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rsc.li/njc

View Article Online
DOI: 10.1039/C9NJ01728C

ARTICLE

Controllable C2 arylation and C3 diazenylation of indoles with arytriazenes under ambient conditions

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

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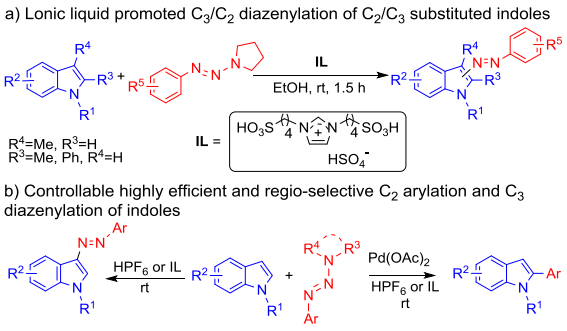
An efficient and regio-divergent method for both C2 arylation and C3 diazenylation of C2,C3-unsubstituted indoles with arytriazenes was developed. At room temperature, both reactions were carried out with HPF_6/ionic liquids (ILs) as the promoter. The C2 arylation and C3 diazenylation activated by HPF_6/ILs show a remarkable reactivity, which results in corresponding products with yields up to 99%. Notably, the practicability of the protocol was further demonstrated via gram-scale operations, late-stage modification and the reusability of ILs.

Introduction

Indoles and their derivatives widely exist in pharmaceuticals, natural products and bioactive molecules, and exhibit a wide range of significant biological activities.[1] Up to now, various of well-established classical methods for functionalized indoles are available.[2] Among all the successful strategies,[3] the direct C–H activation of indole for generating carbon-carbon bond or carbon-heteroatom bond seems to be the most straightforward pathway.[4-6] The direct site-selective arylation of indoles at the C3 and C2 positions *via* ligand, directing group and reagent controlled methods have also been reported.[4, 6, 7] However, most of protocols often suffer from harsh reaction conditions including high reaction temperatures, anaerobic and anhydrous conditions, long reaction time, poor substrate scope and functional group tolerance.[4c, 6d, 6e, 8] Wang group developed a palladium-catalyzed method for C2 arylation of *N*-substituted indoles with 1-aryltriazenes in the presence of $BF_3 OEt_2$, however, the reaction was carried out at higher temperature (80 °C), longer reaction time (12 h), and with stoichiometric Lewis acid.[8d] Furthermore, compared with arylation reaction, direct diazenylation of C2, C3-unsubstituted indoles at the C3 or C2 positions is less studied.[9] Despite that Tu and co-workers[9b] implemented the selective sulfonylation and diazotization of indoles with arylsulfonyl hydrazide through TBHP/TBAI-mediated oxidative coupling reaction, they mainly got the non-regioselective 3-sulfonyl-2-sulfonyldiazenyl-1*H*-indoles when C2, C3-unsubstituted indoles was used as substrates, and the 2-sulfonyldiazenyl-1*H*-indoles were obtained only by using C3-methyl indoles. Few investigations have been done on intermolecular selective C2 arylation and C3 diazenylation of indoles with the same coupling partners in high regio-selectivity.[9a, 9c] Consequently, achieving C2 arylation and C3 diazenylation of C2, C3-unsubstituted indoles with the same reagent presents some challenges, especially with good chemo- and regio-selectivities.

Reagents are key factors for indole functionalization. Compared with most of arylated reagents,[4b, 5b, 6e, 10] aryltriazenes are one of the most powerful and versatile candidates because of their superior reactivity, good stability, and diverse transformations.[9a, 11] Recently, our lab established a direct C3/C2 diazenylation of C2/C3 subsituted indoles with aryltriazenes using Brønsted ionic liquid (IL) as a promoter at room temperature (Scheme 1a).[9a] To the best of our knowledge, aryltriazenes simultaneously participated in arylation and diazenylation of indoles under controllable reaction conditions have rarely been reported. Enlightened by these reactions and our interests in triazene chemistry,[9a, 11c, 11e, 11g] we supposed that the

Scheme 1. C–C/C–N bond formation with arytriazenes.



reaction of indoles with triazenes would form 2-arylindole derivatives at mild reaction condition by synergistic effect of palladium and suitable acids. As a result, it was something of satisfaction to find that aryl triazenes not only play the dual roles as both aryl precursors and aryl azo donors, but also participate in arylation and diazotization of indole with good regioselectivity.

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Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/x0xx00000x

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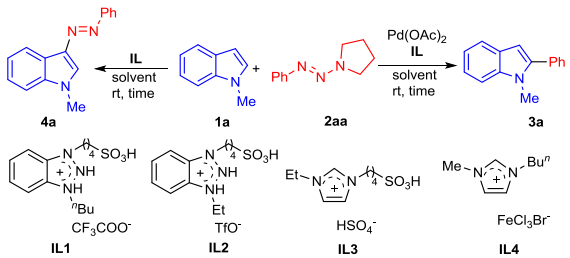
DOI: 10.1039/C9NJ01728C

Herein, we report a highly efficient and divergent method for both C2 arylation and C3 diazenylation of indoles with arytriazenes under ambient condition (Scheme 1b).

Results and discussion

At the outset of our investigation, 1-methylindole **1a** and (*E*)-1-phenyl-2-(pyrrolidin-1-yl)diazene **2aa** were selected as the model substrate to optimize the C2 arylation (Table 1). Among a series of screened additives (Table 1, entries 1-5), HPF_6 was eventually identified as the optimal promoter and the reaction could be completed in 30 minutes when 1.0 equiv. of HPF_6 was used (Table 1, entry 5). Considering the solvent effect for arylation, it was revealed that DMF was more effective than the other solvents (Table S1 and S2, ESI†). Upon further examination, we found that 0.6 equiv. of HPF_6 as additive was sufficient for the transformation (Table 1, entries 6, 7). When the volume of solvent was 1 mL and the molar ratio of indole to aryltriazene was 1:1.3, compound **3a** could reach 84% isolated yield (entries 8, 9). Due to the fascinating features of ILs, such as good stability, nonvolatility and recyclability, the **IL3** loading and the solvents were further screened (Table 1, entries 10-12), we found that by the time an aqueous solution of **IL3** was added to the reaction system by dropwise, the yield of product **3a** improved dramatically (83% isolated yield). When 0.8 equiv. of **IL3** was used as promoter, DMF aqueous solution (V_{DMF}: V_{water} = 1:1) proved to be the optimum choice for arylation (Table 1, entry 12). Gratifyingly, in the absence of palladium, it was more advantageous to the formation of C3 diazenylation products in moderate to excellent yield (Table 1, entries 13-17). After a brief screening of additives, **IL4** was by far the best (Table 1, 16). Solvent effects have also been examined (Table S1 and S2, ESI†), and TFE was shown as the ideal solvent for C3 diazenylation. Decreasing the **IL4** loading from 1.0 equiv. to 0.6 equiv., **4a** could also be obtained in excellent yields (entry 18). It is worth noting that by using HPF_6 as the promoter, **4a** could reach 94% isolated yield (Table 1, entry 19), which matches with the case of **IL4** as additive (Table 1, entry 18).

Table 1. Optimization of C2 arylation and C3 diazenylation of indole [a]

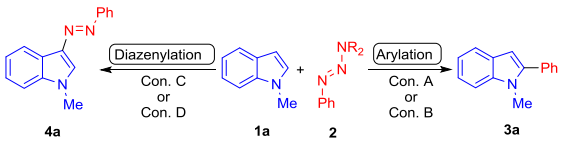


Entry[a]	Catalyst	Additives	Solvent	Yield (%)[b]	
				3a	**4a**
1	$Pd(OAc)_2$	**IL1**	DMF	32	ND
2	$Pd(OAc)_2$	**IL2**	DMF	54	ND
3	$Pd(OAc)_2$	**IL3**	DMF	57	ND
4	$Pd(OAc)_2$	**IL4**	DMF	Trace	ND
5	$Pd(OAc)_2$	HPF_6	DMF	67	Trace
6[d]	$Pd(OAc)_2$	HPF_6	DMF	77[c]	ND
7[e]	$Pd(OAc)_2$	HPF_6	DMF	78[c]	ND
8[e,f]	$Pd(OAc)_2$	HPF_6	DMF	82	ND
9[e,f,g]	$Pd(OAc)_2$	HPF_6	DMF	84[c]	ND
10[d]	$Pd(OAc)_2$	**IL3**	DMF	62	ND
11[e]	$Pd(OAc)_2$	**IL3**	DMF	55	ND
12[d,h,i]	$Pd(OAc)_2$	**IL3**	DMF/H_2O	83(83[c])	ND
13[j]	-	**IL1**	TFE	ND	41
14[j]	-	**IL2**	TFE	ND	90
15[j]	-	**IL3**	TFE	ND	92
16[j]	-	**IL4**	TFE	ND	96
17[j]	-	HPF_6	TFE	ND	93[c]
18[e,j]	-	**IL4**	TFE	ND	95(95[c])
19[e,j]	-	HPF_6	TFE	ND	94[c]

[a] Reaction conditions: **1a** (0.2 mmol), **2aa** (0.24 mmol), additives (1 equiv), solvent (2 mL), $Pd(OAc)_2$ (5 mol%), HPF_6 or IL aqueous solution was added slowly over 30 min, the reaction time was determined by TLC detection. For C3 diazenylation [b] GC yield (benzophenone as internal standard). [c] Isolated yield. [d] Additive (0.8 equiv). [e] Additive (0.6 equiv). [f] DMF (1 mL) [g] **2aa** (0.26 mmol). [h] V=2 mL (V_{DMF}:V_{water} = 1:1). [i] The IL3 was added slowly. [j] Free of $Pd(OAc)_2$. TFE = 2,2,2-Trifluoroethanol. ND = No detection.

With the optimized reaction conditions in hand, we examined the nature of the terminal tertiary amine substituent of phenyldiazenes with ionic liquid or HPF_6 as additive separately (Table 2). Except for dibutylamino group, the other tested linear and cyclic substituents could effectively promote the formation of **3a** or **4a** (Table 2, entries 1-5). Although phenyldiazene with dimethylamino group performed unsatisfactorily for HPF_6 as the promoter, it could be made up by using ionic liquid **IL4** as additive (Table 2, entry 3). For C2 arylation, phenyldiazene with diethylamino group was selected as the optimum substrate, which produced **3a** in 91% (Con. A) and 89% (Con. B) isolated yields (Table 2, entry 2). For C3 diazenylation, phenyldiazene with pyrrolidine substituent was proved to be efficient partners, affording product **4a** in 95% (Con. C) and 94% (Con. D) isolated yields (Table 2, entry 1).

Table 2. Substrate Scope of *N*-substituted 1-Aryltriazenes

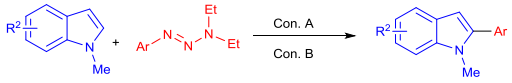


Entry	R	2	Yield **3a**		Yield **4a**	
			con. A	con. B	con. C	con. D
1		**2aa**	83%	84%	95%	94%
2	$-NEt_2$	**2ba**	91%	89%	82%	91%
3	$-NMe_2$	**2ca**	86%	65%	80%	58%
4	$-NBu_2$	**2da**	79%	74%	47%	79%
5		**2ea**	81%	81%	91%	85%

Con. A: **1a** (0.20 mmol), **2** (0.24 mmol), $Pd(OAc)_2$ (5.0 mol%), **IL3** (0.8 equiv), DMF (1 mL), H_2O (1 mL), rt, 5 h, isolated yields. Con. B: **1a** (0.2 mmol), **2** (0.26 mmol), HPF_6 (0.6 equiv) was added slowly over 30 min, DMF (1 mL), $Pd(OAc)_2$ (5.0 mol%), rt, 4 h, isolated yields. Con. C: **1a** (0.20 mmol), **2** (0.24 mmol), **IL4** (0.6 equiv), TFE (2 mL), rt, 2 h, isolated yields. Con. D: **1a** (0.2 mmol), **2** (0.24 mmol), HPF_6 (0.6 equiv) was added slowly over 30 min, CF_3CH_2OH (2 mL), rt, 1 h, isolated yields.

Next, the applicability of substrates was studied in more detail. Once 2-arylindole library was firstly established, a series of aryltriazenes and indoles were then selected to realize the structural diversities of 2-arylindole (Table 3). Aryltriazene with electron-neutral or electron-rich substituent on aryl groups gave the corresponding 2-arylindole smoothly (**3a-3m**). Interestingly, the sterically hindered 2-arylindoles, such as 2-methoxylphenyl (**3b**), 2-methylphenyl (**3c**), 2,6-dimethoxylphenyl (**3j**), 3,5-dimethylphenyl (**3k**), and 3,4,5-trimethoxylphenyl (**3m**) groups, were still successfully obtained in good to excellent isolated yield. In light of the important role of fluorine compounds in medicinal chemistry, fluorine atom was introduced into 2-aryl indole skeleton under the promotion of **IL3**, in which 2-(3-fluorophenyl)-1-methyl-1*H*-indole (**3e**) could be afforded in 67% isolated yield by reaction at 60 ℃ for 5 h. *N*- and *C*-substituted indoles also gave the corresponding products in good yield (**3n-o**, **3p-3q**). The bromo substituent in compound **3q** could be further used in cross coupling reactions. Remarkably, we also observed that *N*-substitution of indole has a certain influence on the formation of 2-arylindole. Compared with the other tested *N*-substituents, methyl group is more conducive to the formation of 2-arylated products.

Table 3. Substrate scope of C2 arylation of indole



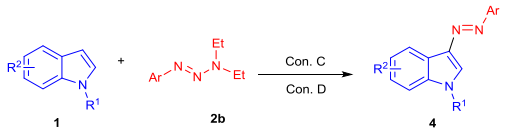
1 2b 3

Entry	R^1	R^2	Ar	3	Yield (%)[a] Con. A	Con. B
1	Me	H	Ph	**3a**	91	89
2	Me	H	2-MeOC$_6$H$_4$	**3b**	96	93
3	Me	H	2-MeC$_6$H$_4$	**3c**	85	82
4	Me	H	3-MeC$_6$H$_4$	**3d**	91	89
5	Me	H	3-FC$_6$H$_4$	**3e**	67[b]	Trace
6	Me	H	4-MeC$_6$H$_4$	**3f**	91	88
7	Me	H	4-MeOC$_6$H$_4$	**3g**	93	90
8	Me	H	4-*i*-PrC$_6$H$_4$	**3h**	92	89
9	Me	H	4-*t*-BuC$_6$H$_4$	**3i**	94	90
10	Me	H	2,6-(MeO)$_2$C$_6$H$_3$	**3j**	71[b]	65[c]
11	Me	H	3,5-Me$_2$C$_6$H$_3$	**3k**	80	82
12	Me	H	3,4-(MeO)$_2$C$_6$H$_3$	**3l**	79	66
13	Me	H	3,4,5-(MeO)$_3$C$_6$H$_2$	**3m**	82	72
14	Et	H	2-MeOC$_6$H$_4$	**3n**	92	82
15	*n*-Pr	H	2-MeOC$_6$H$_4$	**3o**	89	71
16	Me	4-Me	2-MeOC$_6$H$_4$	**3p**	87	83[c]
17	Me	5-Br	2-MeOC$_6$H$_4$	**3q**	69[b]	79[c]

Reaction conditions A: **1** (0.20 mmol), **2b** (0.24 mmol), $Pd(OAc)_2$ (5.0 mol %), DMF (1 mL), **IL3** (0.8 equiv.) was dissolved in H_2O (1 mL) and then added to the above solution by dropwise, rt, 5 h; Reaction conditions B: **1** (0.2 mmol), **2a** (0.26 mmol), DMF (1 mL), HPF_6 (0.6 equiv) was added slowly over 30 min, $Pd(OAc)_2$ (5.0 mol%), rt, 4 h. [a] Isolated yields. [b] 60 °C, 5 h. [c] 60 °C, 10 h.

Moreover, 3-arylazoindole library was then investigated with the established optimization method (Table 4). Firstly, aryltriazenes bearing electron-rich, -neutral, and -deficient groups were studied. All of them proceeded smoothly with 1-methylindole to afford the corresponding 3-arylazoindoles prosperously (**4a-4k**). Secondly, the scope of indole nucleus was carefully considered. Both *N*-alkyl and *N*-benzyl indoles performed well, diazenylation products obtained accordingly in high yields (**4l-4o**). 4-methyl indole and 2-phenyl indole could also form the target molecules (**4p** and **4q**), and the compound **4q** could be gained almost in quantitative yield.

Table 4. Substrate scope of C3 diazenylation of indole



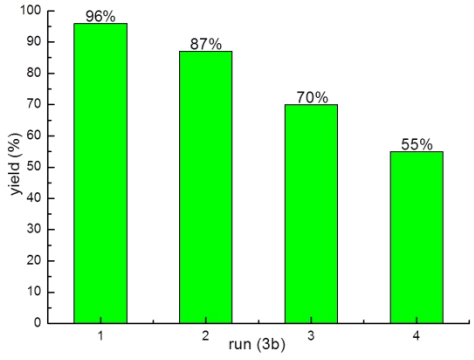
1 2b 4

Entry	R^1	R^2	Ar	4	Yield (%)[a] Con. C	Con. D
1	Me	H	Ph	**4a**	95	94
2	Me	H	2-OMeC$_6$H$_4$	**4b**	82	72
3	Me	H	3-MeC$_6$H$_4$	**4c**	81	79
4	Me	H	3-ClC$_6$H$_4$	**4d**	71[b]	73
5	Me	H	4-MeC$_6$H$_4$	**4e**	85	80
6	Me	H	4-OMeC$_6$H$_4$	**4f**	87	82
7	Me	H	4-*i*-PrC$_6$H$_4$	**4g**	90	81
8	Me	H	4-*t*-BuC$_6$H$_4$	**4h**	92	79
9	Me	H	4-FC$_6$H$_4$	**4i**	81[b]	86
10	Me	H	4-ClC$_6$H$_4$	**4j**	79[b]	76
11	Me	H	3,5-(OMe)$_2$C$_6$H$_3$	**4k**	64	66
12	Et	H	Ph	**4l**	95	92
13	*n*-Pr	H	Ph	**4m**	98	91
14	*i*-Pr	H	Ph	**4n**	89	84
15	Bn	H	Ph	**4o**	88	69[b]
16	Me	4-Me	Ph	**4p**	83	76[b]
17	Me	2-Ph	Ph	**4q**	99	99

Reaction conditions C: **1** (0.20 mmol), **2b** (0.24 mmol), **IL4** (60 mol %), TFE (2 mL), rt, 2 h; Reaction conditions D: **1** (0.2 mmol), **2a** (0.24 mmol), HPF_6 (0.6 equiv), TFE (2 mL), rt, 1 h. [a] Isolated yields. [b] 4 h.

The recyclability of **IL** was investigated subsequently under the optimized conditions (Figure 1). **IL** could be easily recovered from the reaction mixture by extraction with water and reused for the next cycle. For the diazenylation reaction, **IL4** can be reused at least three times without a significant loss of activity (Figure 1, right). However, for the arylation reaction, the yield of product **3b** gradually decreased as the number of cycles increased (Figure 1, left).

Figure 1. ILs Recycling Experiment.



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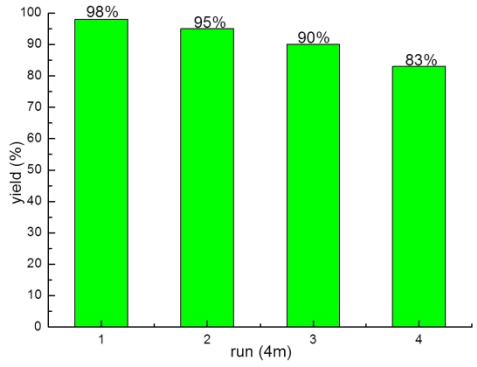
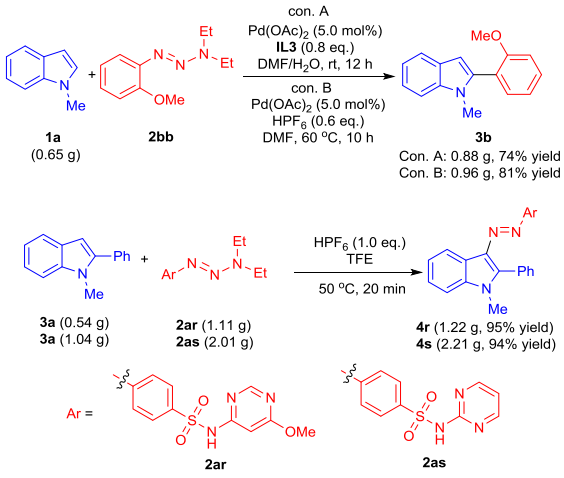
DOI: 10.1039/C9NJ01529C



In order to further explore the efficiency and practicability of the protocol, gram scale experiments and late-stage diversification were carried out. As is shown in Scheme 2, 2-(2-methoxyphenyl)-1-methyl-1*H*-indole **3b** could be obtained in 74% (Con. A) and 81% (Con. B) isolated yield. We then performed late-stage diversification of sulfadiazine drug candidates with the developed method for C3 diazenylation of indole. The results showed that 3-sulfanilamido-azoindoles (**4r**, **4s**) could be successfully synthesized at the preferable effect of HPF_6. However, **IL4** does not show feasibility for this protocol.

Scheme 2. Gram-scale experiment and late-stage modification of sulfadiazines

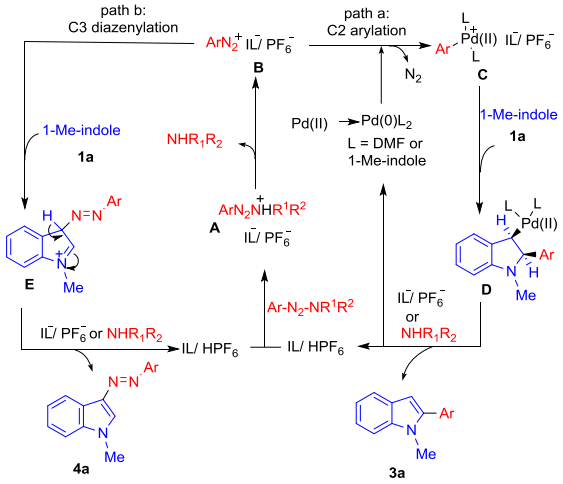


Based on the literature,[8d, 9a, 11a, 12] the possible reaction mechanisms for the formation of 2-aryl and 3-aryldiazenyl indoles are depicted in Scheme 3. In this process, aryltriazene **2** was activated by IL or HPF_6 to give ammonium salt **A**, then **B** and the secondary amine (R^1R^2NH) emerged accordingly. For C2 arylation, the diazonium salt **B** underwent oxidative addition of Pd(0), which was in situ reduced from $Pd(OAc)_2$ by DMF, the ensuing extrusion of N_2 led to the formation of arylpalladium species **C**. Afterwards, **C** alternatively reacted with **1a** *via* a Heck-type carbopalladation reaction,[12] thus providing intermediate **D**. Finally, IL^-/PF_6^- or R^1R^2NH promoted anti-β-deprotonation aromatization from **D**, producing the coupling product **3a**, in which Pd(0) was regenerated. For C3 diazenylation, 1-methylindole **1a** reacted with electrophile diazonium salt **B** to get the intermediate **E**. Then, the 3-arylazoindole **4a** was generated by IL^-/PF_6^- or R^1R^2NH assisted deprotonation and rearomatization of **E**. For both reactions mentioned above, IL and HPF_6 were concurrently released whereby another triazene substrate was activated.

Conclusions

In summary, aryltriazenes were applied successfully to the synthesis of 2-aryl and 3-aryldiazenyl indoles by the function of **IL** or HPF_6 promoting effect under mild conditions. In which, aryl triazenes play the dual roles as both aryl precursors and aryl azo donors in arylation and diazotization of indole, the reactions selectively establish C-C and C-N bonds through regio- and chemo-selective C2 arylation and C3 diazenylation of the indole framework in controllable reaction conditions, enabling a mild and practical access to functionalized indoles with good to excellent selectivity and chemical yields. For C3 diazenylation, the products could be easily achieved by simple precipitation and recrystallization. Furthermore, complementary effects of IL and HPF_6 existed in the synthesis of special compounds, **IL3** favored the formation of fluorinated C2 aryl indole, and HPF_6 contributed the late-stage diversification of sulfadiazine in C3 diazenylation of indole. The viability of late-stage and site-selective diversification of sulfadiazine drug candidates will provide candidate compounds for the discovery of new biologically active compounds. Unfortunately, when free (NH)-indoles or *N*-substitution indole with electron-withdrawing group were used, products were hardly obtained for both C2 arylation and C3 diazenylation. The biological activity of modified drugs and optical properties of the diazenylated adducts are being studied in the laboratory.

Scheme 3. The proposed reaction mechanism



Conflicts of interest

There are no conflicts to declare.

Acknowledgements

This work was financially supported by the National Natural Science Foundation of China (21462042, 21502162, 21262036, 21762041,

and 21861036), China Postdoctoral Science Foundation (2017-015 and 2017M613256). The authors thank the Ministry Key Laboratory of Oil and Gas Fine Chemicals for the assistance of GC-MS testing. The authors also acknowledge facilities and staff at the Physics and Chemistry Detecting Center of Xinjiang University.

Notes and references

1. (a) Brown, R. K. In *Indoles*; Houlihan, W. J., Ed.; Wiley-Interscience: New York, 1972. (b) Sundberg, R. J. In *Best Synthetic Methods, Indoles*; Academic Press: New York, 1996; pp 7–11. (c) Humphrey, G. R.; Kuethe, J. T. *Chem. Rev.*, 2006, **106**, 2875-2911.
2. (a) Bheeter, C. B.; Chen, L.; Soulé, J-F.; Doucet, H. *Catal. Sci. Technol.*, 2016, **6**, 2005-2049. (b) Modha, S. G.; Greaney, M. F. *J. Am. Chem. Soc.*, 2015, **137**, 1416-1419. (c) Broggini, G.; Beccalli, E. M.; Fasana, A.; Gazzola, S. *Beilstein J. Org. Chem.*, 2012, **8**, 1730-1746. (d) Shiri, M. *Chem. Rev.*, 2012, **112**, 3508-3549. (e) Cho, S. H.; Kim, J. Y.; Kwak, J.; Chang, S. *Chem. Soc. Rev*., 2011, **40**, 5068-5083. (f) Vila, C.; Tortosa, A.; Blay, G.; Munoz, M. C.; Pedro, J. R. *New J. Chem*., 2019, **43**, 130-134.
3. (a) Yang, Y.; Shi, Z. *Chem. Commun.*, 2018, **54**, 1676-1685. (b) Yang, Y.; Gao, P.; Zhao, Y.; Shi, Z. *Angew. Chem. Int. Ed.*, 2017, **56**, 3966-3971. (c)Ping, L.; Chung, D. S.; Bouffard, J.; Lee, S.-G. *Chem. Soc. Rev*., 2017, **46**, 4299-4328. (d) Leitch, J. A.; McMullin, C. L.; Mahon, M. F.; Bhonoah, Y.; Frost, C. G. *ACS Catal*., 2017, **7**, 2616-2623.(e) Neufeldt, S. R. Sanford, M. S. *Acc. Chem. Res*., 2012, **45**, 936-946.
4. (a) Kalepu, J.; Gandeepan, P.; Ackermann, L.; Pilarski, L. T. *Chem. Sci.*, 2018, **9**, 4203-4216. (b) Chen, J.; Wu, J. *Angew. Chem. Int. Ed*., 2017, **56**, 3951-3955. (c) Chen, Y.; Guo, S.; Li, K.; Qu, J.; Yuan, H.; Hua, Q.; Chen, B. *Adv. Synth. Catal*., 2013, **355**, 711-715.
5. (a) Yang, Y.; Qiu, X.; Zhao, Y.; Mu, Y.; Shi, Z. *J. Am. Chem. Soc.*, 2016, **138**, 495-498. (b) Luo, H.; Liu, H.; Zhang, Z.; Xiao, Y.; Wang, S.; Luo, X.; Wang, K. *RSC Adv.*, 2016, **6**, 39292-39295. (c) Paul, S.; Chotana, G. A.; Holmes, D.; Reichle, R. C.; Maleczka, R. E.; Smith, M. R. *J. Am. Chem. Soc*., 2006, **128**, 15552–15553. (d) Robbins, D. W.; Boebel, T. A.; Hartwig, J. F. *J. Am. Chem. Soc*., 2010, **132**, 4068-4069. (e) Yang, Y.; Li, R.; Zhao, Y.; Zhao, D.; Shi, Z. *J. Am. Chem. Soc*., 2016, **138**, 8734-8737. (f) Joucla, L.; Batail, N.; Djakovitch, L. *Adv. Synth. Catal.*, 2010, **352**, 2929-2936.
6. (a) Leitch, J. A.; Bhonoah, Y.; Frost, C. G. *ACS Catal.*, 2017, **7**, 5618-5627. (b) Maity, S.; Karmakar, U.; Samanta, R. *Chem. Commun*., 2017, **53**, 12197-12200. (c) Stuart, D. R.; Fagnou, K. *Science*, 2007, **316**, 1172-1175. (d) Stuart, D. R.; Villemure, E.; Fagnou, K. *J. Am. Chem. Soc.*, 2007, **129**, 12072-12073. (e) Lane, B. S.; Brown, M. A.; Sames, D. *J. Am. Chem. Soc*., 2005, **127**, 8050-8057.
7. (a) Zhou, S.; Wang, J.; Wang, L.; Chen, K.; Song, C.; Zhu, J. *Org. Lett.*, 2016, **18**, 3806-3809. (b) Jin, L-K.; Wan, L.; Feng, J.; Cai, C. *Org. Lett.*, 2015, **17**, 4726-4729. (c) Li, Y.; Wang, W-H.; He, K-H.; Shi, Z-J. *Organometallics*, 2012, **31**, 4397-4400. (d) Li, Y.; Wang, W-H.; Yang, S-D.; Li, B-J.; Feng, C.; Shi, Z-J. *Chem. Commun*., 2010, **46**, 4553-4555.
8. (a) Cornella, J.; Lu, P.; Larrosa, I. *Org. Lett.*, 2009, **11**, 5506-5509. (b) Wang, X.; Lane, B. S.; Sames, D. *J. Am. Chem. Soc.*, 2005, **127**, 4996-4997. (c) Lane, B. S.; Sames, D. *Org. Lett*., 2004, **6**, 2897-2900. (d) Liu, C.; Miao, T.; Zhang, L.; Li, P.; Zhang, Y.; Wang, L. *Chem. Asian J.*, 2014, **9**, 2584-2589.
9. (a) Cao, D.; Zhang, Y.; Liu, C.; Wang, B.; Sun, Y.; Abdukadera, A.; Hu, H.; Liu, Q. *Org. Lett.*, 2016, **18**, 2000-2003. (b) Qiu, J-K.; Hao, W-J.; Wang, D-C.; Wei, P.; Sun, J.; Jiang. B; Tu, S-J. *Chem. Commun.*, 2014, **50**, 14782-14785. (c) Joucla, L.; Djakovitch, L. *Adv. Synth. Catal*., 2009, **351**, 673-741.
10. (a) Yang, S-D.; Sun, C-L.; Fang, Z.; Li, B-J.; Li, Y-Z.; Shi, Z-J. *Angew. Chem. Int. Ed*., 2008, **47**, 1473-1476. (b) Kalyani, D.; Deprez, N. R.; Desai, L. V.; Sanford, M. S. *J. Am. Chem. Soc*., 2005, **127**, 7330-7331. (c) Barak, D. S.; Dighe, S. U.; Avasthi, I.; Batra, S. *J. Org. Chem*., 2018, **83**, 3537-3546.
11. (a) Dai, W-C.; Wang, Z-X. *Org. Chem. Front.*, 2017, **4**, 1281-1288. (b) Yin, Z.; Wang, Z.; Wu, X-F. *Eur. J. Org. Chem.*, 2017, **2017**, 3992-3995. (c) Zhang, Y.; Hu, H.; Liu, C-J.; Cao, D.; Wang, B.; Sun, Y.; Abdukader, A. *Asian J. Org. Chem.*, 2017, **6**, 102-107. (d) Ando, S.; Burrows, J.; Koide, K. *Org. Lett.*, 2017, **19**, 1116-1119. (e) Zhang, Y.; Cao, D.; Liu, W.; Hu, H.; Zhang, X.; Liu, C. *Curr. Org. Chem.*, 2015, **19**, 151-178. (f) Li, H.; Li, P.; Wang, L. *Org. Lett.*, 2013, **15**, 620-623. (g) Zhang, Y.; Liu, Y.; Ma, X; Ma, X.; Wang, B.; Li, H.; Huang, Y.; Liu, C. *Dyes & Pigm.*, 2018, **158**, 438-444. (h) Mao, S.; Chen, Z.; Wang, L.; Khadka, D. B.; Xin, M.; Li, P.; Zhang, S-Q. *J. Org. Chem.*, 2019, **84**, 463-471.
12. Gemoets, H. P. L.; Kalvet, I.; Nyuchev, A. V.; Erdmann, N.; Hessel, V.; Schoenebeck, F.; Noël, T. *Chem. Sci.*, 2017, **8**, 1046-1055.

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DOI: 10.1039/C9NJ01728C

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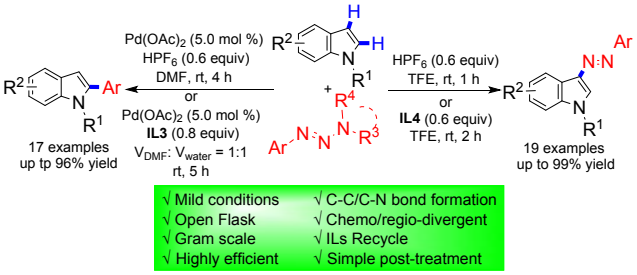

Controllable C2 arylation and C3 diazenylation of indoles with arytriazenes under ambient conditions