ChemComm

RSC Publishing

COMMUNICATION

View Article Online
View Journal | View Issue

Cite this: *Chem. Commun.*, 2013, **49**, 4244

Received 26th May 2012,
Accepted 19th July 2012

DOI: 10.1039/c2cc33789d

www.rsc.org/chemcomm

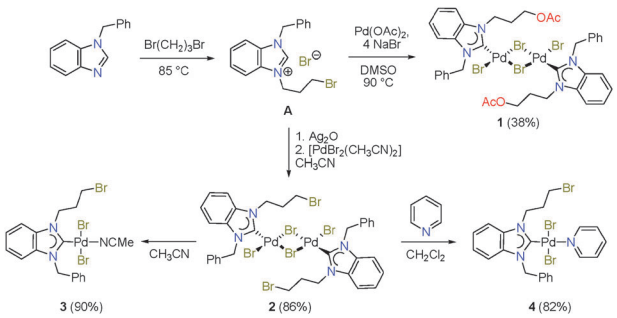
Highly modular access to functionalised metal-carbenes *via* post-modifications of a single bromoalkyl-substituted NHC–Pd(II) complex†‡

Han Vinh Huynh* and Qiaoqiao Teng

The synthesis of a bromopropyl-substituted NHC–Pd(II) complex, which can undergo exemplary and versatile 2nd and 3rd generation post-modifications easily affording 7 new functionalised NHC complexes, is demonstrated.

The rich chemistry of N-heterocyclic carbenes (NHCs)[1–3] does not only stem from their strong σ-donating ability,[4] but also from the ease of their modifications *via* the introduction of various *N*-substituents. By doing so, the sterical demand and the electronic properties of the resulting ligand can be tuned, and perhaps more importantly, functional groups can be introduced. Generally, functionalised NHC complexes are obtained *via* metallation of prefunctionalised azolium salts.[5–9] In this approach, the functional group may interfere negatively with the coordination process leading to the undesired formation of by-products and lower yields. Furthermore, versatility and modularity are limited, and only a small number of complexes can be obtained from a single functionalised ligand precursor. Although, the majority of transition metal carbenes are usually stable, a highly versatile post-functionalisation strategy has not been reported thus far. As our contribution to this field we herein report the synthesis of a bromopropyl-substituted NHC–Pd(II) complex, which can undergo exemplary post-modifications easily affording 7 new functionalised NHC complexes.

The suitable ligand precursor **A** that contains a bromopropyl *N*-substituent can be prepared by reacting benzylbenzimidazole with an excess of 1,3-dibromopropane (Scheme 1).[10] It was anticipated that the flexible bromoalkyl substituent could be used to install a variety of functional groups *via* nucleophilic substitution reactions (*e.g.* S_N2) after NHC-complex formation. Initial attempts to synthesise a dimeric monocarbene–Pd(II) species according to a previously published standard procedure[11] using



Scheme 1 Synthesis of ligand precursor **A** and complex precursors **1–4**.

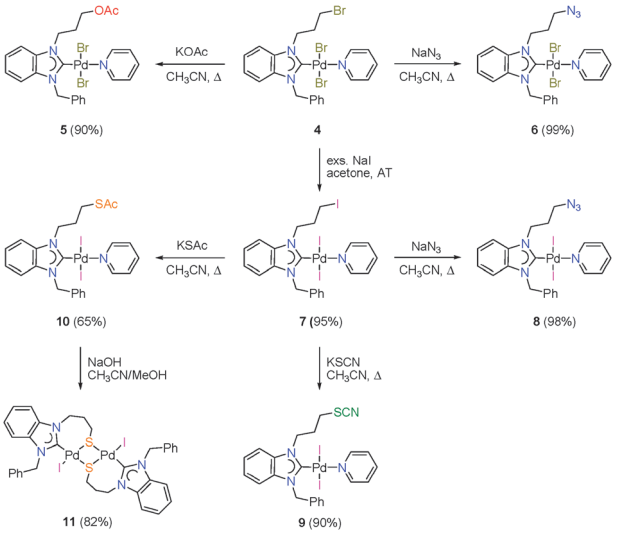
$Pd(OAc)_2$/NaBr gave rise to an ester-functionalised Pd–NHC dimer **1**, which has been fully characterised by spectroscopic and spectrometric methods including single crystal X-ray diffraction (*vide infra*). Apparently, one equivalent of acetate deprotonated the benzimidazolium salt, while the 2nd equivalent underwent a S_N2 reaction with the bromopropyl arm forming the ester function. In order to prevent such interferences the milder Ag-carbene transfer[12,13] was investigated. Indeed, the reaction of salt **A** with Ag_2O and subsequent transfer to $[PdBr_2(CH_3CN)_2]$ gave the desired product **2** in 86% yield. The dissolution of complex **2** in CH_3CN leads to the formation of the mononuclear acetonitrile complex **3**. Similarly dimeric **2** can undergo bridge-cleavage reaction with pyridine affording the more stable pyridine adduct **4** (Scheme 1), which was anticipated to be better suitable for post-modifications.

The treatment of complex **4** with KOAc or NaN_3 gave the respective ester- and azido-functionalised NHC complexes **5** and **6** in high yields without affecting the bromido ligands (Scheme 2). Notably, possible olefinic byproducts due to base-catalyzed HBr elimination of the bromopropyl sidearm were not observed. Complex **5** can also be obtained by bridge-cleavage reaction of dimer **1** with pyridine. Reaction with NaI on the other hand is expected to affect both bromo-substituents as well as the bromido ligands. In order to avoid halide scrambling in this reaction, 10 equiv. of NaI was added to **4**, which cleanly afforded the Pd(II)–diiodido complex **7** bearing an

Department of Chemistry, National University of Singapore, 3 Science Drive 3, 117543, Singapore. E-mail: chmhhv@nus.edu.sg; Fax: +65 6779 1691; Tel: +65 6516 2670

† This article is part of the *ChemComm* 'Emerging Investigators 2013' themed issue.

‡ Electronic supplementary information (ESI) available. See DOI: 10.1039/c2cc33789d



Scheme 2 Post-functionalisations of complexes **4** and **7**.

iodo-functionalised NHC. The combination of a better iodo leaving group at the sidearm with stronger coordinating iodido ligands makes **7** an even better precursor for (here 2nd generation) post-modifications. Thus, its S_N2 reactions with the nucleophiles NaN_3, KSCN and KSAc yielded three new derivatives bearing azido (**8**), thiocyanato (**9**) and thioester (**10**) functional groups. Notably, complexes **9** and **10** are not obtainable *via* palladation of the respective pre-functionalised azolium salts.[14] In this respect, we have previously reported reactions of thioester-functionalised imidazolium[15] and benzimidazolium[16] salts with $Pd(OAc)_2$ that directly give rise to dimeric thiolato–NHC complexes *via in situ* hydrolysis of the thioester groups. This fact highlights the importance of the current post-modification protocol, which not only complements the traditional methodology, but also provides functionalised NHC compounds that are otherwise not accessible.

It is conceivable that the functional groups in complexes **8–10** could be subjected to a 3rd generation post-functionalisation. To demonstrate such feasibility, complex **10** was chosen for a base-assisted hydrolysis reaction, which led to the formation of the anticipated thiolato-donor functionalised NHC complex-dimer **11** in a good yield.

Further explorations along this line could include copper-catalyzed azide–alkyne cycloaddition (Click) reactions of the azido–NHC complex **8** to form triazole NHC-complexes, or a Staudinger reduction of **8** to form a NHC complex bearing an amino group. Complex **9** could be hydrolyzed to a thiocarbamate in the Riemschneider thiocarbamate synthesis.

Apart from the spectroscopic signatures of the functional group itself, such post-modifications can be best traced by monitoring the ^{1}H NMR signal of the α-methylene group with respect to the reactive site. Other resonances of the ligands remain largely unaffected by the post-modifications.

Table 1 summarizes and compares the α-CH_2 ^{1}H NMR resonances for complexes **1**, **2** and **4–10**. Comparing those of the dimers **1** and **2** reveals that the ester group in **1** is more deshielding than the bromo substituent in **2**, which reflects

Table 1 Comparison of α-CH_2 and $C_{carbene}$ NMR resonances[a]

Complex	δ (^{1}H)	δ ($^{13}C_{carbene}$)	Functional group
1	4.26	160.6	OAc
2[b]	3.76	/[d]	Br
3[c]	3.65	161.8	Br
4	3.67	164.6	Br
5	4.31	164.3	OAc
6	3.60	164.4	N_3
7	3.43	163.3	I
8	3.60	163.0	N_3
9	3.28	163.9	SCN
10	3.14	162.9	SAc
11	3.05	174.8	S^-

[a] Measured in $CDCl_3$. [b] Measured in d_6-DMSO. [c] Measured in CD_3CN. [d] The $C_{carbene}$ signal could not be resolved.

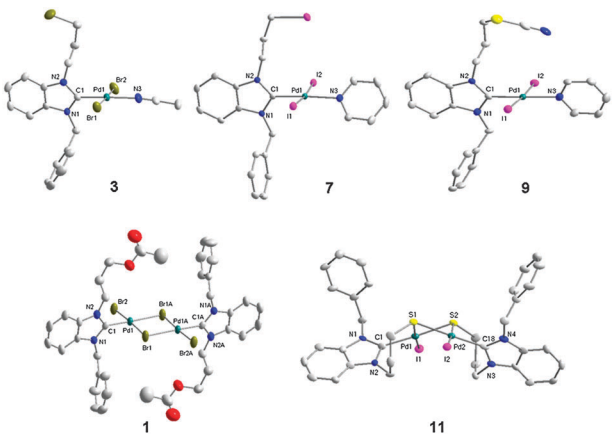


Fig. 1 Molecular structures of complexes **1**, **3**, **7**, **9** and **11** showing 50% probability ellipsoids; hydrogen atoms are omitted for clarity. ''A'' letter in the atom labels for complex **1** indicates atoms at equivalent positions (−*x*, 1−*y*, −*z*).

their inductive effects. The same trend can be observed for their respective mononuclear pyridine adducts **4** and **5**. The reduced −*I* effect of the azido group in **6** and **8**, on the other hand, leads to an upfield shift. The identical α-CH_2 chemical shift for complexes **6** and **8** also reveals that substitution of bromido *versus* iodido ligands has no significant effect on the post-modifications. Overall, the negative inductive effects of the functional groups investigated here can be ranked in the order SAc < SCN < I < N_3 < Br < OAc based on the comparison of the α-CH_2 ^{1}H NMR signals of their respective complexes.

The ^{13}C NMR signals for the carbene atom of the pyridine complexes **4–10** are found in the narrow range of 162.9–164.6 ppm. Those of the complexes **1** and **3** are shifted upfield indicating more Lewis acidic metal centres, while that of the dimer **11** is found downfield at 174.8 ppm due to the electron-rich thiolato donors.[16]

The solid state molecular structures of complexes **1**, **3**, **7**, **9** and **11** have also been determined by single crystal X-ray diffraction and are depicted in Fig. 1. As expected, complex **1** is a dimeric monocarbene–Pd(II) complex with two bridging bromido ligands. The molecule lies at an inversion centre. The coordination sphere at each square planar Pd centre is completed by an ester–NHC and a terminal bromido ligand. The two alkylester N-substituents point in different directions

resulting in an *anti*-arrangement with respect to the coordination plane. The carbene plane deviates from the coordination plane with a dihedral angle of $\sim 83^\circ$.

Apart from their different functional groups, the mononuclear complexes **3**, **7** and **9** have a very similar structure. All contain a square planar Pd(II) centre that is coordinated by one functionalised benzimidazolin-2-ylidene, two *trans*-halido and an acetonitrile (**3**) or a pyridine (**7** and **9**) ligand. As expected the carbene planes are oriented almost perpendicularly to the coordination planes by angles of $\sim 75^\circ$ (**3**) and $\sim 82^\circ$ (**7** and **9**), respectively. Notably, there is no correlation between the C–X bond length (X = functional group) and the $-I$ effects of the functional groups.

Complex **11** is a dimeric species, in which the two Pd(II) centres are coordinated and bridged by two μ-thiolato-functionalised NHCs in a chelating fashion. The square-planar coordination sphere at each Pd(II) is completed by one terminal iodido ligand. Both dihedral angles between these $[PdCS_2I]$ coordination planes and the carbene ring planes amount to $\sim 63^\circ$, which deviate substantially from the favoured perpendicular orientation (90°) due to the chelating binding mode of the *S*-functionalized carbene ligand. The $[Pd_2S_2]$ core of **11** is significantly bent with a hinge angle of $\sim 128^\circ$, which is slightly larger than the reported value of $\sim 119^\circ$ for a similar complex bearing a shorter ethylthiolato chelate.[16]

In summary, we have reported the synthesis of a bromopropyl-substituted NHC complex that provides easy and efficient access to a range of 2nd and 3rd generation functionalised NHC complexes *via* a versatile post-modification strategy. It is feasible that such a strategy will be useful in the anchoring of NHC based complexes on various solid supports for heterogeneous catalysis. In addition, extension of this approach to other heterocycles and haloalkyl/aryl spacers as well as to other metal centres, which is currently ongoing in our laboratories, will result in a large library of new functionalised NHC complexes with various potential applications.

We thank the National University of Singapore and the Singapore Ministry of Education for financial support (WBS R-143-000-407-112). Technical support from staff at the CMMAC of our department is appreciated. In particular, we thank Ms Geok Kheng Tan, Ms Yimian Hong and Prof. Lip Lin Koh for determining the X-ray molecular structures.

Notes and references

1 W. A. Herrmann and C. Köcher, *Angew. Chem., Int. Ed. Engl.*, 1997, **36**, 2162.
2 D. Bourissou, O. Guerret, F. P. Gabbaï and G. Bertrand, *Chem. Rev.*, 2000, **100**, 39.
3 F. E. Hahn and M. C. Jahnke, *Angew. Chem., Int. Ed.*, 2008, **47**, 3122.
4 Non-negligible π-accepting properties of NHCs in electron rich complexes have been reported: X. Hu, I. Castro-Rodriguez, K. Olsen and K. Meyer, *Organometallics*, 2004, **23**, 755.
5 O. Kühl, *Chem. Soc. Rev.*, 2007, **36**, 592.
6 H. M. Lee, C. C. Lee and P. Y. Cheng, *Curr. Org. Chem.*, 2007, **11**, 1491.
7 A. T. Normand and K. J. Cavell, *Eur. J. Inorg. Chem.*, 2008, 2781.
8 M. Bierenstiel and E. D. Cross, *Coord. Chem. Rev.*, 2011, **255**, 574.
9 D. Yuan and H. V. Huynh, *Molecules*, 2012, **17**, 2491.
10 H. V. Huynh and R. Jothibasu, *J. Organomet. Chem.*, 2011, **696**, 3369.
11 H. V. Huynh, Y. Han, J. H. H. Ho and G. K. Tan, *Organometallics*, 2006, **25**, 3267.
12 H. M. J. Wang and I. J. B. Lin, *Organometallics*, 1998, **17**, 972.
13 J. C. Y. Lin, R. T. W. Huang, C. S. Lee, A. Bhattacharyya, W. S. Hwang and I. J. B. Lin, *Chem. Rev.*, 2009, **109**, 3561.
14 The reaction of thiocyanato-functionalised azolium salts led to organic products that did not contain any Pd–NHC complexes.
15 D. Yuan and H. V. Huynh, *Dalton Trans.*, 2011, **40**, 11698.
16 D. Yuan and H. V. Huynh, *Organometallics*, 2010, **29**, 6020.

