields.
[b] With 3% substrate recovery.
[c] With 68% substrate recovery.

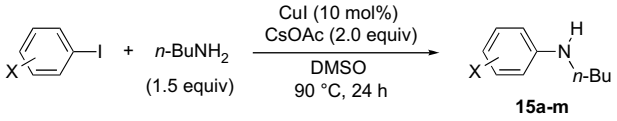
Table 8
Optimization of intermolecular aryl amination



Entry	*n*-$BuNH_2$ (equiv)	CuI (mol %)	CsOAc (equiv)	Yield[a] (%)
1	2.0	100	2.5	93
2	2.0	10	2.5	89
3	2.0	5	2.5	69
4	1.5	10	2.5	85
5	1.2	10	2.5	74
6	1.1	10	2.5	58
7	1.5	10	2.0	89
8	1.5	10	1.5	75

[a] Isolated yields.

Table 9
Substitution effects on the intermolecular aryl amination

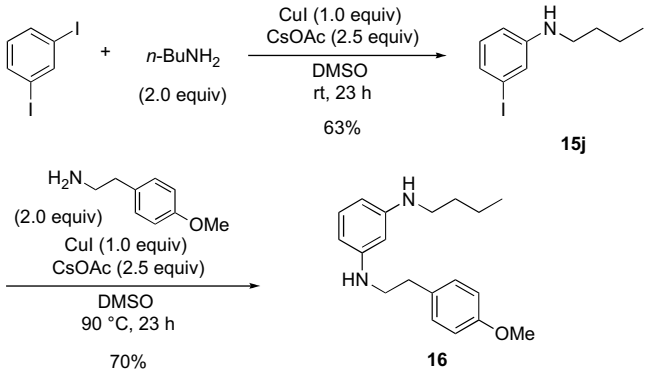


Entry	X		Product	Yield[a] (%)
1	*o*	NO_2	**15a**	78
2	*m*		**15b**	95
3	*p*		**15c**	99
4	*o*	Me	**15d**	21
5	*m*		**15e**	99
6	*p*		**15f**	86
7	*o*	OMe	**15g**	49
8	*m*		**15h**	89
9	*p*		**15i**	84
10	*m*	I	**15j**	50
11	*p*		**15k**	76
12	*o*	F	**15l**	37
13	*p*	Br	**15m**	76

[a] Isolated yields.

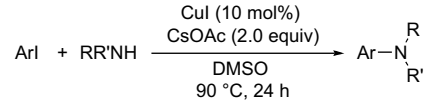
since it would be difficult to differentiate the two amines of phenylenediamines.

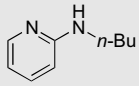
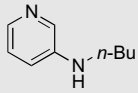
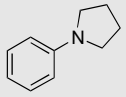
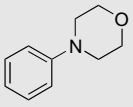
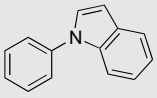
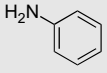
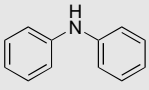
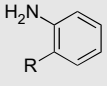
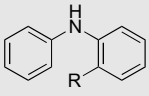
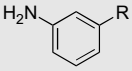
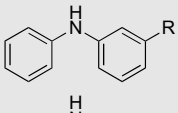
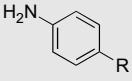
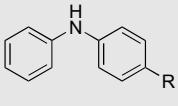
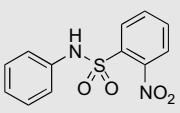
Finally, the generality of our amination reaction was examined using various substrates and amines (Table 10). 2- and 3-Iodopyridine are also suitable substrates for the amination, giving the corresponding pyridylamines in good yields. Cyclic secondary amines and indole could be introduced to the aromatic rings in good yields. On the other hand, anilines appeared to be less reactive, providing the corresponding products in low to moderate yields. In addition, Ns-amide was coupled with iodobenzene in high yield to afford



Scheme 3. A successive amination of 1,3-diiodobenzene.

Table 10
Intermolecular aryl amination of various substrates

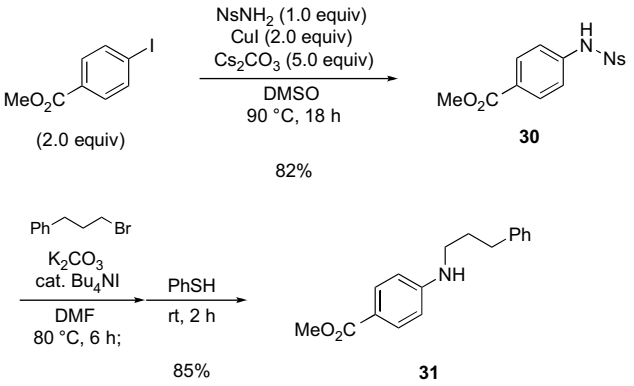


ArI	RR'NH	Product		Yield[a] (%)
	*n*-BuNH$_2$		**17**	70
	*n*-BuNH$_2$		**18**	96
			**19**	68
			**20**	83
			**21**	63
			**22**	24
			R=OMe; **23** R=NO$_2$; **24**	44 63
			R=OMe; **25** R=NO$_2$; **26**	4 12
			R=OMe; **27** R=NO$_2$; **28**	38 64
	*o*-NsNH$_2$		**29**	91[b]

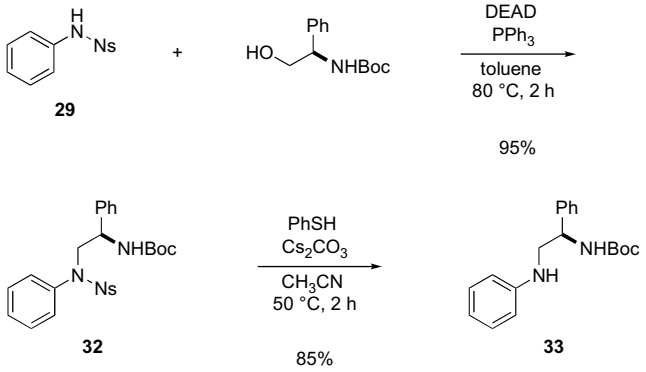
[a] Isolated yields.
[b] Reaction conditions: 1.0 mmol of iodobenzene, 0.50 mmol of NsNH$_2$, 1.0 mmol of CuI, 2.5 mmol of Cs_2CO_3, dry DMSO (0.50 mL), under argon atmosphere. The yield is calculated based on NsNH$_2$.

Ns-protected aniline derivative with stoichiometric CuI, which is particularly suited for further functionalizations by means of conventional alkylation or by Mitsunobu reactions.[14]

For example, after amination of methyl 4-iodobenzoate with Ns-amide, Ns-anilide **30** was treated in one-pot with phenylpropyl bromide in the presence of K_2CO_3 and a catalytic amount of Bu_4NI in DMF followed by addition of PhSH to furnish methyl 4-(3-phenylpropylamino)benzoate (**31**) in 85% yield over 2 steps (Scheme 4). Alternatively, N-alkylation could be performed by the Mitsunobu reaction. The Mitsunobu reaction of the relatively less reactive Ns-anilide (**29**) with *N*-Boc-(*R*)-phenylglycinol took place upon heating, and the subsequent deprotection of the Ns group gave the chiral β-diamine derivative **33** in high yield (Scheme 5). This method is applicable to the general synthesis of chiral *N*-aryl-1,2-diamines, since various chiral amino alcohols are easily accessible by reduction of α-amino acids.



Scheme 4. Synthesis of a *N*-aryl secondary amine.



Scheme 5. Synthesis of a chiral β-diamine.

3. Conclusion

In summary, we have developed a copper-catalyzed aryl amination that proceeds under mild conditions using a unique combination of CuI and CsOAc without the addition of ligands. The key features of this reaction are summarized as follows: (1) The intramolecular reaction proceeds at a congested position, possibly due to ligand free conditions; (2) The Ns group was found to be the suitable protecting group on the nitrogen in both the intra- and intermolecular processes; and (3) In the case of diiodobenzene, monoamination takes place even at room temperature without the loss of the other iodo group, which provides a definitive advantage over the conventional palladium-mediated aryl aminations and enabled us to develop a protocol for the synthesis of unsymmetrical phenylenediamine derivatives. Furthermore, Ns-anilides, obtained by the amination using NsNH$_2$, have proven to be particularly useful intermediates for the stepwise synthesis of functionalized *N*-aryl secondary amines. Since the synthetic utility of the mild reaction conditions and the high chemoselectivity have been fully demonstrated in this work as well as our previously reported total syntheses of duocarmycins and yatakemycins, we believe our amination reaction would be useful for the synthesis of a wide variety of nitrogen-containing compounds.

4. Experimental section

4.1. General

All reactions were carried out in flame-dried glassware under argon atmosphere unless otherwise noted. CsOAc was weighed

under argon atmosphere to prevent absorption of moisture. CuI (99.5% purity) and CsOAc (95% purity) were purchased from Wako Pure Chemical Industries, Ltd. and were used as-supplied. Dry DMSO was purchased from Aldlich Chemical Co. and was used as-supplied.

4.2. General procedure for the catalytic intramolecular aryl amination with *N*-nosyl-2-bromophenylethylamine (4c)

An oven-dried round-bottomed flask was charged with CsOAc (3.75 g, 19.5 mmol, 2.5 equiv), CuI (14.9 mg, 78.1 μmol, 1.0 mol %), and *N*-nosyl-2-bromophenylethylamine (**4c**) (3.01 g, 7.81 mmol, 1.0 equiv). The flask was evacuated and backfilled with argon. To the mixture was added dry DMSO (39 mL). The reaction mixture was stirred at 90 °C for 24 h. After cooling to room temperature, to the resulting mixture were added ethyl acetate and ammoniacal aqueous NaCl. The mixture was shaken vigorously to dissolve the precipitate, then extracted three times with ethyl acetate. The combined organic extracts were dried over sodium sulfate, filtered, and concentrated under reduced pressure. The crude material was purified by column chromatography to afford *N*-nosylindoline (**5c**) (2.30 g, 7.56 mmol, 97%) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.93 (dd, J=8.2, 1.2 Hz, 1H), 7.68 (td, J=7.6, 1.2 Hz, 1H), 7.61–7.57 (m, 2H), 7.45 (d, J=8.0 Hz, 1H), 7.18 (td, J=8.2, 0.9 Hz, 2H), 7.02 (td, J=7.6, 0.9 Hz, 1H), 4.14 (t, J=7.0 Hz, 2H), 3.07 (t, J=8.4 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.3, 141.0, 134.0, 131.7, 131.6, 131.4, 130.0, 127.7, 125.4, 124.2, 124.1, 114.4, 50.3, 27.9. IR (neat, cm^{-1}): 3095, 2905, 1592, 1543, 1478, 1460, 1440, 1367, 1244, 169, 1126, 1106, 1064, 1028, 981, 851, 745. Anal. Calcd for $C_{14}H_{12}N_2O_4S$: N, 9.21; C, 55.25; H, 3.97. Found: N, 8.99; C, 55.36; H, 4.21.

4.3. General procedure for the catalytic intermolecular aryl amination of iodobenzene and *n*-butylamine

An oven-dried round-bottomed flask was charged with CsOAc (9.66 g, 50.3 mmol, 2.0 equiv) and CuI (478 mg, 2.51 mmol, 10 mol %). The flask was evacuated and backfilled with argon. To the mixture were added iodobenzene (2.80 mL, 25.1 mmol, 1.0 equiv), *n*-$BuNH_2$ (3.73 mL, 37.7 mmol, 1.5 equiv), and dry DMSO (25 mL). The reaction mixture was stirred at 90 °C for 24 h. After cooling to room temperature, to the resulting mixture were added ethyl acetate and ammoniacal aqueous NaCl. The mixture was shaken vigorously to dissolve the precipitate and then extracted twice with ethyl acetate. The combined organic extracts were washed with brine, dried over sodium sulfate, filtered, and concentrated under reduced pressure. The crude material was purified by column chromatography to afford *N*-butylaniline (**14**) (3.34 g, 22.4 mmol, 89%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.17 (t, 2H, J=7.6 Hz), 6.68 (t, 1H, J=7.6 Hz), 6.60 (d, 2H, J=7.6 Hz), 3.57 (br s, 1H), 3.11 (t, 2H, J=7.1 Hz), 1.60 (tt, 2H, J=7.1, 7.1 Hz), 1.43 (tq, 2H, J=7.3, 7.1 Hz), 0.96 (t, 3H, J=7.3 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.5, 129.2, 117.0, 112.7, 43.6, 31.7, 20.3, 13.9. IR (neat, cm^{-1}): 3410, 3052, 3020, 2957, 2930, 2871, 1604, 1506, 1478, 1430, 1321, 1264, 1179, 1153, 992, 867, 748, 692. HRMS-FAB cacld for $C_{10}H_{16}N$ (M^++H), 150.1282; found 150.1283.

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Supplementary data

Detailed experimental procedure containing preparation of substrates and spectroscopic data. Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2008.09.042.

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11. While 1 equiv of CsOAc is theoretically enough to promote the amination as a base, the reaction rate was quite slow with 1 equiv of CsOAc.
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