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ARTICLE

A concise approach to the indoles via oxidative C–H amination of 2-alkenylanilines using dioxygen as the sole oxidant

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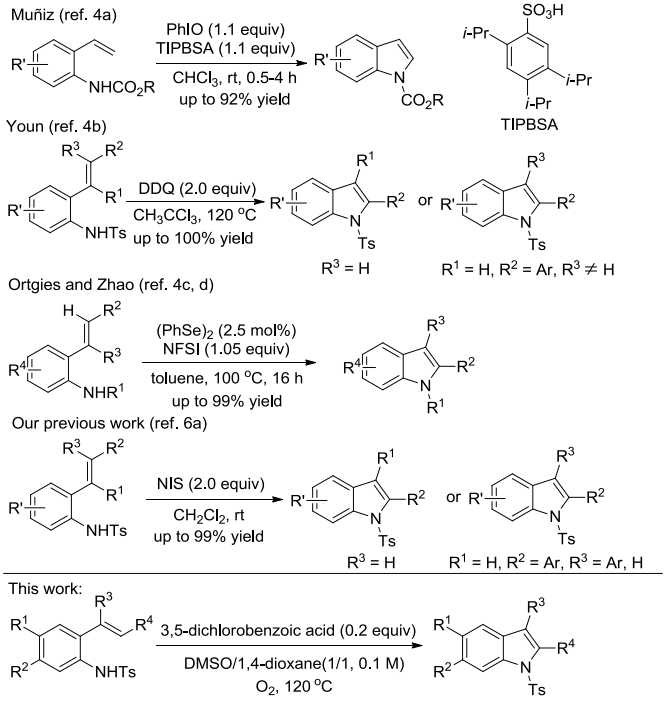
A novel synthetic method to prepare indole derivatives from *N*-Ts-2-alkenylanilines has been achieved. This reaction through an oxidative intramolecular C-H amination by using molecular oxygen as sole oxidant. This protocol is operationally simple and environmental friendly, and provides a diverse range of substrate scope.

Introduction

Indoles are important and valuable heterocycles because their wide application in chemistry, biology, and material sciences.[1] Therefore the synthesis of indole derivatives have long been of great interest in organic synthesis.[2] A great number of superior methods have been established, and a large portion of these methods employ transition metal catalysts.[3] These protocols are efficient and have been widely applied in organic synthesis. While to be more friendly to the environment and economic, developing a metal-free methodology to prepare indole derivatives is an attractive goal.[4]

The intramolecular amination reaction of alkenes is a direct approach to indole synthesis and these approaches are known in the literature.[5] The different oxidants were utilized for the metal-free version (Scheme 1), for example, Muñiz reported a sulfonic acid-catalyzed synthesis of indoles using iodosobenzene as the oxidant.[4a] Later on, Youn reported a synthesis of indoles through oxidative C–H amination of 2-alkenylanilines by 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) at 120 °C.[4b] Recently, Ortgies and Zhao successively demonstrated the protocols involving the use *N*-fluorobenzenesulfonimide as the terminal oxidant catalyzed by selenium via the intramolecular amination of C(sp^2)-H bonds.[4c, d] Our laboratory is engaged in developing transition-metal-free methods for the synthesis of heterocycles, especially through new C–N, C–O bond formation.[6] Although we have achieved the synthesis of indoles by *N*-Iodosuccinimide (NIS) mediated cascade C-N bond formation/aromatization of 2-alkenylanilines under temperate conditions,[6a] we became interested in the design of the novel method to replace these oxidants by more environmentally friendly and economical reagent. Since dioxygen is very cheap and produces no environmentally hazardous byproduct, and has been extensively applied in organic synthesis.[7] Consequently we wish to communicate here our success in achieving the practical and novel synthesis of indole derivatives using molecular oxygen as the terminal oxidant.



Scheme 1: Metal-free indole synthesis from 2-alkenylanilines.

Results and discussion

We began our investigation with the anilide **1a** as the model substrate to search for the optimal reaction conditions (Table 1). First, we evaluated the solvent effect on this reaction. Various solvents were tested, only dimethyl sulfoxide (DMSO) and 1,4-dioxane showed relatively high yield (Table 1, entries 1, 2).

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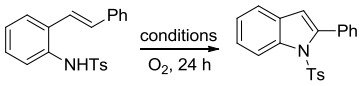
Table 1. Optimization of reaction conditions[a]



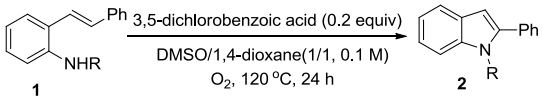
1a 2a

Entry	Reagent (0.2 equiv)	Solvent	Yield (%)[b]
1	—	1,4-dioxane	30
2	—	DMSO	22
3	—	toluene	<10
4	—	THF	0
5	—	$ClCH_2CH_2Cl$	<10
6	—	CCl_4	<10
7	—	$HOCH_2CH_2OH$	15
8	—	EtOH	<10
9	—	DMSO/1,4-dioxane	32
10	K_2CO_3	DMSO/1,4-dioxane	0
11	*t*-BuONa	DMSO/1,4-dioxane	0
12	CH_3COOH	DMSO/1,4-dioxane	44
13	TsOH	DMSO/1,4-dioxane	50
14	benzoic acid	DMSO/1,4-dioxane	58
15	3-chlorobenzoic acid	DMSO/1,4-dioxane	61
16	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	73
17	3,5-difluorobenzoic acid	DMSO/1,4-dioxane	58
18[c]	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	61
19[d]	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	37
20[e]	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	46
21[f]	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	ND
22[g]	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	20
23[h]	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	47
24[i]	3,5-dichlorobenzoic acid	DMSO/1,4-dioxane	29

[a]Reaction conditions: **1a** (0.1 mmol), additive (0.2 equiv), solvent (1.0 mL), 120 °C under O_2 (balloon). [b]Isolated yield, ND = Not detected. [c]DMSO/Dioxane (3:7). [d]DMSO/1,4-dioxane (7:3) [e]Using 1.0 equiv additive. [f]At 100 ° C. [g]At 150 ° C. [h]0.05 M. [i]0.15 M.

Combination of these two solvents and gratifyingly provided a higher yield (Table 1, entry 9). Next, we then turned our attention to screen the additives. When the benzoic acid as additive for this reaction, the corresponding indole was obtained in good yield (Table 1, entry 14), however, poorer yields were obtained when we use acetic acid and *p*-toluenesulfonic acid (Table 1, entries 12, 13). Base such as potassium carbonate and sodium *tert*-butoxide proved to be ineffective for this transformation and resulted in no reaction (Table 1, entries 10, 11). Subsequently, we examined benzoic acid derivatives and delightfully find that the 3,5-dichlorobenzoic acid appeared preferable with regard to product yield (Table 1, entry 16). We attempted to increase the amount of 3,5-dichlorobenzoic acid to 1 equiv and it led to decrease the yield to 46% (Table 1, entry 20). We changed the ratio of DMSO and 1,4-dioxane, and the yield is decreasing (Table 1, entries 18, 19). Alteration of key operating parameters was also examined, e.g., neither lower nor raise the temperature could increase the yield (Table 1, entries 21, 22). Last but not the least, we examined the concentration of this reaction and it turned out the 0.1 M is appropriate (Table 1, entries 23, 24). After all above experiments, the optimal conditions for the synthesis of indole derivatives using molecular oxygen as the sole oxidant were established [0.2 equiv 3,5-dichlorobenzoic acid, DMSO/1,4-dioxane (1/1, 0.1 M), O_2, 120 °C].

Table 2. Effects of protecting groups[a]



1 2

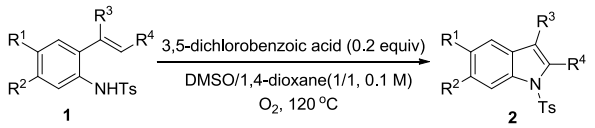
Entry	R	Yield (%)[b]
1	Ts (**1a**)	73 (**2a**)
2	$C_6H_5SO_2$ (**1b**)	11 (**2b**)
3	*p*-$ClC_6H_4SO_2$ (**1c**)	44 (**2c**)
4	*p*-$NO_2C_6H_4SO_2$ (**1d**)	25 (**2d**)
5	*p*-$MeOC_6H_4SO_2$ (**1e**)	Trace
6	Ms (**1f**)	63 (**2f**)
7	Ac (**1g**)	ND
8	Cbz (**1h**)	Trace
9	H (**1i**)	ND

[a]Reaction conditions: Substrate **1** (0.1 mmol), 3,5-dichlorobenzoic acid (0.2 equiv), DMSO/1,4-dioxane (1:1, 1.0 mL), 120 °C under O_2 (balloon), 24 h. [b]Isolated yield. ND = Not detected.

With optimized conditions in hand, a brief survey of the effect of *N*-protecting groups including sulfonyl (entries 1-6), acyl (entry 7) reconfirmed the effectiveness of *p*-toluenesulfonyl as the preferred group for this reaction (Table 2). These observations proved that the pK_a of the N-H units plays a significant role in the reaction.

To probe the flexibility of this methodology, we proceeded to explore the substituent effect at the alkene moiety (Table 3, entries 1-14). We tested the substrates with various *ortho-, meta-* and *para-,* substitution on the phenyl ring at the alkene moiety. The results reveal that there is a certain influence on the substitution pattern of the substituent on the phenyl ring of the substrates. The electron-donating

Table 3. Scope of 2-alkenylanilines[a]



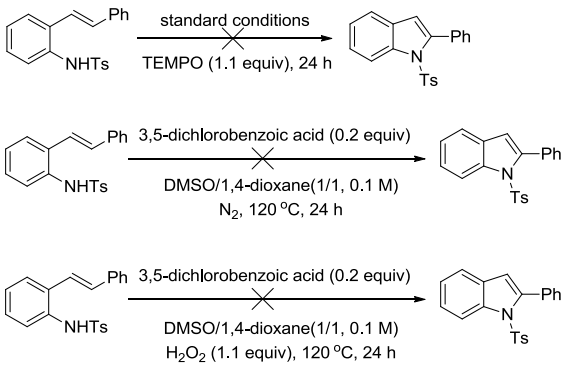
Entry	R^1	R^2	R^3	R^4	Time (h)	Yield (%)[b]
1	H	H	H	Ph(**1a**)	24	73(**2a**)
2	H	H	H	2-MeC_6H_4(**1j**)	36	70(**2j**)
3	H	H	H	3-MeC_6H_4(**1k**)	36	50(**2k**)
4	H	H	H	4-MeC_6H_4(**1l**)	24	64(**2l**)
5	H	H	H	2-$MeOC_6H_4$(**1m**)	24	69(**2m**)
6	H	H	H	3-$MeOC_6H_4$(**1n**)	24	45(**2n**)
7	H	H	H	4-$MeOC_6H_4$(**1o**)	5	72(**2o**)
8	H	H	H	4-*tert*-ButylC_6H_4(**1p**)	24	53(**2p**)
9	H	H	H	cyclopropyl (**1q**)	36	51(**2q**)
10	H	H	H	2-naphthyl(**1r**)	17	76(**2r**)
11	H	H	H	H(**1s**)	48	37(**2s**)
12	H	H	H	4-FC_6H_4(**1t**)	36	44(**2t**)
13	H	H	H	4-ClC_6H_4(**1u**)	36	36(**2u**)
14	H	H	H	4-$NO_2C_6H_4$(**1v**)	48	ND
15	Me	H	H	Ph(**1w**)	48	55(**2w**)
16	MeO	H	H	Ph(**1x**)	36	64(**2x**)
17	F	H	H	Ph(**1y**)	36	50(**2y**)
18	Cl	H	H	Ph(**1z**)	36	47(**2z**)
19	CF_3	H	H	Ph(**1aa**)	36	36(**2aa**)
20	H	F	H	Ph(**1ab**)	24	30(**2ab**)
21	H	Cl	H	Ph(**1ac**)	36	37(**2ac**)
22	Me	H	H	4-MeC_6H_4(**1ad**)	48	64(**2ad**)
23	CF_3	H	H	4-MeC_6H_4(**1ae**)	36	32(**2ae**)

[a]Reaction conditions: Substrate **1** (0.1 mmol), 3,5-dichlorobenzoic acid (0.2 equiv), DMSO/1,4-dioxane (1:1, 1.0 mL), 120 °C under O_2 (balloon). [b]Isolated yield. ND = Not detected.

groups at different positions furnished the corresponding products in moderate to good yields. For example, substrates with a methyl or methoxyl group at *ortho-, meta-* and *para-*substitution on the phenyl ring provided the desired products with 45-72% yields (Table 3, entries 2-7). Both *tert*-butylbenzene alkene and cyclopropyl alkene only can obtain about 50% yields (Table 3, entries 8, 9). The alkene without any substitutions is also suitable under the reaction conditions (Table 3, entry 11). It is noted that the naphthyl alkene formed the desired product in best yield (76% yield, Table 3, entry 10). While the electron-withdrawing groups at different positions obtained the corresponding products in lower yields. Such as substrates with F, Cl substituents on the phenyl ring provided the desired products in 44% and 36% yields respectively (Table 3, entries 12, 13). When the substrates with NO_2 on the phenyl ring, the target products cannot be formed (Table 3, entry 14). This result was probably caused by the strong electron-withdrawing characteristic of the nitro group.

Subsequently we also investigated the effect of the substitution pattern of aniline. As shown in Table 3 (entries 15-23), the reaction exhibited poor tolerance to various substituents on the aromatic ring. Substituents (R^1) residing on the aromatic moiety of *N*-Ts-2-styrylanilines showed fair yields. When it is electron-donating group, the reaction took place smoothly to provide the desired indoles in better yields (Table 3, entries 15, 16). When it is electron-withdrawing group such as F, Cl and CF_3, the lower yields were obtained (Table 3, entries 17-19). The substituents (R^2) residing on the aromatic moiety of *N*-Ts-2-styrylanilines showed relatively lower yields (Table 3, entries 20, 21). Apparently, this reaction is affected by the position of the substituents on the aromatic ring of anilines. We then tested substrates with two substituents on the aromatic ring of the alkene and aniline. When both of them are electron-donating group, the reaction took place smoothly to provide a higher yield than electron-withdrawing group was involved (Table 3, entries 22, 23).

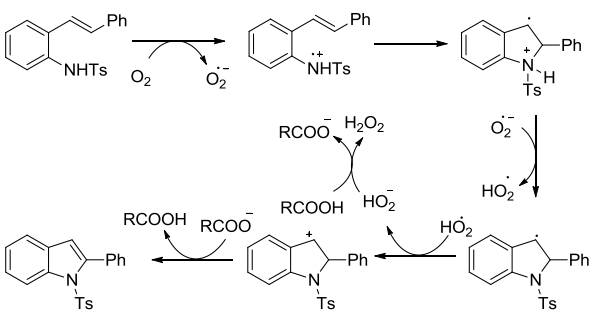
After successfully synthesized a series of Indole derivatives by oxidative C–H amination of 2-alkenylanilines. To gain more insight about the mechanism of above reaction, several control experiments were conducted (Scheme 2). First, TEMPO as a radical scavenger was added into the reaction with optimized conditions. However, there is no desired product was obtained only recovered the starting material. The fact might suggest a radical initiation pathway. Furthermore, this oxidation was completely inhibited under nitrogen. A control study using hydrogen peroxide as the oxidant did not lead to the desired indole. This result indicates that the reaction is not mediated by hydrogen peroxide.



Scheme 2. Control experiments.

Although the reaction mechanism has not been fully established at the present stage,[8,9] a plausible mechanism for this reaction was outlined in Scheme 3. Under thermal condition, anilide was oxidized into nitrogen radical cation by singlet oxygen, then electrophilic addition of this radical cation to alkene to generate benzylic radical, which was oxidated to its corresponding benzylic cation. During this process, 3,5-

dichlorobenzoate anion was formed and it can assist the following aromatization to provide the product.



Scheme 3. A proposed mechanistic pathway.

Conclusions

In conclusion, we have demonstrated a synthetic method to prepare the indole derivatives via an oxidative intramolecular C-H amination of 2-alkenylanilines by using molecular oxygen as sole oxidant. In comparison to other oxidants mediated reactions, this method was an environmentally friendly process. Furthermore, our discovery provides a possibility to design more new reactions in the field of aerobic oxidation of alkene.

Experimental

General Information

All reactions were performed in standard glassware. Solvents were distilled prior to use. All commercially available reagents were used as purchased without further purification. ^{1}H and ^{13}C NMR spectra were obtained on 600 MHz (150 MHz for ^{13}C NMR) spectrometer at 25 °C, using $CDCl_3$ with TMS or residual solvent as standard unless otherwise noted. Chemical-shift values were given in ppm and referenced to the internal standard TMS (tetramethylsilane). The peak patterns are indicated as follows: s, singlet; d, doublet; t, triplet; q, quadruplet; m, multiplet; dd, doublet of doublets, and br s, broad singlet. The coupling constants (*J*) are reported in hertz (Hz). Melting points were determined with a micromelting point apparatus without corrections. High-resolution mass spectrometry (HRMS) was obtained on a Q-TOF microspectrometer. Flash column chromatography was performed over silica gel 200–300 mesh.

General Procedure for the Indole Synthesis.

To a solution of substrate (0.1 mmol) in DMSO/1,4-dixoane (1:1, 1.0 mL) was added 3,5-dichlorobenzoic acid (4 mg, 0.02 mmol) under oxygen (balloon). The resulting mixture was stirred at 120 °C for the reported time, and then the mixture was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel to give the corresponding product.

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***N*-Ts-2-Phenylindole (2a).**[4b] White solid, mp: 145-148 °C (Lit. 142-144 °C); R_f = 0.59 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.27 (s, 3H), 6.54 (s, 1H), 7.03 (d, *J* = 7.8 Hz, 2H), 7.27 (d, *J* = 7.7 Hz, 3H), 7.35 (t, *J* = 7.7 Hz, 1H), 7.43 - 7.44 (m, 4H), 7.49 - 7.50 (m, 2H), 8.31 (d, *J* = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 113.6, 116.6, 120.7, 124.3, 124.8, 126.8, 127.5, 128.6, 129.2, 130.3, 130.5, 132.4, 134.6, 138.2, 142.1, 144.5; HRMS (ESI): m/z calcd for $C_{21}H_{17}NO_2S$ (M+Na)$^+$ 370.0878, found 370.0891.

***N*-(Benzenesulfonyl)-2-Phenylindole (2b).** [4b] White solid, mp: 91-93 °C (Lit. 98-101 °C); R_f = 0.42 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.53 (s, 1H), 7.23 (t, *J* = 7.8 Hz, 2H), 7.27 (d, *J* = 7.2 Hz, 1H), 7.34 - 7.49 (m, 10H), 8.32 (d, *J* = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 112.7, 115.6, 119.7, 123.4, 123.8, 125.7, 126.5, 127.5, 127.7, 129.3, 129.5, 131.3, 132.5, 137.5, 139.2, 142.1; HRMS (ESI): m/z calcd for $C_{20}H_{15}NO_2S$ (M+Na)$^+$ 356.0721, found 356.0729.

***N*-(4-Chlorophenylsulfonyl)-2-phenylindole (2c).**[4b] White solid, mp: 155-157 °C (Lit. 152-158 °C); R_f = 0.59 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.56 (s, 1H), 7.21 (d, *J* = 9.0 Hz, 2H), 7.27 (d, *J* = 8.4 Hz, 3H), 7.36 (t, *J* = 7.8 Hz, 1H), 7.42 - 7.49 (m, 6H), 8.29 (d, *J* = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 113.1, 115.7, 119.9, 123.7, 124.0, 126.6, 127.2, 127.8, 127.9, 129.2, 129.6, 131.1, 134.7, 137.2, 139.2, 141.0; HRMS (ESI): m/z calcd for $C_{20}H_{14}ClNO_2S$ (M+Na)$^+$ 390.0331, found 390.0333.

***N*-Ns-2-phenylindole (2d).**[4b] Light yellow solid, mp: 142-144 °C (Lit. 140-147 °C); R_f = 0.37 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.60 (s, 1H), 7.30 (t, *J* = 7.2 Hz, 1H), 7.39 (t, *J* = 8.4 Hz, 1H), 7.44 - 7.50 (m, 6H), 7.53 (d, *J* = 9.0 Hz, 1H), 8.08 (d, *J* = 9.0 Hz, 2H), 8.29 (d, *J* = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 114.8, 116.7, 121.2, 123.8, 125.2, 125.4, 127.8, 128.1, 129.1, 130.2, 130.8, 131.7, 138.1, 141.9, 142.3, 150.4; HRMS (ESI): m/z calcd for $C_{20}H_{14}N_2O_4S$ (M+Na)$^+$ 401.0572, found 401.0581.

***N*-Ms-2-Phenylindole (2f).**[4b] White solid, mp: 100-102 °C (Lit. 107-108 °C); R_f = 0.38 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.71 (s, 3H), 6.70 (s, 1H), 7.35 (t, *J* = 7.4 Hz, 1H), 7.38 (t, *J* = 7.6 Hz, 1H), 7.41 - 7.42 (m, 3H), 7.54 - 7.55 (m, 2H), 7.59 (d, *J* = 7.4 Hz, 1H), 8.12 (d, *J* = 8.2 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 38.4, 112.0, 114.8, 120.0, 123.5, 124.1, 126.7, 127.9, 129.1, 129.3, 131.0, 137.0, 141.0; HRMS (ESI): m/z calcd for $C_{15}H_{13}NO_2S$ (M+Na)$^+$ 294.0565, found 294.0570.

***N*-Ts-2-*o*-Tolylindole (2j).**[4b] White solid, mp: 90-92 °C (Lit. 82-89 °C); R_f = 0.54 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.21 (s, 3H), 2.31 (s, 3H), 6.46 (s, 1H), 7.08 - 7.10 (m, 3H), 7.20 (t, *J* = 7.4 Hz, 1H), 7.27 (t, *J* = 8.1 Hz, 2H), 7.35 - 7.37 (m, 4H), 7.49 (d, *J* = 7.6 Hz, 1H), 8.33 (d, *J* = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 19.5, 20.5, 111.3, 114.7, 119.6, 122.8, 123.5, 123.6, 125.9, 128.1, 128.3, 128.6, 129.0, 129.8, 131.1, 134.6, 136.3, 138.3, 139.3, 143.6; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_2S$ (M+Na)$^+$ 384.1034, found 384.1049.

***N*-Ts-2-*m*-Tolylindole (2k).**[4b] White solid, mp: 144-147 °C (Lit. 140-144 °C); R_f = 0.43 (10% EtOAc/Petroleum Ether); ^{1}H NMR

(600 MHz, $CDCl_3$) δ 2.28 (s, 3H), 2.41 (s, 3H), 6.52 (s, 1H), 7.03 (d, J = 7.7 Hz, 2H), 7.24 - 7.30 (m, 7H), 7.34 (t, J = 8.0 Hz, 1H), 7.43 (d, J = 7.6 Hz, 1H), 8.30 (d, J = 8.3 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 21.4, 21.6, 113.4, 116.6, 120.7, 124.3, 124.7, 126.8, 127.4, 129.1, 129.4, 130.5, 131.1, 132.3, 134.7, 137.0, 138.2, 142.3, 144.5; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_2S$ $(M+Na)^+$ 384.1034, found 384.1016.

***N*-Ts-2-*p*-Tolylindole (2l).**[4b] White solid, mp: 98-101 °C (Lit. 99-103 °C); R_f = 0.46 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.27 (s, 3H), 2.43 (s, 3H), 6.50 (s, 1H), 7.04 (d, J = 7.7 Hz, 2H), 7.23-7.28 (m, 5H), 7.33 (t, J = 7.7 Hz, 1H), 7.40 (t, J = 8.9 Hz, 3H), 8.30 (d, J = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.4, 21.5, 113.3, 116.7, 120.6, 124.3, 124.6, 126.8, 128.3, 129.2, 129.5, 130.2, 130.7, 134.7, 138.2, 138.6, 142.3, 144.4; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_2S$ $(M+Na)^+$ 384.1034, found 384.1024.

***N*-Ts-2-(2-Methoxyphenyl)indole (2m).**[4b] White solid, mp: 72-75 °C(Lit. 77-80 °C); R_f = 0.50 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.29 (s, 3H), 3.77 (s, 3H), 6.53 (s, 1H), 6.95 (d, J = 8.2 Hz, 1H), 6.99 (t, J = 7.3 Hz, 1H), 7.07 (d, J = 7.9 Hz, 2H), 7.20 - 7.24 (m, 2H), 7.31 (t, J = 7.7 Hz, 1H), 7.39 (d, J = 7.8 Hz, 2H), 7.43 (t, J = 7.9 Hz, 1H), 7.47 (d, J = 7.7 Hz, 1H), 8.22 (d, J = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 55.5, 110.5, 112.4, 115.6, 119.6, 120.7, 121.9, 123.6, 124.4, 126.8, 129.2, 130.2, 130.6, 131.8, 135.8, 137.4, 138.0, 144.3, 158.6; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_3S$ $(M+Na)^+$ 400.0983, found 400.0978.

***N*-Ts-2-(3-Methoxyphenyl)indole (2n).**[4b] White solid, mp: 100-102 °C (Lit. 98-104 °C); R_f = 0.46 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.27 (s, 3H), 3.85 (s, 3H), 6.54 (s, 1H), 6.99 (dd, J = 8.2 Hz, 1H), 7.04 (d, J = 8.4 Hz, 3H), 7.09 (d, J = 7.4 Hz, 1H), 7.25 - 7.36 (m, 5H), 7.44 (d, J = 7.7 Hz, 1H), 8.31 (d, J = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.2, 55.0, 113.3, 114.2, 115.6, 116.4, 120.4, 122.5, 124.0, 124.5, 126.5, 128.2, 128.9, 130.2, 133.3, 134.3, 138.0, 141.6, 144.2, 158.4; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_3S$ $(M+Na)^+$ 400.0983, found 400.0982.

***N*-Ts-2-(4-Methoxyphenyl)indole (2o).**[4b] White solid, mp: 131-133 °C (Lit. 126-128 °C); R_f = 0.42 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.27 (s, 3H), 3.88 (s, 3H), 6.47 (s, 1H), 6.94 (d, J = 7.74 Hz, 2H), 7.03 (d, J = 7.4 Hz, 2H), 7.25 - 7.26(m, 3H), 7.32 (t, J = 7.3 Hz, 1H), 7.41 (d, J = 7.5 Hz, 3H), 8.30 (d, J = 8.1 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 20.5, 55.3, 111.9, 112.0, 115.7, 119.4, 123.2, 123.5, 123.7, 125.7, 128.1, 129.6, 130.6, 133.6, 137.1, 141.0, 143.4, 16059.0; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_3S$ $(M+Na)^+$ 400.0983, found 400.0981.

***N*-Ts-2-*p*-tert-butylindole (2p).**[6a] White solid, mp: 140-143 °C (Lit. 139-143 °C); R_f = 0.71 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.39 (s, 9H), 2.28 (s, 3H), 6.50 (s, 1H), 7.01 (d, J = 7.8 Hz, 2H), 7.23 - 7.27 (m, 3H), 7.33 (t, J = 7.8 Hz, 1H), 7.41 - 7.42 (m, 5H), 8.30 (d, J = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 31.4, 34.7, 113.3, 116.7, 120.6, 124.2, 124.4, 124.6, 126.8, 129.1, 129.4, 130.0, 130.6, 134.7, 138.3, 142.3, 144.4, 151.7; HRMS (ESI): m/z calcd for $C_{25}H_{25}NO_2S$ $(M+Na)^+$ 426.1504, found 426.1503.

***N*-Ts-2-Cyclopropylindole (2q).**[6b] light yellow oil. R_f = 0.43 (5% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.59 (d, J = 5.1 Hz, 2H), 0.95 (d, J = 8.0 Hz, 2H), 2.34 (s, 2H), 2.42 - 2.46 (m, 1H), 6.17 (s, 1H), 7.19 - 7.20 (m, 3H), 7.25 (t, J = 7.6 Hz, 1H), 7.38 (d, J = 7.6 Hz, 1H), 7.71 (d, J = 7.8 Hz, 2H), 8.21 (d, J = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 7.33 8.40, 20.5, 105.0, 113.5, 119.1, 122.3, 122.8, 125.6, 128.2, 128.6, 135.5, 136.3, 143.0, 143.5; HRMS (ESI): m/z calcd for $C_{18}H_{18}NO_2S$ $(M+H)^+$ 312.1058, found 312.1049.

***N*-Ts-2-(1-Naphthyl)indole (2r).**[4b] White solid, mp: 139-143 °C (Lit. 138-142 °C); R_f = 0.45 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.25 (s, 3H), 6.65 (s, 1H), 6.96 (d, J = 7.8 Hz, 2H), 7.25 (d, J = 8.1 Hz, 2H), 7.31 (t, J = 7.4 Hz, 2H), 7.40 - 7.46 (m, 3H), 7.51 (t, J = 7.7Hz, 1H), 7.54 (d, J = 7.7 Hz, 1H), 7.64 (d, J = 8.3 Hz, 1H), 7.87 (d, J = 8.2 Hz, 1H), 7.95 (d, J = 8.2 Hz, 1H), 8.40 (d, J = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 113.7, 115.8, 120.8, 123.9, 124.4, 124.8, 125.8, 126.1, 126.2, 126.9, 128.0, 129.3, 129.4, 129.5, 129.8, 130.0, 133.0, 133.4, 135.3, 137.6, 138.8, 144.5; HRMS (ESI): m/z calcd for $C_{25}H_{19}NO_2S$ $(M+Na)^+$ 420.1034, found 420.1035.

***N*-Ts-Indole (2s).**[4b] White solid, mp: 57-60 °C (Lit. 68-71 °C); R_f = 0.45 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.33 (s, 3H), 6.65 (d, J = 2.9 Hz, 1H), 7.20 - 7.28 (m, 3H), 7.30 (t, J = 7.7 Hz, 1H), 7.52 (d, J = 7.6 Hz, 1H), 7.56 (d, J = 3.0 Hz, 1H), 7.76 (d, J = 7.9 Hz, 2H), 7.99 (d, J = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 20.5, 108.0, 112.5, 120.3, 122.2, 123.5, 125.3, 125.8, 128.8, 129.7, 133.8, 134.3, 143.9; HRMS (ESI): m/z calcd for $C_{15}H_{13}NO_2S$ $(M+Na)^+$ 294.0565, found 294.0598.

***N*-Ts-2-(4-Fluorophenyl)indole (2t).**[6a] White solid, mp: 130-132 °C (Lit. 134-137 °C); R_f = 0.62 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.28 (s, 3H), 6.52 (s, 1H), 7.04 (d, J = 7.8 Hz, 2H), 7.10 (t, J = 8.3 Hz, 2H), 7.24 - 7.27 (m, 3H), 7.35 (t, J = 7.7 Hz, 1H), 7.43 - 7.46 (m, 3H), 8.31 (d, J = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 113.6, 114.5 (d, J = 21.7 Hz), 116.6, 120.7, 124.4, 124.9, 126.7, 128.4 (d, J = 3.2 Hz), 129.3, 130.4, 132.1 (d, J = 8.2 Hz), 134.7, 138.2, 140.9, 144.7, 163.9 (d, J = 247 Hz); HRMS (ESI): m/z calcd for $C_{21}H_{16}FNO_2S$ $(M+Na)^+$ 388.0783, found 388.0776.

***N*-Ts-2-(4-Chlorophenyl)indole (2u).**[4b] Light yellow solid, mp: 134-137 °C (Lit. 133-135 °C); R_f = 0.61 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.29 (s, 3H), 6.54 (s, 1H), 7.06 (d, J = 7.7 Hz, 2H), 7.26 (d, J = 5.1 Hz, 3H), 7.35 - 7.40 (m, 3H), 7.44 (d, J = 7.8 Hz, 3H), 8.30 (d, J = 8.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 20.5, 113.0, 115.7, 119.8, 123.4, 124.0, 125.7, 126.8, 128.2, 129.4, 129.8, 130.5, 133.5, 133.8, 137.3, 139.8, 143.7; HRMS (ESI): m/z calcd for $C_{21}H_{16}ClNO_2S$ $(M+Na)^+$ 404.0488, found 404.0488.

***N*-Ts-5-Methyl-2-phenylindole (2w).**[4b] White solid, mp: 100-103 °C (Lit. 114-115 °C); R_f = 0.50 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.28 (s, 3H), 2.41 (s, 1H), 6.47 (s, 1H), 7.04 (d, J = 7.8 Hz, 2H), 7.16 (d, J = 8.4 Hz, 1H), 7.22 (s, 1H), 7.25 (s, 2H), 7.40 - 7.42 (m, 3H), 7.48 - 7.50 (m, 2H), 8.17 (d, J = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.3, 21.5, 113.6, 116.4, 120.6, 126.2, 126.8, 127.5, 128.6, 129.2, 130.3, 130.8, 132.5, 134.0, 134.6, 136.5, 142.3, 144.4; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_2S$ $(M+Na)^+$ 384.1034, found 384.1029.

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***N*-Ts-5-Methoxy-2-phenylindole (2x).**[6a] White solid, mp: 114-117 °C (Lit. 123-125 °C); R_f = 0.48 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.20 (s, 3H), 3.74(s, 3H), 6.39 (s, 1H), 6.80 (s, 1H), 6.88 (d, *J* = 9.1 Hz, 1H), 6.96 (d, *J* = 7.9 Hz, 2H), 7.16 (d, *J* = 7.8 Hz, 2H), 7.34 - 7.41 (m, 5H), 8.12 (d, *J* = 9.0 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 55.6, 103.1, 113.4, 113.9, 117.7, 126.8, 127.5, 128.6, 129.1, 130.2, 131.7, 132.4, 132.8, 134.3, 143.1, 144.4, 157.0; HRMS (ESI): m/z calcd for $C_{22}H_{19}NO_3S$ (M+Na)$^+$ 400.0983, found 400.0983.

***N*-Ts-5-Fluoro-2-phenylindole (2y).**[6a] Light yellow solid, mp: 104-106 °C (Lit. 110-112 °C); R_f = 0.57 (10% EtOAc/ Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.29 (s, 3H), 6.49 (s, 1H), 7.05 (d, *J* = 7.9 Hz, 2H), 7.08 (d, *J* = 9.0 Hz, 2H), 7.24 (d, *J* = 7.9 Hz, 2H), 7.42 - 7.44 (m, 3H), 7.49 (d, *J* = 7.0 Hz, 2H), 8.26 (dd, *J* = 4.4, 8.8 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 20.5, 105.2 (d, *J* = 23.9 Hz), 111.5 (d, *J* = 24.9 Hz), 112.3 (d, *J* = 3.4 Hz), 116.9 (d, *J* = 9.3 Hz), 125.7, 126.5, 127.9, 128.3, 129.2, 130.6, 131.0, 133.2, 133.5, 142.9, 143.7, 158.3; HRMS (ESI): m/z calcd for $C_{21}H_{16}FNO_2S$ (M+Na)$^+$ 388.0783, found 388.0783.

***N*-Ts-5-Chloro-2-phenylindole (2z).**[4b] White solid, mp: 138-140 °C (Lit. 136-137 °C); R_f = 0.61 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.30 (s, 3H), 6.47 (s, 1H), 7.05 (d, *J* = 7.9 Hz, 2H), 7.24 (d, *J* = 7.9 Hz, 2H), 7.30 (d, *J* = 8.8 Hz, 1H), 7.40 - 7.45 (m, 4H), 7.47 (d, *J* = 7.1 Hz, 2H), 8.23 (d, *J* = 8.8 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 112.6, 117.7, 120.3, 124.9, 126.8, 127.6, 129.0, 129.3, 130.0, 130.4, 131.7, 131.9, 134.5, 136.6, 143.6, 144.8; HRMS (ESI): m/z calcd for $C_{21}H_{16}ClNO_2S$ (M+Na)$^+$ 404.0488, found 404.0488.

***N*-Ts-2-Phenyl-5-(trifluoromethyl)indole (2aa).**[4b] White solid, mp: 115-118 °C (Lit. 120-124 °C); R_f = 0.67 (20% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.31 (s, 3H), 6.59 (s, 1H), 7.08 (d, *J* = 7.7 Hz, 2H), 7.26 (d, *J* = 6.4 Hz, 2H), 7.44 - 7.47 (m, 5H), 7.60 (d, *J* = 8.7 Hz, 1H), 7.74 (s, 1H), 8.42 (d, *J* = 8.7 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.6, 112.7, 116.7, 118.1 (q, *J* = 4.0 Hz), 121.4 (q, *J* = 3.3 Hz), 125.4, 126.6 (q, *J* = 32.3 Hz), 126.8, 127.6, 129.1, 129.5, 130.0, 130.5, 131.6, 134.7, 139.6, 143.7, 145.1; HRMS (ESI): m/z calcd for $C_{22}H_{16}F_3NO_2S$ (M+Na)$^+$ 438.0752, found 438.0757.

***N*-Ts-6-Fluoro-2-phenylindole (2ab).**[6a] White solid, mp: 97-100 °C (Lit. 103-105 °C); R_f = 0.61 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.30 (s, 3H), 6.50 (s, 1H), 7.02 (t, *J* = 8.7 Hz, 1H), 7.07 (d, *J* = 7.9 Hz, 2H), 7.26-7.28 (m, 3H), 7.36 (t, *J* = 6.6 Hz, 1H), 7.42-7.47 (m, 4H), 8.06 (d, *J* = 10.3 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.6, 104.1 (d, *J* = 28.5 Hz), 112.6 (d, *J* = 23.7 Hz), 121.3 (d, *J* = 9.7 Hz), 126.7, 126.8, 127.5, 128.8, 129.3, 130.3, 132.1, 134.6, 138.5 (d, *J* = 12.4 Hz), 142.4, 144.8, 160.1, 161.7; HRMS (ESI): m/z calcd for $C_{21}H_{16}FNO_2S$ (M+Na)$^+$ 388.0783, found 388.0783.

***N*-Ts-6-Chloro-2-phenylindole (2ac).**[4b] White solid, mp: 137-140 °C (Lit. 140-144 °C); R_f = 0.57 (10% EtOAc/Petroleum Ether); ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.30 (s, 3H), 6.49 (s, 1H), 7.06 (d, *J* = 7.9 Hz, 2H), 7.24 - 7,26 (m, 3H), 7.35 (d, *J* = 8.2 Hz, 1H), 7.41 - 7.46 (m, 5H), 8.34 (s, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.6, 112.9, 116.7, 121.3, 124.9, 126.8, 127.5, 128.9, 129.4, 130.4, 130.6, 131.9, 134.5, 138.6, 142.6, 144.9 (One carbon signal was missing due to peak overlap); HRMS (ESI): m/z calcd for $C_{21}H_{16}ClNO_2S$ (M+Na)$^+$ 404.0488, found 404.0488.

***N*-Ts-5-Methyl-2-*p*-tolylindole (2ad).**[6a] White solid, mp: 144-146 °C (Lit. 143-145 °C); R_f = 0.50 (10% EtOAc/Petroleum Ether). ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.28 (s, 3H), 2.40 (s, 3H), 2.44 (s, 3H), 6.44 (s, 1H), 7.03 (d, *J* = 7.7 Hz, 2H), 7.15 (d, *J* = 8.5 Hz, 1H), 7.20 (s, 1H), 7.22 - 7.27 (m, 4H), 7.40 (d, *J* = 7.5 Hz, 2H), 8.16 (d, *J* = 8.4 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.3, 21.4, 21.5, 113.2, 116.4, 120.5, 126.0, 126.8, 128.2, 129.1, 129.7, 130.1, 130.9, 133.9, 134.6, 138.5, 144.3; HRMS (ESI): m/z calcd for $C_{23}H_{21}NO_2S$ (M+Na)$^+$ 398.1191, found 398.1191.

***N*-Ts-5-Trifluoromethyl-2-*p*-tolylindole (2ae).**[6a] White solid, mp: 148-150 °C; R_f = 0.65 (10% EtOAc/Petroleum Ether). ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.31 (s, 3H), 2.45 (s, 3H), 6.56 (s, 1H), 7.07 (d, *J* = 7.7 Hz, 2H), 7.24 - 7.28 (m, 5H), 7.37 (d, *J* = 7.3 Hz, 2H), 7.58 (d, *J* = 8.8 Hz, 1H), 7.72 (s, 1H), 8.41 (d, *J* = 8.7 Hz, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.5, 21.6, 112.5, 116.7, 118.0 (d, *J* = 3.77 Hz), 121.2 (d, *J* = 3.4 Hz), 126.4, 126.6, 126.8, 128.3, 128.7, 129.4, 130.1, 130.4, 134.7, 139.2, 139.6, 143.9, 145.0; HRMS (ESI): m/z calcd for $C_{23}H_{18}F_3NO_2S$ (M+Na)$^+$ 452.0908, found 452.0917.

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A novel approach to indole derivatives from *N*-Ts-2-alkenylanilines has been achieved, which involves an oxidative intramolecular C-H amination by using molecular oxygen as sole oxidant. This protocol is operationally simple and environmental friendly, and provides a diverse range of substrate scope.