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Organocatalytic Arylation of 3-Indolylmethanols via Chemo- and Regiospecific C6-Functionalization of Indoles

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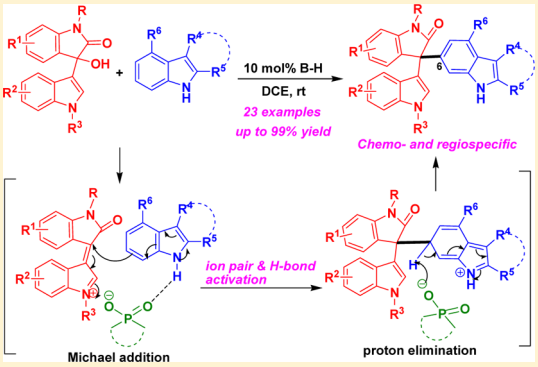
Supporting Information

ABSTRACT: An organocatalytic arylation of 3-indolylmethanols has been established via chemo- and regiospecific C6-functionalization of 2,3-disubstituted indoles, leading to the production of bisindolyloxindoles containing an all-carbon quaternary stereocenter in high yields (up to 99% yield). This reaction not only represents the first catalytic arylation of 3-indolylmethanols using 2,3-disubstituted indoles as aromatic nucleophiles but also serves as a good example of direct catalytic C6-functionalization of indoles, which have been scarcely investigated. Besides, this approach also provides an efficient method to access a biologically important 3,3′-disubstituted oxindole framework and a 3′,6-linked bisindole skeleton. Furthermore, the investigation of the activation mode suggested that the dual activation of an ion pair and H-bond between the substrates and the catalyst cooperatively contributed to the success of the reaction.



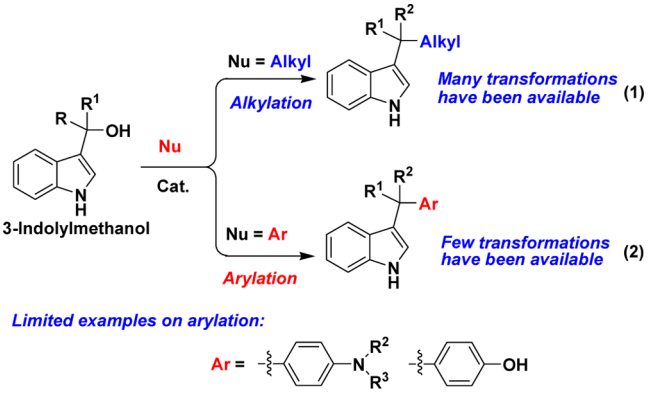
INTRODUCTION

Indole derivatives belong to the most intriguing heterocyclic compounds, which are important members of natural products and pharmaceuticals.[1] Thus, the functionalization of indole and its derivatives has absorbed much attention from the organic community.[2] Recently, 3-indolylmethanols have distinguished themselves to be versatile reactants in nucleophilic substitutions, leading to C3-functionalization of indoles.[3,4] Nevertheless, most of the nucleophilic substitutions were focused on alkylation-related reactions,[4] which introduced alkyl,[4a−h] alkenyl,[4i] and allyl[4j,k] groups to 3-indolylmethanols (eq 1). In sharp contrast, the arylation of 3-indolylmethanols has met with little success (eq 2), and only limited examples using electron-rich anilines or phenols as nucleophiles were sporadically reported in the literature (Scheme 1).[5] Therefore, the arylations of 3-indolylmethanols, especially those employing other types of aromatic nucleophiles, are highly desirable.

Indoles are capable of performing [2 + 3] or [2 + 4] cycloadditions via their C2,C3-anulations with a variety of reactants.[6] As a continuation of our efforts on cycloaddition reactions,[7] we conceived that 2,3-disubstituted indoles **2** might undergo [2 + 3] cycloadditions with isatin-derived 3-indolylmethanols **1** to afford spiro-fused indoles **3** in the presence of Brønsted acid (B-H). However, the experimental results revealed that no desired [2 + 3] cycloaddition products **3** were generated at all (Scheme 2). Instead, a type of C6-functionalized 2,3-disubstituted indoles **4** were produced in a chemo- and regiospecific way, thus providing an efficient method on arylation of 3-indolylmethanols as well as C6-functionalization of 2,3-disubstituted indoles. It should be noted that the direct organocatalytic C6-functionalizations of indoles are rather rare, and controlling the chemo- and regioselectivity of the reaction is even challenging.[8]

More importantly, the arylation products **4** contain an oxindole framework bearing an all-carbon quaternary stereocenter, which constitutes the core structure of numerous natural products and synthesized compounds with biological relevance.[9] Besides, products **4** also include a 3′,6-linked bisindole motif, which exists in some natural alkaloids and pharmaceuticals (Scheme 3).[10] Therefore, this reaction

Scheme 1. Profile of Nucleophilic Substitutions of 3-Indolylmethanols



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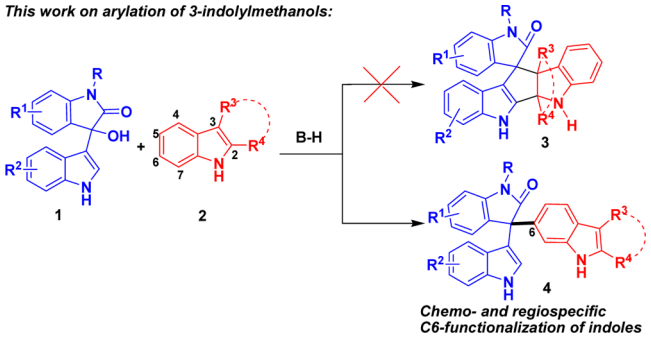
Scheme 2. Our Investigation of the Reactions of 3-Indolylmethanols with 2,3-Disubstituted Indoles



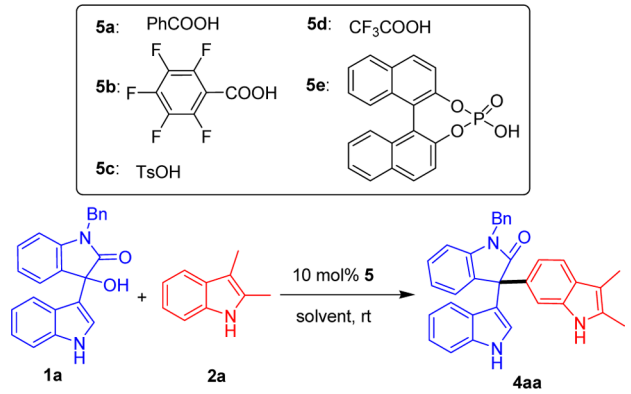
integrates bioactive oxindole and 3′,6-linked bisindole skeletons into a novel type of bisindolyloxindole structure, which may exhibit valuable bioactivities.

Herein, we report the first organocatalytic arylation of 3-indolylmethanols using 2,3-disubstituted indoles as aromatic nucleophiles, which led to chemo- and regiospecific C6-functionalization of 2,3-disubstituted indoles and the synthesis of bisindolyloxindoles containing an all-carbon quaternary stereocenter in high yields (up to 99% yield).

RESULTS AND DISCUSSION

Initially, the reaction of 3-indolylmethanol **1a** and 2,3-disubstituted indole **2a** in 1,2-dichloroethane (DCE) was employed to screen a variety of Brønsted acids **5** with different acidities (Table 1, entries 1−5). The results revealed that the acidity of the catalysts imposed some effect on the reaction, since benzoic acid **5a** with weak acidity failed to catalyze the reaction (entry 1), while racemic phosphoric acid **5e** with stronger acidity afforded the arylation product **4aa** in the highest yield of 86% (entry 5). Then, in the presence of catalyst **5e**, different types of solvents were evaluated (entries 5−9), which disclosed that ethyl acetate was inferior to other solvents (entry 6) and there was no obvious difference among acetone, THF, and toluene (entries 7−9) with regard to the yields (71%−72%). Finally, using DCE as the most suitable solvent, the mole ratio of the two reactants was adjusted to further improve the yield (entries 10−11). It was found that properly increasing the stoichiometry of 2,3-disubstituted indole **2a** could remarkably increase the yield to a quantitative level (entry 11). Under this optimal condition, we checked the performance of inorganic phosphoric acid as a catalyst, but no reaction occurred (entry 12), which demonstrated the superiority of organocatalysts. Furthermore, we also investigated the catalytic activity of some Lewis acids under the same reaction conditions (entries 13−18). In most cases, the model reaction proceeded smoothly to afford the product **4aa** (entries 13−14 and 17−18), while copper salts failed to catalyze the

Table 1. Screening of Catalysts and Optimization of Reaction Conditions[a]



entry	cat.	solvent	1a:2a	yield (%)[b]
1	**5a**	DCE	1:1.2	[c]
2	**5b**	DCE	1:1.2	21
3	**5c**	DCE	1:1.2	36
4	**5d**	DCE	1:1.2	68
5	**5e**	DCE	1:1.2	86
6	**5e**	EtOAc	1:1.2	59
7	**5e**	acetone	1:1.2	72
8	**5e**	THF	1:1.2	72
9	**5e**	toluene	1:1.2	71
10	**5e**	DCE	1:2	96
11	**5e**	DCE	1:3	99
12	H_3PO_4	DCE	1:3	[c]
13	$AlCl_3$	DCE	1:3	51
14	$InBr_3$	DCE	1:3	69
15	CuCl	DCE	1:3	[c]
16	$Cu(OTf)_2$	DCE	1:3	[c]
17	$In(OTf)_3$	DCE	1:3	60
18	$Sc(OTf)_3$	DCE	1:3	78

[a]Unless indicated otherwise, the reaction was carried out at the 0.1 mmol scale catalyzed by 10 mol % **5** in solvent (1 mL) at room temperature for 12 h. [b]Isolated yields. [c]No reaction occurred.

reaction (entries 15−16). Among the tested Lewis acids, $Sc(OTf)_3$ exhibited the highest catalytic activity (entry 18), but it was still inferior to catalyst **5e** as a Brønsted acid in promoting the model reaction (entry 18 vs 11).

With the optimal reaction conditions in hand, we then investigated the substrate scope of isatin-derived 3-indolylmethanols **1** by the reactions with 2,3-disubstituted indole **2a** (Table 2). First, the influence of *N*-substituents in the isatin moiety was studied (entries 1−7), which found that the arylation reaction was applicable to a wide range of isatin-derived 3-indolylmethanols **1** bearing *N*-benzyl, alkyl, and aryl groups in generally high yields. Among different *N*-benzyl groups, electronically neutral or poor substituents delivered

Scheme 3. Selected Natural Products and Pharmaceuticals Containing 3′,6-Linked Bisindoles

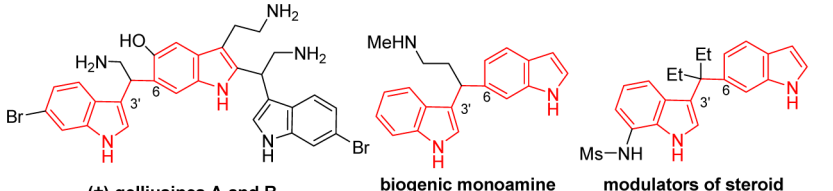


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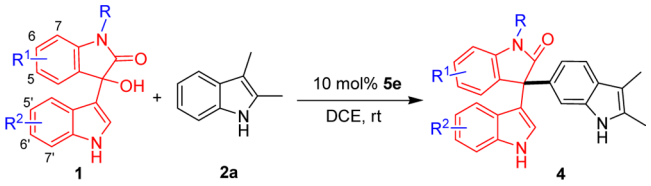
Table 2. Substrate Scope of Isatin-Derived 3-Indolylmethanols 1[a]



entry	4	R/R^1/R^2	yield (%)[b]
1	4aa	Bn/H/H (1a)	99
2	4ba	*p*-MeC$_6$H$_4$CH$_2$/H/H (1b)	67
3	4ca	*p*-*t*BuC$_6$H$_4$CH$_2$/H/H (1c)	80
4	4da	*p*-NO$_2$C$_6$H$_4$CH$_2$/H/H (1d)	99
5	4ea	*m*-ClC$_6$H$_4$CH$_2$/H/H (1e)	94
6	4fa	Me/H/H (1f)	99
7	4ga	Ph/H/H (1g)	57
8	4ha	Bn/5-Cl/H (1h)	99
9	4ia	Bn/5-Me/H (1i)	99
10	4ja	Bn/6-Br/H (1j)	50
11	4ka	Bn/6-MeO/H (1k)	82
12	4la	Bn/7-Br/H (1l)	91
13	4ma	Bn/H/5′-Br (1m)	95
14	4na	Bn/H/5′-MeO (1n)	99
15	4oa	Bn/H/6′-Br (1o)	99
16	4pa	Bn/H/6′-Me (1p)	95
17	4qa	Bn/H/7′-Br (1q)	99
18	4ra	Bn/H/7′-Me (1r)	97

[a]Unless indicated otherwise, the reaction was carried out at the 0.1 mmol scale catalyzed by 10 mol % **5e** in 1,1-dichloroethane (1 mL) at room temperature for 12 h, and the ratio of **1**:**2a** was 1:3. [b]Isolated yields.

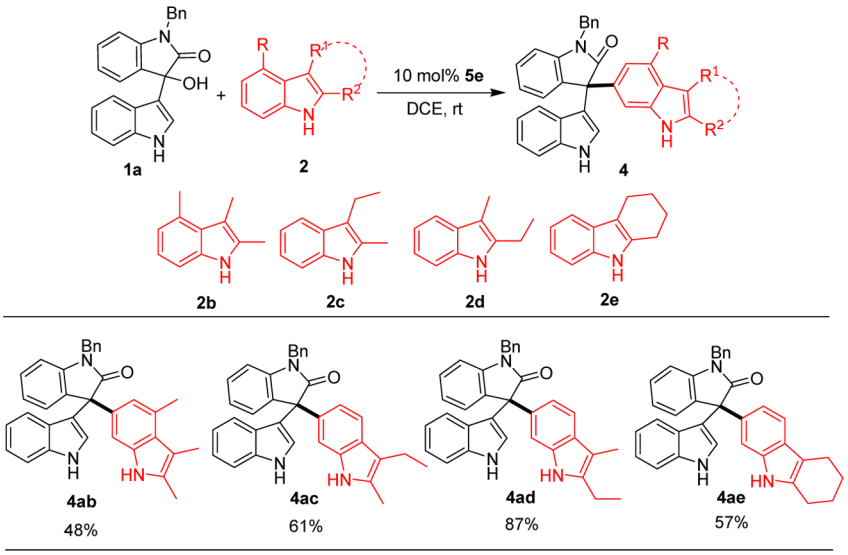
higher yields than electronically rich ones (entries 1 and 4−5 vs 2−3). Besides, *N*-alkyl groups as exemplified by *N*-methyl substituted substrate **1f** participated in the reaction with an excellent yield of 99% (entry 6), but *N*-phenyl substituted substrate **1g** just exhibited moderate reactivity (entry 7). Second, the effect of substituents on the phenyl ring of the isatin motif was examined. As shown in entries 8−12, either electron-donating or electron-withdrawing groups at different positions of C5−C7 could smoothly take part in the reaction. It was found that C5-substituted substrates were much superior to C6- or C7-substituted counterparts in providing the arylation products with quantitative yields of 99% (entries 8−9 vs 10−12). Finally, a series of 3-indolylmethanols with various substituents at different positions of the indole moiety were utilized to the reaction (entries 13−18). It seemed that there was no evident difference among C5′-, C6′-, or C7′-substituted substrates in terms of reactivity, and all of them offered the arylation products in uniformly excellent yields of 95%−99%. Therefore, the electronic nature and the position of the substituents linked to the benzene ring of the indole moiety imposed little effect on the reactivity.

Next, the applicability of 2,3-disubstituted indoles **2** to the arylation reaction was tested by the reactions with 3-indolylmethanols **1a**. As illustrated in Table 3, several representative 2,3-disubstituted indoles **2b**−**2e** bearing different groups on the benzene ring or on the pyrrole motif could be engaged in the reaction, providing the arylation products in moderate to high yields. Not only can substrates **2c**−**2d** with elongated alkyl groups at C2- or C3-positions smoothly participate in the reaction but also C4-substituted substrate **2b** and cyclic tetrahydrocarbazole **2e** could undergo C6-functionalization with chemo- and regiospecificity, which is challenging in C6-functionalization of 2,3-disubstituted indoles.

The structures of all the products **4** were unambiguously determined by IR, ^{1}H NMR, ^{13}C NMR, and HRMS. Moreover, the structure of compound **4aa** was further confirmed by single-crystal X-ray diffraction analysis.[11]

In order to get some clue on the activation mode of this organocatalytic arylation of 3-indolylmethanols, some control experiments were carried out under the optimal reaction conditions (Scheme 4). First, *N*-methyl protected 3-indolylmethanols **1s** was employed in the reaction instead of *N*-unprotected counterpart **1a**, which also afforded the corresponding arylation product **4sa** in a perfect yield of 99% (eq 3). This result indicated that the N−H group in the indole moiety

Table 3. Applicability of 2,3-Disubstituted Indoles 2 to the Reaction[a]



[a]Unless indicated otherwise, the reaction was carried out at the 0.1 mmol scale catalyzed by 10 mol % **5e** in 1,1-dichloroethane (1 mL) at room temperature for 12 h, and the ratio of **1a**:**2** was 1:3. Yields referred to isolated yields.

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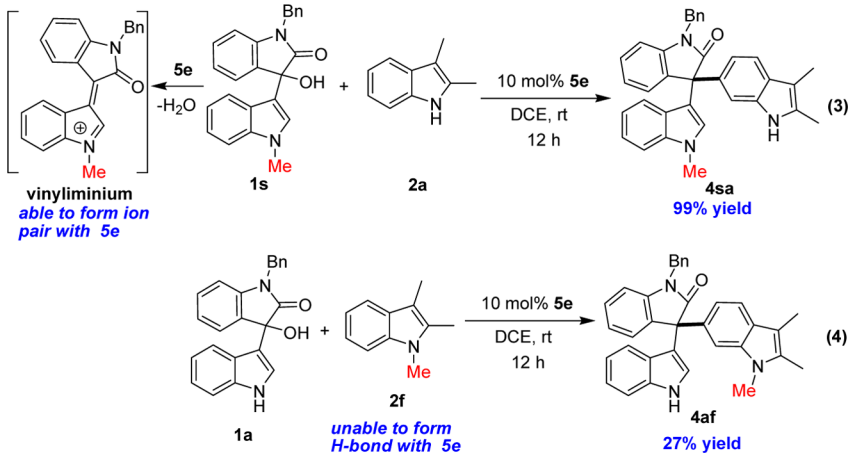
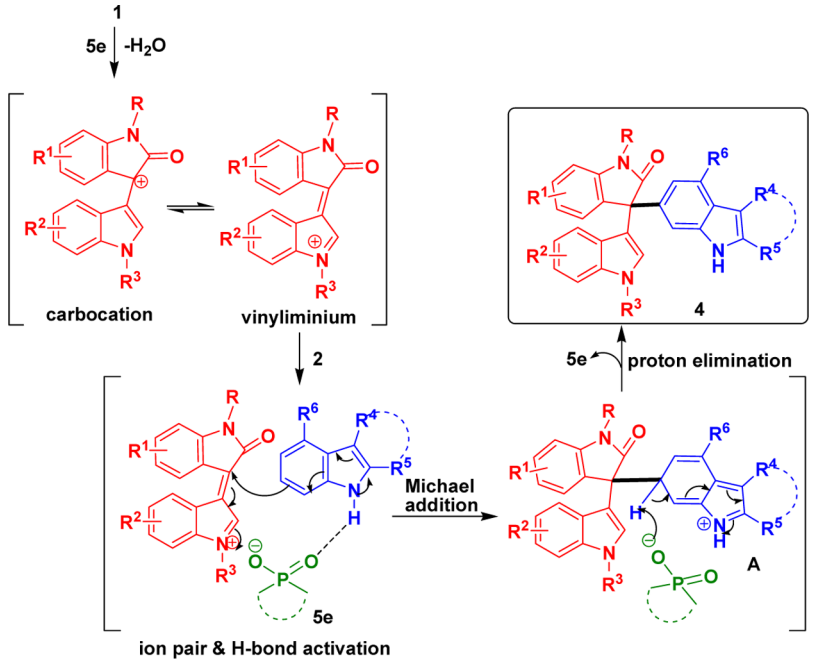
Scheme 4. Control Experiments to Demonstrate the Activation Mode



Scheme 5. Suggested Reaction Pathway and Activation Mode



of 3-indolylmethanols was not essential to the reaction. Although the vinyliminium intermediate generated from **1s** cannot form a H-bond with catalyst **5e** due to the lack of a N–H group in **1s**, it is able to form an ion pair with catalyst **5e**. Therefore, the activation mode between substrates **1** and the catalyst **5e** is an ion pair rather than a H-bond. Second, *N*-methyl protected 2,3-disubstituted indole **2f** was utilized as a substrate to react with **1a**. In this case, the arylation product **4af** was still generated but in a rather low yield of 27% (eq 4). This outcome implied that the N–H group in 2,3-disubstituted indoles **2** played a crucial role in the arylation reaction by forming a H-bond with the catalyst **5e**. Because substrate **2f** is unable to create a H-bond with **5e**, it cannot be activated by the catalyst. Thus, only substrate **1a** was activated by the catalyst via an ion pair interaction. This single activation mode is much inferior to the dual activation mode, which should account for the low yield of the reaction. Therefore, the two control experiments demonstrated that the success of the reaction should be largely ascribed to the dual activation of the two substrates **1** and **2** by the catalyst **5e** via an ion pair and H-bond interaction, respectively.

On the basis of the experimental results, we suggested a possible reaction pathway and activation mode to explain the chemistry of the arylation reaction. As illustrated in Scheme 5, 3-indolylmethanol **1** was readily dehydrated under the catalysis of **5e** to produce a carbocation or vinyliminium intermediate, which formed an ion pair with the catalyst. At the same time, 2,3-disubstituted indole **2** was activated by the same catalyst via a H-bond interaction, thus enabling the C6-position of the indole ring to become more nucleophilic than other sites because of the long-range conjugative effect. Therefore, owing to the dual activation of the ion pair and H-bond, the Michael addition of C6 in the 2,3-disubstituted indole to vinyliminium occurred with chemo- and regiospecificity, which generated another transient intermediate **A**. Then, in order to restore the original indole structure, this intermediate rapidly underwent proton elimination with the aid of the catalyst to give the final arylation product **4**.

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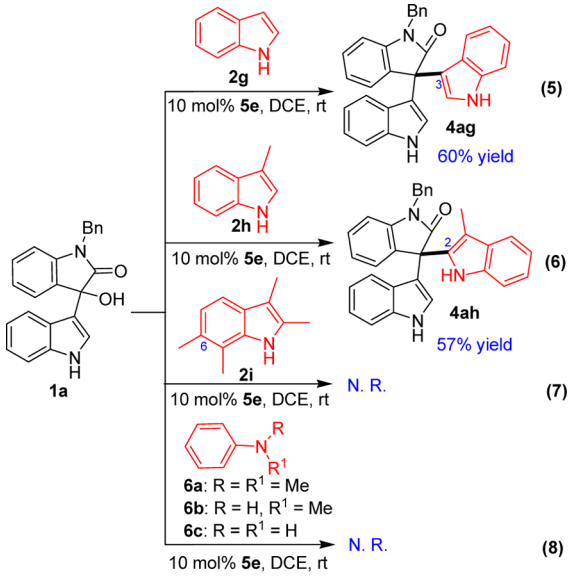
To demonstrate the chemo- and regiospecificity of the 2,3-disubstituted indole-involved reaction, some control experiments were performed by using other types of nucleophiles instead of 2,3-disubstituted indoles under the optimal conditions (Scheme 6). As shown in eqs 5 and 6, non-

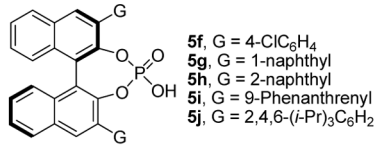
Scheme 6. Control Experiments To Demonstrate the Chemo- and Regiospecificity of the Reaction

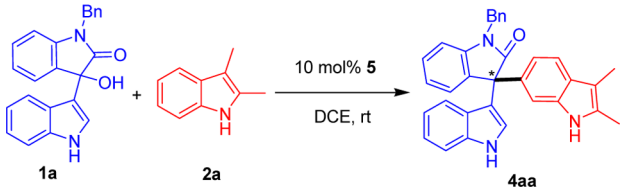


substituted indole **2g** attacked 3-indolylmethanol **1a** at the C3-position to afford 3′,3-linked bisindole **4ag**, while 3-methyl indole **2h** used its C2-position to attack 3-indolylmethanol **1a** and gave 3′,2-linked bisindole **4ah**. The similar results were also reported in the literature.[12] These two experiments indicated that only 2,3-disubstituted indoles could utilize their C6-position to carry out the nucleophilic substitution with 3-indolylmethanols, thus performing the regiospecific C6-functionalization of indoles. As expected, when the C6-position of 2,3-disubstituted indoles was blocked, no reaction occurred under the standard conditions (eq 7), which verified the regiospecificity of the reaction. Besides, aniline derivatives **6a**–**6c** were also employed as substrates to the reaction, but no reaction took place under our optimized conditions (eq 8), which implied that the arylation of 3-indolylmethanol was indeed a formidable task and the success of the 2,3-disubstituted indole-involved reaction might largely be ascribed to the ion pair and H-bond interaction and long-range conjugative effect. Notably, no [3 + 2] cycloaddition products **3** (in Scheme 2) were observed in all of our experiments, which illustrated the chemospecificity of our reactions, since [3 + 2] cycloaddition was reported to occur in Lewis acid catalyzed related transformations.[8]

Finally, some preliminary experiments were carried out to investigate whether the chirality of products **4** could be induced by a chiral catalyst. As shown in Table 4, several chiral phosphoric acids[13] **5f**–**5j** with varied 3,3′-substituents were employed as catalysts to the model reaction under the optimal conditions, but low enantioselectivities were observed in all cases (<10% ee). This result indicated that the chirality of the product was difficult to induce under the current reaction conditions, which might be mainly attributed to the great challenge in remote activation and control of the catalyst over

Table 4. Preliminary Investigation of Catalytic Asymmetric Transformation[a]





entry	5	yield (%)[b]	ee (%)[c]
1	5f	64	8
2	5g	62	3
3	5h	57	9
4	5i	38	8
5	5j	trace	[d]

[a]Unless indicated otherwise, the reaction was carried out at the 0.1 mmol scale catalyzed by 10 mol % **5** in DCE (1 mL) at room temperature for 12 h, and the ratio of **1a**:**2a** was 1:3. [b]Isolated yields. [c]Determined by HPLC. [d]Not tested.

the reactive site of the C6-position of the 2,3-disubstituted indole to generate the stereogenic center.

CONCLUSIONS

In summary, we have established an organocatalytic arylation of 3-indolylmethanols via chemo- and regiospecific C6-functionalization of 2,3-disubstituted indoles, leading to the production of bisindolyloxindoles containing an all-carbon quaternary stereocenter in high yields (up to 99% yield). This reaction not only represents the first catalytic arylation of 3-indolylmethanols using 2,3-disubstituted indoles as aromatic nucleophiles but also serves as a good example of direct catalytic C6-functionalization of indoles, which have been scarcely investigated. Besides, this approach also provides an efficient method to access a biologically important 3,3′-disubstituted oxindole framework and a 3′,6-linked bisindole skeleton. Furthermore, the investigation of the activation mode suggested that the dual activation of an ion pair and H-bond between the substrates and the catalyst cooperatively contributed to the success of the reaction. This protocol will not only provide a useful tool in the arylation of 3-indolylmethanols and the construction of a quaternary stereocenter but also enlighten the investigation of direct catalytic C6-functionalization of indoles.

EXPERIMENTAL SECTION

General Information. ^{1}H and ^{13}C NMR spectra were measured, respectively, at 400 and 100 MHz, respectively. The solvents used for NMR spectroscopy were $CDCl_3$, acetone-d_6, and DMSO-d_6, using tetramethylsilane as the internal reference. HRMS spectra were recorded on an LTQ-Orbitrap mass spectrometer (ionization mode: ESI^+). Analytical grade solvents for the column chromatography and commercially available reagents were used as received. Substrates **1** and **2** were synthesized according to the literature methods.[4a,14]

General Procedure for the Synthesis of Arylation Product 4. 1,2-Dichloroethane (1 mL) was added to the mixture of 3-indolylmethanols **1** (0.1 mmol), 2,3-disubstituted indoles **2** (0.3 mmol), and catalyst **5e** (0.01 mmol). Then, the reaction mixture was

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stirred at rt for 12 h. After stopping the reaction, the reaction mixture was directly purified through flash column chromatography on silica gel to afford pure products **4**.

1′-Benzyl-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4aa). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (47.6 mg); white solid; mp 172.1−173.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.22 (s, 1H), 7.48 (s, 1H), 7.42−7.37 (m, 1H), 7.37−7.30 (m, 5H), 7.26−7.17 (m, 5H), 7.10 (t, J = 7.3 Hz, 1H), 7.04−6.97 (m, 2H), 6.92−6.84 (m, 2H), 6.78 (d, J = 2.5 Hz, 1H), 5.03 (s, 2H), 2.21 (s, 3H), 2.20 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.7, 142.0, 137.1, 136.1, 135.2, 134.7, 132.7, 131.5, 128.8, 128.6, 127.7, 127.5, 127.3, 126.0, 125.7, 124.5, 122.8, 121.9, 121.7, 119.4, 118.7, 117.6, 116.9, 111.5, 110.3, 109.3, 106.5, 57.9, 44.0, 11.4, 8.5; IR (KBr): 3660, 3525, 3440, 2922, 1702, 1461, 1342, 1016, 742, 576; ESI FTMS exact mass calcd for $(C_{33}H_{27}N_3O + Na)^+$ requires m/z 504.2052, found m/z 504.2057.

2″,3″-Dimethyl-1′-(4-methylbenzyl)-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ba). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 67% (33.1 mg); white solid; mp 146.4−147.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.18 (s, 1H), 7.44 (s, 1H), 7.37 (t, J = 7.1 Hz, 2H), 7.29−7.17 (m, 6H), 7.11 (d, J = 7.9 Hz, 3H), 7.02−6.98 (m, 2H), 6.95−6.83 (m, 2H), 6.78 (d, J = 2.5 Hz, 1H), 4.99 (s, 2H), 2.34 (s, 3H), 2.21 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.6, 142.0, 137.2, 137.1, 135.2, 134.7, 133.0, 132.8, 131.4, 129.5, 129.4, 128.5, 127.7, 127.3, 126.1, 125.6, 124.5, 122.7, 121.9, 121.8, 119.4, 118.7, 117.5, 116.9, 111.5, 110.3, 109.3, 106.5, 57.8, 43.8, 21.1, 11.4, 8.5; IR (KBr): 3636, 3524, 3051, 2917, 2361, 1702, 1602, 1462, 1345, 1234, 1172, 1013, 907, 807, 744; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2209.

1′-(4-(*tert*-Butyl)benzyl)-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ca). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 80% (43.2 mg); white solid; mp 156.1−157.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.15 (d, J = 1.7 Hz, 1H), 7.40−7.31 (m, 5H), 7.29−7.25 (m, 2H), 7.23 (d, J = 1.2 Hz, 1H), 7.21−7.16 (m, 3H), 7.08 (d, J = 8.0 Hz, 1H), 6.99−6.97 (m, 2H), 6.92−6.84 (m, 2H), 6.73 (d, J = 2.5 Hz, 1H), 4.98 (s, 2H), 2.19 (s, 3H), 2.16 (s, 3H), 1.31 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.5, 150.4, 142.1, 137.1, 135.2, 134.6, 133.1, 132.9, 131.3, 128.6, 127.7, 127.1, 126.1, 125.7, 124., 122.6, 122.0, 121.8, 119.4, 118.8, 117.6, 117.1, 111.4, 110.2, 109.4, 106.6, 57.8, 43.7, 34.5, 31.3, 11.4, 8.5; IR (KBr): 3365, 3314, 2962, 2361, 1688, 1602, 1466, 1361, 1341, 1172, 1101, 1015, 908, 809, 744; ESI FTMS exact mass calcd for $(C_{37}H_{35}N_3O + Na)^+$ requires m/z 560.2672, found m/z 560.2682.

2″,3″-Dimethyl-1′-(4-nitrobenzyl)-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4da). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (54.6 mg); white solid; mp 158.2−159.3 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 11.04 (d, J = 2.1 Hz, 1H), 10.54 (s, 1H), 8.22 (d, J = 8.7 Hz, 2H), 7.59 (d, J = 8.7 Hz, 2H), 7.41−7.33 (m, 2H), 7.26 (t, J = 8.3 Hz, 2H), 7.14 (d, J = 1.3 Hz, 1H), 7.12−6.99 (m, 4H), 6.86−6.84 (m, 2H), 6.76 (t, J = 7.5 Hz, 1H), 5.21 (d, J = 16.4 Hz, 1H), 5.14 (d, J = 16.4 Hz, 1H), 2.27 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 177.9, 143.7, 137.6, 136.7, 135.4, 134.1, 132.3, 132.1, 129.2, 128.5, 128.0, 127.6, 127.3, 125.9, 125.5, 124.9, 121.6, 121.6, 120.9, 118.9, 118.2, 117.6, 115.3, 112.8, 112.2, 109.9, 105.4, 57.4, 11.7, 8.8; IR (KBr): 3652, 3307, 3056, 2362, 1696, 1523, 1446, 1343, 1173, 1014, 854, 746; ESI FTMS exact mass calcd for $(C_{33}H_{26}N_4O_3 + Na)^+$ requires m/z 549.1897, found m/z 549.1904.

1′-(3-Chlorobenzyl)-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ea). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 94% (48.6 mg); white solid; mp 168.6−169.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.15 (s, 1H), 7.52 (s, 1H), 7.42−7.37 (m, 2H), 7.32 (d, J = 7.8 Hz, 2H), 7.29−7.19 (m, 6H), 7.15−7.11 (m, 1H), 7.07−7.00 (m, 2H), 6.95−6.88 (m, 1H), 6.86−6.80 (m, 2H), 4.99 (s, 2H), 2.26 (s, 3H), 2.20 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.7, 141.6, 138.2, 137.1, 135.2, 134.6, 131.3, 130.0, 128.6, 127.8, 127.4, 126.0, 125.7, 125.4, 124.2, 122.9, 122.1, 121.9, 119.5, 118.8, 117.8, 111.3, 110.0, 109.0, 57.8, 43.4, 11.4, 8.4; IR (KBr): 3635, 3525, 3446, 3296, 2361, 1690, 1600, 1462, 1429, 1339, 1259, 1098, 1015, 804, 741; ESI FTMS exact mass calcd for $(C_{33}H_{26}ClN_3O + Na)^+$ requires m/z 538.1656, found m/z 538.1674.

1′,2″,3″-Trimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4fa). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (48.0 mg); white solid; mp 186.5−187.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.17 (s, 1H), 7.46 (s, 1H), 7.33 (t, J = 7.5 Hz, 3H), 7.18 (t, J = 7.4 Hz, 3H), 7.07 (t, J = 7.7 Hz, 1H), 7.04−6.99 (m, 1H), 6.98−6.92 (m, 2H), 6.92−6.86 (m, 1H), 6.69 (d, J = 2.5 Hz, 1H), 3.28 (s, 3H), 2.17 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.7, 142.8, 137.0, 135.1, 134.6, 132.7, 131.5, 128.5, 127.8, 126.0, 125.6, 124.5, 122.7, 121.9, 121.6, 119.4, 118.6, 117.5, 116.7, 111.5, 110.2, 108.3, 106.4, 57.8, 26.6, 11.4, 8.5; IR (KBr): 3636, 3524, 3309, 2918, 2360, 1697, 1604, 1465, 1344, 1245, 1090, 909, 802, 744, 695; ESI FTMS exact mass calcd for $(C_{27}H_{23}N_3O + Na)^+$ requires m/z 428.1733, found m/z 428.1719.

2″,3″-Dimethyl-1′-phenyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ga). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 57% (26.5 mg); white solid; mp 99.2−100.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.14 (s, 1H), 7.56−7.45 (m, 4H), 7.46−7.36 (m, 4H), 7.28−7.18 (m, 3H), 7.12−7.03 (m, 3H), 6.99−6.91 (m, 2H), 6.78 (d, J = 2.4 Hz, 1H), 2.20 (s 3H), 2.19 (s 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.0, 142.8, 137.0, 135.2, 134.8, 134.3, 132.7, 131.5, 129.5, 128.6, 127.9, 127.7, 126.8, 126.0, 124.7, 123.1, 121.9, 121.5, 119.5, 118.7, 117.6, 117.0, 111.5, 110.3, 109.5, 106.5, 57.9, 11.3, 8.4; IR (KBr): 3370, 3052, 2946, 2362, 1706, 1599, 1497, 1459, 1366, 1327, 1260, 1097, 1020, 799, 743, 696; ESI FTMS exact mass calcd for $(C_{32}H_{25}N_3O + Na)^+$ requires m/z 490.1890, found m/z 490.1892.

1′-Benzyl-5′-chloro-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ha). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (51.0 mg); white solid; mp 164.2−165.7 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 11.10 (d, J = 2.2 Hz, 1H), 10.58 (s, 1H), 7.39 (d, J = 8.2 Hz, 1H), 7.33−7.28 (m, 8H), 7.15 (d, J = 1.3 Hz, 1H), 7.12−6.98 (m, 3H), 6.90 (d, J = 2.5 Hz, 1H), 6.88−6.85 (m, 1H), 6.77 (t, J = 7.5 Hz, 1H), 5.07 (d, J = 15.8 Hz, 1H), 5.00 (d, J = 15.8 Hz, 1H), 2.28 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 177.6, 141.0, 137.6, 136.8, 136.7, 135.4, 132.4, 132.0, 129.1, 128.5, 128.2, 128.0, 127.6, 126.9, 125.9, 125.3, 125.0, 121.7, 121.5, 118.9, 118.2, 117.7, 115.3, 112.2, 111.4, 109.9, 105.4, 57.8, 43.4, 11.7, 8.8; IR (KBr): 3635, 3525, 3446, 3296, 2964, 2361, 1690, 1600, 1462, 1339, 1259, 1098, 804, 741; ESI FTMS exact mass calcd for $(C_{33}H_{26}ClN_3O + Na)^+$ requires m/z 538.1656, found m/z 538.1668.

1′-Benzyl-2″,3″,5′-trimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ia). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (49.3 mg); white solid; mp 156.4−157.9 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 11.01 (d, J = 2.1 Hz, 1H), 10.54 (s, 1H), 7.37 (d, J = 8.1 Hz, 1H), 7.33 (d, J = 4.3 Hz, 4H), 7.26 (d, J = 8.1 Hz, 2H), 7.15 (d, J = 1.2 Hz, 1H), 7.11 (s, 1H), 7.05−7.02 (m, 3H), 6.91 (d, J = 8.0 Hz, 1H), 6.89−6.83 (m, 2H), 6.75 (t, J = 7.5 Hz, 1H), 5.03 (d, J = 15.7 Hz, 1H), 4.95 (d, J = 15.7 Hz, 1H), 2.27 (s, 3H), 2.21 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 177.9, 139.7, 137.5, 137.1, 135.4, 134.8, 132.9, 132.1, 131.7, 129.0, 128.4, 128.3, 127.8, 127.6, 126.1, 126.1, 124.9, 121.9, 121.5, 118.7, 118.4, 117.5, 116.1, 112.1, 110.0, 109.6, 105.4, 57.7, 21.2, 11.6, 8.8; IR (KBr): 3636, 3524, 3443, 3314, 2361, 1685, 1493, 1338, 1251, 1190, 808, 738, 732; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2206.

1′-Benzyl-6′-bromo-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ja). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 50% (28.0 mg); white solid; mp 168.1−169.2 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 11.08 (d, J = 2.2 Hz, 1H), 10.55 (s, 1H), 7.42−7.32 (m, 5H), 7.31−7.28 (m, 2H), 7.27−7.18 (m, 3H), 7.13 (d, J = 1.3 Hz, 1H), 7.07−6.99 (m, 2H), 6.87 (d, J = 2.5 Hz, 1H), 6.86−

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6.81 (m, 1H), 6.76 (t, J = 7.5 Hz, 1H), 5.08 (d, J = 15.8 Hz, 1H), 5.01 (d, J = 15.8 Hz, 1H), 2.27 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 177.9, 143.3, 137.6, 136.7, 135.4, 134.0, 132.3, 132.1, 129.2, 128.5, 128.0, 127.6, 127.3, 125.9, 125.5, 124.9, 121.6, 121.6, 120.9, 118.9, 118.2, 117.6, 115.3, 112.7, 112.2, 109.9, 105.4, 57.4, 11.7, 8.7; IR (KBr): 3691, 3437, 2959, 2294, 1699, 1576, 1475, 1341, 1260, 1027, 807, 703, 568; ESI FTMS exact mass calcd for $(C_{33}H_{26}BrN_3O + Na)^+$ requires m/z 582.1152, found m/z 582.1134.

1′-Benzyl-6′-methoxy-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ka). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 82% (42.0 mg); white solid; mp 168.1−169.2 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 11.00 (s, 1H), 10.53 (s, 1H), 7.35 (t, J = 7.7 Hz, 5H), 7.30−7.24 (m, 2H), 7.21 (d, J = 8.2 Hz, 1H), 7.15 (s, 1H), 7.02 (t, J = 7.4 Hz, 2H), 6.90−6.81 (m, 2H), 6.75 (t, J = 7.5 Hz, 1H), 6.66 (d, J = 1.9 Hz, 1H), 6.60−6.56 (m, 1H), 5.04 (d, J = 15.7 Hz, 1H), 4.98 (d, J = 15.6 Hz, 1H), 3.71 (s, 3H), 2.27 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm):178.5, 159.7, 143.3, 137.5, 137.1, 135.4, 133.2, 132.1, 129.1, 128.3, 127.9, 127.7, 126.8, 126.2, 126.1, 124.7, 121.7, 121.5, 118.7, 118.4, 117.4, 116.5, 112.0, 109.9, 106.9, 105.3, 97.4, 57.1, 55.8, 43.3, 11.7, 8.8; IR (KBr): 3634, 3312, 2918, 2361, 1692, 1624, 1598, 1498, 1460, 1371, 1333, 1265, 1200, 1158, 1024, 806, 736, 701; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O_2 + Na)^+$ requires m/z 534.2152, found m/z 534.2132.

1′-Benzyl-7′-bromo-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-on (4la). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 91% (51.1 mg); white solid; mp 157.4−158.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.14 (s, 1H), 7.41−7.31 (m, 4H), 7.27 (d, J = 10.7 Hz, 4H), 7.21−7.16 (m, 3H), 7.10 (t, J = 7.7 Hz, 1H), 6.99−6.80 (m, 3H), 6.70 (d, J = 2.4 Hz, 1H), 5.59−5.43 (m, 2H), 2.20 (s, 3H), 2.18 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 179.4, 139.5, 137.9, 137.8, 137.0, 135.1, 133.7, 132.3, 131.7, 128.7, 128.5, 127.0, 126.5, 125.8, 125.0, 124.6, 124.0, 122.1, 121.7, 119.5, 118.5, 117.6, 116.5, 111.5, 110.3, 106.5, 102.5, 57.5, 44.8, 11.3, 8.4; IR (KBr): 3636, 3313, 3057, 2914, 2361, 1704, 1574, 1455, 1336, 1241, 1159, 1100, 1017, 803, 740; ESI FTMS exact mass calcd for $(C_{33}H_{26}BrN_3O + Na)^+$ requires m/z 582.1152, found m/z 582.1176.

1′-Benzyl-5-bromo-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ma). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 95% (53.2 mg); white solid; mp 197.2−198.8 °C;^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 11.16 (d, J = 2.0 Hz, 1H), 10.53 (s, 1H), 7.56 (d, J = 1.7 Hz, 1H), 7.39−7.20 (m, 8H), 7.09 (d, J = 1.2 Hz, 1H), 7.04 (d, J = 1.8 Hz, 1H), 7.02 (s, 1H), 6.99 (d, J = 8.8 Hz, 1H), 6.92−6.88 (m, 1H), 6.87 (d, J = 2.5 Hz, 1H), 6.82−6.76 (m, 1H), 5.04 (d, J = 15.7 Hz, 1H), 4.97 (d, J = 15.7 Hz, 1H), 2.26 (s, 3H), 2.11 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 177.8, 142.0, 138.4, 137.0, 135.4, 134.4, 132.6, 132.3, 129.1, 128.4, 128.3, 127.9, 127.6, 125.8, 125.5, 125.2, 123.6, 122.9, 121.7, 118.2, 117.6, 116.3, 114.6, 114.48, 109.9, 109.8, 105.4, 57.5, 11.6, 8.7; IR (KBr): 3658, 3523, 3441, 2924, 2283, 1975, 1572, 1460, 1381, 1027, 567; ESI FTMS exact mass calcd for $(C_{33}H_{26}BrN_3O + Na)^+$ requires m/z 582.1152, found m/z 582.1137.

1′-Benzyl-5-methoxy-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4na). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (50.6 mg); white solid; mp 160.9−161.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.14 (s, 1H), 7.52 (s, 1H), 7.47−7.24 (m, 8H), 7.24−7.15 (m, 1H), 7.12−7.02 (m, 2H), 6.99 (t, J = 7.5 Hz, 1H), 6.84 (d, J = 7.8 Hz, 1H), 6.77−6.70 (m, 2H), 6.58 (d, J = 2.3 Hz, 1H), 5.02 (s, 2H), 3.47 (s, 3H), 2.20 (d, J = 1.3 Hz, 3H), 2.18 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 179.0, 153.5, 142.0, 136.0, 135.3, 134.8, 132.6, 132.2, 131.5, 128.8, 128.6, 127.8, 127.6, 127.3, 126.4, 125.7, 125.6, 122.8, 118.5, 117.6, 116.2, 112.2, 112.0, 110.3, 109.3, 106.4, 103.3, 57.9, 55.5, 44.0, 30.9, 11.3, 8.5; IR (KBr): 3317, 3030, 2917, 2362, 1699, 1484, 1461, 1210, 798, 744; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O_2 + Na)^+$ requires m/z 534.2152, found m/z 534.2175.

1′-Benzyl-6-bromo-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4oa). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (55.4 mg); white solid; mp 241.3−242.8 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 11.17 (d, J = 2.0 Hz, 1H), 10.54 (s, 1H), 7.57 (d, J = 1.6 Hz, 1H), 7.34 (d, J = 4.3 Hz, 4H), 7.31−7.23 (m, 4H), 7.10 (d, J = 1.2 Hz, 1H), 7.07−6.98 (m, 3H), 6.94−6.86 (m, 2H), 6.81 (dd, J = 8.3, 1.6 Hz, 1H), 5.05 (d, J = 15.7 Hz, 1H), 4.98 (d, J = 15.7 Hz, 1H), 2.27 (s, 3H), 2.12 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 177.8, 142.0, 138.4, 137.0, 135.4, 134.4, 132.6, 132.3, 129.1, 128.4, 128.3, 127.9, 127.6, 125.8, 125.5, 125.2, 123.6, 122.9, 121.7, 118.2, 117.6, 116.3, 114.6, 114.5, 109.9, 105.4, 57.5, 43.3, 11.6, 8.7; IR (KBr): 3633, 3525, 3433, 3268, 2362, 1682, 1461, 1370, 808, 643, 799; ESI FTMS exact mass calcd for $(C_{33}H_{26}BrN_3O + Na)^+$ requires m/z 582.1152, found m/z 582.1172.

1′-Benzyl-2″,3″,6-trimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4pa). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 95% (47.2 mg); white solid; mp 160.3−161.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.01 (s, 1H), 7.48 (s, 1H), 7.44−7.21 (m, 8H), 7.16 (t, J = 7.7 Hz, 1H), 7.07 (d, J = 7.8 Hz, 2H), 7.03−6.94 (m, 2H), 6.81−6.77 (m, 2H), 6.72 (d, J = 8.2 Hz, 1H), 5.00 (d, J = 3.3 Hz, 2H), 2.37 (s, 3H), 2.25 (s, 3H), 2.18 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.4, 141.9, 137.5, 136.2, 135.2, 133.0, 131.8, 131.2, 128.7, 127.3, 125.5, 123.9, 123.5, 122.6, 121.5, 121.2, 118.9, 117.6, 116.9, 111.2, 57.8, 44.0, 21.6, 11.48, 8.4; IR (KBr): 3631, 3524, 3441, 3290, 3131, 2362, 1687, 1462, 1374, 1171, 805, 745, 700; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2209.

1′-Benzyl-7-bromo-2″,3″-dimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4qa). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (55.3 mg); white solid; white solid; mp 110.8−112.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.37 (s, 1H), 7.68 (s, 1H), 7.40 (d, J = 8.0 Hz, 2H), 7.35−7.27 (m, 7H), 7.25−7.15 (m, 2H), 7.11−7.06 (m, 1H), 7.03 (t, J = 7.5 Hz, 1H), 6.93 (d, J = 2.5 Hz, 1H), 6.87 (d, J = 7.8 Hz, 1H), 6.77 (t, J = 7.8 Hz, 1H), 5.02 (s, 2H), 2.25 (s, 3H), 2.25 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.3, 142.0, 136.0, 135.7, 135.2, 134.2, 132.6, 131.5, 128.8, 128.7, 128.0, 127.6, 127.4, 125.6, 124.85, 124.4, 122.8, 121.3, 120.7, 118.8, 118.5, 117.8, 109.9, 109.4, 106.7, 104.7, 57.8, 44.0, 11.47, 8.5; IR (KBr): 3313, 3058, 2970, 2917, 2858, 1703, 1605, 1487, 1462, 1432, 1342, 1171, 1103, 808, 736, 698; ESI FTMS exact mass calcd for $(C_{33}H_{26}BrN_3O + Na)^+$ requires m/z 582.1152, found m/z 582.1129.

1′-Benzyl-2″,3″,7-trimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ra). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 97% (48.2 mg); white solid; mp 131.4−132.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.20 (s, 1H), 7.42 (d, J = 6.9 Hz, 1H), 7.40−7.32 (m, 3H), 7.32−7.23 (m, 6H), 7.22−7.14 (m, 1H), 7.06−6.95 (m, 3H), 6.91 (d, J = 7.0 Hz, 1H), 6.88−6.77 (m, 3H), 5.00 (s, 2H), 2.38 (s, 3H), 2.19 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.5, 142.0, 136.6, 136.1, 135.2, 134.6, 132.7, 131.4, 128.7, 128.5, 127.7, 127.5, 127.3, 125.7, 125.6, 124.2, 122.7, 122.5, 120.5, 119.6, 119.4, 118.8, 117.5, 117.5, 110.2, 109.2, 106.5, 57.8, 44.0, 16.5, 11.4, 8.4; IR (KBr): 3633, 3525, 3438, 3307, 3052, 2915, 2362, 1698, 1602, 1462, 1345, 1171, 904, 803, 746, 698; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2214.

1′-Benzyl-2″,3″,4″-trimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ab). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 48% (24.0 mg); white solid; mp 156.4−157.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.15 (s, 1H), 7.39 (d, J = 5.6 Hz, 1H), 7.35 (d, J = 9.0 Hz, 2H), 7.33−7.27 (m, 3H), 7.25 (d, J = 7.4 Hz, 2H), 7.19 (t, J = 7.7 Hz, 1H), 7.11 (t, J = 7.6 Hz, 1H), 7.05 (s, 1H), 6.99 (t, J = 7.4 Hz, 1H), 6.91 (t, J = 7.8 Hz, 1H), 6.85−6.82 (m, 2H), 6.70 (s, 1H), 5.06 (d, J = 15.6 Hz, 1H), 5.00 (d, J = 15.7 Hz, 1H), 2.60 (s, 3H), 2.38 (s, 3H), 2.21 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.5, 142.0, 137.0, 136.2, 135.3, 134.6, 132.8, 130.8, 129.9, 128.7, 127.6, 127.5, 127.4, 126.8, 126.1, 125.6, 124.4, 122.6, 122.0, 121.9, 120.2, 119.4, 116.8, 111.3, 109.2, 108.3, 107.3, 57.6, 44.0, 20.3, 11.3; IR (KBr): 3659, 3525, 3440, 3267, 2921, 1699, 1584, 1458, 1339, 1169, 1018,

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741, 697; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2218.

1′-Benzyl-3″-ethyl-2″-methyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ac). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 61% (30.1 mg); white solid; mp 146.1−147.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.20 (s, 1H), 7.49 (s, 1H), 7.44−7.38 (m, 2H), 7.30 (d, J = 4.9 Hz, 2H), 7.25 (s, 3H), 7.21 (d, J = 7.7 Hz, 3H), 7.14−7.08 (m, 1H), 7.05−6.98 (m, 3H), 6.91 (d, J = 7.7 Hz, 1H), 6.87−6.80 (m, 2H), 5.11−4.91 (m, 2H), 2.71−2.66 (m 2H), 2.24 (s, 3H), 1.26−1.15 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.7, 142.0, 137.1, 136.1, 135.3, 134.7, 132.7, 130.9, 128.8, 127.7, 127.6, 127.5, 127.4, 126.0, 125.7, 124.5, 122.8, 122.0, 121.7, 119.4, 118.7, 117.8, 113.4, 111.4, 110.3, 109.3, 57.8, 44.1, 17.4, 15.5, 11.4; IR (KBr): 3640, 3525, 3442, 3275, 2362, 1697, 1460, 1345, 906, 740, 574; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2221.

1′-Benzyl-2″-ethyl-3″-methyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4ad). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 87% (43.3 mg); white solid; mp 171.9−173.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.18 (s, 1H), 7.52 (s, 1H), 7.41−7.38 (m, 2H), 7.35−7.27 (m, 6H), 7.24−7.18 (m, 3H), 7.11 (t, J = 7.6 Hz, 1H), 7.06−6.97 (m, 2H), 6.91 (t, J = 7.6 Hz, 1H), 6.85 (d, J = 7.8 Hz, 1H), 6.79 (d, J = 2.0 Hz, 1H), 5.03 (s, 2H), 2.67−2.61 (m, 2H), 2.23 (s, 3H), 1.17 (t, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.6, 142.0, 137.2, 137.1, 136.1, 135.1, 134.6, 132.9, 128.7, 128.6, 127.7, 127.5, 127.3, 126.0, 125.6, 124.4, 122.7, 121.9, 121.8, 119.4, 118.8, 117.7, 116.9, 111.4, 110.3, 109.3, 105.7, 57.8, 44.0, 19.3, 13.9, 8.3; IR (KBr): 3636, 3524, 3440, 3290, 3054, 2969, 2361, 1693, 1601, 1462, 1343, 1173, 1102, 909, 806, 742, 699, 557; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2207.

1-Benzyl-3-(1*H*-indol-3-yl)-3-(2,3,4,9-tetrahydro-1*H*-carbazol-7-yl)indolin-2-one (4ae). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 57% (28.9 mg); white solid; mp 157.9−159.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.15 (s, 1H), 7.49 (s, 1H), 7.42−7.35 (m, 2H), 7.32−7.29 (m, 5H), 7.25 (d, J = 8.2 Hz, 2H), 7.22−7.17 (m, 2H), 7.13−7.09 (m, 1H), 7.05−6.97 (m, 2H), 6.90 (t, J = 7.3 Hz, 1H), 6.87−6.80 (m, 2H), 5.06 (d, J = 15.6 Hz, 1H), 5.00 (d, J = 15.7 Hz, 1H), 2.65 (d, J = 36.1 Hz, 4H), 1.86 (s, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.6, 142.0, 137.1, 136.1, 135.7, 134.8, 134.7, 132.9, 128.7, 127.7, 127.5, 127.3, 127.0, 126.0, 125.6, 124.4, 122.7, 122.0, 121.8, 119.4, 118.9, 117.4, 117.0, 111.4, 110.5, 109.7, 109.3, 57.9, 44.0, 23.3, 23.2, 23.2, 21.0; IR (KBr): 3635, 3525, 3299, 2923, 2848, 2362, 1696, 1601, 1460, 1343, 1261, 1097, 1018, 904, 801, 736, 696; ESI FTMS exact mass calcd for $(C_{35}H_{29}N_3O + Na)^+$ requires m/z 530.2203, found m/z 530.2205.

1′-Benzyl-1,2″,3″-trimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4sa). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 99% (49.0 mg); mp 175.5−176.8 °C; white solid; mp 160.9−161.6 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm):10.55 (s, 1H), 7.41−7.32 (m, 6H), 7.29−7.22 (m, 3H), 7.18 (d, J = 1.2 Hz, 1H), 7.12−7.07 (m, 1H), 7.03 (d, J = 7.6 Hz, 3H), 6.91−6.86 (m, 2H), 6.82−6.76 (m, 1H), 5.09−4.95 (m, 2H), 3.73 (s, 3H), 2.27 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 177.9, 142.1, 137.9, 137.0, 135.4, 134.6, 132.7, 132.2, 129.1, 128.4, 128.2, 127.9, 127.7, 126.4, 125.6, 122.8, 121.9, 121.7, 118.9, 118.3, 117.6, 115.3, 110.2, 109.9, 109.9, 105.4, 57.5, 32.8, 11.7, 8.8; IR (KBr): 3633, 3525, 3441, 2918, 2362, 1699, 1478, 1343, 746, 699; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2217.

1′-Benzyl-1″,2″,3″-trimethyl-1*H*,1″*H*-[3,3′:3′,6″-terindol]-2′(1′*H*)-one (4af). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 27% (13.6 mg); white solid; mp 110.1−112.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.13 (s, 1H), 7.45−7.36 (m, 4H), 7.34−7.28 (m, 5H), 7.22−7.19 (m, 2H), 7.12−7.10 (m, 2H), 7.03−7.01 (m, 1H), 6.93−6.83 (m, 3H), 5.12 (d, J = 15.6 Hz, 1H), 4.99 (d, J = 15.6 Hz, 1H), 3.49 (s, 3H), 2.33 (s, 3H), 2.25 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 178.5, 141.9, 137.1, 136.5, 136.4, 134.7, 133.2, 132.8, 128.72 127.7, 127.5, 127.5, 127.4, 126.1, 125.6, 124.1, 122.7, 122.0, 119.4, 118.8, 117.8, 117.2, 111.1, 109.2, 107.9, 106.0, 57.9, 44.0, 10.2, 8.8; IR (KBr): 3631, 3569, 3442, 3278, 2363, 1703, 1485, 1360, 742, 700; ESI FTMS exact mass calcd for $(C_{34}H_{29}N_3O + Na)^+$ requires m/z 518.2203, found m/z 518.2208.

1′-Benzyl-1*H*,1″*H*-[3,3′:3′,3″-terindol]-2′(1′*H*)-one (4ag). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 60% (27.2 mg); white solid; mp 286.1−287.9 °C; ^{1}H NMR (400 MHz, Acetone-d_6) δ (ppm): 10.21 (s, 1H), 10.21 (s, 1H), 7.48−7.35 (m, 7H), 7.35−7.22 (m, 4H), 7.11−6.95 (m, 6H), 6.85−6.76 (m, 2H), 5.08 (s, 2H); ^{13}C NMR (100 MHz, Acetone-d_6) δ (ppm): 177.3, 142.3, 137.5, 136.9, 134.3, 128.5, 127.8, 127.7, 127.4, 126.2, 125.1, 124.4, 122.1, 121.4, 121.3, 118.4, 115.1, 111.4, 109.1, 52.8, 43.3; IR (KBr): 3573, 3570, 3360, 3240, 3048, 1702, 1613, 1485, 1458, 1353, 1342, 1166, 1102, 743, 694, 623; ESI FTMS exact mass calcd for $(C_{31}H_{23}N_3O + Na)^+$ requires m/z 476.1739, found m/z 476.1732.

1′-Benzyl-3-methyl-1*H*,1″*H*-[2,3′:3′,3″-terindol]-2′(1′*H*)-one (4ah). Flash column chromatography eluent, petroleum ether/ethyl acetate = 5/1; Reaction time = 12 h; yield: 57% (26.8 mg); white solid; mp 266.4−268.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 8.31 (s, 1H), 8.18 (s, 1H), 7.61−7.53 (m, 1H), 7.50−7.43 (m, 2H), 7.39−7.29 (m, 6H), 7.27 (d, J = 7.9 Hz, 1H), 7.21−7.11 (m, 4H), 7.05 (t, J = 7.5 Hz, 1H), 6.99 (t, J = 7.6 Hz, 1H), 6.93 (d, J = 7.8 Hz, 1H), 6.88 (d, J = 2.5 Hz, 1H), 5.12−4.97 (m, 2H), 1.92 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 176.4, 142.1, 137.1, 135.7, 134.8, 132.4, 130.8, 130.0, 128.8, 128.5, 127.7, 127.5, 125.8, 125.5, 124.0, 123.1, 122.6, 121.7, 121.5, 120.2, 119.1, 118.5, 114.2, 111.5, 110.9, 109.5, 108.8, 53.5, 44.3, 9.1; IR (KBr): 3557, 3435, 3367, 3239, 1702, 1612, 1487, 1459, 1338, 1101, 741, 698, 623; ESI FTMS exact mass calcd for $(C_{32}H_{25}N_3O + Na)^+$ requires m/z 490.1896, found m/z 490.1890.

■ ASSOCIATED CONTENT

Supporting Information

Characterization data (including ^{1}H and ^{13}C NMR spectra) for all products **4**, HPLC chromatograms for compound **4aa**, and crystal data of compound **4aa**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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