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Manuscript Title:
Combining Pd(π-allyl)Cp and PPh₃ as a unique Catalyst for Efficient Synthesis of Alkyliodo Indoles via C(sp³)-I Reductive Elimination

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1) Experimental Details and Characterization Data

General Information

Unless otherwise noted, all starting materials were commercially available and were used without further purification. Solvents were purified by a Mbraun SPS-800 Solvent Purification System. nBuLi, palladium catalyst and phosphine ligand was obtained from Aldrich, TCI, Alfa, Acros, Adamas-beta, J&K and others. All reactions were carried out under a dry and oxygen-free nitrogen atmosphere in slight positive pressure by using Schlenk techniques, unless otherwise noted.

$^1$H and $^{13}$C NMR spectra were recorded on a Bruker ARX400 spectrometer (FT, 400 MHz for $^1$H; 100 MHz for $^{13}$C) or Bruker ARX500 spectrometer (FT, 500 MHz for $^1$H, 125 MHz for $^{13}$C, 202 MHz for $^{31}$P) at room temperature, unless otherwise noted. For $^{31}$P NMR, chemical shifts are referenced to 85% H$_3$PO$_4$ as an external standard. High-resolution mass spectra (HRMS) were recorded on a Bruker Apex IV FTMS mass spectrometer using ESI (electrospray ionization). GC analyses were recorded on SHIMADZU GC-2010 spectrometer using FID.

Procedures and Characterization Data

Typical procedure for the preparation of 2: Under an atmosphere of nitrogen, Pd(π-allyl)(Cp) (5 mol %), PPh$_3$ (10 mol %) and LiO$^-$Bu (0.36 mmol), were added in 2 mL cyclohexane. The reaction mixture was then stirred at room temperature for 5 min and 1 (0.3 mmol) and alkyne (0.36 mmol) were added under nitrogen. The reaction mixture was stirred at 130 °C for 12 h (aliphatic alkynes) or 48 h (aromatic alkynes). The reaction mixture was cooled to room temperature, quenched with water and extracted with Et$_2$O. The combined organic layer was washed with brine and dried over MgSO$_4$. The solvent was then evaporated in vacuo and the residue was purified by silica gel column chromatography with petroleum ether and ethyl acetate (10:1) as eluent to afford the final products. Products 2a-c and 2e-f are known compounds and their NMR spectra are in consistence with those in the literature.1
2a\textsuperscript{1}: Yellow oil, isolated yield 90% (100 mg). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}, Me\textsubscript{4}Si): δ 1.19-1.25 (m, 6H, CH\textsubscript{3}), 1.44-1.52 (m, 2H, CH\textsubscript{2}), 1.73-1.87 (m, 4H, CH\textsubscript{2}), 2.70-2.79 (m, 4H, CH\textsubscript{2}), 3.16 (t, J = 6.9, 2H, CH\textsubscript{2}), 4.05 (t, J = 7.6 Hz, 2H, CH\textsubscript{2}), 7.06 (t, J = 7.4 Hz, 1H, CH), 7.13 (t, J = 7.5 Hz, 1H, CH), 7.24 (d, J = 8.8 Hz, 1H, CH), 7.54 (d, J = 7.8 Hz, 1H, CH).

2b\textsuperscript{1}: Yellow oil, isolated yield 72% (100 mg). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}, Me\textsubscript{4}Si): δ 1.21-1.28 (m, 2H, CH\textsubscript{2}), 1.60-1.71 (m, 4H, CH\textsubscript{2}), 3.02 (t, J = 7.0 Hz 2H, CH\textsubscript{2}), 4.10 (t, J = 7.5 Hz, 2H, CH\textsubscript{2}), 7.23-7.33 (m, 9H, CH), 7.38-7.40 (m, 4H, CH), 7.80 (d, J = 7.9 Hz, 1H, CH).

2c\textsuperscript{1}: Yellow oil, isolated yield 88% (105 mg). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}, Me\textsubscript{4}Si): δ 0.95-1.03 (m, 6H, CH\textsubscript{3}), 1.43-1.50 (m, 2H, CH\textsubscript{2}), 1.56-1.68 (m, 4H, CH\textsubscript{2}), 1.71-1.77 (m, 2H, CH\textsubscript{2}), 1.79-1.86 (m, 2H, CH\textsubscript{2}), 2.65-2.71 (m, 4H, CH\textsubscript{2}), 3.16 (t, J = 6.9 Hz, 2H, CH\textsubscript{2}), 4.04 (t, J = 7.6 Hz, 2H, CH\textsubscript{2}), 7.03-7.07 (m, 1H, CH), 7.10-7.14 (m, 1H, CH), 7.23 (d, J = 8.6 Hz, 1H, CH), 7.52 (d, J = 7.7 Hz, 1H, CH).

2d\textsuperscript{1}: Yellow oil, isolated yield 82% (87 mg). \textsuperscript{1}H NMR (500 MHz, CDCl\textsubscript{3}, Me\textsubscript{4}Si): δ 1.20-1.25 (m, 6H, CH\textsubscript{3}), 1.87-1.89 (m, 4H, CH\textsubscript{2}), 2.71-2.79 (m, 4H, CH\textsubscript{2}), 3.17 (t, J = 6.5 Hz, 2H, CH\textsubscript{2}), 4.08 (t, J = 7.0 Hz, 2H, CH\textsubscript{2}), 7.04-7.08 (m, 1H, CH), 7.12-7.15 (m, 1H, CH), 7.25 (s, 1H, CH), 7.54 (d, J = 7.5 Hz, 1H, CH).

2e: Yellow oil, isolated yield 66% (89 mg). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}, Me\textsubscript{4}Si): δ 1.60-1.67 (m, 2H, CH\textsubscript{2}), 1.75-1.82 (m, 2H, CH\textsubscript{2}), 2.96 (t, J = 6.8 Hz, 2H, CH\textsubscript{2}), 4.12 (t, J = 7.2 Hz, 2H, CH\textsubscript{2}), 7.14-7.20 (m, 2H, CH), 7.23-7.34 (m, 7H, CH), 7.37-7.43 (m, 4H, CH), 7.80 (d, J = 7.9 Hz, 1H, CH); \textsuperscript{13}C NMR (100 MHz, CDCl\textsubscript{3}): δ 5.6 (CH\textsubscript{2}), 30.6 (CH\textsubscript{2}), 30.7 (CH\textsubscript{2}), 42.6 (CH\textsubscript{2}), 109.8 (CH), 115.6 (quat. C), 119.9 (CH), 120.2 (CH), 122.2 (CH), 125.5 (CH), 127.3 (quat. C), 128.1 (2 CH), 128.2 (CH), 128.5 (2 CH), 129.8 (2 CH), 131.2 (2 CH), 132.1 (quat. C), 135.0 (quat. C), 136.3 (quat. C), 137.4 (quat. C). HRMS calcd. for C\textsubscript{24}H\textsubscript{23}IN [M+H]\textsuperscript{+}: 452.0870, found 452.0876.
2f: Yellow oil, isolated yield 75% (107 mg). $^1$H NMR (400 MHz, CDCl$_3$, Me$_4$Si): $\delta$ 1.32-1.40 (m, 2H, CH$_2$), 1.70-1.80 (m, 4H, CH$_2$), 3.10 (t, $J = 6.9$ Hz, 2H, CH$_2$), 4.10 (t, $J = 7.6$ Hz, 2H, CH$_2$), 6.99-7.03 (m, 2H, CH), 7.15-7.23 (m, 4H, CH), 7.29-7.33 (m, 1H, CH), 7.38 (d, $J = 8.2$ Hz, 1H, CH), 7.52-7.54 (m, 1H, CH), 7.93 (d, $J = 8.0$ Hz, 1H, CH).

2g: Yellow oil, isolated yield 62% (89 mg). $^1$H NMR (400 MHz, C$_6$D$_6$, Me$_4$Si): $\delta$ 0.68-0.76 (m, 2H, CH$_2$), 1.04-1.11 (m, 2H, CH$_2$), 1.12-1.19 (m, 2H, CH$_2$), 2.43 (t, $J = 7.1$ Hz, 2H, CH$_2$), 3.58 (t, $J = 7.4$ Hz, 2H, CH$_2$), 6.75-6.77 (m, 1H, CH), 6.84-6.86 (m, 2H, CH), 6.90-6.92 (m, 1H, CH), 6.99-7.00 (m, 1H, CH), 7.09-7.11 (m, 1H, CH), 7.17 (s, 1H, CH), 7.23-7.34 (m, 2H, CH), 7.95 (d, $J = 7.7$ Hz, 1H, CH); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 6.3 (CH$_2$), 27.7 (CH$_2$), 28.9 (CH$_3$), 32.7 (CH$_2$), 43.6 (CH$_2$), 109.7 (CH), 111.2 (quat. C), 119.9 (CH), 120.2 (CH), 120.8 (CH), 122.2 (CH), 124.5 (CH), 126.0 (CH), 126.1 (CH), 126.9 (quat. C), 128.5 (CH), 129.5 (CH), 132.2 (quat. C), 132.3 (quat. C), 135.2 (quat. C), 136.2 (quat. C). HRMS calcd. for C$_{21}$H$_{21}$IN$_2$ [M+H]$^+$: 478.0155, found 478.0152.

Procedure for the preparation of 4: Under an atmosphere of nitrogen, Pd(allyl)(Cp) (5 mol %), PPh$_3$ (10 mol %) and LiO'Bu (0.36 mmol), were added to 2 mL cyclohexane. After this reaction mixture was stirred at room temperature for 5 min, 3 (0.3 mmol) and 3-hexyne (0.36 mmol) were added and the reaction mixture was stirred at 130 °C for 12 h. The reaction mixture was quenched with water and extracted with Et$_2$O. The combined organic layer was washed with brine and dried over MgSO$_4$. The solvent was then evaporated in vacuo and the residue was purified by silica gel column chromatography with petroleum ether and ethyl acetate as eluent to afford the final product 4.

4: Yellow oil, isolated yield 32% (31 mg). $^1$H NMR (400 MHz, C$_6$D$_6$): $\delta$ 0.91-0.99 (m, 2H, CH$_2$), 1.03 (t, $J = 7.6$ Hz, 3H, CH$_3$), 1.20-1.29 (m, 7H, CH$_3$+2CH$_2$), 2.48 (q, $J = 7.5$ Hz, 2H, CH$_2$), 2.70-2.78 (m, 4H, CH$_2$), 3.53 (t, $J = 7.5$ Hz, 2H, CH$_2$), 7.09-7.12 (m, 1H, CH), 7.21-7.29 (m, 2H, CH), 7.65-7.67 (m, 1H, CH); $^{13}$C NMR (100 MHz, C$_6$D$_6$): 15.5 (CH$_3$), 16.5 (CH$_3$), 17.8 (CH$_2$), 18.1 (CH$_3$), 25.7 (CH$_2$), 29.6 (CH$_2$), 32.4 (CH$_2$), 33.2 (CH$_2$), 42.8
(CH₂), 109.4 (CH), 113.3 (quat. C), 118.9 (CH), 119.2 (CH), 121.0 (CH), 128.6 (quat. C), 136.6 (quat. C), 137.0 (quat. C). HRMS calcd. for C₁₇H₂₅BrN [M+H]+: 322.1165, found 322.1174.

2) Reference:

3) Scanned ¹H NMR and ¹³C NMR Spectra of All Compounds