Synthesis of 1-(1*H*-Indol-3-yl)-1,2-dihydroisoquinolines via AgOTf-Catalyzed Three-Component Reactions of 2-Alkynylbenzaldehydes, Amines, and Indoles

Xingxin Yu[†] and Jie Wu*[,†,‡]

Department of Chemistry, Fudan University, 220 Handan Road, Shanghai 200433, China, and State Key Laboratory of Organometallic Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, 354 Fenglin Road, Shanghai 200032, China

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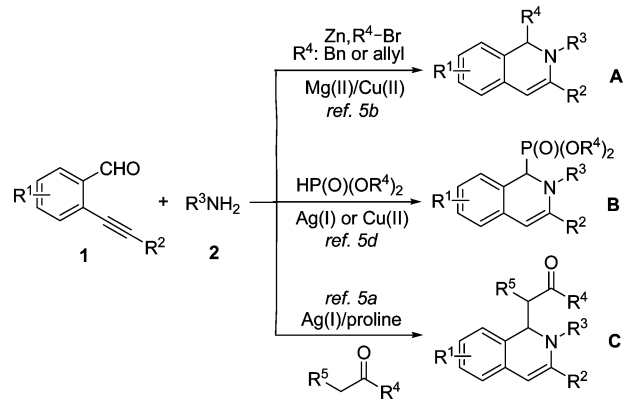
Three-component reactions of 2-alkynylbenzaldehydes, amines, and indoles catalyzed by AgOTf under mild conditions afford the 1-(1*H*-indol-3-yl)-1,2-dihydroisoquinolines in good yields. This silver-catalyzed tandem reaction is found to be workable with various indoles, anilines or alkyl amines, and 2-alkynylbenzaldehydes with electron-withdrawing groups attached on the aromatic backbone.

Introduction

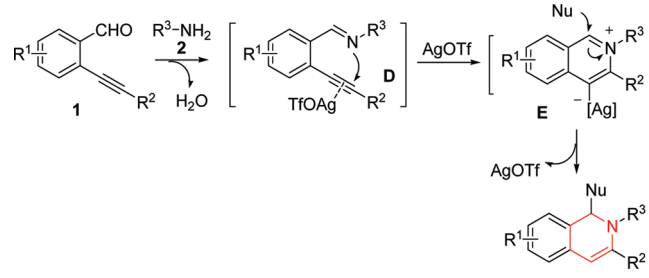
For chemistry to have its maximal effect on biology, it must provide efficient methods for discovering small molecules that are in great demand in the field of chemical genetics.[1] Among the strategies utilized, multicomponent reactions (MCR) have emerged as a powerful tool for delivering the molecular diversity needed in combinatorial approaches for the preparation of bioactive compounds.[2] As a privileged scaffold, the 1,2-dihydroisoquinoline core structure is found in a wide variety of biologically active natural products and pharmaceuticals.[3] The indole skeleton is an important substructure as well in both natural products and therapeutic agents.[4] Recently, we reported a highly efficient and practical approach to functionalized 1,2-dihydroisoquinolines with broad structural diversity, starting from 2-alkynylbenzaldehydes.[5] Its reliability, the ready availability of the starting materials, and the versatility of the resulting products make it a very important process for library generation. Biological screening of a small library of these compounds (Scheme 1) in a PTP1B (protein tyrosine phosphatase) inhibition assay led to the identification of a hit (Compound **B**, IC_{50} 4.68 μM). With an expectation to find more active compounds by evaluation of analogous structures, we conceived that the 1,2-dihydroisoquinoline with an indole substituent might be a good candidate because of the importance of the indole skeleton. Thus, in our ongoing program aimed at developing new approaches to construct natural product-like compounds, we started to explore the methodology for the synthesis of 1,2-isoquinolines with indole substituents.

As described, in our previous reports[5] we disclosed the tandem reactions[6,7] for generation of 1,2-dihydroisoquinoline and related compounds starting from 2-alkynylbenzaldehydes. The key intermediate in the reaction process was believed to be *ortho*-alkynylaryl aldimine **D**.[8−10] After nucleophilic attack of nitrogen on the activated triple bond via 6-*endo* cyclization, iminium **E** would be generated. Subsequent nucleophilic addition would afford the expected *N*-heterocycles (Scheme 2). Prompted by this result and the advancement of multicomponent reactions, we envisioned that in the presence of suitable catalyst, three-component reactions of 2-alkynylbenzaldehyde, amine, and indole would occur via a similar transformation to furnish the desired

Scheme 1. Synthetic Route for the Preparation of Diverse 1,2-Dihydroisoquinolines Screened for PTP1B Activity



Scheme 2. Proposed Mechanism for the Formation of Substituted 1,2-Dihydroisoquinolines



* To whom correspondence should be addressed. E-mail: jie_wu@fudan.edu.cn.
† Fudan University.
‡ Chinese Academy of Sciences.

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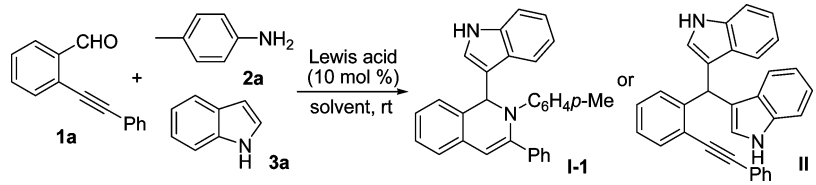
Table 1. Initial Studies for Three-Component Reaction of 2-Alkynylbenzaldehyde **1a**, *p*-Toluidine **2a**, and Indole **3a**[a]



entry	Lewis acid	solvent	additive	product	yield (%)[b]
1	AgOTf	MeCN		**I-1**	58
2	CuI	MeCN		**I-1**	48
3	$Cu(OTf)_2$	MeCN		**I-1**	48
4	$Pd(OAc)_2$	MeCN		**I-1**	46
5	$FeCl_3$	MeCN		**II**	86
6	$Zn(OTf)_2$	MeCN		**II**	82
7	$Yb(OTf)_3$	MeCN		**II**	83
8	$Bi(OTf)_3$	MeCN		**II**	88
9	$Dy(OTf)_3$	MeCN		**II**	85
10	AgOTf	MeCN	4 Å MS	**I-1**	54
11	AgOTf	MeCN	Na_2SO_4	**I-1**	70
12	AgOTf	DCE	Na_2SO_4	**I-1**	68
13	AgOTf	DME	Na_2SO_4	**I-1**	49
14	AgOTf	toluene	Na_2SO_4	**I-1**	54
15	AgOTf	THF	Na_2SO_4	**I-1**	51
16	AgOTf	1,4-dioxane	Na_2SO_4	**I-1**	62
17	AgOTf	DMA	Na_2SO_4	**I-1**	57
18	AgOTf	$CHCl_3$	Na_2SO_4	**I-1**	46
19	AgOTf	CH_2Cl_2	Na_2SO_4	**I-1**	65
20[c]	AgOTf	MeCN	Na_2SO_4	**I-1**	72
21[d]	AgOTf	MeCN	Na_2SO_4	**I-1**	65
22[c,e]	AgOTf	MeCN	Na_2SO_4	**I-1**	72
23[c,f]	AgOTf	MeCN	Na_2SO_4	**I-1**	90

[a] Reaction conditions: 2-alkynylbenzaldehyde **1a** (0.3 mmol), *p*-toluidine **2a** (0.3 mmol, 1.0 equiv), indole **3a** (0.3 mmol, 1.0 equiv), Lewis acid (10 mol %), solvent (2.0 mL), room temperature. [b] Isolated yield based on 2-alkynylbenzaldehyde **1a**. [c] In the presence of 5 mol % of AgOTf. [d] In the presence of 2 mol % of AgOTf. [e] In the presence of 1.5 equiv of indole **3a**. [f] In the presence of 2.0 equiv of indole **3a**.

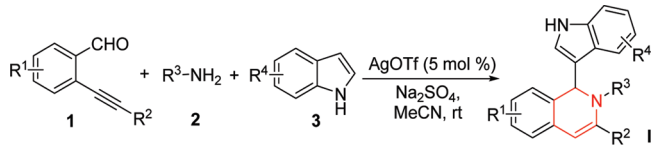
indole-derivatized 1,2-dihydroisoquinolines. Thus, we started to investigate the possibility of this designed transformation.

Result and Discussion

The reaction was initially studied with 2-alkynylbenzaldehyde **1a**, *p*-toluidine **2a**, and indole **3a**, which was selected as a suitable substrate for reaction development. At the outset, different Lewis acids were examined as catalyst in this reaction. To our delight, 58% yield of desired product **I-1** was obtained when the reaction was catalyzed by AgOTf in MeCN at room temperature (Table 1, entry 1). Similar results were observed when CuI, $Cu(OTf)_2$, or $Pd(OAc)_2$ was utilized as a replacement (Table 1, entries 2−4). Interestingly, only double addition adduct **II** was isolated when other Lewis acids were employed (Table 1, entries 5−9).[11] Further extensive studies showed that the yield could be improved when Na_2SO_4 was included as an additive (Table 1, entry 11). Screening of solvents revealed that MeCN and DCE were the best choice in this reaction (Table 1, entries 12−19). The efficiency was not affected when the catalytic amount of AgOTf was reduced to 5 mol % (Table 1, entry 20). Increasing the amount of indole to 2.0 equiv in the transformation afforded the expected product **I-1** in 90% yield (Table 1, entry 23).

To investigate the scope of this three-component reaction, various 2-alkynylbenzaldehydes, amines, and indoles were examined under the optimized conditions [AgOTf (5 mol %), MeCN, room temperature] (Table 2). This silver-catalyzed 1-(1*H*-indol-3-yl)-1,2-dihydroisoquinoline formation was found to be workable with different indoles **3a**-**3g** bearing electron-rich and electron-poor groups attached on the aromatic ring (Table 2, entries 1−7). Thus, 2-alkynylbenzaldehyde **1a** reacted with *p*-toluidine **2a** and 2-methyl indole **3a** leading to the 1-(2-methyl-1*H*-indol-3-yl)-3-phenyl-2-*p*-tolyl-1,2-dihydroisoquinoline **I-2** in 86% yield (Table 2, entry 2). The desired product **I-3** was generated in 80% yield when 4-methoxyindole **3c** was employed as a substrate (Table 2, entry 3). Excellent yields were observed as well when bromo- or nitro-substituted indoles were used in the reaction of 2-alkynylbenzaldehyde **1a** with *p*-toluidine **2a**. Alkyl amine was a suitable partner as well in this transformation. For example, benzyl amine **2b** was utilized in the reaction of 2-alkynylbenzaldehyde **1a** with 6-methoxyindole **3d** instead of *p*-toluidine **2a**, leading to the desired product **I-9** in 43% yield (Table 2, entry 9). Other anilines were tested as well, and all reactions proceeded smoothly to generate the expected products in good yields (Table 2, entries 9−13). Reaction of 2-alkynylbenzaldehyde **1b**, *p*-toluidine **2a**, and 6-methoxyindole **3d** occurred to give rise to the corresponding product **I-15** in 50% yield (Table 2, entry 15). Lower yield was observed when benzyl amine **2b** was employed in the reaction of 2-alkynylbenzaldehyde **1b** with 2-methylindole **3b** (Table 2, entry 16). Meanwhile, fluoro- or chloro-substituted 2-alkynylbenzaldehyde **1c**−**1g** were tested as substrates in the reaction of amines and indoles (Table 2, entries 17−27). As expected, all reactions (including the reaction of benzyl or *n*-octyl amine) worked well to generate the corresponding products in good yields. However, 2-alky-

Table 2. AgOTf-Catalyzed Three-Component Reactions of 2-Alkynylbenzaldehydes, Amines, and Indoles



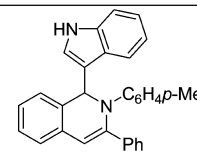
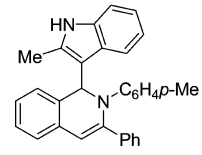
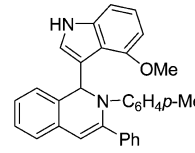
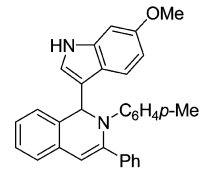
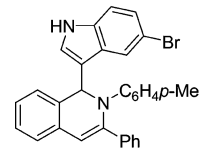
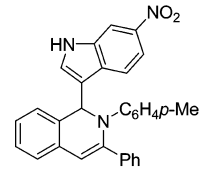
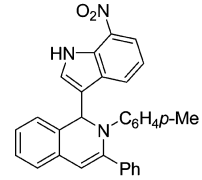
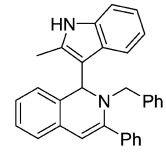
Entry	R^1 / R^2	R^3	R^4	Product / Yield (%)[a]
1	H / Ph (**1a**)	4-MeC_6H_4 (**2a**)	H (**3a**)	 **I-1**: 90% yield
2	H / Ph (**1a**)	4-MeC_6H_4 (**2a**)	2-Me (**3b**)	 **I-2**: 86% yield
3	H / Ph (**1a**)	4-MeC_6H_4 (**2a**)	4-OMe (**3c**)	 **I-3**: 80% yield
4	H / Ph (**1a**)	4-MeC_6H_4 (**2a**)	6-OMe (**3d**)	 **I-4**: 90% yield
5	H / Ph (**1a**)	4-MeC_6H_4 (**2a**)	5-Br (**3e**)	 **I-5**: 93% yield
6	H / Ph (**1a**)	4-MeC_6H_4 (**2a**)	6-NO_2 (**3f**)	 **I-6**: 85% yield
7	H / Ph (**1a**)	4-MeC_6H_4 (**2a**)	7-NO_2 (**3g**)	 **I-7**: 80% yield
8	H / Ph (**1a**)	Bn (**2b**)	2-Me (**3b**)	 **I-8**: 45% yield

Table 2. Continued

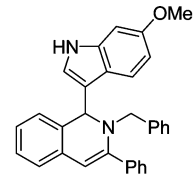
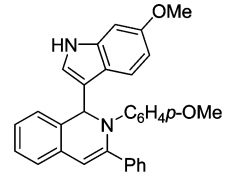
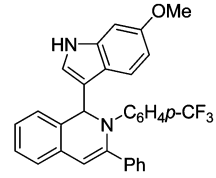
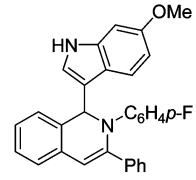
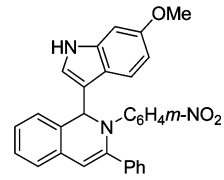
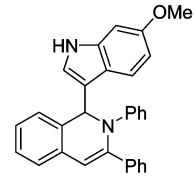
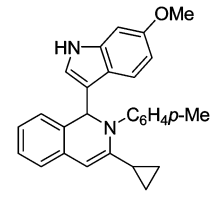
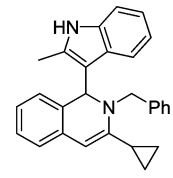
9	H / Ph (**1a**)	Bn (**2b**)	6-OMe (**3d**)	 **I-9**: 43% yield
10	H / Ph (**1a**)	4-MeOC_6H_4 (**2c**)	6-OMe (**3d**)	 **I-10**: 84% yield
11	H / Ph (**1a**)	4-$CF_3C_6H_4$ (**2d**)	6-OMe (**3d**)	 **I-11**: 80% yield
12	H / Ph (**1a**)	4-FC_6H_4 (**2e**)	6-OMe (**3d**)	 **I-12**: 85% yield
13	H / Ph (**1a**)	3-$NO_2C_6H_4$ (**2f**)	6-OMe (**3d**)	 **I-13**: 51% yield
14	H / Ph (**1a**)	C_6H_5 (**2g**)	6-OMe (**3d**)	 **I-14**: 90% yield
15	H / Cyclopropyl (**1b**)	4-MeC_6H_4 (**2a**)	6-OMe (**3d**)	 **I-15**: 50% yield
16	H / Cyclopropyl (**1b**)	Bn (**2b**)	2-Me (**3b**)	 **I-16**: 37% yield

Table 2. Continued

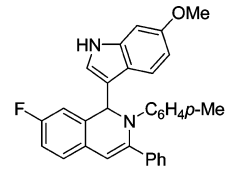
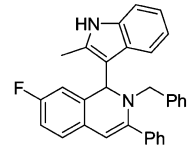
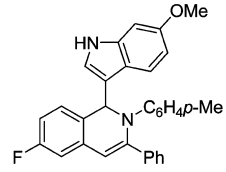
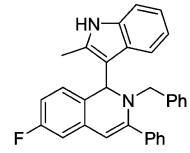
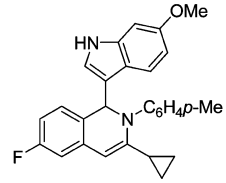
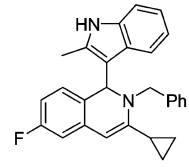
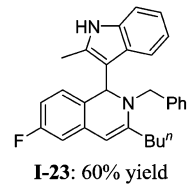
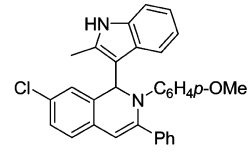
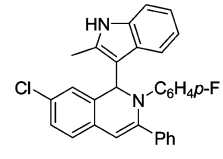
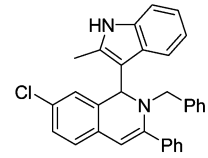
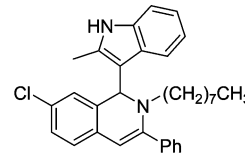
17	5-F / Ph (**1c**)	4-MeC_6H_4 (**2a**)	6-OMe (**3d**)	 **I-17**: 75% yield
18	5-F / Ph (**1c**)	Bn (**2b**)	2-Me (**3b**)	 **I-18**: 52% yield
19	4-F / Ph (**1d**)	4-MeC_6H_4 (**2a**)	6-OMe (**3d**)	 **I-19**: 92% yield
20	4-F / Ph (**1d**)	Bn (**2b**)	2-Me (**3b**)	 **I-20**: 70% yield
21	4-F / Cyclopropyl (**1e**)	4-MeC_6H_4 (**2a**)	6-OMe (**3d**)	 **I-21**: 48% yield
22	4-F / Cyclopropyl (**1e**)	Bn (**2b**)	2-Me (**3b**)	 **I-22**: 53% yield
23	4-F / ^{n}Bu (**1f**)	Bn (**2b**)	2-Me (**3b**)	 **I-23**: 60% yield
24	5-Cl / Ph (**1g**)	4-$MeOC_6H_4$ (**2c**)	2-Me (**3b**)	 **I-24**: 78% yield
25	5-Cl / Ph (**1g**)	4-FC_6H_4 (**2e**)	2-Me (**3b**)	 **I-25**: 68% yield

Table 2. Continued

26	5-Cl / Ph (**1g**)	Bn (**2b**)	2-Me (**3b**)	 **I-26**: 61% yield
27	5-Cl / Ph (**1g**)	$^{n}C_8H_{17}$ (**2b**)	2-Me (**3b**)	 **I-27**: 60% yield
28	4,5-$(OMe)_2$ / *n*-Bu (**1h**)	4-MeC_6H_4 (**2a**)	6-OMe (**3d**)	-

[a] Isolated yield based on 2-alkynylbenzaldehyde **1**.

nylbenzaldehyde with an electron-donating group attached on the aromatic ring (such as compound **1h**) has not been workable as a substrate in the transformation, which might be due to the lower electrophilicity toward nucleophilic attack (Table 2, entry 28).

Conclusion

In summary, we have described an efficient method for the synthesis of 1-(1*H*-indol-3-yl)-1,2-dihydroisoquinolines via AgOTf-catalyzed three-component reactions of 2-alkynylbenzaldehydes, amines, and indoles. This silver-catalyzed 1-(1*H*-indol-3-yl)-1,2-dihydroisoquinoline formation is found to be workable with different indoles bearing electron-rich and electron-poor groups attached on the aromatic ring. Anilines and alkyl amines are also suitable partners in the transformation. However, 2-alkynylbenzaldehyde with an electron-donating group attached on the aromatic backbone is not workable as a substrate, which might be due to the lower electrophilicity toward nucleophilic attack. We believe the mild reaction conditions combined with the efficiency of this synthetic route would be attractive and beneficial for indole-derivatized 1,2-dihydroisoquinoline small library construction.

Experimental Section

General Procedure for AgOTf-Catalyzed Three-Component Reactions of 2-Alkynylbenzaldehyde 1, Amine 2, and Indole 3. Indole **3** (1.0 mmol, 2.0 equiv) and AgOTf (0.025 mmol, 5 mol %) were added to a mixture of 2-alkynylbenzaldehyde **1** (0.5 mmol), amine **2** (0.5 mmol, 1.0 equiv), and Na_2SO_4 (1.0 mmol, 2.0 equiv) in MeCN (2.0 mL). The reaction mixture was stirred at room temperature vigorously until completion of the reaction. Subsequently, the mixture was diluted with ethyl acetate (5.0 mL), and quenched with water (5.0 mL). The organic layer was washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by column chromatography on silica gel (eluting with PE/EA = 30/1 to 5/1) to provide the desired product **I**. Data of selected example: 1-(1*H*-Indol-3-yl)-3-phenyl-2-*p*-tolyl-1,2-dihydroisoquinoline (**I-1**), ^{1}H NMR (400 MHz, $CDCl_3$): 2.16 (s, 3H), 6.36 (s, 1H), 6.59 (s, 1H), 6.68 (s, 1H), 6.90 (d, J = 8.2 Hz, 2H), 6.98 (d, J = 8.2 Hz, 2H), 7.09−7.26 (m, 10H), 7.49 (d, J = 7.8 Hz, 2H), 7.84 (br, 1H), 8.11 (d, J = 8.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.7, 61.7, 111.5, 112.1, 118.7, 119.4, 119.7, 122.0, 123.3, 124.5, 125.7, 126.0, 126.4, 127.3, 127.7, 127.8, 128.3, 129.3, 131.1, 132.2, 136.5, 138.1, 141.7, 145.1; HRMS calcd for $C_{30}H_{24}N_2$ (M^+ − H): 411.1861, found: 411.1883.

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Supporting Information Available. Experimental procedures, characterization data, ^{1}H and ^{13}C NMR spectra of compound **I**. This material is available free of charge via the Internet at http://pubs.acs.org.

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