Aliphatic Palladation of Ketone *N,N*-Dimethylhydrazones

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Reaction of hydrazones with $Pd(PPh_3)_2Cl_2$ and sodium acetate in acetonitrile at 65–75 °C gives rise to carbon-bound palladium enolates resulting from direct aliphatic palladation. The reaction has been carried out with the *N,N*-dimethylhydrazones of 2-propanone, 3-methyl-2-butanone, 1-phenyl-1-ethanone, 1-phenyl-1-propanone, and 3,4-dihydro-1(2*H*)-naphthalenone and with the *N*-aminopiperidine hydrazone of 2-propanone. The structure of the palladacycle derived from the *N,N*-dimethylhydrazone of 1-phenyl-1-ethanone $PhC(=NNMe_2)CH_2Pd(PPh_3)Cl$, has been determined by X-ray diffraction. This complex crystallizes in the monoclinic space group $P2_1/n$, with a = 10.1806(3) Å, b = 21.716(2) Å, c = 9.6678(3) Å, β = 100.10(1)°, Z = 4, and V = 2654.20 Å^3. The complex *trans*-$[Pd(PPh_3)(L)Cl_2]$ (L = 1-phenyl-1-ethanone *N,N*-dimethylhydrazone) was isolated as an intermediate in the formation of the corresponding palladacycle. The palladacycles resulting from aliphatic activation are remarkably stable compounds, even in the presence of β-hydrogens *cis* to the Pd(II) center. However, alkyl halides undergo halide exchange with these palladacycles under mild conditions.

Introduction

The cyclopalladation of aromatic substrates is one of the most thoroughly studied metalation reactions.[1] The resulting cyclopalladated complexes usually have a coordinated donor group within a ring of five members and are useful synthetic intermediates for carbon–carbon bond formation.[2] On the other hand, much less attention has been paid to the aliphatic palladation of sp^3-hybridized carbons,[3-7] in spite of its broad synthetic potential.[8] With few exceptions,[6a] the palladacycles derived from aliphatic metalation lack β-hydrogens or are conformationally rigid in order to prevent β-elimination reactions.[4] Additionally, little is known about the mechanism of many of these palladations.

Among the palladations of aliphatic substrates, the α- and β-metalations of synthetic equivalents of carbonyl compounds such as oximes and hydrazones are of particular importance because of the central role played by enolates and homoenolates in organic synthesis.[9,10] However, the aliphatic palladation of oximes is limited to α,α-disubstituted derivatives in which the nitrogen directs the β-metalation of one of the α-alkyl groups, leading to five-membered-ring metallacycles.[11,12] On the other hand, only two examples of aliphatic palladation[13] of hydrazones have been reported. The *N*-methyl-*N*-phenylhydrazone of 3,3-

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(2) For recent leading references on synthetic applications of aromatic palladated compounds, see: Pfeffer, M. *Pure Appl. Chem.* **1992**, *64*, 335. Pfeffer, M. *Recl. Trav. Chim. Pays-Bas* **1990**, *109*, 567. Girling, I. R.; Widdowson, D. A. *Tetrahedron Lett.* **1982**, *23*, 1957. Girling, I. R.; Widdowson, D. A. *Tetrahedron Lett.* **1982**, *23*, 4281. Tremont, S. J.; Rahman, H. U. *J. Am. Chem. Soc.* **1984**, *106*, 5759. McCallum, J. S.; Gasdaska, J. R.; Liebeskind, L. S.; Tremont, S. J. *Tetrahedron Lett.* **1989**, *30*, 4085. Clinet, J. C.; Balavoine, G. *J. Organomet. Chem.* **1991**, *405*, C29. Holton, R. A.; Sibi, M. P.; Murphy, W. S. *J. Am. Chem. Soc.* **1988**, *110*, 314. Grigg, R.; Devlin, J. *J. Chem. Soc., Chem. Commun.* **1986**, 631. Tao, W.; Silverberg, L. J.; Rheingold, A. L.; Heck, R. F. *Organometallics* **1989**, *8*, 2550. Ryabov, A. D.; van Eldik, R.; Le Borgne, G.; Pfeffer, M. *Organometallics* **1993**, *12*, 1386.

(3) Newkome, G. R.; Puckett, W. E.; Gupta, V. K.; Kiefer, G. E. *Chem. Rev.* **1986**, *86*, 451.

(4) Alphatic palladation assisted by heterocyclic rings. (a) Pyridine: Fuchita, Y.; Hiraki, K.; Uchiyama, T. *J. Chem. Soc., Dalton Trans.* **1983**, 897. Fuchita, Y.; Nakashima, M.; Hiraki, K.; Kawatani, M.; Ohnuma, K. *J. Chem. Soc., Dalton Trans.* **1988**, 785. Hiraki, K.; Fuchita, Y.; Nakashima, M. *Inorg. Chim. Acta* **1985**, *97*, L15. Hiraki, K.; Nakashima, M.; Uchiyama, T.; Fuchita, Y. *J. Organomet. Chem.* **1992**, *428*, 249. (b) Quinoline: Hartwell, G. E.; Lawrence, R. V.; Smas, M. J. *J. Chem. Soc. D* **1970**, 912. Sokolov, V. I.; Sorokina, T. A.; Troitskaya, L. L.; Solovieva, L. I.; Reutov, O. A. *J. Organomet. Chem.* **1972**, *36*, 389. Deeming, A. J.; Rothwell, I. P. *J. Chem. Soc., Chem. Commun.* **1978**, 344. (c) Benzothiazole: Hiraki, K.; Fuchita, Y.; Nakashima, M.; Hiraki, H. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 3073. (d) Oxazoline: Balavoine, G.; Clinet, J. C. *J. Organomet. Chem.* **1990**, *390*, C84. (e) Pyrazole: Alonso, M. T.; Juanes, O.; de Mendoza, J.; Rodríguez-Ubis, J. C. *J. Organomet. Chem.* **1992**, *430*, 349.

(5) Sulfur-assisted aliphatic palladation: (a) Tamaru, Y.; Kagotani, M.; Yoshida, Z. *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 980. (b) Dupont, J.; Beydoun, N.; Pfeffer, M. *J. Chem. Soc., Dalton Trans.* **1989**, 1715.

(6) For the benzylic palladation of amines, see the following. (a) Amines: Mutet, C.; Pfeffer, M. *J. Organomet. Chem.* **1979**, *171*, C34. (b) Alsters, P. L.; Engel, P. F.; Hogerheide, M. P.; Copijn, M.; Spek, A. L.; van Koten, G. *Organometallics* **1993**, *12*, 1831. (c) See also: Alsters, P. L.; Boersma, J.; van Koten, G. *Organometallics* **1993**, *12*, 1629.

(7) For the benzylic palladation of imines, see: Albert, J.; Granell, J.; Sales, J.; Solans, X.; Font-Altaba, M. *Organometallics* **1986**, *5*, 2567. Albert, J.; Ceder, R. M.; Gómez, M.; Granell, J.; Sales, J. *Organometallics* **1992**, *11*, 1536.

(8) Collman, J. P.; Hegedus, L. S.; Norton, J. K.; Finke, R. G. *Principles and Applications of Organotransition Metal Chemistry*; University Science Books: Mill Valley, CA, 1987; p 731.

(9) For recent reviews on enolate chemistry, see: (a) Trost, B. M., Fleming, I., Eds. *Comprehensive Organic Synthesis*; Pergamon: London, 1991; Vol. 2, Chapters 1.4–1.8. (b) Transition metal enolates: Reference 9a, Chapter 1.9.

(10) Homoenolate chemistry: Reference 9a, Chapter 1.14.

(11) Constable, A. G.; McDonald, W. S.; Sawkins, L. C.; Shaw, B. L. *J. Chem. Soc., Chem. Commun.* **1978**, 1061. Constable, A. G.; McDonald, W. S.; Sawkins, L. C.; Shaw, B. L. *J. Chem. Soc., Dalton Trans.* **1980**, 1992.

(12) Carr, K.; Sutherland, J. K. *J. Chem. Soc., Chem. Commun.* **1984**, 1227. Baldwin, J. E.; Nájera, C.; Yus, M. *J. Chem. Soc., Chem. Commun.* **1985**, 126. Baldwin, J. E.; Jones, R. H.; Nájera, C.; Yus, M. *Tetrahedron* **1985**, *41*, 699. Rocherolle, V.; López, J. C.; Olesker, A.; Lukacs, G. *J. Chem. Soc., Chem. Commun.* **1988**, 513. Wells, A. P.; Kitching, W. *Organometallics* **1992**, *11*, 2750.

(13) For the aromatic palladation of hydrazones, see: Espinet, P.; García, G.; Herrero, F. J.; Jeannin, Y.; Philoche-Levisalles, M. *Inorg. Chem.* **1989**, *28*, 4207 and references therein.

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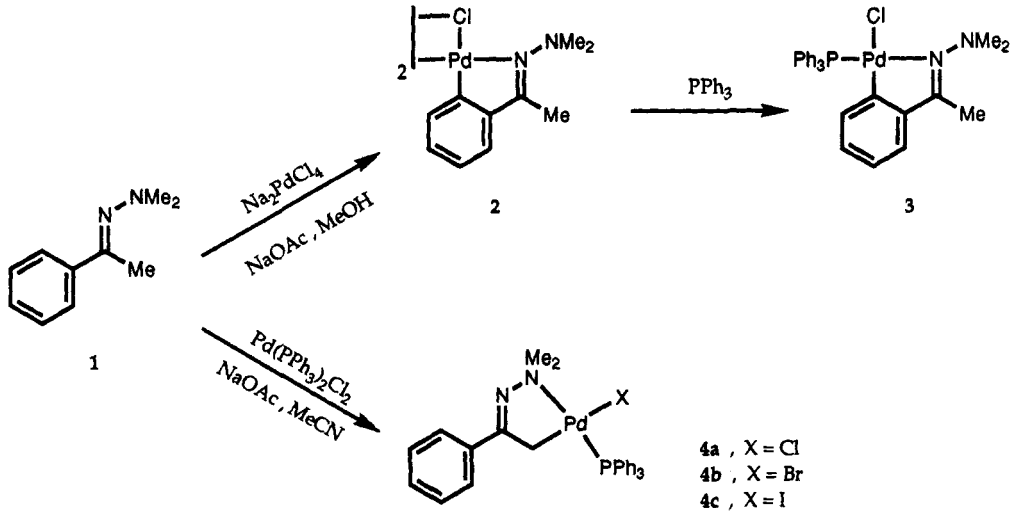
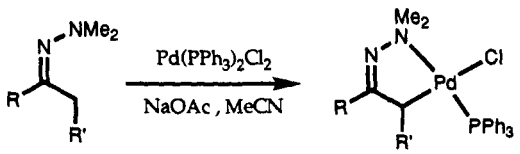
Scheme 1



dimethyl-2-butanone (pinacolone) undergoes α- or β-metalation depending on the reaction conditions,[14] while the corresponding *N,N*-dimethylhydrazone gives α-metalation with Na_2PdCl_4[11] or $Pd(MeCN)_2Cl_2$.[14] However, this reaction is not general, since other hydrazones react with Pd(II) reagents to give only coordination complexes of the type *trans*-$[PdL_2Cl_2]$ (L = hydrazone),[15] which were reported to suffer decomposition on attempted palladation.[11]

We expected that coordination of a suitable palladium complex through the amine nitrogen of the hydrazone would facilitate the activation of the aliphatic C–H bond. Herein we report the first general synthesis of palladacycles from ketone *N,N*-dimethylhydrazones.[16] These metallacycles can be considered to be formally carbon-bound palladium enolates (eq 1).[8b,17]



(1)

Results and Discussion

Palladation of Ketone *N,N*-Dimethylhydrazones. It has been reported that acetophenone *N,N*-dimethylhydrazone (1) undergoes rapid palladation with Na_2PdCl_4 and NaOAc in methanol at 23 °C exclusively on the *ortho* position of the aromatic ring to yield the dimer **2**.[11] Complex **2** originates from coordination of the electrophilic Pd(II) complex with the iminic nitrogen of the hydrazone, followed by metalation. As expected, treatment of dimer **2** with triphenylphosphine breaks down the chloride bridge, giving **3** in quantitative yield. Surprisingly, we found that the five-membered-ring palladacycle **4a** was formed when hydrazone **1** was allowed to react with $Pd(PPh_3)_2Cl_2$ in acetonitrile at 60 °C in the presence of 1 equiv of NaOAc (Scheme 1). Complex **4a** could be isolated by column chromatography in 97% yield as an air-stable pale yellow solid. The structure of **4a** was consistent with the spectroscopic and analytical data. Particularly revealing was the presence of a doublet at 2.55 ppm (J = 3.5 Hz) in the ^1H NMR spectrum corresponding to the methylene hydrogens coupled to ^{31}P of the phosphine ligand. The *N*-methyls appeared at 3.17 ppm as a doublet coupled to phosphorus with J = 2.4 Hz. The most significant features of the $^{13}C\{^1H\}$ NMR spectrum of **2a** were three doublets at δ 176.26 (J = 3.2 Hz), 51.4 (J = 2.0 Hz), and 39.14 (J = 4.7 Hz) corresponding to the hydrazone, methylene, and methyl carbons, respectively. The carbon signal assignments were based on a DEPT experiment. The stereochemistry around Pd was demonstrated by the presence of a cross peak between the signals corresponding to the methylene and the *ortho* phosphine hydrogens in a NOESY experiment. Curiously, in the electron impact mass spectrum (EI-MS) of **4a**, the peaks of higher mass correspond to the bridged chloride dimer, probably formed by decomposition of **4a** under the conditions of the mass spectrum. However, all attempts to prepare this dimer from **1** or **4a** have failed so far. The structure of **4a** was confirmed by X-ray diffraction of a single crystal obtained by slow evaporation of an ethyl acetate solution (Figure 1).

The bromo (**4b**) and iodo (**4c**) complexes were prepared in good yields from **4a** by reaction with LiBr or NaI, respectively. The signals corresponding to the methylene hydrogens move downfield from 2.55 ppm for **4a** to 2.65 ppm for the bromo complex **4b** and 2.83 ppm for the iodo derivative **4c**. In the ^{13}C spectra the methylene carbon shifts from 39.14 (**4a**) to 42.09 (**4b**) and 46.67 ppm (**4c**). The mass spectrum of **4b** also shows the corresponding bromide-bridged dimer as the ions of higher mass.

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(15) Natile, G.; Cattalini, L.; Gasparrini, F. *J. Chem. Soc., Chem. Commun.* **1977**, 89. Gasparrini, F.; Misiti, D.; Cernia, E. *Inorg. Chim. Acta* **1976**, *17*, L3. Postel, M.; Pfeffer, M.; Riess, J. G. *J. Am. Chem. Soc.* **1977**, *99*, 5623. Natile, G.; Gasparrini, F.; Misiti, D.; Perego, G. *J. Chem. Soc., Dalton Trans.* **1977**, 1747. Natile, G.; Cattalini, L.; Gasparrini, F.; Caglioti, L. *J. Am. Chem. Soc.* **1979**, *101*, 498. Natile, G.; Cattalini, L.; Gasparrini, F.; Caglioti, L.; Galli, B.; Misiti, D. *J. Chem. Soc., Dalton Trans.* **1979**, 1262. Biagini Cingi, M.; Natile, G.; Tiripicchio, A.; Gasparrini, F. *J. Chem. Res., Synop.* **1979**, *98*; *J. Chem. Res., Miniprint* **1979**, 1321.

(16) (a) For synthetic applications of hydrazone anions, see: Corey, E. J.; Enders, D.; Bock, M. G. *Tetrahedron Lett.* **1976**, 7. Corey, E. J.; Enders, D. *Tetrahedron Lett.* **1976**, 11. Corey, E. J.; Enders, D. *Chem. Ber.* **1978**, *111*, 1362. (b) For a recent review, see: Reference 9a, Chapter 1.17.

(17) For recent leading references on transition-metal enolates, see the following. (a) Ti: Evans, D. A.; Urpí, F.; Somers, T. C.; Clark, J. S.; Bilodeau, M. T. *J. Am. Chem. Soc.* **1990**, *112*, 8215. Evans, D. A.; Rieger, D. L.; Bilodeau, M. T.; Urpí, F. *J. Am. Chem. Soc.* **1991**, *113*, 1047. (b) Ru: Hartwig, J. F.; Andersen, R. A.; Bergman, R. G. *J. Am. Chem. Soc.* **1990**, *112*, 5670. Hartwig, J. F.; Andersen, R. A.; Bergman, R. G. *Organometallics* **1991**, *10*, 3326. (c) Pd and Ni: Burkhardt, E. R.; Bergman, R. G.; Heathcock, C. H. *Organometallics* **1990**, *9*, 30. (d) Rh: Slough, G. A.; Bergman, R. G.; Heathcock, C. H. *J. Am. Chem. Soc.* **1989**, *111*, 938. Wu, J.; Bergman, R. G. *J. Am. Chem. Soc.* **1989**, *111*, 7628. (e) Re: Stack, J. G.; Simpson, R. D.; Hollander, F. J.; Bergman, R. G.; Heathcock, C. H. *J. Am. Chem. Soc.* **1990**, *112*, 2716.

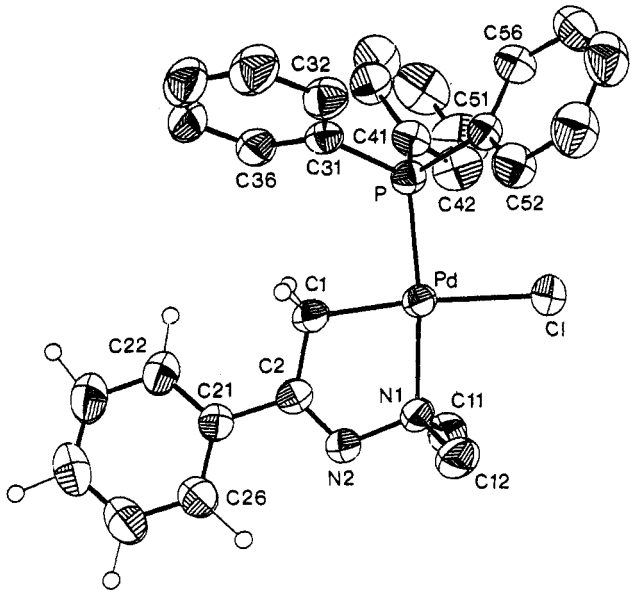


Figure 1. ORTEP drawing of palladacycle **4a** (thermal ellipsoids at the 50% level). PPh_3 and methyl hydrogen atoms are omitted for clarity.

To our knowledge, only three other examples have been reported where an aliphatic position can be activated by palladation in the presence of an aromatic site.[5a,6b,7] Two of these reports refer to the formation of six-membered-ring metallacycles by activation of benzylic positions in preference to the metalation of an aromatic ring.[6b,7] In the third example, the reaction of the benzothioamide of pyrrolidine with $PdCl_2$ in methanol led to the formation of the aromatic palladacycle, while a similar reaction in HMPA as the solvent afforded the aliphatic palladacycle by activation of the methylene carbon α to the heterocyclic nitrogen.[5a]

Palladacycles **9–12** were similarly prepared from the *N,N*-dimethylhydrazones of acetone (**5**),[18] 3-methyl-2-butanone (**6**), propiophenone (**7**), and tetralone (**8**) in fair to good yields. Their structures were assigned on the basis of their spectroscopic data and by comparison with the structure of **4a**. The aliphatic hydrazones **5** and **6** react under conditions similar to those for the aromatic derivatives **1**, **7**, and **8**, indicating that previous aromatic coordination is not required for the metalation. Palladacycle **14** was prepared similarly from the *N*-aminopiperidine hydrazone of acetone (**13**). The formation of **11** and **12** further illustrates that the aliphatic palladation can be carried out in the presence of an aromatic ring. It is noteworthy that palladacycles **11** and **12** are stable compounds, which do not decompose by β-hydride elimination. The formation of **10** from 3-methyl-2-butanone *N,N*-dimethylhydrazone shows that the aliphatic palladation occurs on the less sterically encumbered alkyl group. Similar to the behavior observed for hydrazone **1**, tetralone hydrazone **8** suffers aromatic palladation with Li_2PdCl_4 and NaOAc in methanol at 23 °C for 8 h to afford the dimer **15** in 95% yield.[19] Treatment with PPh_3 in dichloromethane gave palladacycle **16** in 90% yield. The arsine complex $Pd(AsPh_3)_2Cl_2$ reacts with hydrazone **1** under the general conditions developed for the aliphatic palladation to give the palladacycle **17** in 85% yield.

The metalation reactions are slower in tetrahydrofuran or 1,4-dioxane. In these cases, intermediate ligand exchange complexes could be detected in the reaction mixtures. The complex *trans*-$[Pd(PPh_3)LCl_2]$ (L = **1**) (**18**), with the hydrazone coordinated through the imino nitrogen, was isolated in the reaction of hydrazone **1** with $Pd(PPh_3)_2Cl_2$ in 1,4-dioxane. Coordination through the imino nitrogen is consistent with the observed deshielding of the hydrazone carbon (from 161.52 to 175.15 ppm) and follows the pattern generally observed for the complexes *trans*-$[Pd(L)_2Cl_2]$ (L = hydrazone).[15] The known complex *trans*-$[Pd(L)_2Cl_2]$ (L = **1**) (**19**)[15] was obtained by reaction of hydrazone **1** with Li_2PdCl_4 in methanol or $Pd(MeCN)_2Cl_2$ in benzene at 23 °C. The stereochemistry of the hydrazone ligands was assigned as shown on the basis of a positive NOE between NMe_2 and the methyl hydrogens. Heating **18** with NaOAc in MeCN led cleanly to palladacycle **4a**. No other intermediates could be detected when the progress of the reaction was monitored by ^1H NMR.[20] The transformation of **18** into **4a** could also be carried out cleanly in DMF at 90 °C, in the absence of added NaOAc. The fact that **18**, with the correct regiochemistry for aromatic activation, undergoes aliphatic metalation indicates that the presence of a donor ligand slows down the aromatic palladation. Presumably, isomerization of the initially formed complex **i** to the undetected isomer **ii** is followed by deprotonation, giving rise to the aliphatic palladation product (Scheme 2). At this point it is not clear whether the deprotonation step is promoted by the chloride ligand or the added base. In the case of the somewhat related formation of (π-allyl)palladium complexes from olefins and Pd(II) reagents it has been demonstrated that the chloride ion triggers the deprotonation of the organic substrate.[21]

The formation of palladacycle **4** does not involve the aromatic palladation product **3** as an intermediate.[7,22] Thus, **3** did not give **4a** by treatment in MeCN under reflux conditions in the presence of NaOAc. Furthermore, treatment of 1(phenyl-d_5) with $Pd(PPh_3)_2Cl_2$ gave exclusively 4(phenyl-d_5), with no loss of the deuterium content of the aromatic ring. However, heating **3** in glacial HOAc at 60 °C, followed by treatment with excess LiCl, gave a small amount of **4a**, along with recovered starting hydrazone **1**. In this experiment, complex **4a** is probably formed by reaction of **1** with $Pd(PPh_3)_2Cl_2$ or the corresponding acetate, formed *in situ* by decomposition of **3**.

Metallacycle **4a** was recovered unchanged when treated with nucleophiles such as vinyltri-*n*-butylstannane,[23] vinylmagnesium bromide, or lithium acetylide. However, it undergoes surprisingly facile halide exchange reactions with alkyl bromides RBr (R = ethyl, allyl, benzyl) to give

(18) A related platinapyrazoline has been recently obtained by regioselective addition of hydrazine to a σ-allenyl Pt(II) complex: Chen, J.-T.; Huang, T.-M.; Cheng, M.-C.; Lin, Y.-C.; Wang, Y. *Organometallics* **1992**, *11*, 1761.

(19) For the related palladation of tetralone derivatives, see the following. (a) Oxime: Nielson, A. J. *J. Chem. Soc., Dalton Trans.* **1981**, 205. (b) For the platination of the cyclohexylimine: Pregosin, P. S.; Wombacher, F.; Albinati, A.; Lianza, F. *J. Organomet. Chem.* **1991**, *418*, 249.

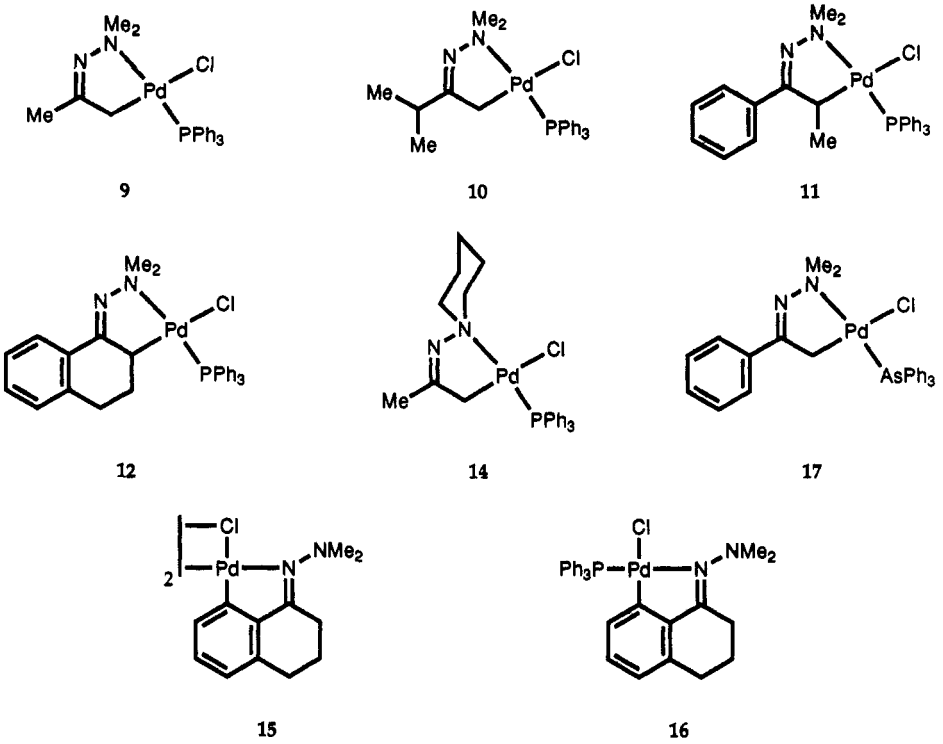
(20) However, small amounts of $Pd(PPh_3)_2(Ph)Cl$ were also observed in the crude reaction mixtures. For the information of this complex from $PdCl_2$ and $Pd(PPh_3)_4$, see: Mason, M. R.; Verkade, J. G. *Organometallics* **1992**, *11*, 2212, and references cited therein.

(21) Chrisope, D. R.; Beak, P. *J. Am. Chem. Soc.* **1986**, *108*, 334. Chrisope, D. R.; Beak, P.; Saunders, W. H. *J. Am. Chem. Soc.* **1988**, *110*, 230.

(22) For an example of an equilibrium between aliphatic and aromatic platination, see: Griffiths, D. C.; Joy, L. G.; Skapski, A. C.; Wilkes, D. J.; Young, G. B. *Organometallics* **1986**, *5*, 1744.

(23) For a recent discussion on the transmetalation reaction of Pd(II) complexes with stannanes, see: Farina, V.; Krishman, B. *J. Am. Chem. Soc.* **1991**, *113*, 9585.

Chart 1



9 10 11 12 14 17

15 16

Scheme 2

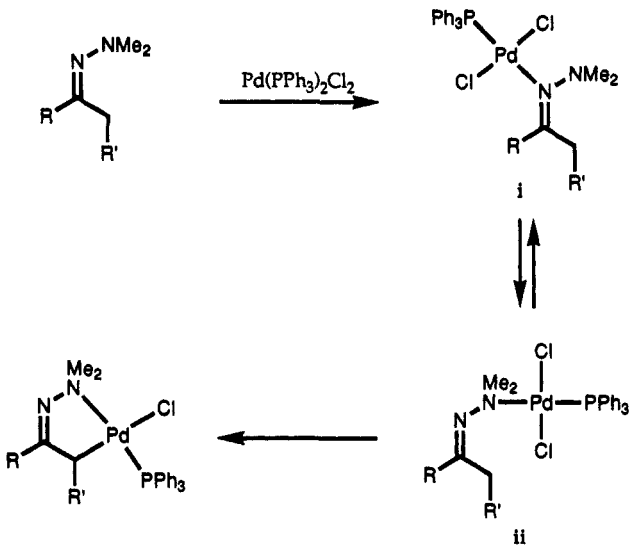
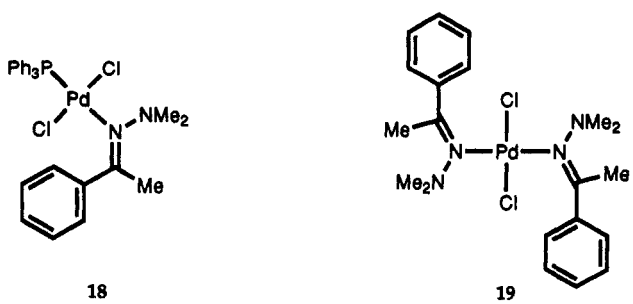


Chart 2



18 19

metallacycle **4b**. The reaction with ethyl iodide, performed in a sealed tube in $CDCl_3$, gave metallacycle **4c** and ethyl chloride in quantitative yield. Similar results were obtained with allyl iodide and *o*-methoxybenzyl iodide.

Structure of Palladacycle 4a. Crystal analysis parameters are listed in Table 1. The structure was solved by Patterson methods. The positional coordinates and thermal parameters for non-hydrogen atoms were anisotropically refined. Hydrogen atoms were located in the difference Fourier maps, except for those of the methyl groups, and were isotropically refined. Selected bond distances and angles are given in Table 2. Atomic coordinates are listed in Table 3.

The coordination around Pd is square-planar, with the metal atom slightly deviating (0.045 Å) from the plane

Table 1. Crystallographic Data, Data Collection Parameters, and Refinement Parameters for 4a

Crystal Data	
formula	$C_{28}H_{28}ClN_2PPd$
fw	565.37
cryst size, mm	0.25 × 0.20 × 0.15
cryst syst	monoclinic
space group	$P2_1/n$
a, Å	10.1806(3)
b, Å	21.716(2)
c, Å	9.6678(3)
β, deg	100.10(1)
V, Å^3	2654.20
Z	4
d_{calcd}, g cm^{-3}	1.415
$F(000)$	1152
μ, cm^{-1}	74.34
Data Collection Parameters	
diffractometer	four-circle Philips PW 1100
radiation	monochromated CuKα (λ = 1.541 78 Å)
T, K	296
2θ range, deg	6.0–130.0
scan technique	$\omega/2\theta$
cryst decay	no
Structure Determination and Refinement	
no. of ind rflns	4327
no. of obsd rflns	3745 ($I \geq 3\sigma$ criterion)
abs cor	applied[a]
min, max abs cor	0.86, 1.16
no. of variables	298
min and max $\Delta\rho$, e Å^{-3}	−0.86, +0.38
final R and R_w, %	4.3, 4.6

[a] Reference 32.

Table 2. Selected Bond Distances (Å) and Bond Angles (deg)

Pd–C(1)	2.007(4)	Pd–P	2.255(1)
Pd–Cl	2.398(1)	Pd–N(1)	2.104(4)
C(1)–C(2)	1.495(7)	N(2)–C(2)	1.276(5)
N(1)–N(2)	1.476(4)	N(1)–C(11)	1.481(7)
N(1)–C(12)	1.494(6)	P–C(31)	1.826(4)
P–C(41)	1.821(6)	P–C(51)	1.823(4)
C(2)–C(21)	1.496(5)		
P–Pd–Cl	93.19(4)	Cl–Pd–N(1)	92.70(9)
N(1)–Pd–C(1)	81.2(2)	C(1)–Pd–P	92.8(1)
N(2)–N(1)–Pd	112.8(2)	C(2)–C(1)–Pd	109.5(3)
C(1)–C(2)–N(2)	124.1(4)	C(2)–N(2)–N(1)	112.2(3)
C(11)–N(1)–C(12)	109.1(4)	C(1)–C(2)–C(21)	119.6(4)
C(11)–N(1)–Pd	112.3(3)	C(12)–N(1)–Pd	111.8(3)
N(2)–N(1)–C(11)	105.3(3)	N(2)–N(1)–C(12)	104.9(3)
Pd–P–C(31)	118.3(1)	Pd–P–C(41)	111.3(2)
Pd–P–C(51)	113.(1)		

defined by the ligand atoms. N(2) and C(2) also deviate (0.022 and 0.040 Å, respectively) in the same direction from that plane. The bond distances and angles are within the range observed for related compounds.[4,11] The dihedral angle between the phenyl ring and the palladacycle is 18.7°. The phosphine ligand is *cis* to the carbon ligand, as previously determined by ^{1}H nuclear Overhauser effect difference spectroscopy (NOEDIFF) experiments.

Conclusions

A simple and general synthesis of cyclopalladated ketone hydrazones has been developed. These results illustrate that the regioselective palladation of organic substrates can be achieved by the fine tuning of the electrophilicity of Pd(II), leading to aliphatic palladation with the less electrophilic Pd(II) reagents.[24] The observed halide exchange reaction with alkyl halides suggests that the square-planar Pd(II) complex undergoes a facile dissociation of the chloride ligand, which reacts with the alkyl halide in a Filkenstein type reaction. Alternatively, oxidative addition of the halide to give a Pd(IV) intermediate[25] followed by reductive elimination could be conceived for these transformations. Further studies on the reactivity of these and related palladacycles are in progress.

Experimental Section

General Procedures. All reactions were carried out under an atmosphere of Ar. Solvents were dried before use by standard methods. $Pd(PPh_3)_2Cl_2$ and $Pd(AsPh_3)_2Cl_2$ were prepared by known methods.[26] Starting hydrazones **1** and **5–8** were prepared from the corresponding ketone and *N,N*-dimethylhydrazine according to known procedures.[27] Hydrazone **13** was prepared in a similar way from acetone and 1-aminopiperidine.[28] 1(phenyl-d_5), pentadeuterated acetophenone, was synthesized by Friedel–Crafts acylation of benzene-d_6.[29]

Table 3. Atomic Coordinates (×10^4) and Equivalent Isotropic Thermal Parameters[a] (Å^2 × 10^4) for Non-Hydrogen Atoms

atom	x	y	z	U(eq)[a]
Pd	1577(1)	979(1)	2191(1)	407(1)
P	2591(1)	1587(4)	2191(3)	405(4)
Cl	−563(1)	1058(1)	143(1)	623(1)
N(1)	804(4)	416(1)	3073(4)	426(1)
N(2)	1822(4)	241(1)	4466(4)	478(1)
C(1)	3226(4)	882(2)	4040(5)	481(2)
C(2)	2969(4)	468(1)	4850(5)	438(2)
C(11)	−456(5)	541(2)	3427(6)	634(2)
C(12)	478(6)	53(2)	2064(6)	686(2)
C(21)	4073(4)	315(2)	6247(5)	462(2)
C(22)	5146(5)	614(2)	6997(6)	711(2)
C(23)	6148(6)	477(2)	8337(7)	833(3)
C(24)	6086(6)	51(2)	8891(6)	784(3)
C(25)	5041(6)	−254(2)	8140(6)	745(2)
C(26)	4032(5)	−126(2)	6816(5)	585(2)
C(31)	4499(4)	1615(1)	2123(5)	439(2)
C(32)	5234(5)	1540(2)	1157(5)	571(2)
C(33)	6696(6)	1529(2)	1687(7)	737(3)
C(34)	7421(5)	1597(2)	3159(7)	752(3)
C(35)	6720(5)	1673(2)	4138(6)	660(2)
C(36)	5264(5)	1683(2)	3614(5)	546(2)
C(41)	2050(5)	2138(2)	2043(5)	477(2)
C(42)	654(6)	2177(2)	1942(7)	768(3)
C(43)	189(8)	2598(3)	2344(9)	1069(4)
C(44)	1081(9)	2965(2)	2862(8)	975(4)
C(45)	2457(8)	2925(2)	2970(7)	865(3)
C(46)	2935(6)	2512(1)	2558(6)	643(2)
C(51)	2111(4)	1630(1)	−518(4)	416(2)
C(52)	2006(5)	1227(2)	−1323(5)	589(2)
C(53)	1713(6)	1237(2)	−2838(6)	744(2)
C(54)	1469(6)	1660(2)	−3550(6)	762(3)
C(55)	1534(6)	2065(2)	−2780(6)	700(2)

[a] Equivalent isotropic *U*, defined as one-third of the trace of the orthogonalized U_{ij} tensor.

Hydrazone 13. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.60 (m, 4H), 1.96 (s, 3H), 1.93 (s, 3H), 1.66 (quint, *J* = 5.6 Hz, 4H), 1.43 (m, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 164.61 (C), 55.96 (CH_2), 25.36 (CH_2), 25.06 (CH_3), 23.82 (CH_2), 18.17 (CH_3).

Hydrazone 1(phenyl-d_5). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.60 (s, 6H), 2.35 (s, 3H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz) (selected signals): δ 161.60, 47.19, 15.47.

Palladacycle 3. A mixture of the known arylpalladium dimer (61 mg, 0.10 mmol) and PPh_3 (53 mg, 0.10 mmol) was stirred in CH_2Cl_2 (5 mL) at 23 °C for 12 h. The mixture was evaporated, and the residue was triturated with Et_2O and dried to give **3** as a yellow solid (96 mg, 85%). IR (KBr): 3150 (w), 2890 (w), 1590 (m), 1580 (sh), 1485 (m), 1445 (s), 1435 (s), 1100 (s), 1025 (m), 760 (s), 750 (s), 705 (m), 695 (s) 540 (s), 520 (s), 505 (s), 470 (m), 445 (m), 430 (m), 285 (m) cm^{-1}. ^{1}H NMR ($CDCl_3$, 200 MHz): δ 7.85–7.73 (m, 6 H), 7.54–7.31 (m, 10 H), 6.92 (m, 1 H), 6.52–6.45 (m, 2 H), 3.09 (s, 6 H), 2.58 (s, 3 H). $^{13}C\{^1H\}$ NMR[30] ($CDCl_3$, 50 MHz): δ 184.70, 158.63, 145.90, 138.40 (d, *J* = 10.9 Hz), 135.41 (d, *J* = 11.7 Hz, PPh_3), 131.39 (d, *J* = 48.6 Hz, PPh_3), 129.80 (d, *J* = 2.2 Hz, PPh_3), 129.67 (br), 127.87 (d, *J* = 10.7 Hz, PPh_3), 127.58, 123.74, 45.33 (2×), 14.55. EI-LRMS: *m/z* (relative intensity, %) 608 (5.2), 606 (5.6), 605 (4.4), 604 (4.5), 529 (0.7), 527 (0.9), 526 (0.6), 525 (0.6), 486 (3.3), 484 (3.9), 483 (3.0), 482 (3.2), 304 (1.5), 302 (1.5), 301 (1.4), 278 (8.9), 277 (15), 262 (100), 183 (65), 162 (63), 77 (57). Anal. Calcd for $C_{28}H_{28}ClN_2PPd$: C, 59.48; H, 4.49; N, 4.96. Found: C, 59.37; H, 5.24; N, 5.22.

Palladacycle 15. A suspension of $PdCl_2$ (135 mg, 0.76 mmol) and LiCl (64 mg, 1.52 mmol) in MeOH (2 mL) was heated under

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reflux conditions for 2 h to give a dark red solution of Li_2PdCl_4. After this solution was cooled to room temperature, tetralone *N,N*-dimethylhydrazone (8; 119 mg, 0.63 mmol) and NaOAc (52 mg, 0.63 mmol) were added. The resulting suspension was stirred at 23 °C for 8 h. The yellow-orange solid was filtered, washed with MeOH and Et_2O, and dried to give **15** (197 mg, 95%). IR (KBr): 3060 (w), 2960 (w), 2940 (w), 1595 (m), 1560 (s), 1480 (m), 1435 (m), 1180 (w), 1100 (w), 765 (s), 520 (w), 380 (w), 325 (w) cm^{-1}. ^1H NMR ($CDCl_3$, 200 MHz): δ 7.33 (d, 7.2 Hz, 1 H), 6.92 (t, J = 7.5 Hz, 1 H), 6.77 (dd, J = 7.4, 0.9 Hz, 1 H), 2.94 (dd, J = 7.1, 6.1 Hz, 2 H), 2.74 (m, 2 H), 2.74 (s, 6 H), 1.85 (q, J = 6.2 Hz, 2 H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz): δ 185.02, 155.45, 143.04, 139.80, 131.54, 129.92, 124.15, 45.16 (2×), 29.54, 28.09, 23.11. EI-LRMS: m/z (relative intensity, %) 662 (0.9), 660 (1.6), 659 (1.1), 658 (1.8, M^+), 657 (1.4), 656 (1.3), 655 (0.9), 538 (1.2), 536 (1.5), 534 (1.2), 533 (0.9), 395 (0.5), 393 (0.7), 392 (0.5), 374 (0.5), 330 (0.5), 328 (0.4), 188 (100), 173 (34), 145 (42), 117 (60), 89 (24). Anal. Calcd for $(C_{12}H_{15}ClN_2Pd)_2$: C, 43.79; H, 4.59; N, 8.51. Found: 43.39; H, 4.48; N, 8.26.

Palladacycle 16. A mixture of palladacycle **15** (66 mg, 0.10 mmol) and PPh_3 (52 mg, 0.20 mmol) was stirred in CH_2Cl_2 (5 mL) at 23 °C for 12 h. The mixture was evaporated, and the residue was triturated with Et_2O and dried to give **3** as a yellow solid (106 mg, 90%). IR (KBr): 3050 (w), 2950 (w), 2890 (w), 1585 (m), 1555 (m), 1470 (m), 1430 (s), 1310 (m), 1090 (s), 760 (m), 750 (m), 740 (s), 690 (vs), 535 (s), 515 (s), 495 (s), 460 (w), 380 (w) cm^{-1}. ^1H NMR ($CDCl_3$, 200 MHz): δ 7.84–7.63 (m, 6 H), 7.47–7.27 (m, 9 H), 6.66 (dd, J = 7.2, 1.1 Hz, 1 H), 6.40 (t, J = 7.5 Hz, 1 H), 6.33 (br t, J = 7.2 Hz, 1 H), 3.09 (m, 2 H), 4.04 (s, 6 H), 2.77 (t, J = 6.2 Hz, 2 H), 1.93 (q, J = 6.2 Hz, 2 H). ^1H NOEDIFF ($CDCl_3$, 300 MHz) showed the following enhancements on irradiation of the corresponding signals: δ 7.75 [δ 7.37 (6%), 6.33 (10%)], 6.66 [6.40 (8%), 2.77 (3%)]. $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 185.19 (C), 158.90 (C), 142.48 (C), 141.80 (C), 136.47 (d, J = 15.1 Hz; CH), 135.48 (J = 11.8 Hz, PPh_3; CH), 131.48 (d, J = 48.5 Hz, PPh_3; C), 130.37 (d, J = 2.4 Hz, PPh_3; CH), 129.38 (d, J = 5.6 Hz, CH), 127.88 (d, J = 10.7 Hz, PPh_3; CH), 123.93 (CH), 45.35 (CH_3, 2×), 30.42 (CH_2), 28.42 (CH_2), 22.72 (CH_2). EI-LRMS: two products are formed in this experiment, one of them being assigned as **15**, m/z (relative intensity, %) 662 (1.1), 660 (2.0), 659 (1.4), 658 (2.2), 657 (1.8), 538 (1.5), 536 (1.8), 535 (1.5), 534 (1.5), 533 (1.2), 395 (0.6), 393 (0.9), 392 (0.7), 391 (0.6), 188 (100), 145 (49), 117 (68), 89 (27), 262 (100), 183 (80), 152 (17), 108 (43), 77 (11); the other being identified as PPh_3, m/z (relative intensity, %) 262 (100), 183 (80), 152 (17), 108 (43), 77 (11). Anal. Calcd for $C_{30}H_{30}ClN_2PPd$: C, 60.92; H, 5.11; N, 4.74. Found: 60.75; H, 4.81; N, 4.47.

General Aliphatic Palladation Procedure. A mixture of freshly distilled hydrazone (0.1–0.2 mmol), NaOAc (1 equiv), and $Pd(PPh_3)_2Cl_2$ (1 equiv) in MeCN (6–10 mL) was heated at 65–75 °C for 24–48 h. After the mixture was cooled to room temperature, the solvent was evaporated and the residue was chromatographed (flash column, SiO_2, hexane–EtOAc) to give the palladacycles as pale yellow solids. In some instances, cleaner reactions were observed when the starting hydrazone was used in slight excess (1.5–2.0 equiv). Some decomposition was observed when the reaction was heated under reflux with slightly impure hydrazones. In most cases a second chromatography was necessary to obtain analytical samples of the palladacycles. Complex **17** was prepared by starting from $Pd(AsPPh_3)_2Cl_2$.

Palladacycle 4a: reaction temperature 75 °C; reaction time 48 h; eluent 4:1 hexane–EtOAc; pale yellow solid (97%). IR (KBr): 3070 (w), 2950 (w), 1635 (w), 1485 (m), 1440 (s), 1100 (s), 1005 (m), 755 (m), 720 (m), 695 (vs), 530 (s), 505 (s), 495 (s), 460 (w), 450 (w) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.82–7.76 (m, 6 H), 7.50–7.39 (m, 11 H), 7.30 (m, 1 H), 7.25–7.20 (m, 2 H), 3.17 [d, $^4J(^1H–^{31}P)$ = 2.4 Hz, 6 H], 2.55 [d, $^3J(^1H–^{31}P)$ = 3.5 Hz, 2 H]. $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 176.26 [d, $^2J(^{13}C–^{31}P)$ = 3.2 Hz; C], 134.62 (d, J = 11.7 Hz, PPh_3; CH), 133.53 (C), 131.31 (CH), 131.02 (d, J = 49.2 Hz, PPh_3; C), 130.55 (d, J = 1.9 Hz, PPh_3; CH), 128.15 (2×; CH), 127.76 (2×, CH), 128.23 (d, J = 10.8 Hz, PPh_3; CH), 51.54 [d, $^3J(^{13}C–^{31}P)$ = 2.0 Hz, 2×; CH_2], 39.14 [d, $^2J(^{13}C–^{31}P)$ = 4.7 Hz; CH_3]. ^{13}C NMR (only significant signals): δ 51.54 [dd, $^1J(^{13}C–^1H)$ = 134.1 Hz], 39.14 [dd, $^1J(^{13}C–^1H)$ = 139.1 Hz], 39.14 [dd, $^1J(^{13}C–^1H)$ = 139.1 Hz]. $^{31}P\{^1H\}$ NMR ($CDCl_3$, 121.4 MHz): δ 33.70. EI-LRMS: m/z (relative intensity, %) 608 (0.3), 606 (0.3), 605 (0.2), 568 (1.5), 566 (2.8), 565 (1.2), 564 (2.7, M^+), 530 (0.3), 528 (0.4), 527 (0.3), 368 (0.6), 367 (0.6), 262 (100), 183 (78), 161 (27), 118 (23), 108 (42), 107 (22), 77 (29). EI-HRMS: calcd for $C_{28}H_{28}ClN_2PPd$ 564.0713, found 564.0709. Anal. Calcd for $C_{28}H_{28}ClN_2PPd$: C, 59.48; H, 4.99; N, 4.96. Found: C, 59.45; H, 5.10; N, 5.15.

Palladacycle 4b. A mixture of **4a** (57 mg, 0.10 mmol) and LiBr (13 mg, 0.15 mmol) in CH_2Cl_2 (5 mL) was heated under reflux conditions for 12 h. After being cooled to room temperature, the mixture was filtered through Celite. The filtrate was evaporated, and the residue was partially dissolved in Et_2O and the solution filtered. The filtrate was evaporated to give **4b** as a yellow solid (44 mg, 72%). IR (KBr): 3040 (w), 2920 (w), 1625 (w), 1485 (m), 1450 (m), 1435 (s), 1380 (m), 1185 (m), 1100 (s), 1010 (m), 1000 (m), 935 (m), 755 (s), 720 (s), 700 (vs), 530 (s), 505 (s), 445 (w), 430 (w) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.80–7.73 (m, 6 H), 7.49–7.42 (m, 11 H), 7.34 (m, 1 H), 7.24 (m, 2 H), 3.21 [d, $^4J(^1H–^{31}P)$ = 2.5 Hz, 6 H], 2.65 [d, $^3J(^1H–^{31}P)$ = 3.4 Hz, 2 H]. $^{31}P\{^1H\}$ NMR ($CDCl_3$, 121.4 MHz): δ 34.52. EI-LRMS: m/z (relative intensity, %) 696 (0.1), 694 (0.1), 610 (1.9), 609 (1.0, M^+), 608 (1.4), 531 (0.2), 529 (0.3), 528 (0.2), 367 (0.2), 293 (0.4), 291 (0.5), 289 (0.4), 277 (3.2), 262 (100), 183 (72), 108 (37), 77 (32). EI-HRMS: calcd for $C_{28}H_{28}BrN_2PPd$ 608.0208, found 608.0211. Anal. Calcd for $C_{28}H_{28}BrN_2PPd$: C, 55.15; H, 4.63; N, 4.59. Found: C, 55.22; H, 4.69; N, 4.39.

Palladacycle 4c. This palladacycle was prepared, according to the procedure described for **4b** using LiI (20 mg, 0.15 mmol), in 95% yield. This and the above metallacycle were also formed in the reactions of MeI, EtI, EtBr, allyl bromide, allyl iodide, benzyl bromide, and *o*-$MeC_6H_4CH_2I$ with **4a**. Typically, **4a** (10 mg, 0.02 mmol) was treated with the halide (1.0–1.5 equiv) in a sealed 5-mm NMR tube in $CDCl_3$ at 23 °C. After 24 h, halogen exchange was shown to be quantitative by ^1H NMR. IR (KBr): 3040 (w), 2910 (w), 1625 (w), 1480 (m), 1435 (s), 1370 (w), 1180 (w), 1100 (s), 1010 (m), 1000 (m), 750 (s), 700 (vs), 525 (s), 505 (s) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.80–7.73 (m, 6 H), 7.49–7.42 (m, 11 H), 7.34 (m, 1 H), 7.24 (m, 2 H), 3.30 [d, $^4J(^1H–^{31}P)$ = 2.6 Hz, 6 H], 2.83 [d, $^3J(^1H–^{31}P)$ = 3.4 Hz, 2 H]. $^{31}P\{^1H\}$ NMR ($CDCl_3$, 121.4 MHz): δ 35.53. EL-LRMS: m/z (relative intensity, %) 658 (0.1), 656 (0.1, M^+), 655 (0.1), 531 (0.4), 529 (0.5), 528 (0.4), 322 (1.2), 262 (100), 183 (70), 159 (20), 108 (34), 77 (33).

Palladacycle 9: reaction temperature 65 °C; reaction time 36 h; eluent 2:1 hexane–EtOAc; pale yellow solid (63%). IR (KBr): 3060 (w), 2910 (m), 2870 (w), 1650 (w), 1440 (s), 1190 (w), 1100 (s), 750 (s), 725 (s), 700 (vs), 535 (s), 510 (m), 500 (m), 460 (w), 440 (w), 295 (w) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.72 (m, 6 H), 7.43 (m, 9 H), 3.05 [d, $^4J(^1H–^{31}P)$ = 2.5 Hz, 6 H], 2.15 [d, $^3J(^1H–^{31}P)$ = 3.5 Hz, 2 H], 1.81 (s, 3 H). ^1H NOEDIFF ($CDCl_3$) showed the following enhancements on irradiation of the corresponding signals: δ 2.15 [δ 7.72 (1.5%)], 3.05 [7.72 (0%)]. $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 177.52 [d, $^3J(^{13}C–^{31}P)$ = 3.8 Hz; C], 134.52 (d, J = 11.8 Hz, PPh_3; CH), 131.08 (d, J = 49.0 Hz, PPh_3; C), 130.41 (d, J = 2.2 Hz, PPh_3; CH), 128.15 (d, J = 10.7 Hz, PPh_3; CH), 51.33 [d, $^3J(^{13}C–^{31}P)$ = 2.0 Hz, 2×; CH_3], 41.97 [d, $^2J(^{13}C–^{31}P)$ = 4.8 Hz; CH_2], 18.69 (CH_3). $^{31}P\{^1H\}$ NMR ($CDCl_3$, 32.4 MHz): δ 33.0. EI-LRMS: m/z (relative intensity, %) 504 (2.5), 503 (1.0), 502 (2.4, M^+), 501 (1.6), 368 (0.5), 367 (0.6), 297 (1.1), 291 (0.8), 289 (0.7), 288 (0.4), 262 (100), 183 (75), 108 (37). EI-HRMS: calcd for $C_{23}H_{26}ClN_2PPd$ 502.0557, found 502.0560. Anal. Calcd for $C_{23}H_{26}ClN_2PPd$: C, 54.88; H, 5.21; N, 5.57. Found: C, 55.01; H, 5.31; N, 5.12.

Palladacycle 10: reaction temperature 65 °C; reaction time 24 h; eluent 2:1 hexane–EtOAc; pale yellow solid (68%). IR (KBr): 3040 (w), 2950 (m), 2910 (m), 2860 (w), 1640 (w), 1480 (m), 1455 (m), 1440 (s), 1430 (s), 1380 (m), 1100 (s), 995 (m), 940

(m), 765 (m), 750 (m), 710 (s), 700 (vs), 540 (s), 515 (s), 500 (m), 355 (w) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.75 (m, 6 H), 7.43 (m, 9 H), 3.04 [d, $^4J(^1H-^{31}P)$ = 2.6 Hz, 6 H], 2.48 (septet, J = 6.9 Hz, 1 H), 2.07 [d, $^3J(^1H-^{31}P)$ = 3.5 Hz, 2 H], 0.87 (d, J = 6.9 Hz, 6 H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 184.46 [d, $^3J(^{13}C-^{31}P)$ = 3.9 Hz; C], 134.66 (d, J = 10.8 Hz, PPh_3; CH), 131.23 (d, J = 48.3 Hz, PPh_3; C), 130.49 (s, PPh_3; CH), 128.23 (d, J = 10.5 Hz, PPh_3; CH), 51.36 (br, 2×; CH_3), 37.32 [d, $^2J(^{13}C-^{31}P)$ = 4.3 Hz; CH_2], 31.72 (CH), 20.83 (2×; CH_3). $^{31}P\{^1H\}$ NMR ($CDCl_3$, 121.4 MHz): δ 33.72. EI-LRMS: m_z (relative intensity, %) 533 (0.7), 532 (1.9, M^+), 530 (1.7), 529 (1.3), 446 (1.5), 367 (2.3), 262 (100), 183 (72), 127 (85), 108 (37). EI-HRMS: calcd for $C_{25}H_{30}ClN_2PPd$ 530.0870, found 530.0878.

Palladacycle 11: reaction temperature 65 °C; reaction time 24 h; eluent 4:1 hexane–EtOAc; pale yellow solid (58%). IR (KBr): 3050 (w), 2980 (w), 2925 (w), 2870 (w), 1630 (w), 1480 (m), 1430 (s), 1365 (w), 1160 (w), 1110 (s), 1000 (m), 930 (m), 785 (m), 755 (s), 745 (m), 695 (vs), 670 (m), 535 (s), 515 (s), 500 (s), 470 (w), 440 (w) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.82 (m, 6 H), 7.44 (m, 11 H), 7.29 (m, 3 H, Ph), 3.31 [d, $^4J(^1H-^{31}P)$ = 2.0 Hz, 3 H], 3.08 [d, $^4J(^1H-^{31}P)$ = 2.0 Hz, 3 H], 2.92 (dq, J = 7.8 Hz, $^3J(^1H-^{31}P)$ = 7.8 Hz, 1 H], 0.84 [dd, J = 7.4 Hz, $^4J(^1H-^{31}P)$ = 6.2 H, 3 H]. ^1H NOEDIFF ($CDCl_3$) showing the following enhancements on irradiation of the corresponding signals: δ 0.84 [δ 7.82 (2%), 2.92 (12%)], 2.92 [7.82 (1%), 7.44 (1%), 0.84 (2%)]. $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 179.73 (C), 134.78 (d, J = 11.8 Hz, PPh_3; CH), 132.11 (C), 130.98 (d, J = 47.2 Hz, PPh_3; C), 130.54 (d, J = 2.4 Hz, PPh_3; CH), 130.27 (CH), 128.40 (CH), 128.27 (d, J = 10.6 Hz, PPh_3; CH), 128.00 (CH), 52.48 [d, $^3J(^{13}C-^{31}P)$ = 1.9 Hz; CH_3], 52.28 [d, $^3J(^{13}C-^{31}P)$ = 2.0 Hz; CH_3], 50.44 (CH), 20.98 (CH_3). EI-LRMS: m/z (relative intensity, %) 446 (0.3), 337 (0.3), 277 (0.6), 262 (100), 183 (60), 159 (17), 108 (32), 77 (26). Anal. Calcd for $C_{29}H_{30}ClN_2PPd$: C, 60.12; H, 5.22; N, 4.84. Found: C, 60.24; H, 5.65; N, 4.68.

Palladacycle 12: reaction temperature 65 °C; reaction time 22 h; eluent 9:2 hexane–EtOAc; pale yellow solid (41%). IR (KBr): 3050 (w), 2930 (w), 1635 (w), 1480 (m), 1430 (s), 1315 (w), 1215 (w), 1095 (s), 930 (w), 775 (m), 760 (w), 740 (m), 700 (vs), 530 (s), 515 (s) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz):[31] δ 7.85 (dd, J = 7.8, 1.4 Hz, H-8), 7.76 (m, 6 H, PPh_3), 7.43 (m, 9 H, PPh_3), 7.24 (td, J = 7.5, 1.5 Hz, H-6), 7.12 (td, J = 8.5, 1.5 Hz, H-7), 6.92 (d, J = 7.6 Hz, H-5), 3.21 [d, $^4J(^1H-^{31}P)$ = 2.3 Hz, 3 H], 3.19 [d, $^4J(^1H-^{31}P)$ = 2.3 Hz, 3 H], 3.03 (ddd, J = 13.7, 5.4 Hz, $^3J(^1H-^{31}P)$ = 3.0 Hz, H-2], 2.30 (m, H-4), 1.83 (m, H-3), 1.79 (m, H-4′), 1.47 (m, H-3′). ^1H NOEDIFF ($CDCl_3$) showed the following enhancements on irradiation of the corresponding signals: δ 6.92 [δ 7.24 (6%), 2.30 (4%)], 3.03 [7.76 (3%), 1.83 (4%)]. $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 177.57 [d, $^3J(^{13}C-^{31}P)$ = 1.3 Hz; C], 140.48 (C), 134.86 (d, J = 11.8 Hz, PPh_3; CH), 131.16 (d, J = 47.2 Hz, PPh_3; C), 130.50 (d, J = 2.3 Hz, PPh_3; CH), 130.44 (CH), 130.05 (C), 128.66 (CH), 128.29 (d, J = 10.4 Hz, PPh_3; CH), 127.13 (CH), 125.82 (CH), 54.18 [d, $^2J(^{13}C-^{31}P)$ = 2.1 Hz; CH], 52.12 (br s; CH_3), 51.88 [d, $^3J(^{13}C-^{31}P)$ = 2.2 Hz; CH_3], 33.12 [d, $J(^{13}C-^{31}P)$ = 2.0 Hz; CH_2], 31.62 [d, $J(^{13}C-^{31}P)$ = 5.3 Hz; CH_2]. $^{31}P\{^1H\}$ NMR ($CDCl_3$, 32.4 MHz): δ 33.9. EI-LRMS: m/z (relative intensity, %) 660 (0.1), 658 (0.1), 657 (0.1), 656 (0.1), 592 (0.1), 590 (0.1, M^+), 370 (0.1), 368 (0.1), 278 (2.5), 277 (5), 262 (100), 183 (73), 108 (39). EI-HRMS: Calcd for $C_{30}H_{30}ClN_2PPd$ 590.0870, found 590.0867. Anal. Calcd for $C_{30}H_{30}ClN_2PPd$: C, 60.93; H, 5.11; N, 4.74. Found: C, 60.63; H, 5.40; N, 4.82.

Palladacycle 14: reaction temperature 65 °C; reaction time 24 h; eluent 8:1 hexane–EtOAc; pale yellow solid (30%). IR (KBr): 3020 (w), 2920 (w), 2850 (w), 1660 sh, 1650 (w), 1475 (m), 1430 (sh), 1425 (s), 1090 (s), 765 (m), 755 (m), 710 (s), 700 (s), 530 (s), 515 (s), 495 (s) cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.71 (m, 6 H), 7.39 (m, 9 H), 4.29 (td, J = 13.2, 3.3 Hz, 2 H), 3.13 (br dd, J = 13.1, 1.5 Hz, 2 H), 2.23 (qt, J = 13.3, 1.8 Hz, 2 H), 2.14 [d, $^3J(^1H-^{31}P)$ = 3.5 Hz, 2 H], 1.82 (s, 3 H), 1.69 (qt, J = 13.1, 3.9 Hz, 2 H), 1.35 (br d, J = 13.1 Hz). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 177.15 [d, $^3J(^{13}C-^{31}P)$ = 4.5 Hz; C], 134.64 (d, J = 11.8 Hz, PPh_3; CH), 131.30 (d, J = 48.2 Hz, PPh_3; C), 130.38 (d, J = 2.4 Hz, PPh_3; CH), 128.17 (d, J = 10.5 Hz, PPh_3; CH), 58.95 [d, $^3J(^{13}C-^{31}P)$ = 2.5 Hz, 2×; CH_2], 42.78 [d, $^2J(^{13}C-^{31}P)$ = 4.8 Hz; CH_2], 23.89 (CH_2), 20.56 (CH_2), 19.19 (CH_2). $^{31}P\{^1H\}$ NMR ($CDCl_3$, 32.4 MHz): δ 33.0. EI-LRMS: m/z (relative intensity, %) 564 (0.1), 562 (0.1), 546 (0.6), 544 (1.1), 542 (1.1, M^+), 541 (0.7), 453 (0.5), 451 (0.5), 450 (0.5), 384 (0.2), 382 (0.2), 381 (0.2), 297 (0.5), 291 (0.4), 289 (0.4), 262 (100), 183 (74), 139 (33), 108 (39). EI-HRMS: calcd for $C_{26}H_{30}ClN_2PPd$ 542.0870, found 542.0877. Anal. Calcd for $C_{26}H_{30}ClN_2PPd$: C, 57.47; H, 5.56; N, 5.16. Found: C, 57.52; H, 5.80; N, 5.25.

Palladacycle 17: reaction temperature 75 °C; reaction time 48 h; eluent 4:1 hexane–EtOAc; pale yellow solid (85%). IR (KBr): 3040 (w), 2900 (w), 1615 (m), 1565 (m), 1475 (m), 1450 (s), 1435 (s), 1380 (m), 1175 (m), 1080 (s), 1015 (m), 1000 (m), 940 (m), 735 (vs), 720 (vs), 555 (m), 465 (s), 340 (m), 320 (m) cm^{-1}. ^1H NMR (200 MHz, $CDCl_3$): δ 7.74 (m, 6 H), 7.50 (m, 2 H), 7.43 (m, 9 H), 7.25 (m, 3 H), 3.23 (s, 6 H), 2.71 (s, 2 H), $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz; DEPT): δ 175.47 (C), 133.85 (CH, $AsPh_3$), 133.05 (C), 132.75 (C), 130.35 (CH), 130.15 (CH), 128.74 (CH, $AsPh_3$), 128.12 (CH), 127.79 (CH), 52.13 (CH_3), 35.41 (CH_2). EI-LRMS: m/z (relative intensity, %): 608 (4.4), 607 (3.1), 606 (4.8, M^+), 605 (3.9), 604 (3.7), 306 (8.2), 227 (7.3), 196 (20), 162 (62), 161 (66), 118 (68), 103 (54), 77 (100). Anal. Calcd for $C_{28}H_{28}AsClN_2Pd$: C, 55.19; H, 4.63; N, 4.60. Found: C, 55.40; H, 4.92; N, 4.68.

Complex 18. A mixture of Li_2PdCl_4 (39 mg, 0.15 mmol), $Pd(PPh_3)_2Cl_2$ (104 mg, 0.15 mmol), and 1 (49 mg, 0.30 mmol) were heated under reflux conditions in 1,4-dioxane (6 mL) for 2 h. The solvent was evaporated to give a yellow-orange solid. This solid was dissolved in EtOAc (8 mL). Slow evaporation of the solution at 23 °C afforded orange crystals. The crystals were filtered off and washed with 1:1 Et_2O–hexanes and dried to give 18 (61 mg, 36%). IR (KBr): 3030 (w), 2940 (w), 2860 (w), 1605 (w), 1480 (w), 1430 (s), 1310 (w), 1260 (w), 1120 (m), 1105 (m), 1095 (s), 880 (m), 765 (s), 750 (s), 700 (s), 690 (s), 535 (s), 510 (s), 355 (m) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 7.96 (m, 2 H), 7.60–7.20 (m, 18 H), 3.12 [d, $^5J(^1H-^{31}P)$ = 1.5 Hz, 6 H], 2.55 [d, $^5J(^1H-^{31}P)$ = 0.6 Hz, 3 H]. ^1H NOEDIFF ($CDCl_3$) showed the following enhancements on irradiation of the corresponding signals: δ 3.12 [δ 2.55 (5%)], 2.55 [7.96 (5%)]. $^{13}C\{^1H\}$ NMR ($CDCl_3$, 50 MHz): δ 175.15 [d, $^3J(^{13}C-^{31}P)$ = 3.0 Hz], 139.62, 134.63 (d, J = 10.2 Hz, PPh_3), 130.55 (d, J = 2.6 Hz, PPh_3), 129.54, 129.21 (d, J = 55.7 Hz, PPh_3), 128.08 (2×), 128.24 (2×), 127.79 (d, J = 11.3 Hz, PPh_3), 47.34, 22.84 [d, $^4J(^{13}C-^{31}P)$ = 3.6 Hz]. Anal. Calcd for $C_{29}H_{30}Cl_2N_2PPd$: C, 55.88; H, 4.86; N, 4.66. Found: C, 55.58; H, 5.10; N, 4.35.

X-ray Data Collection, Structure Determination, and Refinement of 4a. Crystals were grown from ethyl acetate solution. Selected crystal data for $C_{28}H_{28}ClN_2PPd$ (**4a**) from supplementary material: monoclinic, space group $P2_1/n$, a = 10.1806(3) Å, b = 21.716(2) Å, c = 9.6678(3) Å, β = 100.10(1)°, Z = 4. The determination of the cell constants and the intensity data collection were carried out at room temperature. Unit cell constants were determined by least-squares refinement of 25 accurately centered reflections. Pertinent crystal and collection data can be found in Table 1. The structure was solved by Patterson and Fourier synthesis. As indicated above, hydrogen atoms were located (except those of the methyl groups) and

(31) Assignments were made on the basis of $^1H-^1H$ (COSY, 300 MHz) and $^1H-^{13}C$ (HMQC, 500 MHz for ^1H) correlations.

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isotropically refined. All non-hydrogen atoms were refined with anisotropic thermal parameters. An empirical absorption correction was applied,[32] with minimum and maximum corrections being 0.86 and 1.16, respectively. Scattering and anomalous dispersion factors were taken from the literature.[33] Final R and R_w values were 4.3 and 4.6, respectively. All calculations were performed on a VAX 11/750 computer by using the following programs: XRAY80 System,[34a] DIRDIF,[34b] and PARST.[34c]

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Supplementary Material Available: Listings of crystal data, atomic coordinates, thermal parameters, bond distances and angles, and dihedral angles (9 pages). Ordering information is given on any current masthead page.

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