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Palladium-Catalyzed Coupling of Heteroaromatic Triflates with Acetylene and its Application for a Dynemicin A Intermediate

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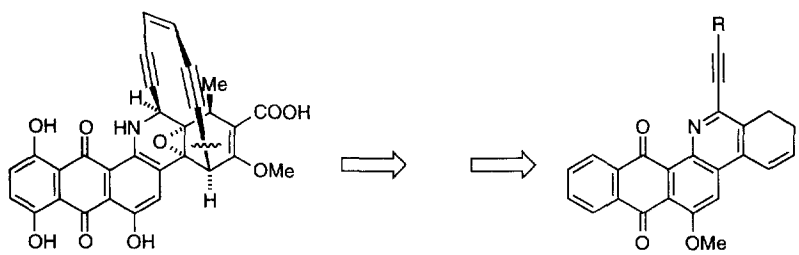
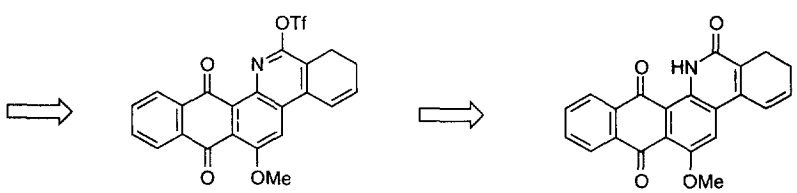
Abstract: *An acetylene moiety was introduced to a carbonyl carbon of amide group via its triflate in the presence of palladium catalyst. The reaction proceeded smoothly under mild conditions. Utilizing this methodology, a model compound of dynemicin A bearing acetylene group was synthesized.*

In 1989 dynemicin A (**1**) was isolated from *Micromonospora chersina* by Konishi and his colleagues at Research Institute of Bristol-Myers in Tokyo. This antibiotic exhibits potent antitumor activity[1] and also has unique structure; a hybrid of two typical chemotypes of antitumor agent, enediyne and anthraquinone. Dynemicin appeared to undergo bioreduction with concomitant ring-opening of the epoxide to generate the 1,4-benzenoid biradicals. Hydrogen abstraction by the radicals from the bound DNA causes cleavage of the DNA strand.[2]

Scheme 1.



dynemicin A (**1**) **2**



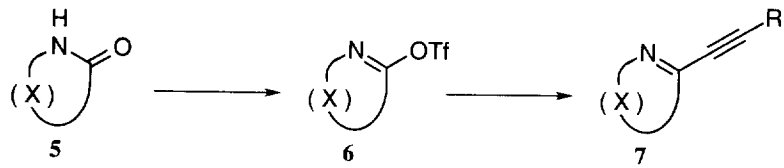
3 **4**

A number of synthetic approaches towards total synthesis of **1**,[3,4] including Schreiber's impressive work,[4b] and cyclic enediyne system have been reported. The Yamaguchi procedure[5] for the 1,2-addition of

acetylides to N-acylated pyridines is so useful that it has been employed in all of these syntheses[2,3,4] to construct enediyne system. However, introduction of an acetylene moiety to sterically hindered molecule appeared to be quite difficult. Actually, alkynylation of a pentacyclic framework having anthraquinone moiety was not found in the literature. Therefore, as shown in Scheme 1 we tried to prepare acetylene containing intermediate **2** *via* the substitution reaction between acetylene and trifluoromethanesulfonate (triflate) **3**,[6,7] which was derived from the reported pentacycle **4**.[3d]

Cross-coupling reaction with palladium catalyst has been an extremely useful tool in organic synthesis.[8,9,10,11,12,13] One of the most striking examples is palladium-catalyzed coupling between triflates and organostannanes including acetylene derivatives which has been extensively studied by the Stille group.[9] Recent application of Stille's methodology for several heteroaromatics including acetylene introduction has been reported[13] and another great progress for this method was made by Farina and his coworkers by designing new ligands.[14] Sonogashira[10] found cross-coupling between aryl halide and mono-substituted acetylene under Pd(0)-Cu(I) conditions and their protocol was applied to heteroaromatics.[15] Here we report introduction of acetylene functionality to heteroaryls through their triflates (Scheme 2) and also its application for a model compound of dynemicin A.

Scheme 2.

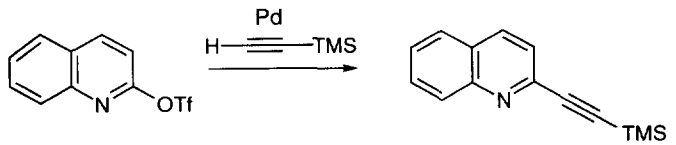


The palladium-mediated alkylation and alkynylation *via* triflates has been of great importance in C-C bond formation since the triflate can be conveniently available from carbonyl compounds or alcohol. For example, as shown in Scheme 2, triflate **6** will be readily prepared from the corresponding amide **5** by treatment with triflic anhydride in pyridine. We expected that acetylene could be introduced by catalytic reaction of palladium mediated C-C bond formation to give acetylene-containing product **7**.

We tried to find conditions that would lead to effective coupling under mild conditions, and moreover, it is preferable to accomplish this reaction without using highly toxic organostannanes. Coupling reaction between triflates and acetylenes was investigated using readily available 2-quinolinyl triflate **8** (Table 1), because it is a partial structure of dynemicin A. Initially, we tried to carry out the reaction at elevated temperature (entries 1, 2).[16] The reaction proceeded so smoothly that it appeared the coupling would proceed at lower temperature. Therefore the reaction was carried out at room temperature (entry 3). With aryl and vinyl triflates, the oxidative addition takes place readily to give the palladium-triflate complex, which is incapable of proceeding further in the catalytic cycle. This problem was overcome by the addition of lithium chloride, presumably due to form a more stable palladium-chloride complex.[9] Copper salts, such as CuI,[10] is indispensable for Sonogashira's protocol. In this case, however, these inorganic salt additives did not give better results (entries 4, 5 and 6).[11] As for base diisopropylethylamine (*i*-Pr_2NEt) is little better than triethylamine (entries 4 and 7). Reaction with tetrakis(triphenylphosphine)palladium(0), $Pd(PPh_3)_4$, or bis(triphenylphosphine)palladium(II) chloride, $Pd(PPh_3)_2Cl_2$, resulted in lower yields of the product (entries

8 and 9), probably due to decomposition of the catalysts during the reaction.[9] In contrast, tris(dibenzylideneacetone)palladium(0)-chloroform complex, $Pd_2(dba)_3 \cdot CHCl_3$, is a particularly effective catalyst for this coupling reaction (entries 7, 8, 9 and 10). The catalyst is more air-stable than $Pd(PPh_3)_4$ and was rapidly converted into a palladium-phosphine catalyst *in situ* by ligand-exchange between the weakly coordinated dibenzylideneacetone and phosphines.[14] The purple color of the dibenzylideneacetone catalyst was discharged to a pale yellow color in a few minutes to afford a palladium-phosphine catalyst. Acetonitrile was slightly less effective than DMF and THF (entries 10, 11 and 12). As a phosphine ligand tris(2-methylphenyl)phosphine[17] was slightly superior to triphenylphosphine (entries 10 and 13). Attempt of this cross-coupling under "ligandless" conditions (without phosphine ligands) recovered the triflate **8**. It proved to be phosphine ligands, such as P(*o*-tol)$_3$, being indispensable (entry 14).[14]

Table 1. Effect of varying catalyst and reaction conditions on the coupling



8 **9**

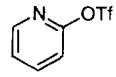
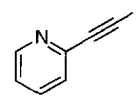
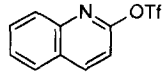
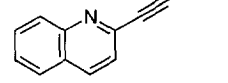
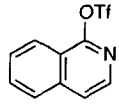
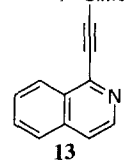
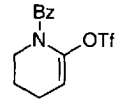
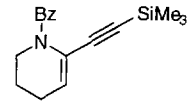
entry	catalyst	ligand	base	additives	solvent	conditions temp	h	yield
1	$Pd(AcO)_2$	$P(C_6H_5)_3$	Et_3N	–	DMF	70	1.5	51%
2	$Pd(AcO)_2$	$P(C_6H_5)_3$	*i*-Pr_2NEt	–	DMF	70	1.5	58%
3	$Pd(AcO)_2$	$P(C_6H_5)_3$	*i*-Pr_2NEt	–	DMF	rt	9.5	73%
4	$Pd(AcO)_2$	P(*o*-tol)$_3$	Et_3N	–	DMF	rt	4	60%
5	$Pd(AcO)_2$	P(*o*-tol)$_3$	Et_3N	CuI	DMF	rt	4	47%
6	$Pd(AcO)_2$	P(*o*-tol)$_3$	Et_3N	LiCl	DMF	rt	4	44%
7	$Pd(AcO)_2$	P(*o*-tol)$_3$	*i*-Pr_2NEt	–	DMF	rt	15	75%
8	$Pd(PPh_3)_4$	–	*i*-Pr_2NEt	–	DMF	rt	15	25%
9	$Pd(PPh_3)_2Cl_2$	–	*i*-Pr_2NEt	–	DMF	rt	15	10%
10	$Pd_2(dba)_3 \cdot CHCl_3$	P(*o*-tol)$_3$	*i*-Pr_2NEt	–	DMF	rt	2	93%
11	$Pd_2(dba)_3 \cdot CHCl_3$	P(*o*-tol)$_3$	*i*-Pr_2NEt	–	MeCN	rt	4	84%
12	$Pd_2(dba)_3 \cdot CHCl_3$	P(*o*-tol)$_3$	*i*-Pr_2NEt	–	THF	rt	2	90%
13	$Pd_2(dba)_3 \cdot CHCl_3$	$P(C_6H_5)_3$	*i*-Pr_2NEt	–	DMF	rt	4	85%
14	$Pd_2(dba)_3 \cdot CHCl_3$	–	*i*-Pr_2NEt	–	DMF	60	15	0%

We investigated application of the above-mentioned methodology to the various heterocycles as shown in Table 2. Reaction between triflates of heteroaromatics (entries 1–8) and (trimethylsilyl)acetylene in DMF or THF with palladium catalyst proceeded smoothly at room temperature in good yields. There was no significant difference between DMF and THF in the reaction of these heteroaromatics.

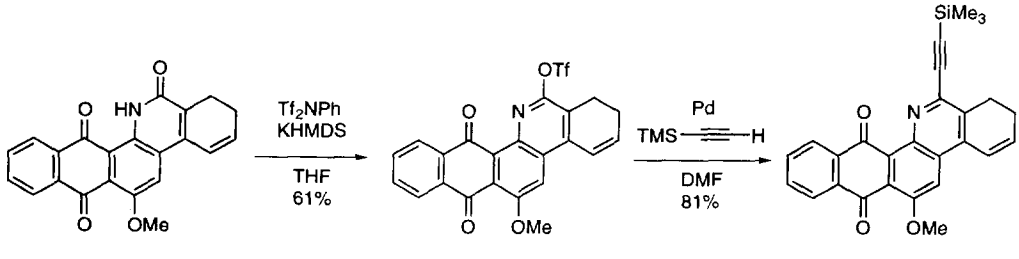
In order to explore the scope of this reaction, we further investigated the reactivity of the cyclic amide (entries 7 and 8). Alkynylation for these nitrogen-containing ring systems serves as functionalization and

derivatization in alkaloid chemistry. However reports on the alkynylation reaction of lactams is few.[18] For this purpose we chose benzoylamide derivatives as substrates.[19] The triflate **14** was prepared from the corresponding *N*-benzoyl-(2-piperidone) in 60% yield. To the 6-membered derivative **15** acetylene was successfully introduced at 60 °C. In this case DMF was superior to THF. Attempts of acetylene introduction to 5 and 7-membered derivatives were unsuccessful, probably due to the instability of the triflates.[20]

Table 2. Generalized coupling between triflates and acetylene

entry	triflate	solvent	temp (°C)	time (h)	product	yield
1	 **10**	DMF	rt	3	 **11**	52%
2		THF	rt	1		58%
3	 **8**	DMF	rt	2	 **9**	90%
4		THF	rt	1		92%
5	 **12**	DMF	rt	2	 **13**	88%
6		THF	rt	2		88%
7	 **14**	DMF	60	15	 **15**	69%
8		THF	60	15		25%

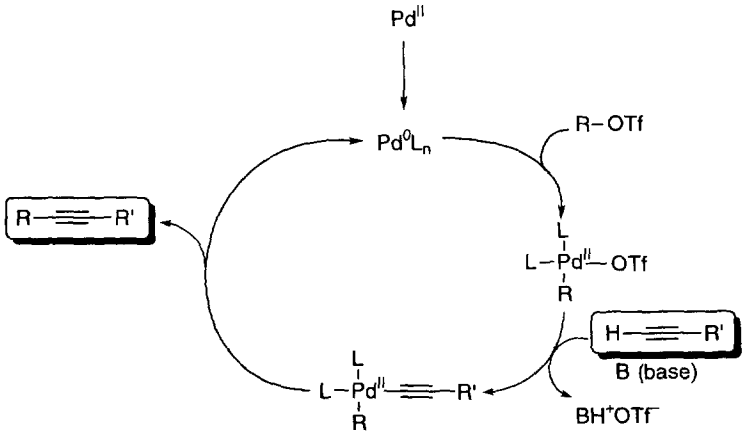
Finally we applied this coupling reaction to the model compound of dynemicin A. The triflate **17** was prepared from the amide **4**[3d] in 61%. The obtained triflate was subjected to the coupling reaction. A mixture of the triflate **3**, 5 mol % of $Pd_2(dba)_3{\cdot}CHCl_3$, 20 mol % of P(*o*-tol)$_3$, *i*-Pr_2NEt (2.0 eq) and ethynyltrimethylsilane (1.5 eq) in DMF was stirred at room temperature for 1 h under nitrogen atmosphere. Luckily the desired product **16** was crystallized from the solution in 81% yield.



4 **3** **16**

The currently accepted mechanism for this sp^2-sp cross-coupling reaction (the Sonogashira reaction) is illustrated in Scheme 3.[8a] The reaction conditions are similar to the Heck reaction, but the mechanism is different: it appears to involve attack of acetylide anion on a palladium-triflate complex, followed by reductive elimination to provide the disubstituted acetylene since a base is required by the reaction.

Scheme 3.



In conclusion, palladium-catalyzed alkynylation of the aryl and vinyl triflate from amide derivatives proceeded smoothly under mild conditions, because of the easiness of the oxidative addition of triflates to palladium complexes. This conversion also proved to be useful tool for the highly functionalized molecules containing the carbonyl function as the triflate **3**. Introduction of acetylene adjacent to either aliphatic or aromatic amino group was achieved by this exchange reaction.

Experimental Section

General: Melting points were recorded on a Yanaco MP-S3 apparatus and are uncorrected. Infrared spectra were recorded on a JASCO FT/IR spectrophotometer. ^1H and ^{13}C NMR spectra were recorded on JEOL EX-270 (^1H, 270 MHz; ^{13}C, 67.9 MHz) and JEOL FX-90 (^1H, 90 MHz) spectrometers. Ultra-violet spectra were recorded on a JASCO Ubest-50. Mass spectra were recorded on a JEOL DX-705L and JEOL JMS-D 100 spectrometers. Elemental analyses were performed by Analytical Laboratory at School of Agriculture, Nagoya University. Unless otherwise noted, non aqueous reactions were carried out under nitrogen atmosphere. THF was distilled from potassium metal in the color development by benzophenone ketyl. Chlorinated solvents, CH_2Cl_2 and $ClCH_2CH_2Cl$, were dried over active alumina. DMF and acetonitrile were dried over MS 4A. Amines and HMPA were dried over CaH_2 and distilled before use. Column chromatography was routinely performed on Fuji Devison (BW 820-MH) silica gel. Merck precoated silica gel (Art 5715) was used for analytical purpose. Silica gel (Merck Art 7747) preparative plates were used for separation.

The following compounds were prepared according to literature procedures: 2-quinolyl trifluoromethanesulfonate (**8**),[9c] 2-pyridyl trifluoromethanesulfonate (**10**)[21] and 1-isoquinolyl trifluoromethanesulfonate (**12**).[13]

Typical Procedure for Palladium-Catalyzed Coupling Reaction: 2-(Trimethylsilylethynyl)quinoline (9)[15] A mixture of triflate **8** (80.0 mg, 0.29 mmol), $Pd_2(dba)_3{\cdot}CHCl_3$ (15.5 mg, 0.015 mmol), P(*o*-tol)$_3$ (18.2mg, 0.056 mmol), *i*-Pr_2NEt (0.150mL, 0.87mmol) and (trimethylsilyl)acetylene (0.065 mL, 0.44 mmol) in THF (1 mL) was stirred for 1 h at rt. The reaction mixture was partitioned with ice water and ether. The ethereal solution was separated and dried over magnesium sulfate and concentrated under reduced pressure to give an oil. The residue was purified by chromatography on a column of silica gel (CH_2Cl_2–*n*-Hex = 1:4) to afford **9** (59.5 mg, 92%): UV (EtOH) λ_{max} (log ε) 212 (4.44), 248 (4.51), 306 (3.85), 320 (3.84), 334 (3.79) nm. IR (KBr) ν_{max} 2953, 2154, 1591, 1553, 1499 cm^{-1}. ^{1}H NMR ($CDCl_3$, 270 MHz) δ 0.34 (9H, s, TMS), 7.52 (1H, dd, *J* = 8.5, 1 Hz, C-3), 7.53 (1H, td, *J* = 8.5, 1 Hz, C-6), 7.70 (3H, tt, *J* = 8.5, 1.5 Hz, C-7), 7.76 (1H, d, *J* = 8.5 Hz, C-5), 8.07 (1H, d, *J* = 8.5 Hz, C-4), 8.11 (1H, d, *J* = 8.5 Hz, C-8). ^{13}C NMR ($CDCl_3$, 67.9 MHz) δ –0.13 (q), 22.2 (t), 23.8 (t), 56.5 (q), 100.2 (s), 102.6 (s), 107.5 (d), 120.8 (d), 126.0 (d), 126.4 (s), 126.7 (d), 127.8 (s), 131.0 (s), 131.2 (s), 133.0 (d), 133.4 (d), 133.8 (s), 134.8 (s), 135.0 (s), 135.5 (d), 139.8 (s), 143.6 (s), 156.1 (s), 183.8 (s), 184.6 (s). HRMS (FAB) calcd for $C_{14}H_{16}NSi$ (MH^+) 226.1052, found 226.1038.

2-(Trimethylsilylethynyl)pyridine (11) The same procedure as described for **9** was used: (52%). ^{1}H NMR ($CDCl_3$, 90 MHz) δ 0.26 (9H, s, TMS), 7.1–7.9 (3H, m, C-3~5), 8.61 (1H, dd, *J* = 5, 1 Hz, C-6). The NMR spectrum was identical with the published one.[15]

1-(Trimethylsilylethynyl)isoquinoline (13)[15] The same procedure as described for **9** was used: (88%). UV (EtOH) λ_{max} (log ε) 221 (4.47), 286 (3.77), 298 (3.77), 326 (3.96), 337 (3.99) nm. IR (KBr) ν_{max} 2959, 2158, 1621, 1580, 1553 cm^{-1}. ^{1}H NMR ($CDCl_3$, 270 MHz) δ 0.00 (9H, s, TMS), 7.62 (1H, dd, *J* = 5.5, 0.5 Hz, C-4), 7.67 (1H, ddd, *J* = 8, 7, 1.5 Hz, C-7), 7.72 (1H, dd, *J* = 7, 1.5 Hz, C-6), 7.83 (1H, ddd, *J* = 7, 1.5, 0.5 Hz, C-5), 8.41 (1H, dddd, *J* = 8, 1.5, 1.0, 0.5 Hz, C-8), 8.51 (1H, d, *J* = 5.5 Hz, C-3). ^{13}C NMR ($CDCl_3$, 67.9 MHz) δ 0.00 (q), 100.0 (s), 101.6 (s), 120.8 (d), 126.7 (s), 126.8 (d), 127.0 (d), 127.9 (d), 129.3 (s), 130.5 (d), 135.7 (s), 142.8 (d). HRMS (FAB) calcd for $C_{14}H_{16}NSi$ (MH^+) 226.1052, found 226.1036.

***N*-Benzoyl-2-ene-2-piperidinyl trifluoromethanesulfonate (14)** To a suspension of *N*-benzoyl-2-piperidone (1.00 g, 5.3 mmol) in THF (4 mL) was added 1 M $LiN(TMS)_2$ (6.94 mL, 6.9 mmol) in toluene at –78 °C and the mixture was stirred for 20 min at the same temperature. HMPA (1.42 mL, 8.0 mmol) was added to the suspension at –78 °C. After stirring for 2 h, *N*-phenyltrifluoromethanesulfonimide (2.29 g, 6.4 mmol) in THF (10 mL) was added at 0 °C. The mixture was warmed to rt and stirred for 2 h. The reaction mixture was subjected to aqueous work-up. Purification by silica-gel chromatography (Silica gel 50 g, eluent Et_2O-*n*-Hex = 2:1) gave crystalline **14** (1.09 g, 79%): Mp 92-93°C (from *i*-Pr_2O). UV (EtOH) λ_{max} (log ε) 229 (4.02). IR (KBr) ν_{max} 2934, 1688, 1660, 1417 cm^{-1}. ^{1}H NMR ($CDCl_3$, 270 MHz) δ 1.81 (2H, m, C-5), 2.35 (2H, td, *J* = 7, 4 Hz, C-4), 3.77 (2H, t, *J* = 5.5 Hz, C-6), 5.48 (1H, t, *J* = 4 Hz, C-3), 7.40–7.60 (5H, m, aromatic). ^{13}C NMR ($CDCl_3$, 67.9 MHz) δ 21.9 (t), 22.8 (t), 47.5 (t), 107.9 (s), 115.9 (q, *J* = 321 Hz), 128.3 (d), 128.5 (d), 131.7 (d), 133.9 (s), 140.1 (s), 170.2 (s). HRMS (FAB) calcd for $C_{13}H_{13}F_3NO_4S$ (MH^+) 336.0517, found 336.0496. Anal. Calcd for $C_{13}H_{12}F_3NO_4S$: C, 46.34 H, 3.59; N, 4.16. Found: C, 46.39; H, 3.51; N, 4.13.

***N*-Benzoyl-2-ene-2-(trimethylsilylethynyl)piperidine (15)** The same procedure as described for **9** was used: (69%). UV (EtOH) λ_{max} (log ε) 229 (3.83), 248 (3.74) nm. IR (KBr) ν_{max} 2935, 2154, 1647, 1610, 1499 cm^{-1}. ^1H NMR ($CDCl_3$, 270 MHz) δ 0.00 (9H, s, TMS), 1.95 (2H, m, C-5), 2.30 (2H, td, *J* = 7, 4 Hz, C-4), 3.81 (2H, t, *J* = 9 Hz, C-6), 5.68 (1H, t, *J* = 4 Hz, C-3), 7.30–7.60 (5H, m, aromatic). ^{13}C NMR ($CDCl_3$, 67.9 MHz) δ –0.4 (q), 22.9 (t), 23.9 (t), 43.2 (t), 99.7 (s), 123.5 (s), 123.9 (d), 127.9 (d), 128.3 (d), 128.7 (d), 130.5 (d), 137.0 (s), 169.6 (s), HRMS (FAB) calcd for $C_{17}H_{22}NOSi$ (MH^+) 284.1471, found 284.1464.

1,2-Dihydro-6-methoxyanthra[1,2-*c*]isoquinolin-7,12-dione-14-yl trifluoromethanesulfonate (3) To a suspension of **4**[3d] (1.437 g, 4.0 mmol) in THF (45 mL) was added 0.645 M $KN(TMS)_2$ (7.48 mL, 4.8 mmol) in toluene at 0 °C and the mixture was stirred for 30 min at the same temperature. HMPA (1.05 mL, 6.0 mmol) was added to the dark blue suspension at 0 °C. After stirring for 1 h, *N*-phenyltrifluoromethanesulfonimide (1.75 g, 4.8 mmol) in THF (10 mL) was added at 0 °C. The mixture was warmed to rt and stirred for 2 h. Aqueous work-up followed by chromatographic purification (Silica gel 100 g, eluent CH_2Cl_2) gave 1.21 g (61%) of **3** UV (EtOH) λ_{max} (log ε) 262 (4.30), 419 (3.52) nm. IR (KBr) ν_{max} 2923, 1749, 1671, 1637 cm^{-1}. ^1H NMR ($CDCl_3$, 270 MHz) δ 2.55 (2H, tdd, *J* = 9, 4.5, 2 Hz, CH_2CH=CH), 3.03 (2H, t, *J* = 9 Hz, CH_2CH_2), 4.06 (3H, s, OCH_3), 6.65 (1H, dt, *J* = 10, 4.5 Hz, CH_2CH=CH), 7.14 (1H, dt, *J* = 10, 2 Hz, CH_2CH=CH), 7.59 (1H, s, aromatic), 7.75 (2H, m, aromatic), 8.17 (2H, m, aromatic). ^{13}C NMR ($CDCl_3$, 67.9 MHz) δ 20.3 (t), 21.6 (t), 56.6 (q), 107.6 (d), 118.8 (q, *J* = 320 Hz,), 120.7 (d), 120.8 (s), 120.9 (s), 126.2 (d), 126.3 (d), 127.0 (s), 128.5 (s), 133.0 (s), 133.3 (d), 133.6 (d), 133.7 (s), 134.5 (s), 136.6 (s), 137.1 (d), 140.8 (s), 152.9 (s), 156.5 (s), 183.2 (s), 183.3 (s). HRMS calcd for $C_{23}H_{14}F_3NO_6S$ 489.0494, found 489.0469.

1,2-Dihydro-6-methoxy-14-trimethylsilylethynylanthra[1,2-*c*]isoquinolin-7,12-dione (16) A mixture of **4** (530.6 mg, 1.08 mmol), $Pd_2(dba)_3{\cdot}CHCl_3$ (55.9 mg, 0.054 mmol), P(*o*-tol)$_3$ (65.8 mg, 0.22 mmol), *i*-Pr_2NEt (0.377 mL, 2.2 mmol) and (trimethylsilyl)acetylene (0.223 mL, 1.6 mmol) in DMF (21.2 mL) was stirred for 1 h at rt. The resulting crystals were filtered off and washed with a small amount of diisopropyl ether to give **16** (385 mg, 81%): Mp 212 °C (dec, from acetone). UV (EtOH) λ_{max} (log ε) 220 (4.44), 259 (4.53), 435 (3.78) nm. IR (KBr) ν_{max} 2927, 1668, 1594, 1410 cm^{-1}. ^1H NMR ($CDCl_3$, 270 MHz) δ 0.00 (9H, s, TMS), 2.55 (2H, tdd, *J* = 9, 4.5, 2 Hz, CH_2CH=CH), 3.00 (2H, t, *J* = 9 Hz, CH_2CH_2), 4.07 (3H, s, OCH_3), 6.65 (1H, dt, *J* = 10, 4.5 Hz, CH_2CH=CH), 7.14 (1H, dt, *J* = 10, 2 Hz, CH_2CH=CH), 7.64 (1H, s, aromatic), 7.77 (2H, m, aromatic), 8.18 (2H, m, aromatic). ^{13}C NMR ($CDCl_3$, 67.9 MHz) δ –0.13 (q), 22.2 (t), 23.8 (t), 56.5 (q), 100.2 (s), 102.6 (s), 107.5 (d), 120.8 (d), 126.0 (d), 126.4 (s), 126.7 (d), 127.8 (s), 131.0 (s), 131.2 (s), 133.0 (d), 133.4 (d), 133.8 (s), 134.8 (s), 135.0 (s), 135.5 (d), 139.8 (s), 143.6 (s), 156.1 (s), 183.8 (s), 184.6 (s). HRMS calcd for $C_{27}H_{23}O_3NSi$ 437.1447, found 437.1429. Anal. Calcd for $C_{27}H_{23}O_3NSi$: C, 74.11; H, 5.30; N, 3.20. Found: C, 74.11; H, 5.27; N, 3.15.

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(20) *N*-Benzoyl-2-pyrrolin-2-yl trifluoromethanesulfonate (5-membered ring) was prepared from the corresponding *N*-benzoyl-2-pyrrolidone by a procedure similar to the triflate **14** in 60% yield, except omitting the aqueous work-up: UV (EtOH) λ_{max} (log ε) 229 (4.02). IR (KBr) ν_{max} 2958, 1683, 1595, 1303 cm^{-1}. ^1H NMR ($CDCl_3$, 270 MHz) δ 1.81 (2H, tdd, J = 9, 4.5, 2 Hz, C-5), 2.35 (2H, td, J = 7, 4 Hz, C-4), 3.77 (2H, t, J = 9Hz, C-6), 5.48 (2H, t, J = 4 Hz, C-3), 7.40–7.60 (5H, m, aromatic). ^{13}C NMR ($CDCl_3$, 67.9 MHz) δ 21.9 (t), 22.8 (t), 47.5 (t), 107.9 (s), 115.9 (q, J = 321 Hz), 128.3 (d), 128.5 (d), 131.7 (d), 133.9 (s), 140.1 (s), 170.2 (s). HRMS (FAB) calcd for $C_{13}H_{13}F_3NO_4S$ (MH^+) 336.0517, found 336.0496.

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