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Mononuclear palladacycles of *N,N′*-diaryl-2-iminoisoindolines

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ABSTRACT

Reaction of acetato-bridged dinuclear palladacycles, [Pd(iminoisoindoline)(μ-OAc)]$_2$, with stoichiometric amounts of PR_3 (where R = Ph or Cy) resulted in formation of the corresponding mononuclear phosphine-ligated, six-membered palladacycles with the general formula [Pd(iminoisoindoline)(OAc)PR_3]. The analogous chloride complexes were synthesized by reaction of [Pd(iminoisoindoline)(μ-OAc)]$_2$ with LiCl in acetone followed by addition of phosphine to afford the monomeric derivatives [Pd(iminoisoindoline)(Cl)PR_3]. Representative crystal structures of both types of mononuclear palladacycles confirmed the mononuclear nature of the complexes and showed a trans-arrangement of the phosphine ligand to the heterocyclic imine-nitrogen of the palladacycles.

1. Introduction

Isoindoline derivatives have found widespread applications in the pharmaceutical, herbicidal and dye industries. For example pazinaclone, staurosporine, and indoprofen all possess an isoindoline substructure [1]. We are interested in one particular family of isoindolines, specifically *N,N′*-diaryl-2-iminoisoindolines for applications as ligands in group 10 coordination chemistry. The specific interest in diaryliminoisoindolines lies in their extreme ease of synthesis, the ease in which they can be sterically and electronically tuned and their potential ability to form metallacycles. Despite their ease of synthesis, iminoisoindolines remain relatively unexplored as ligands. While the original synthesis for diphenyliminoisoindoline dates back to 1910 [2], few reports exist concerning *N,N′*-diaryl-2-iminoisoindolines indicating few applications have been found for this isoindoline subclass [1,3]. *N,N′*-Diaryl-2-iminoisoindolines are easily synthesized by reaction of phthalaldehyde with two equivalents of an aryl amine in ether as solvent (Scheme 1). The resulting iminoisoindoline usually precipitates from solution as an analytically pure solid, allowing for easy isolation [1,4].

We have recently shown that the reaction proceeds through a double condensation reaction to form a γ-diimine which then undergoes intramolecular cyclization to form the corresponding iminoisoindoline [5]. *para*-Substituted *N,N′*-diaryl-2-iminoisoindolines readily react with $Pd(OAc)_2$ at room temperature resulting in formation of six-membered [C,N] dinuclear cyclopalladated complexes with the general formula [Pd(iminoisoindoline)(μ-OAc)]$_2$ (Scheme 1) [4].

Palladacycles represent an increasingly important class of organometallic compounds, where their influence is especially dominant in the field of coupling reactions for organic transformations [6,7]. Many palladium-mediated coupling reactions are thought to involve palladacyclic intermediates [8] and several palladacycles are also reported to be biologically active compounds for cancer therapy [9]. Herein we report the synthesis and characterization of mononuclear iminoisoindoline-based six-membered palladacycles with the general formula [Pd(iminoisoindoline)(OAc)(PR_3)] and [Pd(iminoisoindoline)(Cl)PR_3].

2. Results and discussion

2.1. Synthesis and characterization of [Pd(iminoisoindoline)(OAc)(PR_3)] complexes

We previously described the formation of six-membered, acetato-bridged dinuclear palladacycles **1**–**4** of the general formula [Pd(iminoisoindoline)(μ-OAc)]$_2$ from the reaction of the corresponding iminoisoindoline with $Pd(OAc)_2$ [4]. The solid state structures of these complexes show that they adopt a characteristic closed book conformation where the two iminoisoindoline ligands stacked on top of the other in an *anti* configuration. In an extension of our previously reported work, we describe here the synthesis and characterization of a series of mononuclear phosphine-ligated, six-membered palladacycles from complexes **1**–**4**.

Palladacycles **5**–**10**, of the general formula [Pd(iminoisoindoline)(OAc)(PR_3)], (where R = Ph or Cy), were obtained by

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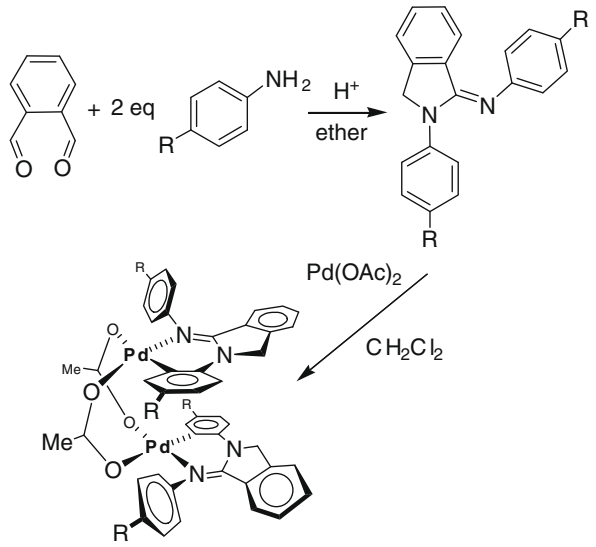


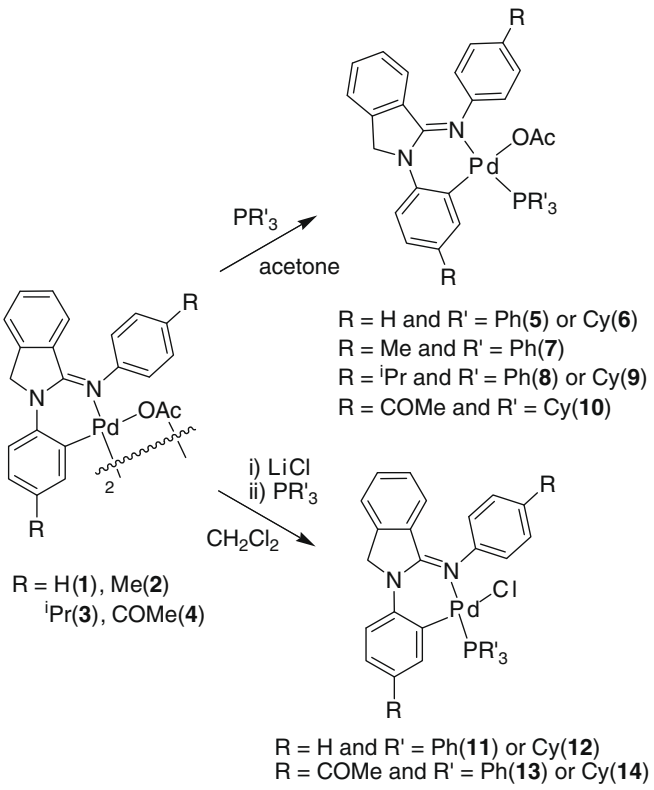
Scheme 1. Synthesis of iminoisoindoline ligands and corresponding acetato-bridged dinuclear palladacycles.

the reaction of acetato-bridged dinuclear palladacycles **1**–**4** with stoichiometric amounts of phosphine in acetone at room temperature (scheme 2). Thus, treatment of dinuclear complexes **1**–**3** with two equivalents of PPh_3 afforded the corresponding mononuclear phosphine-ligated complexes **5**, **7** and **8** in good yield as yellow solids. Analogous treatment of complexes **1**, **3** and **4** with PCy_3 also afforded the corresponding mononuclear tricyclohexylphosphine-ligated complexes **6**, **9** and **10** (Scheme 2).

The mononuclear palladacycles were obtained in good to excellent yields (60–94%) and were fully characterized by elemental analysis, mass spectrometry and NMR spectroscopy. A characteristic indication of the formation of mononuclear species is the observed ^1H NMR resonance for the CH_2 protons of the iminoisoindoline ring. In dinuclear complexes **1**–**4**, the methylene protons are diastereotopic resulting in formation of two doublets each integrating for one proton at ~4.6 and ~3.5 ppm. After reaction with phosphine, the ^1H NMR spectra show the disappearance of the two doublets coincident with the appearance of a new singlet at ~5 ppm integrating for two protons indicating the methylene protons are now chemically equivalent and the new complexes have an average C_s symmetry in solution. The free iminoisoindoline ligands also show a singlet which is ~0.1 ppm upfield relative to that of phosphine-ligated palladacycles [4,5]. The ^{31}P NMR spectra of these complexes show a singlet at ~33 ppm consistent with only one isomer being present in solution. The mass spectra of all complexes show a strong signal which was assigned to their respective molecular cation $[M-OAc]^+$.

2.2. Synthesis and characterization of [Pd(iminoisoindoline)(Cl)(PR_3)] complexes

The acetato-bridged dinuclear palladacycles **1** and **4** were treated with LiCl in acetone at room temperature resulting in formation of a yellow precipitate which was presumably the chloride-bridged analogue of **1** and **4**. The products were not characterized but used as is for the subsequent steps. Addition of LiCl is a general route for the conversion of acetate-bridged dinuclear palladacycles to their chloro-bridged analogues [6]. The resulting yellow powder was isolated and suspended in dichloromethane. Palladacycles



Scheme 2. Synthesis of mononuclear iminoisoindoline-based palladacycles.

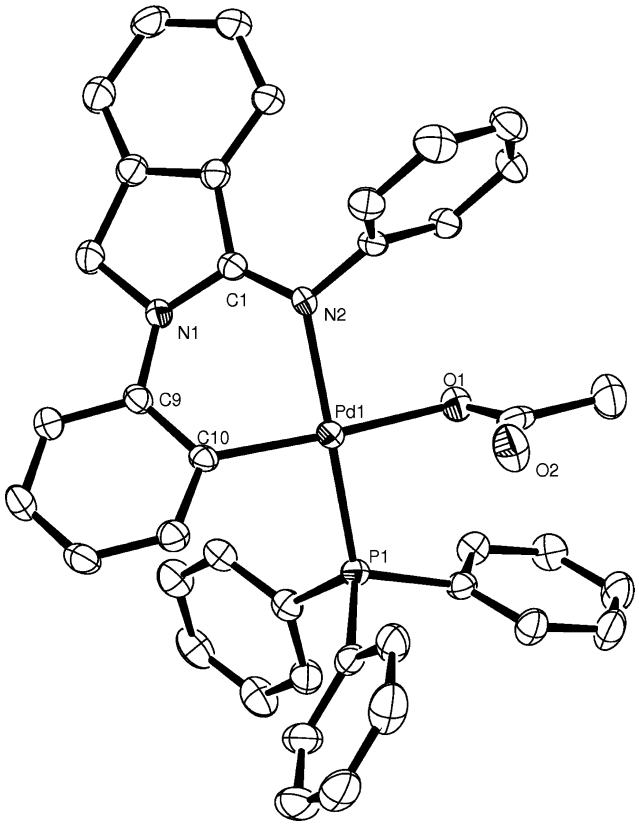


Fig. 1. ORTEP plot of **5** at the 50% probability level. The hydrogen atoms have been omitted for clarity. Selected bond lengths [Å] and angles [°]: Pd(1)–C(10) = 1.998(3), Pd(1)–N(2) = 2.086(2), Pd(1)–O(1) = 2.092(2), Pd(1)–P(1) = 2.2739(8), C(10)–Pd(1)–N(2) = 87.23(10), C(10)–Pd(1)–O(1) = 174.97(10), N(2)–Pd(1)–O(1) = 90.55(9), C(10)–Pd(1)–P(1) = 93.83(8), N(2)–Pd(1)–P(1) = 171.92(7), O(1)–Pd(1)–P(1) = 87.74(6).

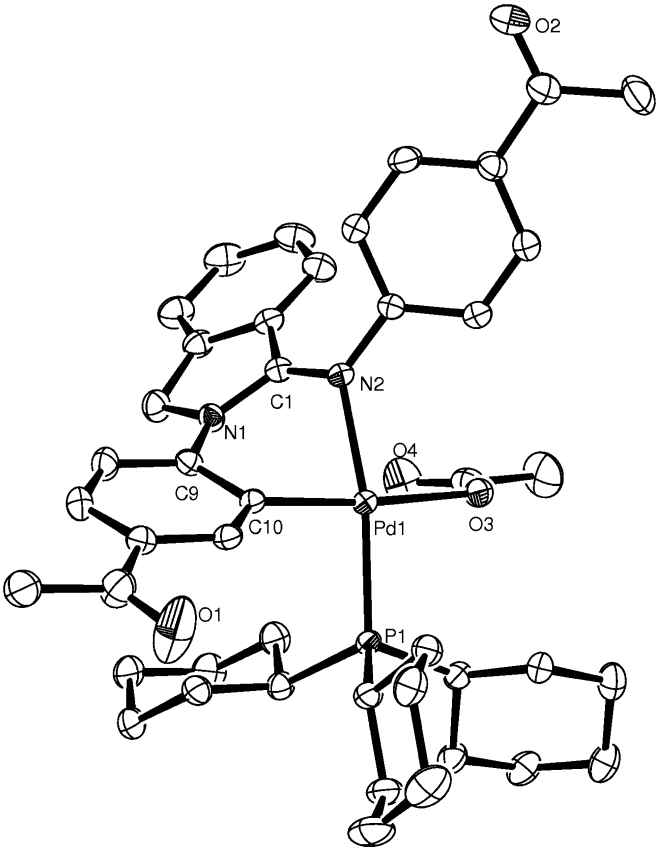


Fig. 2. ORTEP plot of **10** at the 30% probability level. The hydrogen atoms have been omitted for clarity. Symmetry transformations used to generate equivalent atoms: (i) *y*, *x*, $-z+2$. Selected bond lengths [Å] and angles [°]: Pd(1)–C(10) = 1.987(3), Pd(1)–N(2) = 2.138(2), Pd(1)–O(3) = 2.1142(19), Pd(1)–P(1) = 2.2767(7), C(10)–Pd(1)–N(2) = 83.42(9), C(10)–Pd(1)–O(3) = 174.58(9), N(2)–Pd(1)–O(3) = 91.30(8), C(10)–Pd(1)–P(1) = 91.80(7), N(2)–Pd(1)–P(1) = 167.71(6), O(3)–Pd(1)–P(1) = 93.15(5).

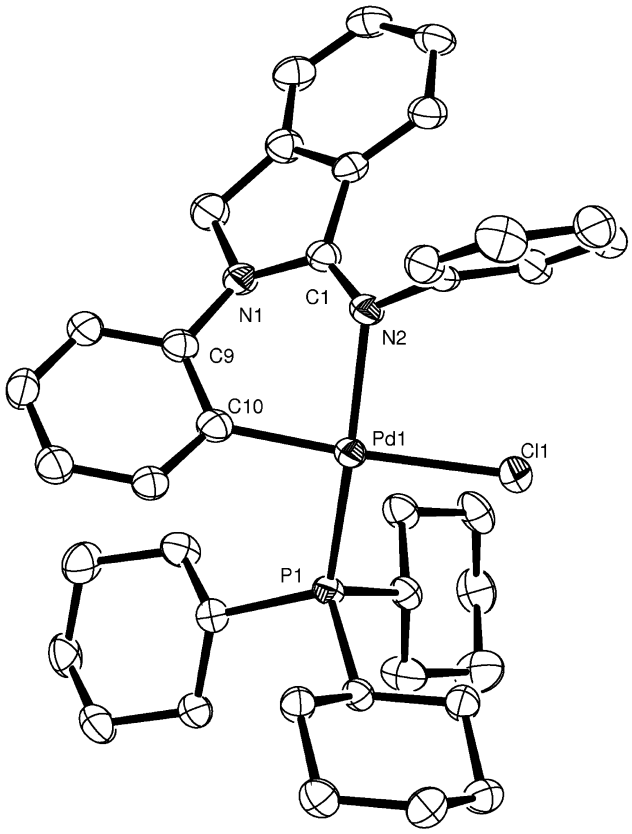


Fig. 3. ORTEP plot of **12** at the 50% probability level. The hydrogen atoms have been omitted for clarity. Selected bond lengths [Å] and angles [°]: Pd(1)–C(10) = 1.995(3), Pd(1)–N(2) = 2.130(3), Pd(1)–Cl(1) = 2.4077(9), Pd(1)–P(1) = 2.2901(8), C(10)–Pd(1)–N(2) = 84.26(12), C(10)–Pd(1)–Cl(1) = 174.30(9), N(2)–Pd(1)–Cl(1) = 91.17(8), C(10)–Pd(1)–P(1) = 94.38(9), N(2)–Pd(1)–P(1) = 166.64(8), Cl(1)–Pd(1)–P(1) = 90.85(3).

11–**14**, of the general formula [Pd(iminoisoindoline)(Cl)PR_3], (where R = Ph or Cy), were obtained by the reaction of the yellow suspension with stoichiometric amounts of phosphine at room temperature (Scheme 2). Over the course of 12 h, the yellow suspension gradually became a clear solution which, after work up, afforded the desired products. Thus, treatment of dinuclear complexes **1** and **4** with LiCl followed by two equivalents of PPh_3 afforded the corresponding mononuclear phosphine-ligated complexes **11** and **13** in good yields (84% and 78%, respectively). Analogous treatment of complexes **1** and **4** with LiCl and PCy_3 also afforded the corresponding mononuclear tricyclohexylphosphine-ligated complexes **12** and **14** in 80% and 90% yields, respectively (Scheme 2). The NMR spectra were consistent with those observed for the mononuclear acetato analogues **5**–**10**. The mass spectra of all complexes show a strong signal which was assigned to their respective molecular cation $[M-Cl]^+$.

2.3. Crystal structures of complexes *5*, *10*, *12* and *13*

To further clarify the coordination environment around the metal center, representative molecular structures of **5**–**14** have been ascertained by means of X-ray diffraction studies. Single crystals of complexes **5**, **10**, **12** and **13** were obtained by slow evaporation of a concentrated dichloromethane/hexane (1:1) solution. ORTEP plots are shown in Figs. 1–4, and included in their respective captions are selected bond distances and angles. Palladacycles **10** and **15** co-crystallized with a molecule of dichloromethane. Table 1 shows selected crystal data and refinement parameters for the structures. In all four palladacyclic compounds, the crystal structures revealed mononuclear species with a slightly distorted square-planar coordination geometry around the palladium atom. The environment around each palladium atom consists of a bidentate iminoisoindoline [C,N], a terminal chloride or acetate and a phosphine. The phosphine ligands are always *trans* to the donor N atom of the iminoisoindoline ligand. This is consistent with other reports of mononuclear palladacycles, where the phosphine and aryl ligands have a well-demonstrated tendency not to be *trans* to each other when coordinated to palladium.[10] The six-membered palladacycles adopt a pseudo-boat conformation which is illustrated in Fig. 5 using palladacycle **12** as a representative example. In all four palladacycles the Pd–P bond distances range from 2.274(1) to 2.290(1) Å. The Pd–$C_{palladate}$ bond distances are all similar at 2.00(1) Å. These values are within the range usually reported by five- and six-membered palladacycles (1.99–2.01 Å) [10]. As would be expected, the Pd–N distance for the imine *trans* to the PCy_3 moiety in complexes **10** and **12** is noticeably shorter than the corresponding distance in complexes **5** and **13** where the imine is *trans* to a PPh_3 moiety, consistent with the stronger *trans* influence of PCy_3. The Pd–N distance for complexes **10** and **12** is 2.138(2) and 2.130(3) Å, respectively, whereas the Pd–N distance for **5** and **13** is 2.086(2) and 2.110(3) Å, respectively.

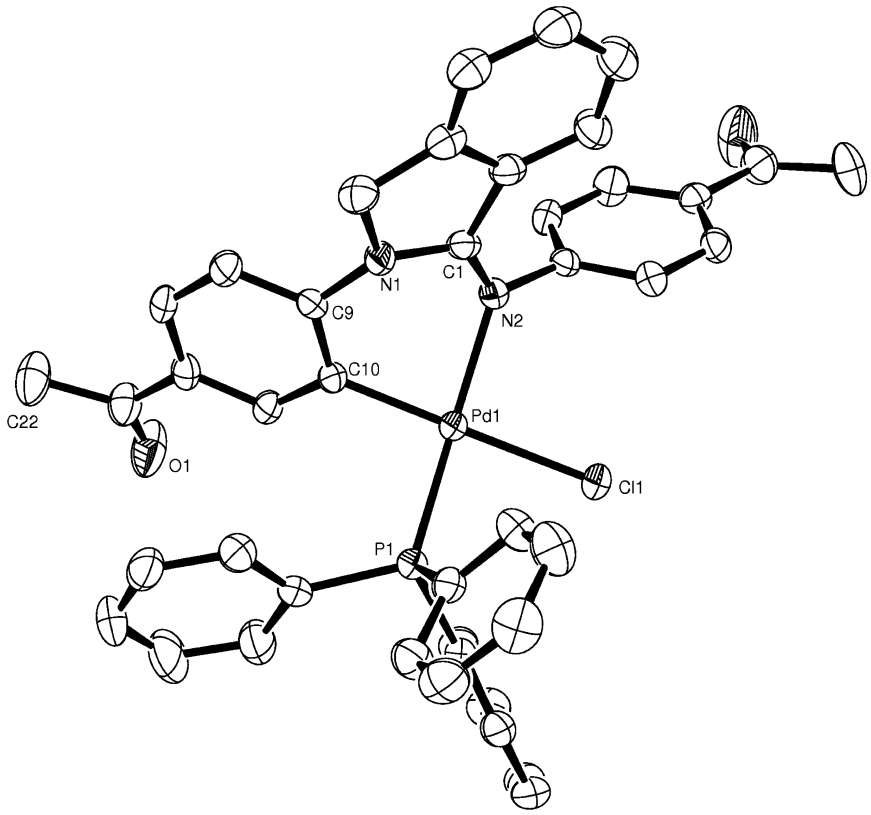


Fig. 4. ORTEP plot of **13** at the 50% probability level. The hydrogen atoms have been omitted for clarity. Selected bond lengths [Å] and angles [°]: Pd(1)–C(10) = 1.992(4), Pd(1)–N(2) = 2.110(3), Pd(1)–Cl(1) = 2.3990(10), Pd(1)–P(1) = 2.2540(11), C(10)–Pd(1)–N(2) = 85.25(14), C(10)–Pd(1)–Cl(1) = 174.02(11), N(2)–Pd(1)–Cl(1) = 94.47(9), C(10)–Pd(1)–P(1) = 93.93(11), N(2)–Pd(1)–P(1) = 160.16(9), Cl(1)–Pd(1)–P(1) = 88.35(4).

Table 1
Crystal data and refinement parameters for complexes **5**, **10** · CH_2Cl_2, **12** and **13** · CH_2Cl_2.

	5	**10** · CH_2Cl_2	**12**	**13** · CH_2Cl_2
Formula	$C_{40}H_{33}N_2O_2PPd$	$C_{45}H_{57}Cl_2N_2O_4PPd$	$C_{38}H_{48}ClN_2PPd$	$C_{43}H_{36}Cl_3N_2O_2PPd$
Formula weight	711.05	898.20	705.60	856.46
Color	Pale yellow	Yellow	Yellow	Yellow
Crystal size (mm)	0.22 × 0.12 × 0.12	0.18 × 0.11 × 0.08	0.25 × 0.20 × 0.18	0.15 × 0.15 × 0.10
Crystal system	Triclinic	Triclinic	Monoclinic	Monoclinic
Space group	$P\bar{1}$	$P\bar{1}$	$P21/c$	$P21/c$
a (Å)	10.2458(3)	9.8823(2)	11.7619(2)	17.0313(4)
b (Å)	12.6323(3)	12.1332(2)	19.3702(4)	15.4993(3)
c (Å)	13.8280(3)	17.9651(3)	15.9664(3)	29.3952(8)
α (°)	83.401(2)	88.5070(10)	90	90
β (°)	81.0430(10)	86.9870(10)	113.0660(10)	90.6215(9)
γ (°)	66.857(2)	81.5910(10)	90	90
Z	2	2	4	4
ρ_{calc} (Mg m^{-3})	1.455	1.402	1.400	1.466
T (K)	173(2)	173(2)	173(2)	173(2)
Collec./Ind. Ref.	23729/7437	49446/14683	44459/6834	60310/8877
R_{int}	0.0563	0.0731	0.0850	0.0997
$F(000)$	728	936	1472	3488
θ range (°)	3.28–27.53	2.06–31.99	2.52–26.37	1.78–27.48
Final R_1 ($I > 2\sigma I$)	R_1 = 0.0411, wR_2 = 0.0810	R_1 = 0.0555, wR_2 = 0.1099	R_1 = 0.0427, wR_2 = 0.0955	R_1 = 0.0529 wR_2 = 0.1046
R_1 (all data)	R_1 = 0.0550, wR_2 = 0.0884	R_1 = 0.0903, wR_2 = 0.1259	R_1 = 0.0595, wR_2 = 0.1064	R_1 = 0.0970 wR_2 = 0.1216

3. Conclusion

We have successfully synthesized and characterized a series of six-membered, mononuclear iminoisoindoline-based palladacycles as air and moisture stable complexes. Much of the recent activity in palladacyclic chemistry has been prompted by the fact that they are particularly good precatalysts for carbon–carbon bond forming reactions. Mononuclear trialkylphosphine-ligated palladacycles have been shown to be especially effective for Suzuki and Heck coupling chemistry [10b,11]. Currently in progress are catalytic studies of these mononuclear complexes in C–C coupling reactions and this work will be reported at a later date.

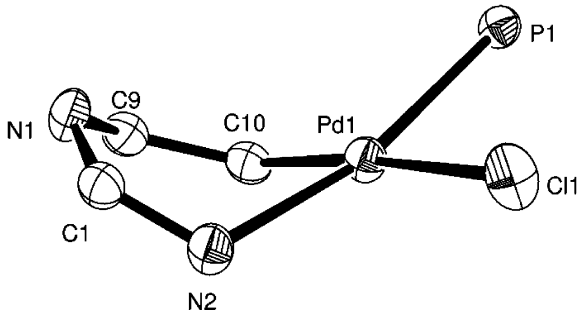


Fig. 5. ORTEP plot illustrating the core geometry of palladacycle **12**.

4. Experimental

4.1. General

Unless otherwise stated, all reactions were performed under N_2 using standard Schlenk techniques or in a N_2-filled drybox. Solvents were dried using a MBraun solvent purification system and stored under nitrogen. ^{1}H, ^{31}P and ^{13}C {^{1}H} NMR spectra were recorded on a Bruker 500 MHz Avance spectrometer. Chemical shifts for ^{1}H and ^{13}C NMR are reported in ppm in reference to the residual ^{1}H and ^{13}C resonances of $CDCl_3$ (^{1}H: δ 7.24; ^{13}C: δ 77.23). ^{31}P NMR chemical shifts are also reported in ppm with respect to 85% H_3PO_4, set to zero as an external standard. Coupling constants are given in Hz. High resolution mass spectra (HRMS) were measured on an Applied Biosystem QSTAR® XL MS/MS system (ESI-QTOF). Elemental analyses were performed on a Perkin–Elmer 2400 CHN elemental analyzer. [Pd(iminoisoindoline)(μ-OAc)]$_2$ complexes were synthesized following literature procedures [4]. Tricyclohexylphosphine, triphenylphosphine, aniline, *p*-acetoaniline, *p*-isopropylaniline, *p*-tertiarybutylaniline were purchased from the Sigma–Aldrich Chemical Company. Phthalaldehyde was purchased from Alfa Aesar. All chemicals were used as received.

4.2. General procedure (A) for synthesis of [Pd(iminoisoindoline)(OAc)(PR$_3$)] complexes 5–10

A flask was charged with [Pd(iminoisoindoline)(μ-OAc)]$_2$, **1**–**4** and either triphenylphosphine or tricyclohexylphosphine (stoichiometric amounts) in acetone (30 mL, degassed). The resulting suspension slowly became a clear, colourless solution over the course of 12 h. The resulting solution was filtered and the filtrate was concentrated to circa 2 mL. Hexanes were then added to precipitate out the desired complex, which was filtered, washed with 3×10 mL of hexanes, and then dried under vacuum. Single crystals of palladacycles **5** and **10** were obtained from slow evaporation of a dichloromethane/hexane (1:1) solution.

4.3. Synthesis of [Pd(N,N′-diphenyl-2-iminoisoindoline)(OAc)PPh$_3$] (5)

Compound **5** was obtained as a yellow powder in 94% yield from palladacycle **1** (203 mg, 0.226 mmol) and triphenylphosphine (130 mg, 0.497 mmol) using procedure A. ^{1}H NMR ($CDCl_3$, ppm) δ 7.51 (m, 7H, Ar), 7.39 (m, 1H, Ar), 7.33 (m, 3H, Ar), 7.27 (m, 10H, Ar), 7.22 (m, 1H, Ar), 7.00 (m, 2H, Ar), 6.87 (m, 1H, Ar), 6.75 (m, 1H, Ar), 6.23 (m, 1H, Ar), 6.03 (d, J = 8.0, 1H, Ar), 5.16 (s, 2H, –CH_2–), 1.04 (s, 3H, CO_2CH_3); ^{13}C NMR ($CDCl_3$, ppm): δ 175.36 (CO_2CH_3), 155.94 (C=N), 146.27, 141.24, 140.21, 140.10, 137.68, 134.71, 134.62, 131.65, 131.58, 130.89, 130.82, 130.44, 130.15, 129.61, 128.78, 128.24, 128.15, 127.92, 127.60, 127.52, 127.33, 126.30, 125.30, 124.05, 122.66, 122.19, 124.33, 51.63 (–CH_2–), 23.69 (CO_2CH_3). ^{31}P NMR ($CDCl_3$, ppm) δ 34.04. Elemental Anal. Calc. for $C_{40}H_{33}N_2O_2PPd$ $(CH_2Cl_2)_{0.7}$: C, 63.44; H, 4.50; N, 3.64. Found: C, 63.17; H, 4.40; N, 3.96% (^{1}H NMR analysis of sample showed presence of 0.6 equiv of CH_2Cl_2 which was used as the crystallization solvent). HRMS *m/z* Calc. for $C_{40}H_{33}N_2O_2PPd$: 710.1314 [M], 651.1181 [M−OAc]$^+$. Found 651.1155 [M−OAc]$^+$.

4.4. Synthesis of [Pd(N,N′-diphenyl-2-iminoisoindoline)(OAc)PCy$_3$] (6)

Compound **6** was obtained as a yellow powder in 90% yield from palladacycle **1** (341 mg, 0.380 mmol) and tricyclohexylphosphine (224 mg, 0.799 mmol) using procedure A. ^{1}H NMR ($CDCl_3$, ppm) δ 7.47 (m, 2H, Ar), 7.39 (m, 1H, Ar), 7.26 (m, 2H, Ar), 7.18 (m, 3H, Ar), 7.00 (m, 2H, Ar), 6.84 (m, 2H, Ar), 6.15 (d, J = 8.1, 1H, Ar), 5.08 (s, 2H, –CH_2–), 2.01 (m, 3H, PCy_3), 1.82 (m, 6H, PCy_3), 1.71 (m, 6H, PCy_3), 1.63 (m, 3H, PCy_3), 1.59 (s, 3H, CO_2CH_3), 1.42(m, 6H, PCy_3), 1.13(m, 9H, PCy_3); ^{13}C NMR ($CDCl_3$, ppm): δ 176.43 CO_2CH_3), 157.18 (C=N), 146.63, 141.98, 140.63, 140.56, 139.54, 134.28, 131.16, 130.75, 128.52, 127.17, 126.48, 126.48, 125.36, 124.08, 123.38, 123.35, 122.63, 114.26, 51.49 (–CH_2–), 33.28, 33.11, 29.72, 28.14, 28.05, 26.76, 25.71. ^{31}P NMR ($CDCl_3$, ppm) δ 32.96. Elemental Anal. Calc. for $C_{40}H_{51}N_2O_2PPd$: C, 65.88; H, 7.05; N, 3.39. Found: C, 65.58; H, 7.04; N, 3.64%. HRMS *m/z* Calc. for $C_{40}H_{51}N_2O_2PPd$: 728.2723 [M], 669.2590 [M−OAc]$^+$. Found 669.2574 [M−OAc]$^+$.

4.5. [Pd(N,N′-di(p-methylphenyl)-2-iminoisoindoline)(OAc)PPh$_3$] (7)

Compound **7** was obtained as a yellow powder in 70% yield from palladacycle **2** (237 mg, 0.249 mmol) and triphenylphosphine (144 mg, 0.549 mmol) using procedure A. ^{1}H NMR ($CDCl_3$, ppm) δ 7.49 (m, 8H, Ar), 7.35 (m, 5H, Ar), 7.27 (m, 4H, Ar), 7.13 (d, J = 7.4, 2H, Ar), 7.02 (m, 3H, Ar), 6.82 (d, J = 7.8, 1H, Ar), 6.66 (d, J = 7.0, 1H, Ar), 6.47 (br, s, 1H, Ar), 6.14 (d, J = 7.8, 1H, Ar), 5.12 (s, 2H, –CH_2–), 2.32 (s, 3H, C_6H_4–CH_3), 1.57 (s, 3H, C_6H_3–CH_3), 1.07 (s, 3H, CO_2CH_3); ^{13}C NMR ($CDCl_3$, ppm): δ 176.06 (CO_2CH_3), 156.17 (C=N), 144.24, 141.65, 136.23, 135.38, 135.29, 135.18, 132.29, 131.64, 131.28, 131.12, 131.07, 129.51, 129.10, 128.65, 128.11, 128.02, 127.82, 127.11, 126.58, 126.12, 125.51, 124.99, 122.45, 114.01, 52.08 (–CH_2–), 24.30 (C_6H_4–CH_3), 21.35 (C_6H_3–CH_3), 20.21 CO_2CH_3). ^{31}P NMR ($CDCl_3$, ppm) δ 33.90. Elemental Anal. Calc. for $C_{42}H_{37}N_2O_2PPd$: C, 68.25; H, 5.05; N, 3.79. Found: C, 67.89; H, 4.97; N, 3.84%. HRMS *m/z* Calc. for $C_{42}H_{37}N_2O_2PPd$: 738.1627 [M], 679.1494 [M−OAc]$^+$. Found 679.1475 [M−OAc]$^+$.

4.6. [Pd(N,N′-di(p-isopropylphenyl)-2-iminoisoindoline)(OAc)PPh$_3$] (8)

Compound **8** was obtained as a yellow powder in 60% yield from palladacycle **3** (255 mg, 0.239 mmol) and triphenylphosphine (144 mg, 0.549 mmol) using procedure A. ^{1}H NMR ($CDCl_3$, ppm) δ 7.52 (m, 6H, Ar), 7.45 (d, J = 7.6, 1H, Ar), 7.35 (m, 5H, Ar), 7.25 (m, 5H, Ar), 7.18 (d, J = 8.2, 2H, Ar), 7.09 (d, J = 8.2, 2H, Ar), 6.96 (m, 1H, Ar), 6.92 (d, J = 8.4, 1H, Ar), 6.77 (m, 2H, Ar), 5.99 (d, J = 8.2, 1H, Ar), 5.13 (s, 2H, –CH_2–), 2.88 (sept., J = 6.9, 1H, –CH(CH_3)$_2$), 2.10 (sept., J = 6.9, 1H, –CH(CH_3)$_2$), 1.22 (d, J = 6.9, 6H, –CH(CH_3)$_2$), 1.05 (s, 3H, CO_2CH_3), 0.61 (d, J = 6.9, 6H, –CH(CH_3)$_2$); ^{13}C NMR ($CDCl_3$, ppm): δ 176.01 (–CO_2CH_3), 155.82 (C=N), 146.25, 144.55, 143.03, 141.53, 136.41, 135.53, 135.44, 135.36, 131.87, 131.50, 131.13, 131.01, 130.03, 128.65, 128.40, 128.12, 128.04, 127.76, 127.14, 126.74, 126.30, 122.61, 122.37, 114.45, 52.32 (–CH_2–), 33.91 (–CH(CH_3)$_2$), 33.11 (–CH(CH_3)$_2$), 24.33 (–CH(CH_3)$_2$), 23.98 (–CO_2CH_3), 23.54 (–CH(CH_3)$_2$). ^{31}P NMR ($CDCl_3$, ppm) δ 34.20. Elemental Anal. Calc. for $C_{46}H_{45}N_2O_2PPd$: C, 69.47; H, 5.70; N, 3.52. Found: C, 69.30; H,

5.48; N, 3.70%. HRMS *m/z* Calc. for $C_{46}H_{45}N_2O_2PPd$: 794.2253 [M], 735.2120 $[M-OAc]^+$. Found 735.2088 $[M-OAc]^+$.

4.7. [Pd(N,N′-di(p-isopropylphenyl)-2-iminoisoindoline)(OAc)PCy$_3$] (**9**)

Compound **9** was obtained as a yellow powder in 82% yield from palladacycle **3** (250 mg, 0.235 mmol) and tricyclohexylphosphine (139 mg, 0.496 mmol) using procedure A. ^{1}H NMR ($CDCl_3$, ppm) δ 7.44 (d, J = 7.5, 1H, Ar), 7.36 (m, 2H, Ar), 7.09 (d, J = 8.3, 2H, Ar), 7.05 (d, J = 8.3, 2H, Ar) 6.98 (m, 1H, Ar), 6.83 (d, J = 8.2, Ar), 6.77 (d, J = 8.2, 1H, Ar), 6.14 (d, J = 8.1, 1H, Ar), 5.03 (s, 2H, –CH_2–), 2.91 (sept., J = 6.9, 1H, –CH(CH_3)$_2$), 2.77 (sept., J = 6.9, 1H, –CH(CH_3)$_2$), 2.01 (m, 3H, PCy_3), 1.84 (m, 7H, PCy_3), 1.69 (m, 7H, PCy_3), 1.61 (m, 4H, PCy_3), 1.57 (s, 3H, –CO_2CH_3), 1.38 (m, 6H, PCy_3), 1.22 (m, 12H, –CH(CH_3)$_2$) 1.17 (m, 4H, PCy_3), 1.06 (m, 7H, PCy_3); ^{13}C NMR ($CDCl_3$, ppm): δ 176.33 (–CO_2CH_3), 156.92 (C=N), 145.69, 144.34, 143.05, 141.86, 138.76, 138.69, 137.48, 134.30, 130.92, 130.88, 127.71, 127.15, 126.27, 122.51, 122.03, 113.94, 100.17, 51.53 (–CH_2–), 34.03, 33.90, 33.31, 33.15, 30.20, 29.69, 28.11, 28.02, 26.71, 26.56, 25.62, 24.45, 24.36. ^{31}P NMR ($CDCl_3$, ppm) δ 33.16. HRMS *m/z* Calc. for $C_{46}H_{63}N_2O_2PPd$: 812.3662 [M], 753.3529 $[M-OAc]^+$. Found 753.3557 $[M-OAc]^+$.

4.8. [Pd(N,N′-di(p-acetophenyl)-2-iminoisoindoline)(OAc)PCy$_3$] (**10**)

Compound **10** was obtained as a yellow powder in 78% yield from palladacycle **4** (228 mg, 0.214 mmol) and tricyclohexylphosphine (126 mg, 0.449 mmol) using procedure A. ^{1}H NMR ($CDCl_3$, ppm) δ 8.15 (m, 1H, Ar), 7.90 (d, J = 8.1, 2H, Ar), 7.63 (d, J = 8.2, 1H, Ar), 7.51 (d, J = 7.4, 1H, Ar), 7.45 (m, 1H, Ar), 7.27 (d, J = 8.1, 2H, Ar), 7.05 (m, 1H, Ar), 6.92 (d, J = 8.4, 1H, Ar), 6.31 (d, J = 8.1, 2H, Ar), 5.16 (s, 2H, –CH_2–), 2.60 (s, 3H, —C(=O)CH_3), 2.53 (s, 3H, —C(=O)CH_3), 2.01 (m, 3H, PCy_3), 1.83 (m, 6H, PCy_3), 1.71 (m, 6H, PCy_3), 1.62 (m, 3H, PCy_3), 1.53 (s, 3H, –CO_2CH_3), 1.48 (m, 6H, PCy_3), 1.15 (m, 3H, PCy_3), 1.04 (m, 6H, PCy_3); ^{13}C NMR ($CDCl_3$, ppm): δ 197.90 (—C(=O)CH_3), 197.78 (—C(=O)CH_3), 176.47 (–CO_2CH_3), 157.03 (—C=N—), 150.99, 143.09, 141.86, 141.63, 141.56, 134.86, 134.17, 132.44, 132.42, 132.00, 130.05, 130.00, 128.25, 127.21, 126.43, 124.90, 122.91, 114.04, 52.21, 33.55, 33.38, 29.79, 28.13, 28.05, 26.89, 26.87, 26.63, 25.42; ^{31}P NMR ($CDCl_3$, ppm) δ 35.16. Elemental Anal. Calc. for $C_{44}H_{55}N_2O_4PPd \cdot (CH_2Cl_2)_{0.3}$: C, 63.43; H, 6.68; N, 3.34. Found: C, 63.47; H, 6.51; N, 3.27% (^{1}H NMR analysis of the sample showed presence of 0.3 equiv of CH_2Cl_2 which was used as the crystallization solvent). HRMS *m/z* Calc. for $C_{44}H_{55}N_2O_4PPd$: 812.2934 [M], 753.2801 $[M-OAc]^+$. Found 753.2754 $[M-OAc]^+$.

4.9. General procedure (B) for synthesis of [Pd(iminoisoindoline)(Cl)PR$_3$] complexes **11**-**14**

A flask was charged with [Pd(iminoisoindoline)(μ-OAc)]$_2$ and excess (20 equiv) LiCl in acetone and the mixture was stirred for 12 h. The resulting yellow precipitate was isolated, washed with water then acetone and dried under vacuum. The resulting yellow powder then suspended in dichloromethane. Palladacycles **11**–**14** were obtained by the reaction of the yellow suspension with equimolar amounts of phosphine (PPh_3 or PCy_3) at room temperature. Over the course of 12 h with stirring, the yellow suspension gradually became a clear colourless solution. The resulting solution was filtered and the filtrate was concentrated to circa 2 mL. Hexanes were then added to precipitate out the desired complex, which was filtered, washed with 3 × 10 mL of hexanes, then dried under vacuum. Single crystals of palladacycles **12** and **13** were obtained from slow evaporation of a concentrated dichloromethane/hexane (1:1) solution.

4.10. Synthesis of [Pd(N,N′-diphenyl-2-iminoisoindoline)(Cl)PPh$_3$] (**11**)

(84.0%, yellow powder). ^{1}H NMR ($CDCl_3$, ppm) δ 7.56 (m, 7H, Ar), 7.48 (m, 3H, Ar), 7.41 (m, 1H,Ar), 7.29 (m, 6H, Ar), 7.22 (m, 5H, Ar), 7.03 (m, 1H, Ar), 6.80 (m, 3H, Ar) 6.15 (m, 2H, Ar), 5.15 (s, 2H, –CH_2–); ^{13}C NMR ($CDCl_3$, ppm): δ 157.65 (—C=N—), 147.03, 141.98, 141.77, 141.67, 137.32, 136.86, 135.30, 135.21, 132.28, 131.90, 131.33, 131.00, 130.00, 128.22, 128.08, 128.00, 127.71, 127.16, 125.99, 123.98, 123.85, 122.62, 51.46 (–CH_2–). ^{31}P NMR ($CDCl_3$, ppm) δ 34.81. Elemental Anal. Calc. for $C_{38}H_{30}ClN_2PPd$: C, 66.39; H, 4.40; N, 4.07. Found: C, 66.56; H, 4.42; N, 3.93%. HRMS *m/z* Calc. for $C_{38}H_{30}ClN_2PPd$: 686.0870 [M], 651.1181 $[M-Cl]^+$. Found 651.1194 $[M-Cl]^+$.

4.11. Synthesis of [Pd(N,N′-diphenyl-2-iminoisoindoline)(Cl)PCy$_3$] (**12**)

(80.0%, yellow powder). ^{1}H NMR ($CDCl_3$, ppm) δ 7.49 (m, 3H, Ar), 7.40 (m, 1H, Ar), 7.24 (m, 3H, Ar), 7.16 (m, 1H, Ar), 7.03 (m, 2H, Ar), 6.92 (m, 1H, Ar), 6.85 (d, J = 7.8, 1H, Ar), 6.31 (d, J = 8.1, 1H, Ar), 5.11 (s, 2H, –CH_2–), 2.21 (m, 3H, PCy_3), 1.84 (m, 6H, PCy_3), 1.69 (m, 6H, PCy_3), 1.56 (m, 9H, PCy_3), 1.19 (m, 3H, PCy_3), 1.05 (m, 6H, PCy_3); ^{13}C NMR ($CDCl_3$, ppm): δ 159.00 (—C=N—), 147.27, 142.43, 139.87, 139.81, 139.64, 138.66, 131.27, 130.75, 130.73, 128.21, 128.02, 127.27, 127.15, 125.56, 124.59, 124.56, 124.11, 122.72, 114.16, 50.84 (–CH_2–), 34.54 (PCy_3), 34.36 (PCy_3), 30.17 (PCy_3), 28.04 (PCy_3), 27.96 (PCy_3), 26.74 (PCy_3). ^{31}P NMR ($CDCl_3$, ppm) δ 34.99. Elemental Anal. Calc. for $C_{38}H_{48}ClN_2PPd$: C, 64.68; H, 6.86; N, 3.97. Found: C, 64.53; H, 6.49; N, 3.97%. HRMS *m/z* Calc. for $C_{38}H_{48}ClN_2PPd$: 704.2 [M], 669.3 $[M-Cl]^+$. Found 669.3 $[M-Cl]^+$.

4.12. Synthesis of [Pd(N,N′-di(p-acetophenyl)-2-iminoisoindoline)(Cl)PPh$_3$] (**13**)

(78.0%, yellow powder). ^{1}H NMR ($CDCl_3$, ppm) δ 7.95 (d, J = 8.6, 2H, Ar), 7.56 (m, 9H, Ar), 7.53 (m, 1H, Ar), 7.42 (m, 2H, Ar), 7.31 (m, 3H, Ar), 7.23 (m, 6H, Ar), 7.07 (m, 1H, Ar), 6.91 (d, J = 8.7, 1H, Ar), 6.31 (d, J = 8.7, 1H, Ar), 5.21 (s, 2H, –CH_2–), 2.60 (s, 3H, —C(=O)CH_3), 2.01 (s, 3H, —C(=O)CH_3); ^{13}C NMR ($CDCl_3$, ppm): δ 197.83 (—C(=O)CH_3), 197.13 (—C(=O)CH_3), 157.55 (—C=N), 150.81, 143.16, 143.05, 141.97, 141.05, 135.19, 135.10, 134.91, 132.21, 131.56, 131.16, 130.43, 130.13, 128.8, 128.49, 128.32, 128.23, 127.66, 127.14, 124.55, 122.96, 113.77, 51.91 (–CH_2–), 26.87 (—C(=O)CH_3), 26.10 (—C(=O)CH_3). ^{31}P NMR ($CDCl_3$, ppm) δ 35.70. Elemental Anal. Calcd. for $C_{42}H_{34}ClN_2O_2PPd \cdot (CH_2Cl_2)$: C, 60.30; H, 4.24; N, 3.27. Found: C, 60.57; H, 3.92; N, 3.45%. HRMS *m/z* Calc. for $C_{42}H_{34}ClN_2O_2PPd$: 770.1081 [M], 735.1393 $[M-Cl]^+$ found 735.1400 $[M-Cl]^+$.

4.13. Synthesis of [Pd(N,N′-di(p-acetophenyl)-2-iminoisoindoline)(Cl)PCy$_3$] (**14**)

(90.0%, pale yellow powder). ^{1}H NMR ($CDCl_3$, ppm) δ 8.17 (s, 1H, Ar), 7.90 (d, J = 8.4, 2H, Ar), 7.67 (d, J = 8.4, 1H, Ar), 7.54 (m, 4H, Ar), 7.09 (m, 1H, Ar), 6.94 (d, J = 8.4, 1H, Ar), 6.47 (d, J = 8.1, 1H, Ar), 5.19 (s, 2H, –CH_2–), 2.59 (s, 3H, —C(=O)CH_3), 2.55 (s, 3H, —C(=O)CH_3), 2.18 (m, 3H, PCy_3), 1.85 (m, 6H, PCy_3), 1.69 (m, 6H, PCy_3), 1.55 (m, 9H, PCy_3), 1.19 (m, 3H, PCy_3), 1.05 (m, 6H, PCy_3).; ^{13}C NMR ($CDCl_3$, ppm): δ 197.84 (—C(=O)CH_3), 197.53 (—C(=O)CH_3), 158.72 (—C=N—), 150.96, 143.26, 142.33, 140.71, 140.65, 138.48, 134.47, 133.64, 132.16, 129.93, 129.22, 128.75, 128.42, 127.23, 127.14, 125.02, 123.02, 113.97, 51.43(–CH_2–), 34.78 (PCy_3), 34.60 (PCy_3), 30.19 (PCy_3), 28.05 (PCy_3), 27.96 (PCy_3), 26.82 (PCy_3), 26.74 (—C(=O)CH_3), 26.61 (—C(=O)CH_3). ^{31}P NMR ($CDCl_3$, ppm) δ

37.29. Elemental Anal. Calc. for $C_{42}H_{52}ClN_2O_2PPd$: C, 63.88; H, 6.64; N, 3.55. Found: C, 63.76; H, 6.77; N, 3.54%. HRMS *m/z* Calc. for $C_{42}H_{52}ClN_2O_2PPd$: 788.2490 [M], 753.2801 $[M-Cl]^+$ found 735.2799 $[M-Cl]^+$.

4.14. X-ray structure determinations

Data were collected at −100 °C on a Nonius Kappa CCD diffractometer, using the COLLECT program [12]. Cell refinement and data reductions used the programs DENZO and SCALEPACK [13]. SIR97 [14] was used to solve the structures and SHELXL97 [15] was used to refine the structures. ORTEP-3 for Windows [16] was used for molecular graphics and PLATON [17] was used to prepare material for publication. H atoms were placed in calculated positions with U_{iso} constrained to be 1.5 times U_{eq} of the carrier atom for methyl protons and 1.2 times U_{eq} of the carrier atom for all other hydrogen atoms.

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Appendix A. Supplementary material

CCDC 707316, 707317, 707318 and 707319 contain the supplementary crystallographic data for **5**, **10** · CH_2Cl_2, **12** and **13** · CH_2Cl_2, respectively. Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jorganchem.2008.12.055.

References

[1] I. Takahashi, K. Nishiuchi, R. Miyamoto, M. Hatanaka, H. Uchida, K. Isa, A. Sakushima, S. Hosoi, Lett. Org. Chem. 2 (2005) 40–43.
[2] J. Thiele, J. Schneider, Justus Liebigs Ann. Chem. 369 (1910) 287–299.
[3] (a) I. Takahashi, R. Miyamoto, K. Nishiuchi, M. Hatanaka, A. Yamano, A. Sakushima, S. Hosoi, Heterocycles 63 (2004) 1267–1271;
(b) A.A. Hassan, D. Dopp, G. Henkel, J. Heterocyclic Chem. 35 (1998) 121–128.
[4] J.M. Chitanda, D.E. Prokopchuk, J.W. Quail, S.R. Foley, Dalton Trans. (2008) 6023–6029.
[5] J.M. Chitanda, D.E. Prokopchuk, J.W. Quail, S.R. Foley, Organometallics 27 (2008) 2337–2345.
[6] (a) J. Dupont, C.S. Consorti, J. Spencer, Chem. Rev. 105 (2005) 2527–2572;
(b) J. Vicente, I. Saura-Llamas, Comments Inorg. Chem. 28 (2007) 39–72;
(c) R.B. Bedford, C.S.J. Cazin, D. Holder, Coord. Chem. Rev. 248 (2004) 2283–2321;
(d) V. Farina, Adv. Synth. Catal. 346 (2004) 1553–1582;
(e) I.P. Beletskaya, A.V. Cheprakov, J. Organomet. Chem. 689 (2004) 4055–4082;
(f) W.A. Herrmann, K. Ofele, D. von Preysing, S.K. Schneider, J. Organomet. Chem. 687 (2003) 229–248.
[7] (a) J. Dupont, M. Pfeffer (Eds.), Palladacycles Synthesis Characterization and Applications, Wiley-VCH, Weinheim, 2008;
(b) J. Tsuji, Palladium Reagents and Catalysts, Wiley, New York, 2004;
(c) A. de Meijere, P.J. Diederich (Eds.), Metal-catalyzed Cross-coupling Reactions, Wiley-VCH, Weinheim, 2004;
(d) E. Negishi, A. de Mejere, Handbook of Organopalladium Chemistry for Organic Synthesis, Wiley-VCH, Weinheim, 2002.
[8] (a) G. Dyker (Ed.), Handbook of C–H Transformations, Wiley-VCH, Weinheim, 2005;
(b) L. Wu, J.F. Hartwig, J. Am. Chem. Soc. 127 (2005) 15824–15832;
(c) R.B. Bedford, Chem. Commun. (2003) 1787–1796;
(d) J.-H. Chu, C.-C. Chen, M. -J. Wu, Organometallics 27 (2008) 5173–5176;
(e) M. Catellani, E. Motti, N.D. Ca, Acc. Chem. Res. 41 (2008) 1512–1522.
[9] (a) A.C.F. Caires, Anti-Cancer Agents Med. Chem. 7 (2007) 484–491;
(b) C.M.V. Barbosa, C.R. Oliveira, F.D. Nascimento, M.C.M. Smith, D.M. Fausto, M.A. Soufen, E. Sena, R.C. Araújo, I.L.S. Tersariol, C. Bincoletto, A.C.F. Caires, Eur. J. Pharmacol. 542 (2006) 37–47.
[10] (a) J. Albert, R. Bosque, J. Granell, R.J. Tavera, Organomet. Chem. 595 (2000) 54;
(b) R.B. Bedford, C.S.J. Cazin, S.J. Coles, T. Gelbrich, P.N. Horton, M.B. Hursthouse, M.E. Light, Organometallics 22 (2003) 987–999;
(c) A. Fernández, D. Vázquez-García, J.J. Fernández, M. López-Torres, A. Suárez, C.-J. Samuel, J.M. Vila, Eur. J. Inorg. Chem. (2002) 2389;
(d) R.Y. Mawo, D.M. Johnson, J.L. Wood, I.P. Smoliakova, J. Organomet. Chem. 693 (2008) 33–45;
(e) J. Vicente, I. Saura-Llamas, J. Cuadrado, Organometallics 22 (2003) 5513–5517;
(f) J. Vicente, J. -A. Abad, E. Martnez-Viviente, P.G. Jones, Organometallics 21 (2002) 4454–4467.
[11] R.B. Bedford, C.S.J. Cazin, Chem. Commun. (2001) 1540–1541.
[12] Nonius., COLLECT, Nonius BV, Delft, The Netherlands, 1998.
[13] Z. Otwinowski, W. Minor, in: C.W. Carter, R.M. Sweet (Eds.), Methods in Enzymology, Macromolecular Crystallography, Part A, vol. 276, Academic Press, London, 1997, pp. 307–326.
[14] A. Altomare, M.C. Burla, M. Camalli, G. Cascarano, C. Giacovazzo, A. Guagliardi, A.G.G. Moliterni, G. Polidori, R. Spagna, J. Appl. Cryst. 32 (1999) 115.
[15] G.M. Sheldrick, SHELXL-97, University of Göttingen, Germany, 1997.
[16] L.J. Farrugia, J. Appl. Cryst. 30 (1997) 565.
[17] A.L. Spek, PLATON, University of Utrecht, The Netherlands, 2001.