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Unexpected formation of fluorine-containing tetrahydrocarbazole during the reaction of indole, paraformaldehyde, and fluorine-containing β-ketoesters

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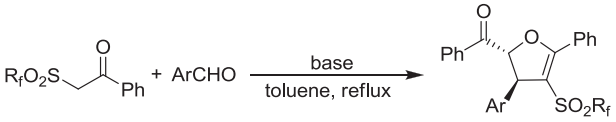
ABSTRACT

A surprise and mild method to prepare fluorine-containing indole derivatives through a one-pot three-component condensation reaction sequence is presented. To our surprise, during the reaction of preparation of fluorine-containing indole derivatives, unexpected formation of fluorine-containing tetrahydrocarbazole was found. Moreover, this method has been demonstrated in the preparation of functionalized polycyclic indole derivatives in a straightforward and atom-economical manner.

1. Introduction

Indoles represent a prominent class of heterocyclic compounds with varied and often potent biological activities.[1] Consequently, there are a large number of methodologies for the synthesis and structural modification of indole scaffold, including acid-induced Fischer indole synthesis from arylhydrazine and ketones,[2] transition metal-catalyzed intramolecular alkylation of alkenyl indoles with unactivated olefins,[3] and Lewis acid-promoted internal olefins in Friedel–Crafts alkylation of indoles.[4] Nevertheless, many of them suffered from some of the following disadvantages, such as difficulty in preparation of complex starting materials, harsh reaction conditions, trouble with operation (excluding air and moisture), expensive reagents (e.g., metal-complex catalysis) and long reaction times, multistep operation, and low overall yields. Thus, in spite of the diverse synthetic routes developed so far, there still remains a need to develop a more concise, benign one-pot option for the synthesis of indole derivatives, especially the fluorinated ones. It is well documented that the introduction of fluorine-containing group into organic molecules can make a profound and unexpected influence on the physical and biological properties of organic compounds.[5] However, to the best of our knowledge, there are few reports about the synthesis of fluorine-containing indole derivatives. Herein, we wish to report a new and efficient method for the synthesis of fluorine-containing indole derivative through a one-pot three-component condensation reaction sequence, which involves a Knoevenagel condensation of paraformaldehyde and fluorine-containing β-ketoesters, followed by trapping with indoles via a Michael-type reaction. Depending on different indoles and fluorine-containing β-ketoesters, different products can be formed through carbon–carbon double-bond isomerization, β-H elimination, or cyclization.

β-Keto polyfluoroalkanesulfones have a moderately active methylene moiety and have been widely used in the synthesis of heterocycles and unsaturated sulfonyl esters. The Knoevenagel condensation reaction between β-keto aryl sulfones or α-perfluoroalkanesulfonyl acetate esters and aldehydes is well-known.[6] Our laboratory has also studied some chemical transformations of these compounds.[7] For instance, in 2004, we reported an unexpected formation of tetrasubstituted *trans*-2,3-dihydrofurans under basic conditions when β-keto polyfluoroalkanesulfones are reacted with aromatic aldehydes (Scheme 1).[7a]



Scheme 1. The formation of tetrasubstituted *trans*-2,3-dihydrofurans.

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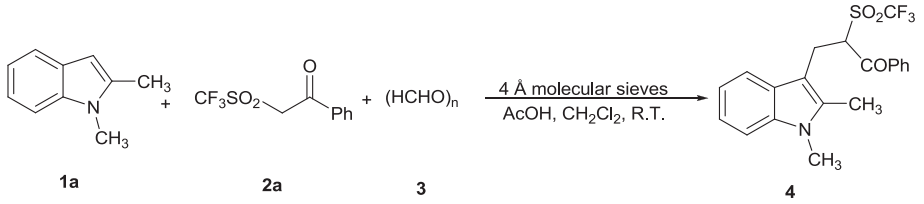
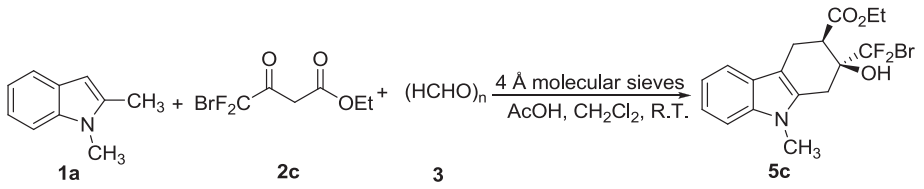
Recently, we studied a one-pot three-component condensation reaction under acidic conditions. As an example, reaction of 1,2-dimethyl-1*H*-indole, 2-(trifluoromethane sulfonyl)-1-phenylethanone, and paraformaldehyde in the presence of acetic acid in DCM at room temperature for 1 h led to isolation of **4** in 56% yield (Scheme 2).



Scheme 2. The reaction of 1,2-dimethyl-1*H*-indole, 2-(trifluoromethane sulfonyl)-1-phenylethanone and paraformaldehyde.



Scheme 3. The formation of tetrahydrocarbazole derivative.

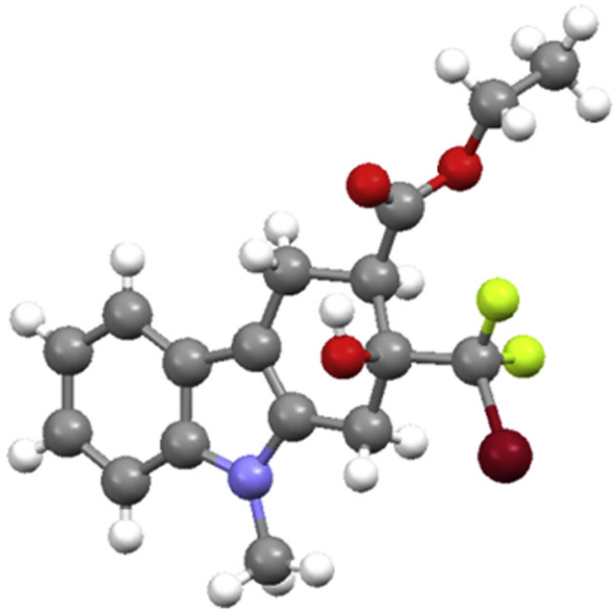


Fig. 1. Molecular structure of **5c**.

In order to examine the generality of this reaction, 2-(trifluoromethanesulfonyl)-1-phenylethanone **2a** was replaced by ethyl 4,4,4-trifluoro-3-oxobutanoate **2b** to react with 1,2-dimethyl-1*H*-indole and paraformaldehyde under the same reaction conditions. To our surprise, the structure of the product was not consistent with what we expected. From the ^{1}H NMR spectrum, the single signal at 2.55 ppm of 2-methyl group of indole molecular disappeared and a diagnostic single signal at −80.1 ppm was found for the ^{19}F NMR spectrum, which suggested that the trifluoromethyl group was quite close to an electron-donating group. Next, ethyl 4-bromo-4,4-difluoro-3-oxybutaneoate **2c** was used to repeat the reaction under the same conditions. The structure of the isolated product was determined to be a fused polycyclic indole derivative, 2-bromodiflurometh substituted tetrahydrocarbazole, by X-ray crystallography (Scheme 3, Fig. 1).

A possible mechanism is outlined in Scheme 4. Under acidic condition, ethyl 4,4,4-trifluoromethyl-3-oxobutanoate first reacts with paraformaldehyde through a Knoevenagel condensation, followed by an in situ trapping of the vinyl product (**I**) with 1,2-dimethyl-1*H*-indole via a Michael-type reaction. The addition product (**II**) is unstable, which undergoes double-bond isomerization, β-H elimination, cyclization to form tetrahydrocarbazole as the final product. To the best of our knowledge,[2a,8] this might represent the first report on the formation of tetrahydrocarbazole derivatives via a one-pot three-component reaction sequence.

As can been seen in Table 1, the reaction did not proceed without acid (Table 1, entry 4). Moreover, use of Lewis acids instead of Brönsted acids resulted in the formation of different products (Table 2).[9,10]

As mentioned above (Scheme 4), product **5** was formed due to the presence of 2-methyl group on the indole motif. So we employed **1b** to react with ethyl 4,4,4-trifluoroacetoacetate **2b** and paraformaldehyde **3**. However, under the same condition, an unexpected six-membered ring product **8** formed instead of the expected product **9** (Scheme 5). The structure of **8** was fully confirmed by spectroscopic method and single-crystal X-ray diffraction analysis. Its molecular structure was showed in Fig. 2.

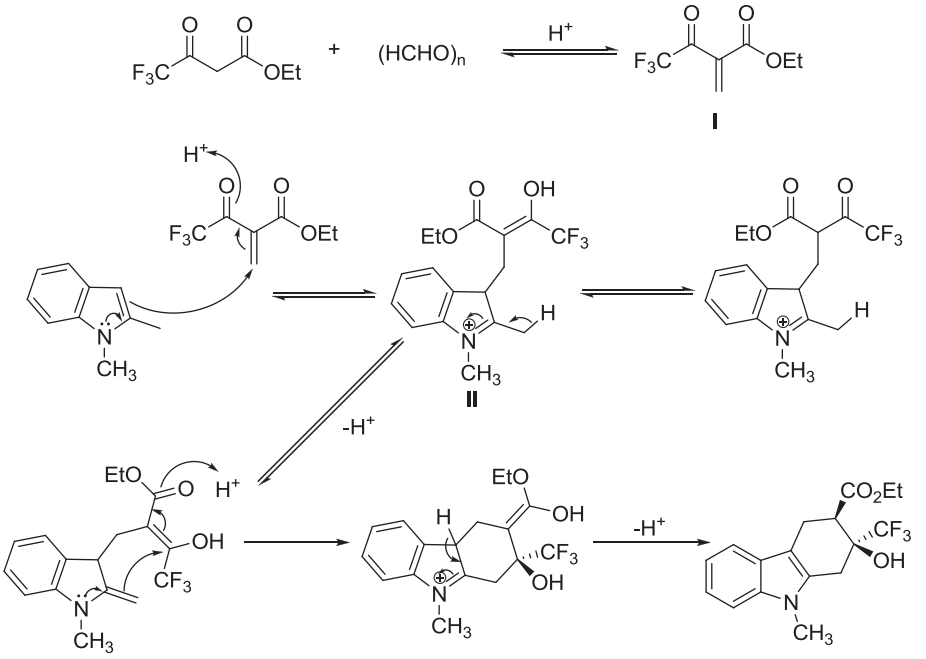
A possible mechanism for the formation of compound **8** is proposed in Scheme 6. In the presence of acetic acid, the unstable Michael-type addition indole intermediate (**III**) further reacted with two formaldehyde molecules, followed by cyclization to give the 1,3-dioxane product.

In summary, we have developed a novel and mild method to prepare fluorine-containing indole derivatives through a one-pot three-component condensation reaction sequence. Moreover, this method has been demonstrated in the preparation of functionalized polycyclic indole derivatives in a straightforward and atom-economical manner. Further studies to expand the scope of this new methodology are underway in our laboratory.

2. Experimental procedure and spectral data

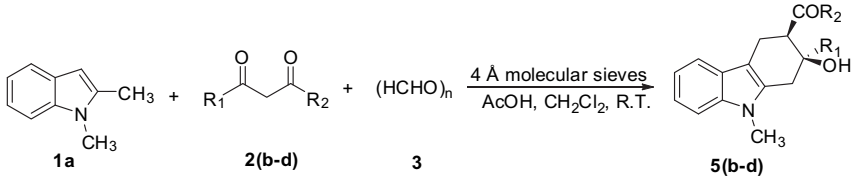
2.1. General

To a solution of paraformaldehyde (2.5 mmol), fluorine-containing β-ketoesters (0.5 mmol), and indole (0.5 mmol) in DCM (3.0 mL) were added acetic acid (50 mol %) and molecular sieves 4 Å (100 mg). The reaction mixture was stirred by magnetic stirrer at



Scheme 4. The possible mechanism of formation of tetrahydrocarbazole derivative.

Table 1
Reaction results of **1a**, **2b**–**d**, and **3**

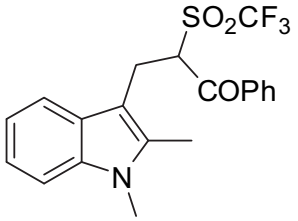


Entry	**2**		Acid	Product	Yield[a] (%)
	R_1	R_2			
1	CF_3	OEt (**2b**)	AcOH	**5b**	50
2	CF_2Br	OEt (**2c**)	AcOH	**5c**	63
3	C_3F_7	^{t}Bu (**2d**)	AcOH	**5d**	47
4	CF_3	OEt (**2b**)	—	—	—

[a] Isolate yield based on **2**.

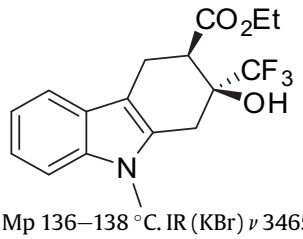
room temperature for about 2 h. The progress of reaction was monitored by TLC. After satisfactory conversion, the product was separated from molecular sieves by filtration. The solvent was removed in vacuum and the residue was purified on silica gel using ethyl acetate–hexane as eluent to afford the pure corresponding products.

*2.1.1. 3-(1,2-Dimethyl-1H-indol-3-yl)-1-phenyl-2-(trifluoromethylsulfonyl)propan-1-one (**4**).*



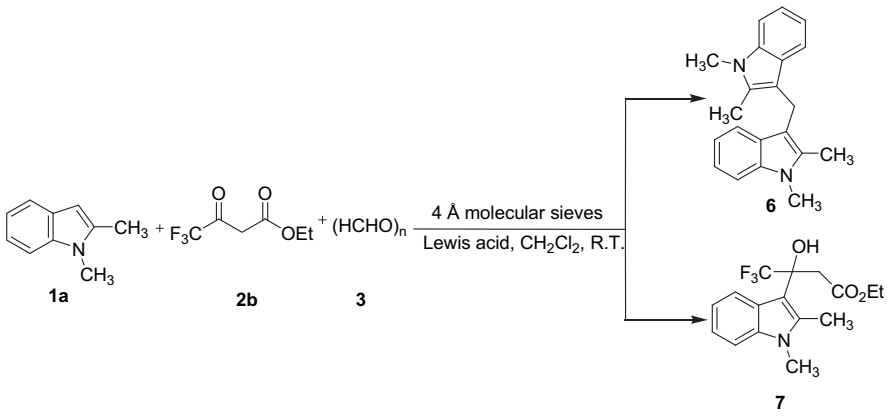
Colorless solid. Mp 105–107 °C. IR (KBr) ν 3435, 3046, 2941, 1684, 1594, 1580, 1476, 1448, 1411, 1363, 1338, 1259, 1237, 1207, 1153, 1109, 934, 773, 741 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 7.53–7.40 (m, 4H), 7.24–7.11 (m, 5H), 5.57 (dd, J_1=3.6 Hz, J_2=11.1 Hz, 1H), 3.91 (dd, J_1=11.1 Hz, J_2=14.1 Hz, 1H), 3.72 (dd, J_1=3.6 Hz, J_2=14.1 Hz, 1H), 3.43 (s, 3H, CH_3), 2.19 (s, 3H, CH_3) ppm. ^{19}F NMR (282 MHz, $CDCl_3$) δ −74.7 (s, 3F) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.0, 136.9, 136.2, 135.0, 134.4, 128.6, 128.3, 126.5, 121.4, 119.9 (q, $^1J_{CF}$=329.7 Hz), 119.9, 116.7, 109.1, 102.9, 64.7, 29.5, 23.8, 10.0 ppm. MS (EI) m/z (%): 409 (M^+, 20), 276 (72), 170 (18), 158 ($C_{11}H_{12}N^+$, 100), 105 (93), 77 (36). Anal. Calcd for $C_{20}H_{18}F_3NO_3S$: C, 58.67, H, 4.43, N, 3.42. Found: C, 58.73, H, 4.58, N, 3.30.

*2.1.2. (2S,3R)-Ethyl 2-hydroxy-9-methyl-2-(trifluoromethyl)-2,3,4,9-tetrahydro-1H-carbazole-3-carboxylate (**5b**).*



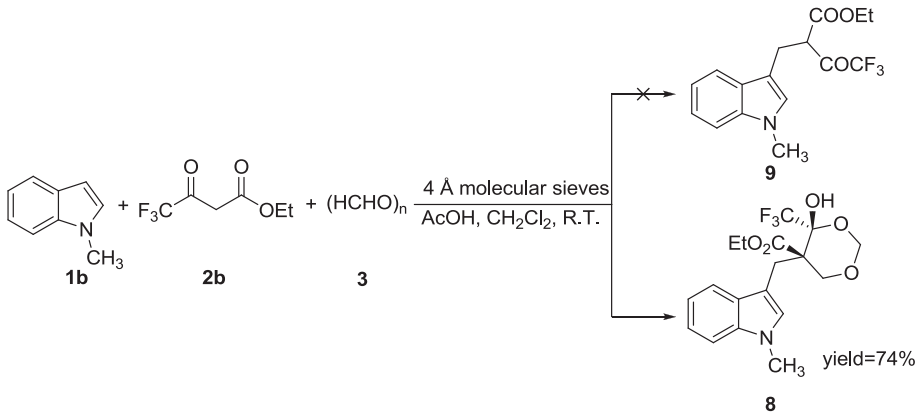
Colorless solid. Mp 136–138 °C. IR (KBr) ν 3465, 2975, 1747, 1709, 1616, 1474, 1395, 1383, 1375, 1345, 1295, 1277, 1189, 1163, 1106, 1062, 1022, 859, 743 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 7.43 (d, J=7.8 Hz, 1H), 7.25 (d, J=7.8 Hz, 1H), 7.18 (t, J=7.2 Hz, 1H), 7.09 (t, J=6.9 Hz, 1H), 4.71 (s, 1H), 4.38–4.20 (m, 2H, CH_2), 3.59 (s, 3H, CH_3),

Table 2
Reaction results of **1a**, **2b**, and **3** in the presence of different Lewis acids



Entry	Acid	Product	Yield[a] (%)
1	$BF_3{\cdot}OEt_2$	**6**	20
2	$FeCl_3$	**6**	24
3	$AlCl_3$	**6**	34
4	$Cu(OTf)_2$	**6**	42
5	$Yb_4(OTf)_3$	**6**	32
6	$ZnCl_2$	**7**	35/59[b]
7	$Sm(OTf)_3$	**7**	41

[a] Isolate yield based on **2**.
[b] Reaction without **3** and molecular sieves.



Scheme 5. The formation of unexpected six-membered ring product **8**.

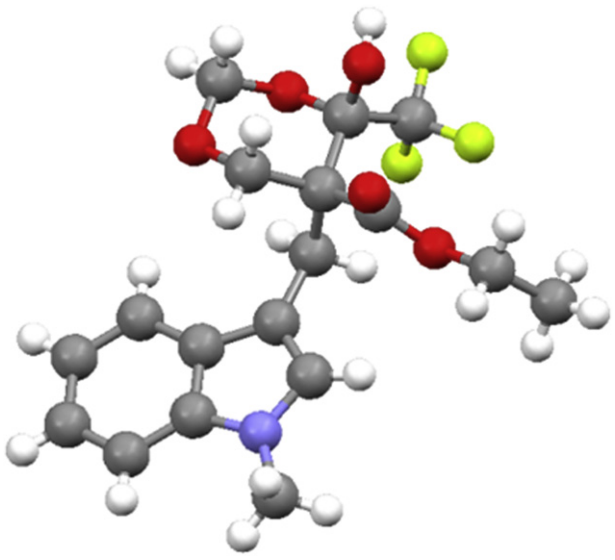
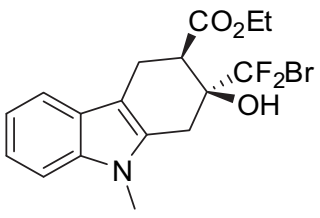
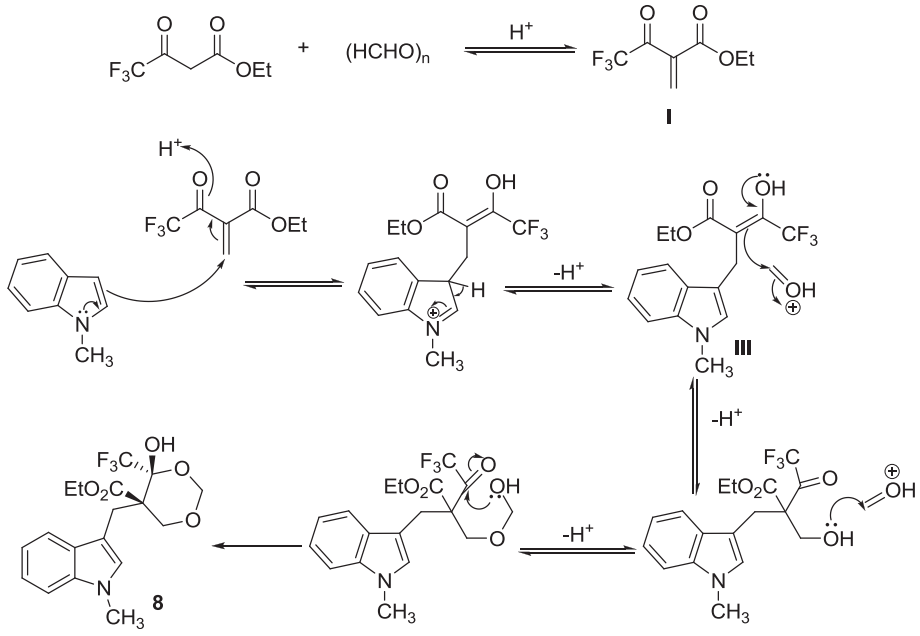


Fig. 2. Molecular structure of **8**.

3.19–2.97 (m, 5H), 1.34 (t, J=7.2 Hz, 3H, CH_3) ppm. ^{19}F NMR (282 MHz, $CDCl_3$) δ −81.1 (s, 3F) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.4, 137.5, 130.0, 125.9 (q, $^1J_{CF}$=286.4 Hz), 125.9, 121.4, 119.3, 117.9, 108.9, 105.0, 74.4 (q, $^2J_{CF}$=27.0 Hz), 62.0, 42.3, 29.3, 28.7, 22.9, 14.0 ppm. MS (EI) m/z (%): 341(M^+, 32), 323 (15), 296 (3), 272 (1), 268 (10), 250 (M^+−Me−Ph, 100), 230 (17), 198 (9), 181 (11), 168 (4), 157 (23). Anal. Calcd for $C_{17}H_{18}F_3NO_3$: C, 59.82, H, 5.32, N, 4.10. Found: C, 59.75, H, 5.26, N, 4.05.

*2.1.3. (2S,3R)-Ethyl 2-(bromodifluoromethyl)-2-hydroxy-9-methyl-2,3,4,9-tetrahydro-1H-carbazole-3-carboxylate (**5c**).*

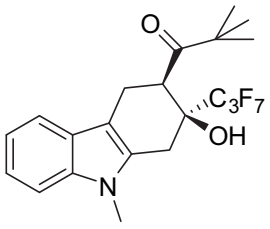




Scheme 6. The possible mechanism of formation of product **8**.

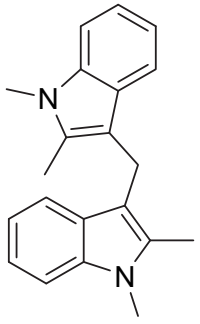
Colorless solid. Mp 138–140 °C. IR (KBr) ν 3463, 2976, 1745, 1708, 1618, 1473, 1449, 1442, 1375, 1342, 1299, 1283, 1265, 1188, 1167, 1131, 1102, 1060, 1018, 1000, 976, 908, 860, 815, 741 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 7.44 (d, J=8.1 Hz, 1H), 7.27 (d, J=8.1 Hz, 1H), 7.19 (t, J=8.4 Hz, 1H), 7.09 (t, J=7.5 Hz, 1H), 4.90 (s, 1H), 4.38–3.63 (m, 2H, CH_2), 3.63 (s, 3H, CH_3), 3.23–3.03 (m, 5H), 1.35 (t, J=7.2 Hz, 3H, CH_3) ppm. ^{19}F NMR (282 MHz, $CDCl_3$) δ −58.5 (d, J=18.0 Hz, 2F) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 175.5, 137.5, 130.3, 127.3 (t, $^1J_{CF}$=313.9 Hz), 125.8, 121.4, 119.3, 108.9, 105.0, 104.9, 79.2 (q, $^2J_{CF}$=20.5 Hz), 62.0, 42.8, 30.7, 29.4, 23.8, 14.1 ppm. MS (EI) m/z (%): 403 (M^+, 35), 401 (34), 383 (2), 356 (4), 328 (9), 304 (96), 276 (36), 230 (M^+−Me−Ph−Br, 100), 210 (15), 198 (29), 182 (28), 157 (56). Anal. Calcd for $C_{17}H_{18}BrF_2NO_3$: C, 50.76, H, 4.51, N, 3.48. Found: C, 50.76, H, 4.51, N, 3.38.

*2.1.4. 1-((2S,3R)-2-Hydroxy-9-methyl-2-(1,1,1,2,2,3,3-heptafluoro)-2,3,4,9-tetrahydro-1H-carbazole-3-yl)-2,2-dimethylpropan-1-one (**5d**).*



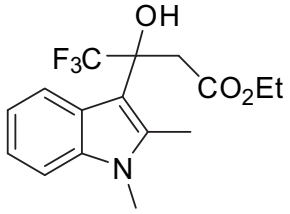
Colorless solid. Mp 175–177 °C. IR (KBr) ν 3409, 2964, 1684, 1476, 1345, 1262, 1223, 1187, 1107, 1068, 1016, 813, 750, 723 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 7.43 (d, J=7.8 Hz, 1H), 7.27 (d, J=8.1 Hz, 1H), 7.19 (t, J=8.4 Hz, 1H), 7.09 (t, J=7.5 Hz, 1H), 5.77 (s, 1H, OH), 3.62 (s, 3H, CH_3), 3.19–2.88 (m, 5H), 1.27 (s, 9H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$) δ −80.8 (t, J=9.9 Hz, 3F), −116.4 to −116.8 (m, 2F), −122.9 to −123.0 (m, 2F) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ 222.3, 137.5, 129.9, 125.6, 121.4, 119.3, 117.7, 108.9, 105.2, 58.5, 45.9, 41.0, 29.3, 27.0, 25.6, 18.5 ppm. MS (ESI): 454 (M^++1). Anal. Calcd for $C_{21}H_{22}F_7NO_2$: C, 55.63, H, 4.89, N, 3.09. Found: C, 55.57, H, 4.90, N, 2.94.

*2.1.5. Bis(1,2-dimethyl-1H-indol-3-yl)methane (**6**).*



Colorless solid. ^1H NMR (300 MHz, $CDCl_3$) δ 7.42(d, J=7.9 Hz, 2H), 7.22 (d, J=7.8 Hz, 2H), 7.06 (t, J=7.1 Hz, 2H), 6.96 (t, J=7.0 Hz, 2H), 3.65 (s, 6H), 3.60 (s, 2H), 2.40 (s, 6H) ppm.

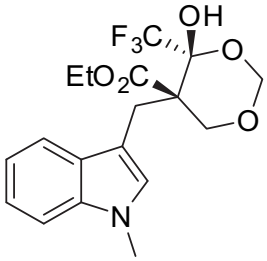
*2.1.6. Ethyl 3-(1,2-dimethyl-1H-indol-3-yl)-4,4,4-trifluoro-3-hydroxobutanoate (**7**).*



Colorless solid. Mp 114–116 °C. ^1H NMR (300 MHz, $CDCl_3$) δ 7.69(d, J=7.8 Hz, 1H), 7.25 (d, J=7.8 Hz, 1H), 7.15 (t, J=7.2 Hz, 1H), 7.07 (t, J=6.9 Hz, 1H), 5.37 (s, 1H), 4.11–4.00 (m, 2H), 3.65 (s, 3H), 3.61 (d, J=16.5 Hz, 1H), 3.25 (d, J=16.5 Hz, 1H), 2.64 (s, 3H), 1.08 (t, J=7.2 Hz, 3H) ppm. ^{19}F NMR (282 MHz, $CDCl_3$) δ −81.5 (s, 3F) ppm.

Anal. Calcd for $C_{16}H_{18}F_3NO_3$: C, 58.35, H, 5.51, N, 4.25. Found: C, 58.44, H, 5.33, N, 4.29.

*2.1.7. (4R,5R)-Ethyl 4-hydroxy-5-((1-methyl-1H-indol-3-yl)methyl)-4-(trifluoromethyl)-1,3-dioxane-5-carboxylate (**8**).*



Colorless solid. Mp 117–119 °C. IR (KBr) ν 3366, 2994, 2958, 2892, 1703, 1474, 1456, 1378, 1326, 1294, 1258, 1223, 1196, 1184, 1160, 1132, 1114, 1095, 1031, 1015, 970, 951, 746 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 7.85 (d, J=7.8 Hz, 1H), 7.24 (t, J=6.6 Hz, 2H), 7.15 (t, J=6.9 Hz, 1H), 6.99 (s, 1H), 5.38 (d, J=5.4 Hz, 1H), 5.21 (s, 1H), 5.14 (d, J=5.7 Hz, 1H), 4.34–4.12 (m, 3H), 3.97 (d, J=11.7 Hz, 1H), 3.78 (s, 3H), 3.61 (dd, J_1=15.0 Hz, J_2=6.0 Hz, 2H), 1.30 (t, 3H, J=7.2 Hz) ppm. ^{19}F NMR (282 MHz, $CDCl_3$) δ −79.1 (s, 3F) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.1, 136.5, 129.4, 129.1, 122.2 (q, $^1J_{CF}$=286.6 Hz), 121.5, 119.7, 118.9, 108.9, 108.1, 95.2 (q, $^2J_{CF}$=32.0 Hz), 87.3, 66.8, 62.8, 62.2, 51.7, 32.7, 23.1, 13.8 ppm. MS (EI) m/z (%): 387 (M^+, 2), 184 (6), 144 ($C_{10}H_{10}N^+$, 100), 131 (4), 128 (4), 115 (5), 77 (8), 42 (5). Anal. Calcd for $C_{18}H_{20}F_3NO_5$: C, 55.81, H, 5.20, N, 3.62. Found: C, 55.79, H, 5.27, N, 3.64.

Acknowledgements

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Supplementary data

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References and notes

1. (a) Nicolaou, K. C.; Pfefferkorn, J. A.; Roecker, A. J.; Cao, G.-Q.; Barluenga, S.; Mitchell, H. J. *J. Am. Chem. Soc.* **2000**, *122*, 9939; (b) Kleeman, A.; Engel, J.; Kutscher, B.; Reichert, D. *Pharmaceutical Substances*, 4th ed.; Thieme: New York, NY, 2001; (c) Saxton, J. E. *Nat. Prod. Rep.* **1997**, 559; (d) Toyota, M.; Ihara, M. *Nat. Prod. Rep.* **1998**, 327.
2. (a) Bhattacharya, D.; Gammon, D. W.; Steen, E. V. *Catal. Lett.* **1999**, *61*, 93; (b) Chen, J.; Hu, Y. Z. *Synth. Commun.* **2006**, *36*, 1485; (c) Xu, D.-Q.; Yang, W.-L.; Luo, S.-P.; Wang, B.-T.; Wu, J.; Xu, Z.-Y. *Eur. J. Chem.* **2007**, 1007; (d) Iwama, T.; Birman, V. B.; Kozmin, S. A.; Rawal, V. H. *Org. Lett.* **1999**, *1*, 673; (e) Chen, C.-Y.; Lieberman, D. R.; Larsen, R. D.; Verhoeven, T. R.; Reider, P. J. *J. Org. Chem.* **1997**, *62*, 2676; (f) Scott, T. L.; Burke, N.; Carrero-Martínez, G.; Söderberg, B. C. G. *Tetrahedron* **2007**, *63*, 1183; (g) Mhaske, S. B.; Narshinha, P. A. *Tetrahedron* **2004**, *60*, 3417.
3. (a) Li, C. F.; Liu, H.; Liao, J.; Cao, Y. J.; Liu, X. P.; Xiao, W. J. *Org. Lett.* **2007**, *9*, 1847; (b) Chen, J. R.; Li, C. F.; An, X. L.; Zhang, J. J.; Zhu, X. Y.; Xiao, W. J. *Angew. Chem., Int. Ed.* **2008**, *47*, 2489; (c) Han, X. Q.; Widenhoefer, R. A. *Org. Lett.* **2006**, *8*, 3801; (d) Liu, C.; Han, X. Q.; Wang, X.; Widenhoefer, R. A. *J. Am. Chem. Soc.* **2006**, *128*, 9066; (e) Liu, C.; Widenhoefer, R. A. *J. Am. Chem. Soc.* **2004**, *126*, 10250; (f) Zhang, Z. B.; Liu, C.; Kinder, R. E.; Han, X. Q.; Widenhoefer, R. A. *J. Am. Chem. Soc.* **2004**, *126*, 3700; (g) Ferreira, E. M.; Stoltz, B. M. *J. Am. Chem. Soc.* **2003**, *125*, 9578; (h) Barluenga, J.; Jiménez-Aquino, A.; Aznar, F.; Valdés, C. *J. Am. Chem. Soc.* **2009**, *131*, 4031; (i) Huang, H. X.; Peters, R. *Angew. Chem., Int. Ed.* **2009**, *48*, 604; (j) Youn, S. W.; Pastine, S. J.; Sames, D. *Org. Lett.* **2004**, *6*, 581; (k) Bandini, M.; Emer, E.; Tommasi, S.; Umani-Ronchi, A. *Eur. J. Org. Chem.* **2006**, 3527.
4. (a) Noland, W. E.; Xia, G. M.; Gee, K. R.; Konkel, M. J.; Wahlstrom, M. J.; Condoluci, J. J.; Rieger, D. L. *Tetrahedron* **1996**, *52*, 4555; (b) Bandini, M.; Melloni, A.; Umani-Ronchi, A. *Org. Lett.* **2004**, *6*, 3199.
5. (a) Goldmand, P. *Science* **1969**, *164*, 1123; (b) Welch, J. T. *Tetrahedron* **1987**, *43*, 3123.
6. (a) Goumont, R.; Magder, K.; Tordeux, M.; Marrot, J.; Terrier, F.; Wakselman, C. *Eur. J. Org. Chem.* **1999**, 2969; (b) Koshar, R. J.; Mitsch, R. A. *J. Org. Chem.* **1973**, *38*, 3358; (c) Menke, O.; Steinhuber, E.; Martinez, A. G.; Subramanian, L. R.; Hanack, M. *Synthesis* **1994**, 1291; (d) Hanack, M.; Bailer, G.; Hackenberg, J.; Subramanian, L. R. *Synthesis* **1991**, 1205.
7. (a) Xing, C. H.; Zhu, S. Z. *J. Org. Chem.* **2004**, *69*, 6486; (b) Zhu, S. Z.; Xu, G. L.; Qin, C. Y.; Xu, Y.; Chu, Q. L.; DesMarteau, D. D. *Heteroat. Chem.* **1999**, *10*, 147; (c) Zhu, S. Z.; Pennington, W. T.; DesMarteau, D. D. *Inorg. Chem.* **1995**, *34*, 792; (d) Zhu, S. Z. *Heteroat. Chem.* **1994**, *5*, 9; (e) Zhu, S. Z. *Synthesis* **1994**, 261; (f) Zhu, S. Z. *J. Fluorine Chem.* **1993**, *64*, 47; (g) Zhu, S. Z.; Li, A. W. *J. Fluorine Chem.* **1993**, *60*, 175.
8. (a) Dhakshinamoorthy, A.; Pitchumani, K. *Appl. Catal., A* **2005**, *292*, 305; (b) Barbieri, V.; Ferlin, M. G. *Tetrahedron Lett.* **2006**, *47*, 8289; (c) Banwell, M. G.; Kelly, B. D.; Kokas, O. J.; Lupton, D. W. *Org. Lett.* **2003**, *5*, 2497; (d) Wagaw, S.; Yang, B. H.; Buchwald, S. L. *J. Am. Chem. Soc.* **1998**, *120*, 6621; (e) Abramovitch, R. A.; Bulman, A. *Synlett* **1992**, 795.
9. (a) Pradhan, P. K.; Dey, S.; Giri, V. S.; Jaisankar, P. *Synthesis* **2005**, *11*, 1779; (b) McDougal, A.; Gupta, M. S.; Morrow, D.; Ramamoorthy, K.; Lee, J.-E.; Safe, S. H. *Breast Cancer Res. Treat.* **2001**, *66*, 147.
10. (a) Abid, M.; Török, B. *Tetrahedron: Asymmetry* **2005**, *16*, 1547; (b) Abid, M.; Török, B. *Adv. Synth. Catal.* **2005**, *347*, 1797.