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First examples of functionalisation of *meso*-aryl tetrabenzotriazaporphyrins (TBTAPs) through cross-coupling reactions

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ABSTRACT

Recent synthetic advances have given convenient access to tetrabenzotriazaporphyrins (TBTAPs) functionalised with *meso*-aryl substituents. In this paper we report the first examples of further functionalization of the *meso*-sites through Suzuki–Miyaura and copper-free Sonagashira cross-coupling reactions of the *meso*-(bromophenyl)TBTAPs, demonstrating the breadth of new materials design now possible in the hybrid macrocycles.

1. Introduction

The tetrabenzotriazaporphyrin (TBTAP) ring system can be regarded as a hybrid between the ubiqitous phthalocyanine (Pc) and (tetrabenzo)porphyrin macrocyclic aromatic structures[1] in which a single nitrogen atom bridge is replaced by carbon (Fig. 1). The hybrid structures are fascinating and potentially very useful materials; they combine the stability, robustness and intense long-wavelength electronic absorption typical of the phthalocyanines but incorporate a bridging atom (*meso*-site) that can be further functionalised for linking to additional moieties, scaffolds or surfaces. Hybrid systems like TBTAPs were first observed by Linstead[2] and Dent[3] as part of seminal studies that formed the basis for prolonged and extensive investigation into synthetic macrocyclic chromophores. However, whereas research and development in phthalocyanine chemistry has led to many thousands of studies, the chemistry of the hybrids has, until recently, remained relatively underexplored.[4] By far the greatest hindrance to the development of the hybrid materials has been the difficulties associated with their synthesis. Indeed the original method of synthesis developed by Linstead,[2] involving the macrocyclisation of phthalonitrile initiated by an organometallic nucleophile (providing the bridging carbon) was employed with little improvement in the majority of studies. Our group has recently reported a new procedure for the controlled synthesis of TBTAP hybrids,[5] and a complementary approach to the *trans*-tetrabenzodiazaporphyrins (*trans*-TBDAPs) has separately been developed by Ceprakov and co-workers.[6] Alongside the new syntheses we have refined and improved the Grignard reagent initiated macrocyclisation approach, delivering the full range of hybrids in specific cases,[7] and most recently reporting the series of isomeric *meso*-(bromophenyl)TBTAPs.[8] The latter series were targeted as particularly useful intermediates for further functionalisation, and this paper describes the first successful extensions of this chemistry through cross-coupling reactions.

2. Results and discussion

The three isomeric *meso*-(bromophenyl)TBTAPs were prepared as previously reported by initially reacting phthalonitrile with 2-, 3-, or 4-bromobenzylmagnesium chloride in THF at room temperature. Exchange of the solvent for quinoline, followed by heating at 220 °C gave, after chromatographic separation, the TBTAP hybrids **2**–**4** (Scheme 1).[8]

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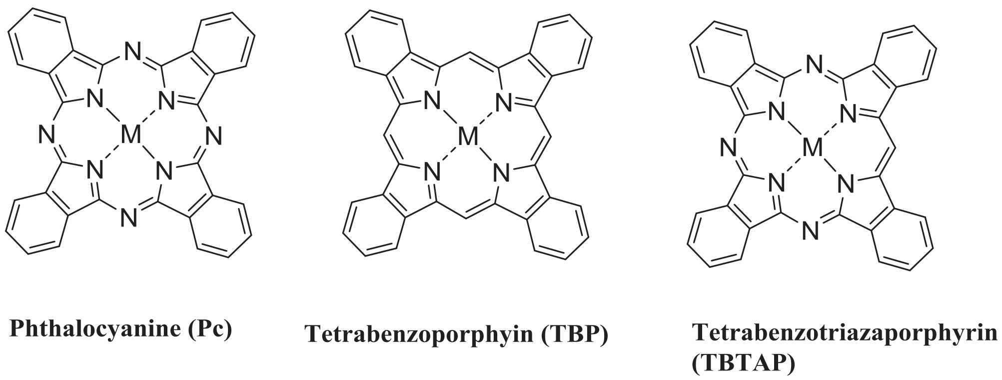
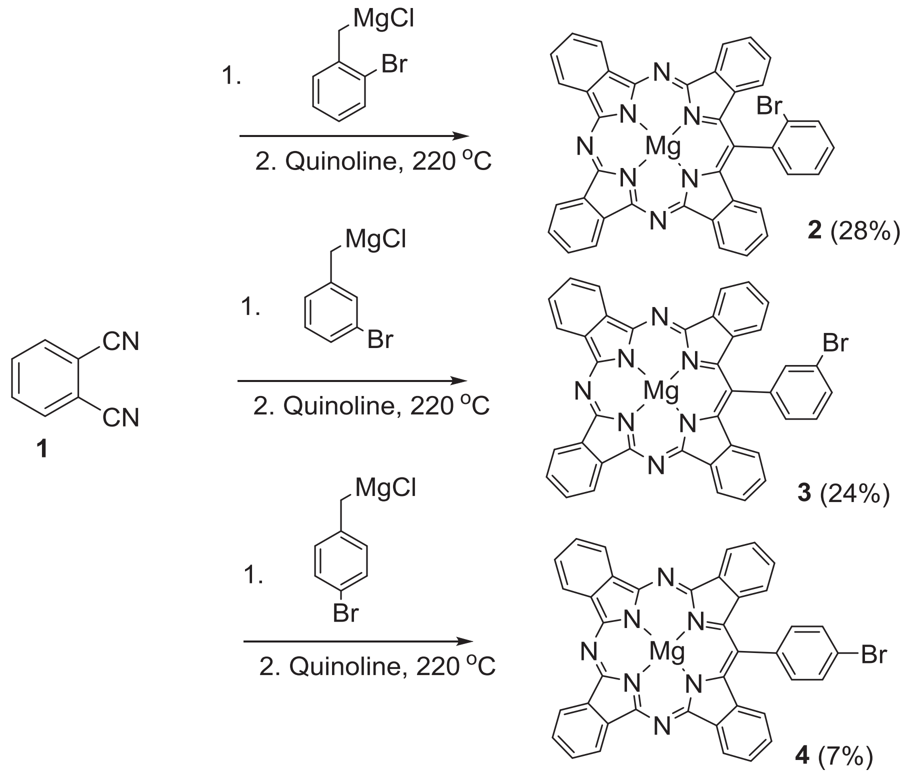


Fig. 1. Structures phthalocyanine (Pc), tetrabenzoporphyrin (TBP) and tetrabenzotriazaporphyrin (TBTAP).



Scheme 1. Synthesis of *meso*-(bromophenyl)-TBTAPs via the Grignard reagent route.[8]

The first attempts at functionalisation through cross-coupling involved treatment of bromides **2**–**4** with phenyl or 4-methoxyphenyl boronic acid under standard Suzuki–Miyaura[9] conditions. In a typical procedure the TBTAP bromide was treated with excess of boronic acid and CsF in refluxing, dry DME in the presence of Pd(dppf)Cl_2. Reactions were very slow and took several days to complete. After this time, most of the starting material (**2**–**4**) had been consumed but the product in each case was the parent *meso*-phenylTBTAP **5** resulting from debromination of the starting materials (Scheme 2). Closer examination of the reaction with 4-methoxyphenyl boronic acid also showed deboronation of the boronic acid reagent was occurring. Both side reactions are well-known in Suzuki–Miyaura cross-coupling chemistry and often dominate when the desired cross-coupling reaction is slow.[10,11]

An effective strategy to overcome protonolysis side-reactions is to take all possible steps to remove proton sources. In this case, this involved replacement of the boronic acid starting material with its corresponding boronate ester. We have had particular success in other projects using ethane diol (rather than the more widely employed pinacol) as protective ester.[10,12] Boronate ester **6** was indeed successfully employed in cross-coupling reactions with bromoTBTAPs **2**–**4**. Reactions were most conveniently performed using microwave heating, and in a typical procedure **2**–**4** were mixed in a microwave vial with excess of boronate ester **6**, DBU and catalytic Pd(dppf)Cl_2 in dry DMF and degassed with argon. The reaction mixtures were irradiated in a microwave reactor at 120 °C for 1 h. Workup and column chromatography gave the isomeric cross-coupled products **7**–**9**, albeit in low yields (Scheme 3). As expected, the absorption spectra of the TBTAPs are insensitive to these synthetic modifications, underlining the (ground-state) electronic isolation of the *meso*-aryl substituent due to the perpendicular orientation with respect to the macrocycle. The arrangement places the new benzene ring of 2-substituted derivative **7** above the aromatic macrocycle core so that the *meta* and *para*

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