SUPPORTING INFORMATION

Palladium-Catalyzed Stille Cross-Coupling of Sulfonyl Chlorides and Organostannanes

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Materials and Methods: Unless stated otherwise, reactions were conducted in flame-dried glassware under a vacuum. THF was distilled before to use from sodium and benzophenone. All commercially reagents were used without further purification. Solvents after reactions and extraction were evaporated in a rotatory evaporator under vacuum (solvents were removed cooling at -20 °C, in the case of low boiling point or low molecular mass compounds). TLC for reaction monitoring was performed on 60 F₂₅₄ (Merck) with detection by UV light and charring with KMnO₄ or Pancaldi reagent. M.p.: uncorrected by using Tottoli (Büchi SMP-20) apparatus. ¹H and ¹³C NMR spectra were recorded by using Bruker-DPX-400, or Bruker-ARX-400 spectrometer at 400 MHz and 100.6 MHz respectively and are reported relative to

Me₄Si (δ 0.0) or to the solvents residual ¹H-signal (CH-Cl₃, δ (H) 7.27). Data for ¹H NMR spectra are reported as follows: Chemical shift (δ ppm), multiplicity, coupling constant (Hz) and integration. Data for ¹³C NMR spectra reported in terms of chemical shift. IR spectra were recorded on a Perkin-Elmer-1420 spectrometer and are reported in frequency of absorption (cm⁻¹). HRMS MALDI-TOF mass spectra were obtained from the Institute of Molecular and Biology Chemistry, Swiss Institute of Technology Mass Spectral Facility.

General Procedure for Stille coupling: In a round bottom flask dried under vacuum were placed the corresponding CuBr.Me₂S (0.10 mmol), the corresponding sulfonyl chloride (1.00 mmol), Pd₂dba₃ (0.015 mmol), and tri-2-furylphosphine (0.05 mmol), then solvent (5 mL) and the organostannane (1.3 mmol) were added under an argon atmosphere. The reaction was stirred at reflux for 2-4 h, then 5 mL of aqueous KF (1M) solution was added and stirred for 10 min. Then the solution was filtered through a pad of Celite rinsed with ether and washed with brine (twice). The aqueous layer was extracted again twice with ether. The combine organic phases were dried (MgSO₄), filtered and concentrated under reduced pressure (solvents were removed under reflux on cooling at -20°C, in the case of low

boiling point or low molecular mass compounds), and purified by flash chromatography.

1-(4-fluorophenyl)-naphthalene (Table 2, entry 1): Using the general procedure for the Stille coupling, the product is obtained (90% yield) as a colourless solid.¹

1-(4-methylphenyl)-naphthalene (Table 2, entry 4): Using the general procedure for the Stille coupling, the product is obtained (81% yield) as a colourless solid.²

1-(3-methylphenyl)-naphthalene (Table 2, entry 5): Using the general procedure for the Stille coupling, the product is obtained (81% yield) as a colourless oil.³

1-(3-nitrophenyl)-naphthalene (Table 2, entry 7): Using the general procedure for the Stille coupling, the product is obtained (82% yield) as a yellow solid.⁴

Biphenyl (Table 2, entry 8): Using the general procedure for the Stille coupling, the product is obtained (84% yield) as a white solid.⁵

¹ Okamoto, H.; Statake, K.; Kimura, M. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 3557-3562.

² Nishimura, M.; Ueda, M.; Miyaura, N. *Tetrahedron* **2002**, *58*, 5779-5787.

³ Leznoff, C. C.; Hayward, R. J. *Can. J. Chem.* **1970**, 1842-1849.

⁴ Hassan, J.; Hathroubi, C.; Gozzi, C.; Lemaire, M. *Tetrahedron* **2001**, *57*, 7845-7855.

⁵ Koza, D.J.; Carita, E. *Synthesis* **2002**, 2183-2186.

4-chloro-4'-methyl-biphenyl (Table 2, entry 9): Using the general procedure for the Stille coupling, the product is obtained (66% yield) as a white solid.⁶

4-chloro-4'-fluoro-biphenyl (Table 2, entry 10): Using the general procedure for the Stille coupling, the product is obtained (66% yield) as a colourless powder.⁷

4-bromo-4'-fluoro-biphenyl (Table 2, entry 11):

In a round bottom flask dried under vacuum were placed CuBr.Me₂S (0.10 mmol), 4-bromobenzenesulfonyl chloride (1.00 mmol), Pd₂dba₃ (0.015 mmol), and tri-2-furylphosphine (0.05 mmol), then THF (5 mL) and 4-fluoro(tributylstannyl)benzene (1.3 mmol) were added under an argon atmosphere. After stirring at reflux for 6h, water (5 mL) was added and stirred for 3h at 30°C. The two layers were separated and the organic layer was washed with water

⁶ Xia, M.; Chen, Z-C. *Synth. Commun.* **1999**, 29, 2457-2465.

⁷ Ulrich, B.; Hans Albert, B. *Zeitschrift fuer Naturforschung, Teil B: Anorganische Chemie, Organische Chemie* (1983), 38B(2), 226-236.

(twice). The combined aqueous phases were evaporated under reduced pressure with cooling at -78°C and dried under vacuum. ^1H -NMR analysis showed that there were two products in the aqueous phase: 4-bromobenzene sulfonic acid **3** (32%) 4'-fluoro-1,1'-biphenyl-4-sulfonic acid **4** (2.5%). 5 mL of aqueous KF (1M) solution was added to the remained organic phase and stirred for 10 min. The solution was then filtered through a pad of Celite, rinsed with ether and washed with brine (twice). The aqueous layer was extracted again twice with ether. The combined organic phases were dried (MgSO_4), filtered and concentrated under reduced pressure. The residue was purified by flash chromatography, (pentane: CH_2Cl_2 :9:1, $R_f = 0.65$) to give **1**⁸ (38%) and **2** (traces).

Reaction between 4-iodobenzenesulfonyl chloride and 4-fluoro(tributylstannyl)benzene (Table 2, entry 12):

⁸ Dayal, S. K.; Taft, R. W. *J. Am. Chem. Soc.* **1973**, *95*, 5595-5604.

In a round bottom flask dried under vacuum were placed CuBr.Me₂S (0.10 mmol), 4-bromobenzenesulfonyl chloride (1.00 mmol), Pd₂dba₃ (0.015 mmol), and tri-2-furylphosphine (0.05 mmol), then THF (5 mL) and 4-fluoro(tributylstannyl)benzene (1.3 mmol) were added under an argon atmosphere. After stirring at reflux for 6h, solvent evaporated, aq. Sol. Of NaOH(10%, 7 mL) and ether (7 mL) were added and stirred for 3h at 30°C. The two layers were separated and the organic layer was washed with water (twice). The combined aqueous phases were evaporated under reduced pressure with cooling at -78°C and dried under vacuum. ¹H-NMR analysis showed that there were two products in the aqueous phase: 4-iodobenzene sodium sulfonate **3** (2%) 4'-fluoro-1,1'-biphenyl-4-sodium sulfonate **4** (67%). 5 mL of aqueous KF (1M) solution was added to the remained organic phase and stirred for 10 min. The solution was then filtered through a pad of Celite, rinsed with ether and washed with brine (twice). The aqueous layer was extracted again twice with ether. The combined organic phases were dried (MgSO₄), filtered and concentrated under reduced pressure. The residue was purified by flash chromatography, (pentane:CH₂Cl₂:9:1) to give **1** (traces) and **2** (2.5%).

4-nitro-4'-fluoro-biphenyl (Table 2, entry 13): Using the general procedure the product is obtained (89% yield) as a yellow powder.⁹

4-nitro-4'-methyl-biphenyl (Table 2, entry 14): Using the general procedure the product is obtained (89% yield) as a yellow solid.¹⁰

4,4'-dimethyl-biphenyl (Table 2, entry 15): Using the general procedure for the Stille coupling, the product is obtained (78% yield) as a white solid.¹¹

3-nitro-4'-methyl-biphenyl (Table 2, entry 16): Using the general procedure for the Stille coupling, the product is obtained (80% yield) as a yellow solid.¹²

3,4'-dimethyl-biphenyl (Table 2, entry 17): Using the general procedure for the Stille coupling, the product is obtained (73% yield) as a colourless oil.¹³

⁹ Zhou, L.; Rajabzadeh, M.; Traficante, D. D.; Cho, B. P. *J. Am. Chem. Soc.* **1997**, *119*, 5384-5389.

¹⁰ Hassan, J.; Hathroubi, C.; Gozzi, C.; Lemaire, M. *Tetrahedron* **2001**, *57*, 7845-7855.

¹¹ Koza, D.J.; Carita, E. *Synthesis* **2002**, 2183-2186.

¹² Hassan, J.; Hathroubi, C.; Gozzi, C.; Lemaire, M. *Tetrahedron* **2001**, *57*, 7845-7855.

¹³ Rao, M.S.C.; Rao, G.S.K. *Synthesis* **1987**, 231-233.

4-fluoro-4'-methyl-biphenyl (Table 2, entry 19): Using the general procedure for the Stille coupling, the product is obtained (70% yield) as a white solid.¹⁴

4-methylbiphenyl (Table 2, entry 21): Using the general procedure for the Stille coupling, the product is obtained (68% yield) as a white solid.¹⁵

4-methylphenyl-2-thiophene (Table 2, entry 23): Using the general procedure for the Stille coupling, the product is obtained (38% yield) as a solid.¹⁶

1-methyl-4-[(E)-2-phenyl-1-ethenyl]benzene (Table 2, entry 25): Using the general procedure for the Stille coupling, the product is obtained (41% yield) as a white solid.¹⁷

4-methylstyrene (Table 2, entry 26): Using the general procedure for the Stille coupling, the product is obtained (25% yield) as a oil.¹⁸

¹⁴ Nishimura, M.; ueda, M.; Miyaura, N. *Tetrahedron*, **2002**, *58*, 5779-5788.

¹⁵ a) Mowery, E. M.; DeShong, P. *J. Org. Chem*, **1999**, *64*, 3266-3270; b) Rao, M.S.C.; Rao, G.S.K. *Synthesis* **1987**, 231-233; c) Srogl, J.; Allred, G.D.; Liebeskind, L.S. *J. Am. Chem. Soc.* **1997**, *119*, 12376-12377; d) Bergbreiter, D.E.; Osburn, P.L.; Wilson, A.; Sink, E.M. *J. Am. Chem. Soc.* **2000**, *122*, 9058-9064.

¹⁶ a) Xia, M.; Chen, Z-C. *Synth. Commun.* **1999**, *29*, 2457-2465.

¹⁷ a) Katritzky, A.R.; Cheng, D.; Henderson, S.A.; Li. *J. J. Org. Chem*, **1998**, *63*, 6704-6709; b) Katritzky, A.R.; Cheng, D.; Henderson, S.A.; Li. *J. J. Org. Chem*, **1998**, *63*, 3438-3444.

2-(4-methylphenyl)pyridine (Table 2, entry 27): Using the general procedure for the Stille coupling, the product is obtained (55% yield) as a oil.¹⁹

4-fluorodiphenylmethane (Table 2, entry 28): Using the general procedure for the Stille coupling, the product is obtained (41% yield) as a colourless viscous oil.²⁰

3-methyldiphenylmethane (Table 2, entry 29): Using the general procedure for the Stille coupling, the product is obtained (38% yield) as a colourless liquid.²¹

4-methyldiphenylmethane (Table 2, entry 30): Using the general procedure for the Stille coupling, the product is obtained (38% yield) as a colourless liquid.²²

General Procedure for Carbonylative-Stille coupling: In a stainless steel autoclave were palced in CuBr.Me₂S (0.10 mmol), the corresponding sulfonyl chloride (1.00 mmol), Pd₂dba₃ (0.015 mmol), and tri-2-furylphosphine (0.05 mmol),

¹⁸ Mowery, M. E.; Deshong, P. J. *Org. Chem*, **1999**, *64*, 1684-1688.

¹⁹ Inada, K.; Miyaura, N. *Tetrahedron*, **2000**, *56*, 8657-8660.

²⁰ Gascoyne, M. J.; Mitchell, P. J.; Phillips, L J. *Chem. Soc, Perkin, Trans. 2*, **1977**, 1051.

²¹ a) Darbeau, R.W.; White, E.H.; Song, F.; Darbeau, N.R.; Chou, J. J. *Org. Chem*, **1999**, *64*, 5966-5978.

²² a) Darbeau, R.W.; White, E.H.; Song, F.; Darbeau, N.R.; Chou, J. J. *Org. Chem*, **1999**, *64*, 5966-5978; b) Kabalka, G.W.; Maddox, J.T.; Bogas, E.; Kelley, S.W. *J. Org. Chem*, **1997**, *62*, 3688-3695.

then toluene or CH₃CN (5 mL) and the organostannane (1.3 mmol) were added under an argon atmosphere. Then CO (60 bar) pressure was applied and stirred at 110 °C for toluene and 150 °C for 15 h. Then 5 mL of aqueous KF (1M) solution was added and stirred for 10 min. Then the solution was filtered through a pad of Celite rinsed with ether and washed with brine (twice). The aqueous layer was extracted again twice with ether. The combine organic phases were dried (MgSO₄), filtered and concentrated under reduced pressure and purified by flash chromatography.

Bis(4-methylphenyl)methanone (Scheme 1): Using the general procedure for the Carbonylative-Stille coupling, the product is obtained (51% yield) as a light yellow soild²³.

(3-methylphenyl)(1-naphthyl)methanone (Scheme 1): Using the general procedure for the Carbonylative-Stille coupling, the product is obtained (41% yield) as a light yellow soild²⁴.

²³ (a) Kang, S-K.; Ryu, H-C.; Choi, S-C. *Synth. Commun.* **2001**, *31*, 1035-1039. (b) Peng, X.; Wang, S.; Cui, J.; Zhang, R.; Yan, Y.; *Synth. Commun.* **2002**, *32*, 2361-2368. (c) Zhou, Tao.; Chen, Z-C. *Synth. Commun.* **2002**, *32*, 3431-3436.

²⁴ Kakino, R.; Yasumi, S.; Shimizu, I.; Yamamoto, S. *Bull. Chem. Soc. Jpn.* **2002**, *75*, 137-148.

(4-fluorophenyl) (1-naphthyl)methanone (Scheme 1): Using the general procedure for the Carbonylative-Stille coupling, the product is obtained (45% yield) as a light yellow solid²⁵.

Preparation of sulfenyl chloride from sulfonyl chloride (Scheme 2):

In a round bottom flask dried under vacuum were placed the 1-naphthalenesulfonyl chloride (1.00 mmol), and tri-2-furylphosphine (2.0 mmol), then solvent (5 mL) was added under an argon atmosphere. The reaction was stirred at 50 °C for 15 h. The solution was allowed to go to room temperature. Then the reaction mixture was diluted with ether and washed with brine (twice). The aqueous layer was extracted again twice with ether. The combine organic phases were dried (MgSO_4), filtered and concentrated under reduced pressure and purified by flash chromatography (pentane). The product is obtained (60%) as a yellow oil. R_F 0.17 (pentane eluent); ^1H NMR (400 MHz, CDCl_3): δ = 8.37 (dd, J = 6.4, 1.2 Hz, 1H), 7.88 (dd, J = 6.4, 1.6 Hz, 1H),

²⁵ Artico, M.; Stefancich, G.; Silvestri, R.; Massa, S.; Apuzzo, G.; *Eur. J. Med. Chem.* **1992**, 27, 693-699.

7.82 (d, $J = 8.3$, 1H), 7.65 (d, $J = 7.0$ Hz, 1H), 7.53 (m, 2H), 7.32 (d, $J = 8.0$ Hz, 1H); ^{13}C NMR (100.6 MHz, CDCl_3): $\delta = 134.1, 133.4, 132.7, 130.3, 129.3, 128.6, 126.7, 126.4, 125.4, 125.1$; IR (NaCl): $\nu = 3052, 2922, 1588, 1562, 1502, 1378, 1334, 1255, 793, 766\text{ cm}^{-1}$; CI-MS (NH_3): $m/z = 194$ (10), 159 (100), 115 (52); HRMS (MALDI-TOF): calcd. ($\text{C}_{10}\text{H}_7\text{ClS}^+$) 193.9957; found 193.9968.

S-1-naphthyl4-fluorobenzenecarbothioate (Scheme 2): In a stainless steel autoclave were placed $\text{CuBr}\cdot\text{Me}_2\text{S}$ (0.10 mmol), 1-naphthalenesulfonyl chloride (1.00 mmol), Pd_2dba_3 (0.028 mmol), and tri-2-furylphosphine (0.3-0.5 mmol), then THF (5 mL) and the 4-fluoro(tributylstannyl)benzene (1.3 mmol) were added under an argon atmosphere. Then CO (60 bar) pressure was applied and stirred at 50 °C for 35 h. Then 5 mL of aqueous KF (1M) solution was added and stirred for 10 min. Then the solution was filtered through pad Celite rinsed with ether and washed with brine (twice). The aqueous layer was extracted again twice with ether. The combine organic phases were dried (MgSO_4), filtered and concentrated under reduced pressure and purified by flash chromatography. The product is obtained (32%) as colourless oil. R_F 0.4 (7:3 pentane and CH_2Cl_2 eluent); ^1H NMR (400 MHz, CDCl_3): $\delta = 8.26$ (dd, $J = 8.0, 2.6$ Hz, 1H), 8.17 (dd, $J = 8.6, 5.5$ Hz, 2H), 8.03 (d, $J = 8.6$, 1H), 7.94 (m, 1H), 7.83

(d, $J = 7.0$ Hz, 1H), 7.59 (m, 3H), 7.23 (t, $J = 8.6$ Hz, 2H); ^{13}C NMR (100.6 MHz, CDCl_3): $\delta = 192.2, 166.6, 135.9, 135.8, 133.8, 131.6, 130.6, 130.1, 129.16, 127.7, 126.9, 126.0, 125.7, 116.4$; IR (NaCl): $\nu = 3056, 1676, 1578, 1503, 1226, 1200, 1156, 1056, 903, 843, 797, 770, 617\text{ cm}^{-1}$; HRMS (MALDI-TOF): calcd. ($\text{C}_{17}\text{H}_{11}\text{FOSNa}^+$) 305.0412; found 305.0483.

S-1-naphthyl3-methylbenzenecarbothioate (Scheme 2): Using above procedure, the product is obtained (40%) as a colourless oil. R_F 0.58 (6:4 pentane and CH_2Cl_2 eluent); ^1H NMR (400 MHz, CDCl_3): $\delta = 8.35$ (d, $J = 8.3$, 1H), 8.18 (d, $J = 7.7$, 1H), 8.03 (d, $J = 8.3$, 1H), 7.96 (d, $J = 7.7$, 1H), 7.86 (d, $J = 7.0$ Hz, 1H), 7.59 (m, 3H), 7.49 (t, $J = 7.4$ Hz, 1H); 7.40 (d, $J = 7.0$ Hz, 1H), 7.32 (d, $J = 7.4$ Hz, 1H), 2.54 (s, 3H); ^{13}C NMR (100.6 MHz, CDCl_3): $\delta = 192.2, 138.0, 135.8, 134.9, 134.7, 132.5, 132.2, 131.4, 129.3, 129.1, 127.6, 126.8, 126.4, 126.1, 125.7, 21.3$; CI-MS (NH_3): 280(49), 279(73), 155(91), 120(100), 91(94); IR (NaCl): $\nu = 3056, 2962, 2926, 1993, 1504, 1455, 1380, 1206, 1190, 1055, 893, 797, 770, 721, 678, 648\text{ cm}^{-1}$; HRMS (MALDI-TOF): calcd. ($\text{C}_{18}\text{H}_{14}\text{OSNa}^+$) 301.0663; found 301.0654.

S14

^1H NMR (400 MHz, CDCl_3)

S15

^{13}C NMR (100.6 MHz, CDCl_3)

S16

^1H NMR (400 MHz, CDCl_3)

S17

^1H NMR (400 MHz, CDCl_3)