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Polymer-Bound 1-Aryl-3-alkyltriazenes as Modular Ligands for Catalysis. Part 1: Synthesis and Metal Coordination

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Abstract—A range of di- and tri-substituted triazenes have been synthesized from a polymer-supported diazonium salt and various primary and secondary amines. The triazenes obtained were treated with transition metal salts to form polymer-supported metal complexes in firstly a general screen and then in a specific manner. © 2002 Published by Elsevier Science Ltd.

Although there are many advantages in using transition metal complexes in synthesis, the problems of metal extraction and product purification make them less than ideal for use in applications such as synthesis of fine chemicals where contamination of the product with heavy metals is highly undesirable. Overcoming these problems has evoked a renewed interest in developing polymer-bound metal catalysts and reagents for organic synthesis that have high activity.[1,2] This has been very successful and in some cases the activity and asymmetric selectivity of the supported complex significantly exceeds that of their homogeneous analogue.[3] The immobilization of transition metals on polystyrene supports offers a number of advantages over traditional solution-phase chemistry. In an ideal case, they can be recovered from reaction mixtures by simple filtration, they do not contaminate the product solution, they can be recycled, they can help increase selectivity and their toxicity and sensitivity to air and moisture can be reduced.[4] As transition metal complexes are often expensive to purchase or prepare, the immobilization on a support thereby enabling simple extraction and recyclability makes for commercial advantage as well as ease of manipulation. There are however a number of disadvantages including the fact that often there is metal leaching during the course of a reaction and they are often not recyclable. In addition when considering asymmetric synthesis, the enantioselectivity of polymer-supported complexes can be less than that of the homogeneous analogue. As a result, much recent work has been focused on developing and screening new derivatized polystyrene supports for attachment of metals and on developing methods for increasing activity and selectivity. Also, there has been an increase in reports presenting the use of combinatorial methods to discover new catalysts.[5,6] Although this method can often be considered to be reliant more on serendipity than planned chemical reactions, it is already clear that it has the potential to reveal unexpected classes of catalyst and catalytic activity.

In this letter, we present the synthesis of immobilized 1-aryl-3-alkyl triazenes as new modular ligands for transition metal catalysis and report the results of reactions with transition metal salts to form polymer-supported metal complexes in firstly a combinatorial and then specific manner.

Whereas the conventional T1 triazene linker synthesis involves reaction of a resin-bound amine with a diazonium salt (Scheme 1a),[7] the T2 linker synthesis represents the reversal of this concept (Scheme 1b),[8,9] the

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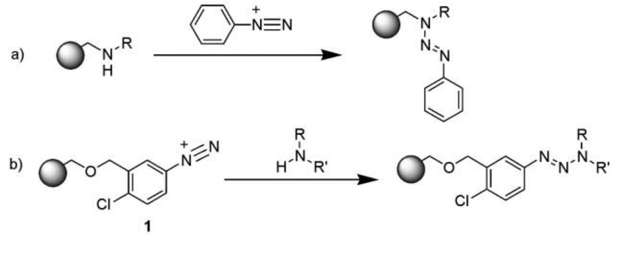
diazonium salt being formed on the resin and then reacted with an amine. The methodology for preparing the polymer-supported diazonium salt **1** is simple. The chloro-substituted aminobenzyl alcohol **2**, prepared in two steps from commercially available 2-chloro-5-aminobenzyl alcohol, is attached to Merrifield's resin via the hydroxy group using sodium hydride in DMF at 40 °C for 4 h. Subsequent diazotation of the resin-bound amine at −10 °C in THF with ^{t}BuONO and BF_3 etherate yields the desired polymer-supported diazonium salt **1** resin.[10] The formation of the diazonium salt is clearly evidenced by the strong ν(N≡N) band observed in the IR spectrum of **1** together with CHN elemental analysis data. The use of **2** as the starting amino alcohol is very important because this leads to a *p*-chloro-substituted diazonium ion which, from previous studies,[11] has been shown to be very stable compared, for example, to either the Cl free or *m*-Cl substituted analogues. Resin **1** has a calculated half-life of 130 days at 20 °C.

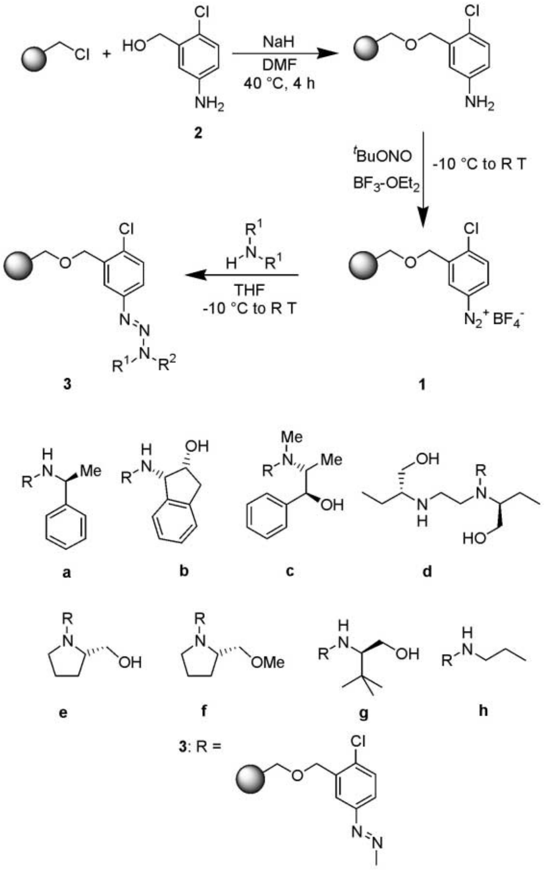
Treatment of **1** with primary and secondary amines leads to the formation of polymer-supported di- and trisubstituted triazene. Starting from **1**, we have prepared a range of novel triazene for use in screening experiments. In a general reaction, **1** is swollen in THF and cooled to −10 °C whereupon the amine is added. After stirring at −10 °C for 15 min, the reaction mixture is warmed to room temperature, the mixture stirred for a further 30 min then the beads filtered and washed thoroughly. The formation of the triazene **3** is evidenced by the loss of the ν(N≡N) band observed in the IR spectrum and the appearance of a ν(N=N) band and, in the case where a di-substituted triazene is formed, a clearly recognizable ν(N–H) stretch. CHN elemental analysis also indicates formation of the desired triazenes. Loadings of triazene of approximately 0.8 mmol/g resin were obtained. The synthesis of **1** and of the library of novel triazenes **3a**–**g** formed is shown in Scheme 2. As well as a simple achiral amine, a range of chiral amines have been used so that chiral triazenes could be prepared. Using these it would then be possible to screen for activity as ligands for asymmetric catalysis.

The transition metal coordination chemistry of triazene complexes has been studied extensively[12] but, with a few recent exceptions,[13,14] there has not been much attention focused on their use as catalysts for organic transformations. Triazenes can bind to metals in both a monodentate or bidentate manner (Fig. 1).[15] The products are air and moisture stable and are easily prepared. The fact that there is the possibility of either mono- or bidentate binding of the triazene to the metal has exciting implications both for catalysis and also for applications as polymer-supported metal complexes. The ability of the ligand to change from bidentate to monodentate coordination with the ligand means that the metal centre can be stabilized but also vacant coordination sites can be made enabling easy coordination of organic substrates. The binding in metal triazenes has advantages in the anchoring of the metal complex to a polymer-support since, unlike simple monodentate congeners such as simple amines, even when the metal triazene binds to organic substrates and the triazene ligand moves from bidentate to monodentate coordination it is still covalently bound to the metal whereas, with amines, there is the possibility of loss of the covalent link between metal and support on reaction with substrates.



Scheme 1. Comparison of the (a) T1 and (b) T2* linker syntheses.

In an attempt to assess the ease of preparation of polymer-supported metal triazene complexes, we embarked on an initial investigation using a simple screening method. Small samples of a range of the triazenes prepared were treated with a range of transition metal salts, namely $Co(acac)_3$, $Cu(OTf)_2$, $FeCl_2$, $Pd(OAc)_2$, $Ti(OiPr)_4$ and $Zr(acac)_4$. In most cases, a strong staining



Scheme 2. Synthesis of **1** and of the novel triazenes **3a**–**g**.

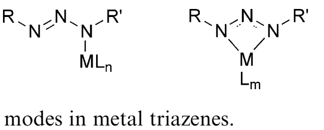
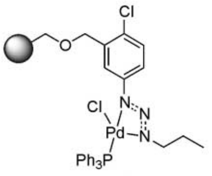


Figure 1. Binding modes in metal triazenes.

was observed. The colour was characteristic for the various metals involved, examples being shown in Figure 2. While the copper and cobalt complexes are quite dark, the analogous zirconium complexes are lighter in colour.

As the initial screening with the polymer-supported triazenes showed that metal coordination was possible and that stable complexes were formed, we decided to look closely at the preparation and characterization of two supported metal triazenes, **4** and **5**, with an additional exchangeable ligand.



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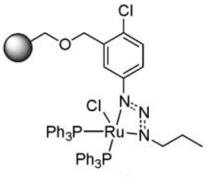

5

These represent an interesting range of potential metal catalysts. The complex **4** is the triazene analogue of $PdCl_2(PPh_3)_2$, a well known catalyst for the Sonogashira and Suzuki reactions,[16] **5** is the triazene analogue of $RuCl_2(PPh_3)_4$, a known catalyst for transfer hydrogenation[17] and also a case where a polymer supported analogue has been previously prepared and studied. The starting metal complexes for **4**, and **5** were $PdCl_2(PPh_3)_2$ and $RuCl_2(PPh_3)_3$ respectively. Resin **3h** was chosen for the immobilization experiments as it is the simplest to prepare in large batches and the least sterically crowded around the triazene moiety thereby maximizing the chance of optimum metal coordination. Both supported metal triazenes were prepared in a similar manner. A THF solution of the metal salt was added to a suspension of polymer-supported triazene. Triethylamine was added and the mixture refluxed under N_2 for 1 h. The supported complex was then filtered and washed thoroughly before drying and storing refrigerated under N_2. The polymer-supported metal triazene complexes **4** and **5** were characterized and the metal loading determined by elemental analysis as 0.1 mmol/g and 0.12 mmol/g for **4** and **5**, respectively.

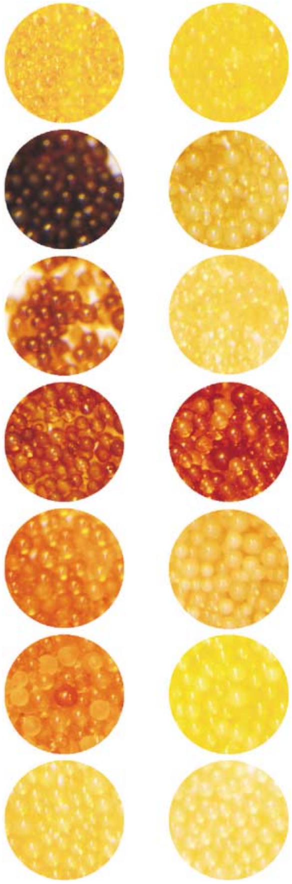

Figure 2. Colour of the metal complexes. Left hand side: resin **3b**, right hand side: resin **3c**. From top to bottom: (1) blank resin, (2) with $Co(acac)_3$, (3) with $Cu(OTf)_2$, (4) with $FeCl_2$, (5) with $Pd(OAc)_2$, (6) with $Ti(OiPr)_4$ and (7) with $Zr(acac)_4$.

The catalytic activity of the metal complexes formed in the initial screening experiments together with that of **4** and **5** is discussed in Part 2 of this letter.

In conclusion, the synthesis of a matrix of immobilized triazene-based ligands was achieved. Metal staining screening experiments indicated a complexation and the formation of stable complexes on reaction with simple transition-metal salts. Building on this, polymer-supported palladium and ruthenium triazene complexes have been prepared and characterized.[18]

Acknowledgements

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