Efficient Synthesis of Monoacyl Dipyrromethanes and Their Use in the Preparation of Sterically Unhindered *trans*-Porphyrins

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Received October 5, 1999

The condensation of an aldehyde with a dipyrromethane bearing a sterically unhindered aryl substituent at the 5-position typically results in low yield and a mixture of porphyrin products derived from acidolytic scrambling. We have developed a concise nonscrambling synthesis of such *trans*-porphyrins that takes advantage of the availability of multigram quantities of dipyrromethanes. This route involves the selective monoacylation of the dipyrromethanes with a pyridyl thioester, reduction of the monoacyl dipyrromethane to the corresponding carbinol, and self-condensation of the carbinol to form the porphyrin. The monoacylation procedure has wide scope as demonstrated by the preparation of a set of 15 diverse monoacyl dipyrromethanes in good yield at the multigram scale. The dipyrromethanecarbinol self-condensation reaction is extremely rapid (<3 min) under mild room-temperature conditions and affords the *trans*-porphyrin in 16−28% yield. Analysis by laser-desorption mass spectrometry (LD-MS) of samples from the crude reaction mixture revealed no scrambling within the limit of detection (1 part in 100). The self-condensation is compatible with a range of electron-withdrawing or -releasing substituents as well as substituents for building block applications (TMS-ethyne, ethyne, iodo, ester). The absence of any detectable scrambling in the self-condensation enables a simple purification. The synthesis readily affords gram quantities of pure, sterically unhindered *trans*-porphyrins in a process involving minimal chromatography.

Introduction

Meso-substituted *trans*-porphyrins are key structural components found in a wide range of model systems in biomimetic and materials chemistry.[1,2] An attractive route for the synthesis of these valuable compounds involves the condensation of a dipyrromethane with an aldehyde, but this approach is often stymied by acid-catalyzed scrambling processes that give rise to undesired porphyrin byproducts.[2] We recently reported a detailed study into the reaction conditions of the dipyrromethane−aldehyde condensation with the aim of preventing the acid-catalyzed scrambling processes.[3] We discovered reaction conditions that eliminated scrambling for condensations involving sterically hindered dipyrromethanes, such as 5-mesityldipyrromethane, allowing preparation of the pure *trans*-porphyrins in good yield with minimal chromatography. Examination of a wide range of reaction conditions for condensations involving sterically unhindered dipyrromethanes, such as 5-phenyldipyrromethane, showed that scrambling was very difficult to suppress for these cases. We identified reaction conditions that dramatically reduced the amount of scrambling, but the persistence of low levels of scrambling as well as the poor yields (<10% in all cases) sharply limited the quality and quantity of material available.

An alternative route to the synthesis of *trans*-porphyrins bearing sterically unhindered substituents is the self-condensation of a dipyrromethanecarbinol (Scheme 1). Implementation of this promising methodology has been limited to the preparation of three *trans*-porphyrins (up to 75 mg scale). Despite the forcing reaction conditions (hot propionic acid in air), this approach was reported to provide less scrambling than analogous dipyrromethane−aldehyde condensations.[4] A fuller examination of this promising methodology, including a thorough investigation of mild reaction conditions, has been hampered by the lack of a simple method for preparing multigram batches of dipyrromethanecarbinols.

Recently, we reported an efficient synthesis of analytically pure 5-substituted dipyrromethanes in multigram batches,[5] providing the critical first step in a route to dipyrromethanecarbinols. We also have developed procedures for the acylation of dipyrromethanes involving treatment of the dipyrromethane with ethylmagnesium bromide followed by an acid chloride.[6,7] Although various ratios of dipyrromethane/ethylmagnesium bromide/acid chloride could be employed to favor either the monoacyl- or diacyldipyrromethane, a mixture of the monoacyl and diacyl compounds was always produced. Quite tedious column chromatography was required to give the pure monoacyldipyrromethane.[6] We have reexamined the

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(2) Lindsey, J. S. In *The Porphyrin Handbook*; Kadish, K. M., Smith, K., Guilard, R., Eds.; Academic Press: San Diego, CA 1999; Vol. 1, pp 45−118.
(3) Littler, B. J.; Ciringh, Y.; Lindsey, J. S. *J. Org. Chem.* **1999**, *64*, 2864−2872.
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(5) Littler, B. J.; Miller, M. A.; Hung, C.-H.; Wagner, R. W.; O'Shea, D. F.; Boyle, P. D.; Lindsey, J. S. *J. Org. Chem.* **1999**, *64*, 1391−1396.
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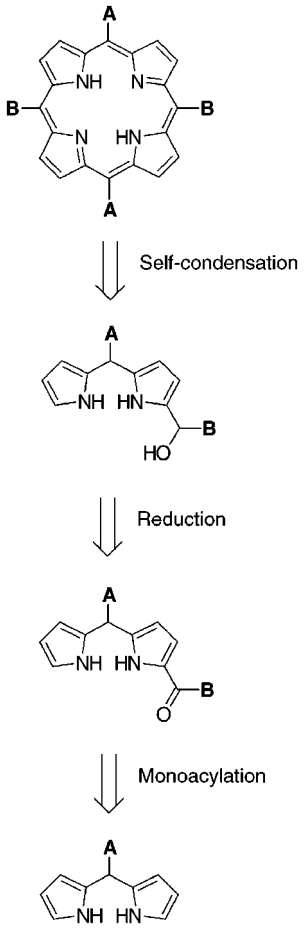
10.1021/jo9915473 CCC: $19.00
Published on Web 01/28/2000

Scheme 1



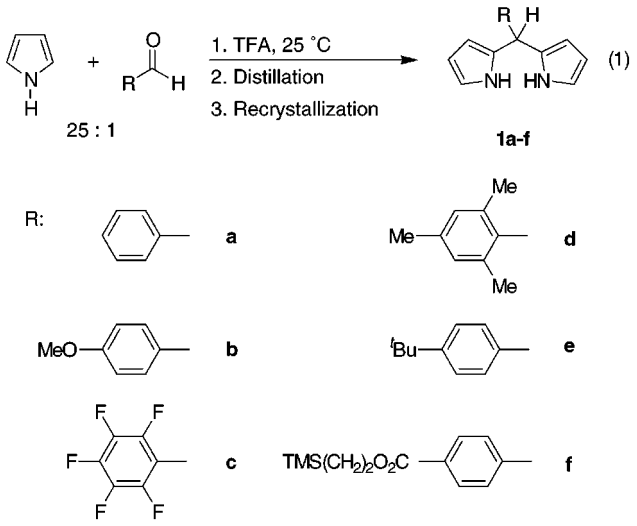
monoacylation of dipyrromethanes by employing 2-pyridyl thioesters[8] instead of acid chlorides, as such thioesters have been reported to be superior for the acylation of pyrrolemagnesium bromide.[9] This approach has provided an efficient, selective procedure for monoacylation of dipyrromethanes, affording the direct precursor to the desired dipyrromethanecarbinols on the gram scale.

In this paper, we describe the monoacylation procedure and demonstrate its wide scope by the preparation of diverse monoacyl dipyrromethanes. Reduction using $NaBH_4$ in methanol/THF provides the corresponding dipyrromethanecarbinols on a multigram scale. Studies of the dipyrromethanecarbinol self-condensation have shown that porphyrin formation is extremely rapid and proceeds with no detectable scrambling. The scope of the synthesis has been investigated by examining the effects on yield of electron-withdrawing or releasing substituents and by preparing a set of porphyrin building blocks for use in the synthesis of multiporphyrin arrays. A key objective has been to minimize chromatography in all aspects of this synthetic route to *trans*-porphyrins.

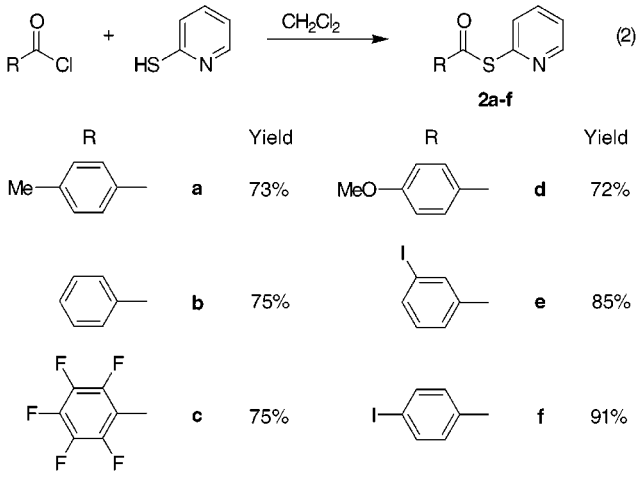
Results and Discussion

1. Monoacylation of Dipyrromethanes and Reduction to the Carbinol. Preparation of Dipyrromethanes.

Dipyrromethanes **1a**−**f** were prepared by condensation of the aldehyde in neat excess pyrrole (eq 1).[5] Dipyrromethanes **1a**−**d** were purified by bulb-to-bulb distillation in order to remove the higher oligomers. Dipyrromethane **1e** was highly crystalline and was purified by precipitation from the crude reaction mixture without distillation. Distillation or direct crystallization of dipyrromethane **1f** was not possible. Therefore, purification was achieved by column chromatography to remove most of the higher weight oligomers, followed by precipitation of the dipyrromethane. Finally, all of the dipyrromethanes (**1a**−**f**) were recrystallized affording multigram batches of pure dipyrromethane.

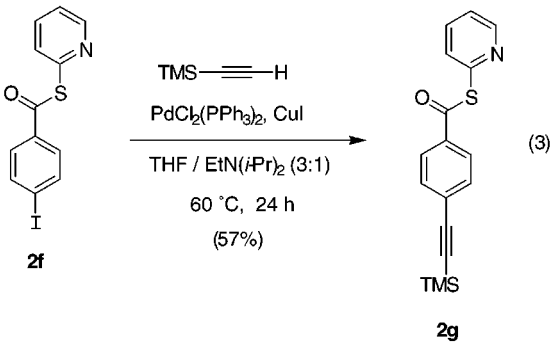


Preparation of Pyridyl Thioesters. The majority of our target thioesters (**2a**−**f**) were readily prepared in high yields by condensing commercially available acid chlorides with 2-mercaptopyridine (eq 2). In three cases, the

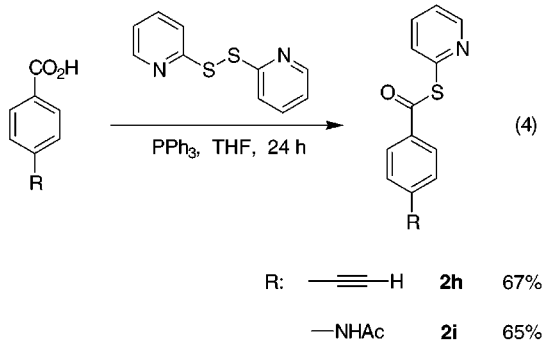


requisite acid chlorides were not commercially available. Thus, the TMS-protected ethynylthioester **2g** was prepared from **2f** and trimethylsilylacetylene via a Pd-mediated coupling reaction (eq 3).[10] The reaction of 2,2′-dipyridyl disulfide with 4-ethynylbenzoic acid or

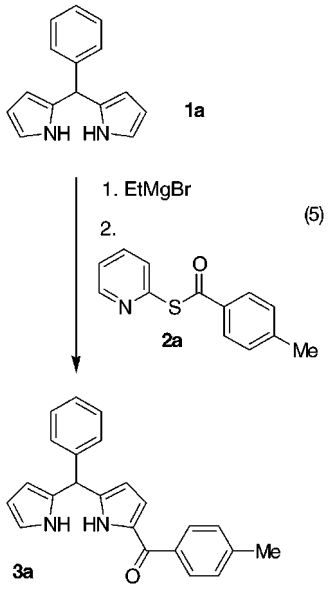
(8) Araki, M.; Sakata, S.; Takei, H.; Mukaiyama, T. *Bull. Chem. Soc. Jpn.* **1974**, *47*, 1777−1780.
(9) Nicolaou, K. C.; Claremon, D. A.; Papahatjis, D. P. *Tetrahedron Lett.* **1981**, *22*, 4647−4650.
(10) Li, J.; Ambroise, A.; Yang, S. I.; Diers, J. R.; Seth, J.; Wack, C. R.; Bocian, D. F.; Holten, D.; Lindsey, J. S. *J. Am. Chem. Soc.* **1999**, *121*, 8927−8940.



4-acetamidobenzoic acid afforded the unprotected ethynylthioester **2h** or acetamidothioester **2i**, respectively (eq 4).[9]



Development of a Selective Monoacylation Procedure. The model system shown in eq 5 was used to examine acylation conditions using the pyridyl thioester. The results of this study, which involve variation in ratios and overall concentrations, are presented in Table 1.



Treatment of 5-phenyldipyrromethane (**1a**) at 0.1 M with EtMgBr (2.0 molar equiv) followed by pyridyl thioester **2a** (2.5 molar equiv) gave a product mixture composed principally of monoacyl dipyrromethane **3a** and unreacted pyridyl thioester **2a** (entry 1). Most importantly, no other acylated products were detected by TLC or ^{1}H NMR spectroscopy. However, the yield could not be determined because separation of monoacyl dipyrromethane **3a** from pyridyl thioester **2a** was extremely difficult by column chromatography or crystallization.

Table 1. Optimization of the Monoacylation Reaction

entry	dipyrromethane (**1a**)	EtMgBr[a] (equiv)	thioester (**2a**)[a] (equiv)	solvent	yield[b] (%)
1	0.10 M, 1.0 equiv	2.0	2.5	toluene	*c*
2	0.30 M, 1.0 equiv	2.0	1.0	toluene	71
3	0.05 M, 1.0 equiv	2.0	1.0	THF	69
4	1.00 M, 1.0 equiv	2.0	1.0	THF	73
5	1.00 M, 1.0 equiv	2.5	1.0	THF	82

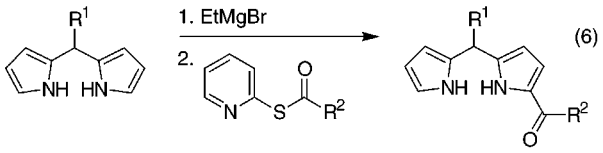
[a] Molar equivalents. [b] Isolated yield of monoacyl dipyrromethane **3a**. [c] Yield not determined due to the difficulty of separating **3a** from unreacted **2a**.

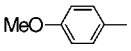
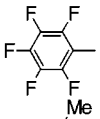
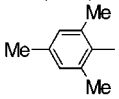
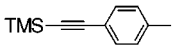
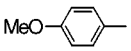
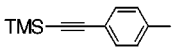
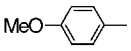
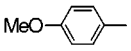
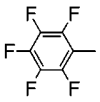
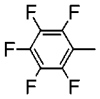
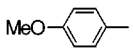
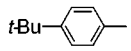
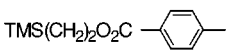
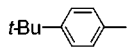
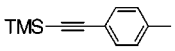
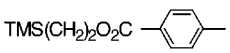
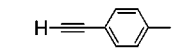
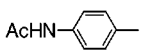
Use of a stoichiometric amount of **2a** in toluene gave monoacyl dipyrromethane **3a** in good yield with complete consumption of the thioester (entry 2). Purification of **3a** from the product mixture by column chromatography was straightforward because the other compounds present [unreacted **1a** and 1-(*p*-tolyl)propan-1-one] eluted much more readily than the desired product. Therefore, an important feature of an effective monoacylation procedure must be the complete consumption of the pyridyl thioester.

Many pyridyl thioesters have poor solubility in toluene, so we examined the use of THF as an alternate reaction solvent. THF provided effective reaction of pyridyl thioesters and Grignard reagents leading to ketones.[8] The reaction was performed at modest concentration (entry 3) or at 1 M (entry 4). Though the yield of monoacylation was good in both cases, the solvent change resulted in incomplete consumption of thioester **2a** even after 2 h at room temperature. Subsequent addition of a further aliquot of EtMgBr (2.0 molar equiv) removed **2a** without attacking the ketone in the monoacyl compound. The requirement to add a second aliquot of EtMgBr was easily avoided by initially adding a slightly larger excess of EtMgBr (2.5 molar equiv) to the dipyrromethane at high concentration in THF (entry 5). These optimized reaction conditions afforded monoacyl dipyrromethane **3a** in excellent yield and purity after straightforward column chromatography.

Scope of the Monoacylation Procedure. The monoacylation procedure (entry 5) was applied to a wide variety of substrates (eq 6). In each case, no diacylation was observed, and the monoacyl product was readily isolated in good yield after straightforward column chromatography. Although the batches of monoacyldipyrromethane produced by this method were faintly colored, all were analytically pure (^{1}H NMR, TLC, elemental analysis). The reaction has wide scope, tolerating a variety of functional groups in the 1- and 5-positions, including the protected carboxylic acid present in dipyrromethane **1f**. The only failure occurred when 5-phenyldipyrromethane (**1a**) was treated with the acetamido-substituted pyridyl thioester **2i**. Presumably, the Grignard reagent is incompatible with the acidic NH group.

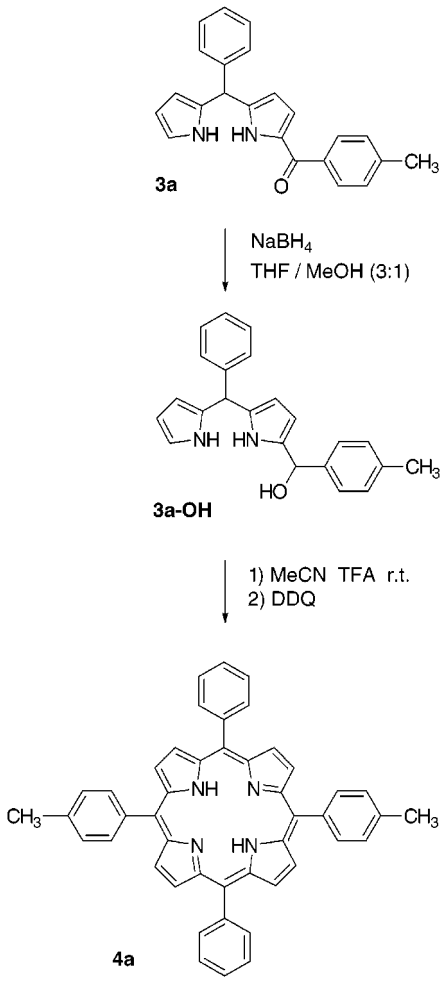
Reduction Affording the Dipyrromethanecarbinol. We recently discovered that diacyldipyrromethanes are readily reduced to dipyrromethanediols by a large excess of $NaBH_4$ in a mixture of THF and methanol.[6] Application of these reaction conditions to the reduction of monoacyl dipyrromethane **3a** gave carbinol **3a**-OH. Carbinol **3a**-OH decomposed when stored, so further characterization was not attempted and the carbinol was used directly in the self-condensation. This same approach was applied successfully with the other monoacyl dipyrromethanes (**3h**−**o**).



R^1	R^2	Product	Yield
		**3a**	82%
		**3b**	74%
		**3c**	75%
		**3d**	70%
		**3e**	71%
		**3f**	65%
		**3g**	72%
		**3h**	65%
		**3i**	76%
		**3j**	71%
		**3k**	73%
		**3l**	71%
		**3m**	68%
		**3n**	76%
		**3o**	66%
		-	0%

2. Self-Condensation of Carbinols. Model Study. The self-condensation of carbinol **3a**-OH leading to 5,15-di-*p*-tolyl-10,20-diphenylporphyrin (**4a**) was employed as a model for exploring appropriate reaction conditions (Scheme 2). This combination of substituents minimized steric and electronic differences while providing a mass difference so that any scrambling will be readily detected by LD-MS.[3] The selection of phenyl and *p*-tolyl substituents also allowed direct comparison with data obtained in our previous study of the dipyrromethane−aldehyde condensation where the same substituents were employed.[3]

Scheme 2



Self-condensation of carbinol **3a**-OH was performed using reaction conditions (5 mM carbinol in acetonitrile containing 30 mM TFA at room temperature) that were developed during a study of the condensation of a dipyrromethanediol and a dipyrromethane.[11] The reaction was monitored by treatment of reaction aliquots with DDQ followed by absorption spectroscopic determination of the yield of porphyrin.[12] Spectroscopic monitoring in this manner revealed the self-condensation to be complete within 1 min with a 26% yield of porphyrin. LD-MS analysis of the crude reaction mixture showed a single porphyrin peak with no detectable scrambled porphyrin byproducts.[13] Therefore, this self-condensation reaction was superior to the dipyrromethane−aldehyde condensation performed under low-scrambling conditions (e.g., catalysis with BF_3−etherate and NH_4Cl in acetonitrile at 0 °C)[3] for the following reasons: (1) Scrambling was reduced from a trace level to a level below the LD-MS detection limit (Figure 1). (2) The spectroscopic

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(12) Lindsey, J. S.; Schreiman, I. C.; Hsu, H. C.; Kearney, P. C.; Marguerettaz, A. M. *J. Org. Chem.* **1987**, *52*, 827−836.

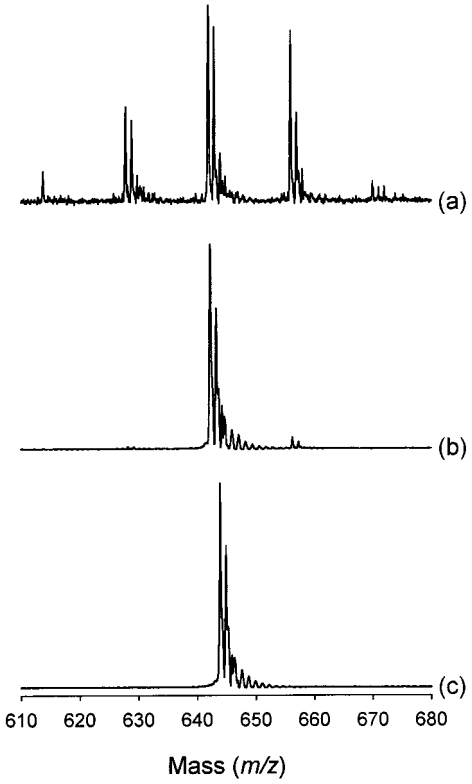
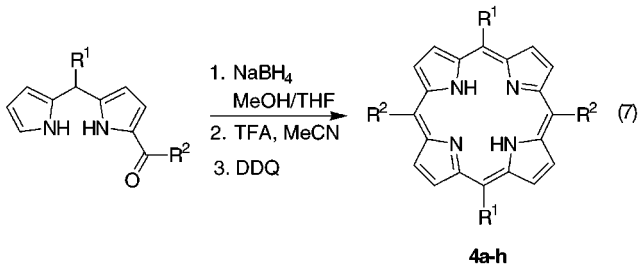


Figure 1. Comparison of the crude porphyrin product distribution formed in the preparation of porphyrin **4a** (*m*/*z* = 642). (a) Condensation of 5-phenyldipyrromethane and *p*-tolualdehyde under standard porphyrin-forming conditions (10 mM dipyrromethane and 10 mM aldehyde in CH_2Cl_2 at room temperature catalyzed by 17.8 mM TFA); extensive scrambling. (b) Condensation of 5-phenyldipyrromethane and *p*-tolualdehyde under low-scrambling conditions;[3] trace scrambling. (c) Self-condensation of carbinol **3a**-OH; no detectable scrambling.

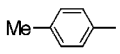
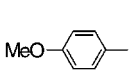
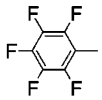
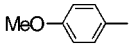
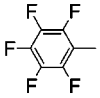
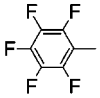
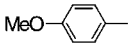
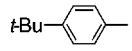
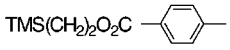
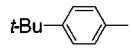
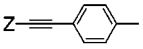
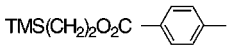
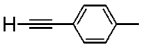
porphyrin yield increased from 9% to 26%. (3) The reaction time decreased from ~4 h to a few min.

Effect of the Electronic Nature of the Substituents. To examine the effect of electron-releasing and electron-withdrawing substituents on the yield and extent of scrambling in the self-condensation reaction, monoacyldipyrromethanes **3h**−**k** were each reduced then immediately self-condensed as described above (eq 7). Despite *p*-anisyl and pentafluorophenyl being extreme examples of electron-releasing and electron-withdrawing groups, respectively, spectroscopic monitoring showed rapid reaction for all cases, and LD-MS analysis of each crude reaction mixture showed a single porphyrin peak, i.e., no scrambling. The byproducts in these reactions were easily removed by filtration first through a pad of alumina then through a pad of silica. This straightforward purification procedure afforded pure samples of porphyrins **4b**−**d** in 16−28% yield.

The data obtained for the four combinations of substituents (**3h**−**k**) reveal higher yields with electron-



4a-h

Monoacyl Dipyrromethane	R^1	R^2	Product	Yield
3a			**4a**	20%
3h			**4b**	28%
3i			**4c**	26%
3j			**4d**	22%
3k			**4b**	16%
3l			**4e**	25%
3m			**4f**	24%
3n (Z = TMS)			**4g** (Z = H)	20%
3o			**4h**	20%

releasing groups in the 5-position and electron-withdrawing groups at the carbinol position. This effect is consistent with the nucleophilic character of the 9-position (α-pyrrole) and the electrophilic character of the carbinol position, which give rise to self-condensation. The effect is clearly illustrated in the self-condensation reactions of **3h**-OH and **3k**-OH. The *p*-anisyl and pentafluorophenyl substituents of **3h**-OH are positioned to enhance the reactivity at both sites engaged in the self-condensation, whereas the same substituents are reversed in **3k**-OH. Both dipyrromethanecarbinols afford the same porphyrin (**4b**), but **3h**-OH gave a yield of 28% compared to 16% for **3k**-OH. The impact on yield of substituent placement in the dipyrromethanecarbinol is modest with the presence of one electronically neutral substituent (phenylcarbinol, **3i**, 26% yield of **4c**) or misplaced substituent (pentafluorophenyl at the 5-position, **3j**, 22% yield of **4d**). These results suggest that attention paid to placement of substituents in the dipyrromethanecarbinols is important for achieving optimal yields of *trans*-porphyrins, but at least within the scope defined by the extreme cases examined, the level of any scrambling is insignificant regardless of choice of substituent placement.

(13) The limit of detection of scrambled porphyrins by LD-MS is approximately 1 part in 100 (see the Experimental Section). Thus, for a *trans*-porphyrin yield of 25%, any putative single scrambled porphyrin (except the *cis*-porphyrin) would be present in no greater than 0.25% yield. Note that the MS method cannot exclude scrambling leading exclusively to the *cis*-porphyrin. However, rearrangement processes leading to such an isomer would be expected to form a distribution of porphyrin products, including those of other masses. See ref 3.

Gram-Scale Preparation of Porphyrins. To establish the preparative value of the self-condensation methodology, we performed the self-condensation on a 20.0 mmol scale using carbinol **3a**-OH derived from monoacyl dipyrromethane **3a**. At this larger scale scrambling was still absent, and filtration of the crude product mixture first through a pad of alumina then through a pad of silica afforded 1.28 g (20% yield) of pure porphyrin **4a**.

The utility of this method has been further explored by the preparation of four *trans*-porphyrins (**4e**−**h**, eq 7) that are useful building blocks in the construction of multiporphyrin arrays.[14−16] In each case, no scrambling was observed, and 0.2−1.2 g batches of the pure porphyrins were readily isolated in 20−25% yield after minimal chromatography. One slight limitation in scope was observed with the TMS-ethyne-substituted monoacyl dipyrromethane **3n**. ^{1}H NMR and LD-MS analysis of the corresponding porphyrin showed loss of some of the TMS protecting groups (presumably during the reduction to give the dipyrromethanecarbinol) and that the initial porphyrin product consisted of a mixture of fully deprotected, partially deprotected, and fully protected porphyrins. Treatment of this mixture with Bu_4NF in THF removed the remaining TMS groups, affording the pure fully deprotected porphyrin **4g**.

A good illustration of the versatility of this methodology is afforded by the synthesis of porphyrin **4h**. This porphyrin bears two free ethynes and two TMS-protected esters; the desire to perform selective chemistry at the ethynes required these groups to be prepared without the typical use of TMS protection. The reaction of dipyrromethane **1f** under our standard conditions with the 4-ethynylbenzothioate **2h** did not afford the desired monoacyl dipyrromethane **3o**. However, the reaction using only 2 mol of ethylmagnesium bromide per mol of dipyrromethane afforded the desired monoacyl dipyrromethane **3o** in 66% yield. The monoacyldipyrromethane underwent reduction and self-condensation in the standard way to afford the diethynyl diester porphyrin **4h** in 20% yield.

Conclusion

Methods for the synthesis of *trans*-porphyrins have evolved from the use of statistical condensations of pyrrole and two aldehydes affording a mixture of six porphyrins, to the more recent condensations of one dipyrromethane and one aldehyde. The latter route has been plagued by acid-catalyzed scrambling affording a mixture of porphyrins, from which small quantities of porphyrins are typically obtained by elaborate chromatography. Recently identified nonscrambling condensation conditions suitable for dipyrromethanes bearing a sterically hindered aryl group (e.g., mesityl) afford gram quantities of *trans*-porphyrins with minimal chromatography, but dipyrromethanes bearing an unhindered aryl group give low yields (<10%) and some scrambling under these conditions. The methodology described herein enables the preparation of sterically unhindered *trans*-porphyrins with no detectable scrambling. The methodology entails a concise series of reactions (dipyrromethane preparation, monoacylation, reduction to the carbinol, and self-condensation of the dipyrromethanecarbinol) that can be implemented to give gram quantities of the desired porphyrin. This approach now completes a set of synthetic methods that should allow the preparation of a wide variety of meso-substituted *trans*-porphyrins via straightforward synthetic methods that require minimal chromatography.

Experimental Section

General Methods. ^{1}H (300 MHz, $CDCl_3$) and absorption spectra were collected routinely. Elemental analyses were performed by Atlantic MicroLab, Inc. Melting points are uncorrected. Bulb-to-bulb distillation was performed using a standard-size Kugelrohr short-path distillation apparatus (Aldrich). Dipyrromethanes **1a**−**d** were prepared as described previously.[5] Column chromatography was performed on silica (Baker, 40 μm average particle size) and alumina (Fisher, 80−200 mesh). The dipyrromethanes were examined by GC analysis as described previously.[5]

For monoacylation and Pd-coupling reactions, THF was distilled from Na/benzophenone. All other chemicals are reagent grade and were used as obtained. Unless otherwise indicated, all reagents were obtained from Aldrich Chemical Co., and all solvents were obtained from Fisher Scientific. The dipyrromethanes, monoacyldipyrromethanes, and their corresponding carbinols were easily visualized upon exposure of TLC plates to Br_2 vapor.

Porphyrins (from crude reaction mixtures, or following purification) were analyzed by laser desorption ionization mass spectrometry (LD-MS) without a matrix[17] using a Bruker Proflex II spectrometer. The progress of the porphyrin forming reactions was monitored spectroscopically, and the extent of scrambling in the crude reaction mixture determined as described previously.[3]

Determination of Limit of Detection of Scrambled Porphyrins by LD-MS Analysis. Various ratios (300:1, 100:1, 30:1, 10:1, 3:1, 1:1, 1:3, 1:10, 1:30, 1:100, 1:300) of tetraphenylporphyrin (TPP) and tetra-*p*-tolylporphyrin (TTP) were prepared by mixing appropriate quantities of each porphyrin. Porphyrin solutions of 1 or 0.01 mM in CH_2Cl_2 were used. The TPP/TTP mixtures were analyzed by LD-MS as described above (see the Supporting Information).

5-(4-*tert*-Butylphenyl)dipyrromethane (1e). A sample of TFA (1.61 mL, 20.8 mmol) was added to a stirred solution of 4-*tert*-butylbenzaldehyde (33.8 g, 208 mmol) in pyrrole (362 mL, 5.21 mol) under Ar. The solution was stirred for 5 min, and then 0.1 M NaOH was added. The mixture was then poured into brine and ethyl acetate. The organic phase was isolated, washed with water, and then dried (Na_2SO_4) and the solvent removed to afford a brown solid. Trituration of the solid with hexanes followed by filtration afforded a colorless powder. Recrystallization [ethanol/water (20:1)] afforded colorless crystals (22.0 g, 38%): mp 160 °C; ^{1}H NMR δ 1.30 (s, 9 H), 5.45 (s, 1 H), 5.94 (m, 2 H), 6.15 (q, J = 2.9 Hz, 2 H), 6.68 (m, 2 H), 7.14 (m, 2 H), 7.33 (m, 2 H), 7.90 (br s, 2 H). Anal. Calcd for $C_{19}H_{22}N_2$: C, 81.97; H, 7.97; N, 10.06. Found: C, 81.80; H, 7.99; N, 10.04.

5-[4-[2-(Trimethylsilyl)ethoxycarbonyl]phenyl]dipyrromethane (1f). A sample of TFA (154 μL, 2.00 mmol) was added to a stirred solution of 4-[2-(trimethylsilyl)ethoxycarbonyl]benzaldehyde[14] (5.0 g, 20 mmol) in pyrrole (35 mL, 0.50 mol) under Ar. The solution was stirred for 5 min, and then 0.1 M NaOH, ethyl acetate, and brine were added. The

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(15) Ravikanth, M.; Strachan, J.-P.; Li, F.; Lindsey, J. S. *Tetrahedron* **1998**, *54*, 7721−7734.

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organic phase was washed with water and then dried (Na_2SO_4) and the solvent removed. The residue was dissolved in CH_2Cl_2 and filtered through a pad of silica gel (CH_2Cl_2) to remove higher weight oligomers. Recrystallization (CH_2Cl_2/hexanes) of the resulting tan solid afforded colorless crystals (4.11 g, 56%): mp 108 °C; ^{1}H NMR δ 0.06 (s, 9 H), 1.12 (dd, J = 9.0, 7.8 Hz, 2 H), 4.40 (m, 2 H), 5.53 (s, 1 H), 5.89 (m, 2 H), 6.16 (m, 2 H), 6.72 (m, 2 H), 7.28 (d, J = 8.1 Hz, 2 H), 7.98 (d, J = 8.1 Hz, 2 H), 7.98 (br s, 2 H). Anal. Calcd for $C_{21}H_{26}N_2O_2Si$: C, 68.81; H, 7.15; N, 7.64. Found: C, 68.70; H, 7.20; N, 7.68.

General Procedure for the Preparation of an *S*-Pyridyl Thioester from 2-Mercaptopyridine and an Acid Chloride. *S*-2-Pyridyl 4-methylbenzothioate (2a). A solution of *p*-toluoyl chloride (6.61 mL, 50.0 mmol) in CH_2Cl_2 (100 mL) was added over 10 min to a stirred solution of 2-mercaptopyridine (5.56 g, 50.0 mmol) in CH_2Cl_2 (250 mL). After a further 60 min, 2 N NaOH was added. The organic phase was isolated, washed with water, and then dried (Na_2SO_4) and the solvent removed to afford a yellow oil. The oil was dissolved in a minimum volume of ethyl acetate and precipitated with hexanes. Filtration afforded colorless crystals (8.34 g, 73%): mp 62 °C; ^{1}H NMR δ 2.44 (s, 3 H), 7.26−7.35 (m, 3 H), 7.73−7.79 (m, 2 H), 7.91 (d, J = 8.1 Hz, 2 H), 8.67 (m, 1 H). Anal. Calcd for $C_{13}H_{11}NOS$: C, 68.10; H, 4.84; N, 6.11. Found: C, 68.16; H, 4.83; N, 6.16.

***S*-2-Pyridyl 4-benzothioate (2b).** Condensation of benzoyl chloride (5.60 g, 40.0 mmol) and 2-mercaptopyridine (4.44 g, 40.0 mmol) as described for **2a** afforded colorless crystals (6.45 g, 75%). Spectral data of **2b** were identical to those reported.[8,18]

***S*-2-Pyridyl Pentafluorobenzothioate (2c).** Condensation of pentafluorobenzoyl chloride (1.3 mL, 9.0 mmol) and 2-mercaptopyridine (1.0 g, 9.0 mmol) as described for **2a** gave a pale yellow solid that turned brown when stored above 0 °C. Recrystallization from hexanes gave brown crystals (2.07 g, 75%): mp 48−51 °C; ^{1}H NMR δ 7.36−7.40 (m, 1 H), 7.74−7.85 (m, 2 H), 8.67−8.69 (m, 1 H). Anal. Calcd for $C_{12}H_4F_5NOS$: C, 47.22; H, 1.32; N, 4.59. Found: C, 47.22; H, 1.34; N, 4.51.

***S*-2-Pyridyl 4-Methoxybenzothioate (2d).** Condensation of 4-methoxybenzoyl chloride (6.82 g, 40.0 mmol) and 2-mercaptopyridine (4.44 g, 40.0 mmol) as described for **2a**, except that recrystallization was from ether/hexanes, afforded colorless crystals (7.06 g, 72%): mp 73 °C; ^{1}H NMR δ 3.87 (s, 3 H), 6.97 (m, 2 H), 7.33 (m, 1 H), 7.76 (m, 2 H), 8.00 (m, 2 H), 8.67 (d, J = 2.7 Hz, 1 H). Anal. Calcd for $C_{13}H_{11}NO_2S$: C, 63.65; H, 4.52; N, 5.71. Found: C, 63.81; H, 4.42; N, 5.66.

***S*-2-Pyridyl 3-Iodobenzothioate (2e).** Condensation of 3-iodobenzoyl chloride[19] (10.6 g, 40.0 mmol) and 2-mercaptopyridine (4.44 g, 40.0 mmol) as described for **2a**, except that recrystallization was from ether/hexanes, afforded colorless needles (11.6 g, 85%): mp 55 °C; ^{1}H NMR δ 7.24 (m, 1 H), 7.33−7.38 (m, 1 H), 7.69−7.72 (m, 1 H), 7.77−7.83 (m, 1 H), 7.93−8.00 (m, 2 H), 8.32 (m, 1 H), 8.68 (m, 1 H). Anal. Calcd for $C_{13}H_{11}NO_2S$: C, 42.25; H, 2.36; N, 4.11. Found: C, 42.24; H, 2.36; N, 4.17.

***S*-2-Pyridyl 4-Iodobenzothioate (2f).** Condensation of 4-iodobenzoyl chloride (2.66 g, 10.0 mmol) and 2-mercaptopyridine (1.11 g, 10.0 mmol) as described for **2a**, except that recrystallization was from ether/hexanes, afforded colorless needles (3.10 g, 91%): mp 128 °C; ^{1}H NMR δ 7.33−7.37 (m, 1 H), 7.70−7.88 (m, 6 H), 8.68 (m, 1 H). Anal. Calcd for $C_{13}H_{11}NO_2S$: C, 42.25; H, 2.36; N, 4.11. Found: C, 42.23; H, 2.35; N, 4.12.

***S*-2-Pyridyl 4-[2-(Trimethylsilyl)ethynyl]benzothioate (2g).** A mixture of **2f** (6.82 g, 20.0 mmol), $Pd(PPh_3)_2Cl_2$ (0.42 g, 0.60 mmol, 3 mol %), and CuI (380 mg, 2.00 mmol, 10 mol %) was placed in a Schlenk flask. The flask was pump-filled with Ar three times, and then a degassed mixture of THF (60 mL) and *N*,*N*-diisopropylethylamine (20 mL) was added followed by trimethylsilylacetylene (4.24 mL, 30.0 mmol). The flask was sealed tightly and then heated for 24 h at 60 °C. After being cooled to room temperature, the solution was gravity filtered, and the solid residue was washed with CH_2Cl_2. The filtrate was washed with water and dried (Na_2SO_4) and the solvent removed. Purification by flash column chromatography [silica; hexanes/ethyl acetate (4:1)] afforded pale yellow crystals. Recrystallization (ethyl acetate) afforded colorless crystals (3.53 g, 57%): mp 105 °C; ^{1}H NMR δ 0.25 (s, 9 H), 7.34 (m, 1 H), 7.56 (d, J = 8.1 Hz, 2 H), 7.70−7.82 (m, 2 H), 7.95 (d, J = 8.1 Hz, 2 H), 8.68 (m, 1 H). Anal. Calcd for $C_{17}H_{17}NOSSi$: C, 65.55; H, 5.50; N, 4.50. Found: C, 65.48; H, 5.44; N, 4.50.

***S*-2-Pyridyl 4-Ethynylbenzothioate (2h).** A solution of 4-ethynylbenzoic acid[20] (1.11 g, 7.50 mmol), 2,2′-dipyridyl disulfide (3.30 g, 15.0 mmol), and triphenylphosphine (3.93 g, 15.0 mmol) in anhydrous THF (20 mL) was stirred for 24 h at room temperature under Ar. Removal of the solvent followed by purification by column chromatography [silica; ethyl acetate/hexanes (1:3)] afforded colorless crystals (1.2 g, 67%): mp 102 °C; ^{1}H NMR δ 3.28 (s, 1H), 7.35 (m, 1H), 7.59 (m, 2 H), 7.71−7.83 (m, 2 H), 7.97 (m, 2 H), 7.69 (m, 1 H). Anal. Calcd for $C_{14}H_9NOS$: C, 70.27; H, 3.79; N, 5.85. Found: C, 69.82; H, 3.87; N, 5.82.

***S*-2-Pyridyl 4-Acetamidobenzothioate (2i).** A suspension of 4-acetamidobenzoic acid (3.58 g, 20.0 mmol), 2,2′-dipyridyl disulfide (6.60 g, 30.0 mmol), and triphenylphosphine (7.87 g, 30.0 mmol) in anhydrous THF (100 mL) was stirred for 24 h at room temperature under Ar. Removal of the solvent followed by purification by column chromatography [silica; CH_2Cl_2/methanol (20:1)] afforded colorless needles (3.78 g, 65%): mp 155 °C; ^{1}H NMR δ 2.21 (s, 3 H), 7.34 (m, 1 H), 7.63 (d, J = 8.1 Hz, 2 H), 7.63 (br s, 1 H), 7.70−7.82 (m, 2 H), 7.97 (d, J = 8.1 Hz, 2 H), 8.67 (m, 1 H). Anal. Calcd for $C_{14}H_{12}N_2O_2S$: C, 61.75; H, 4.44; N, 10.29. Found: C, 61.77; H, 4.40; N, 10.22.

General Procedure for the Monoacylation of Dipyrromethanes. 1-(*p*-Toluoyl)-5-phenyldipyrromethane (3a). A solution of EtMgBr (25 mL, 25 mmol, 1.0 M in THF) was carefully added via syringe to a stirred solution of 5-phenyldipyrromethane (**1a**) (2.22 g, 10.0 mmol) in THF (10 mL) under Ar. The mixture was stirred at room temperature for 10 min and then cooled to −78 °C. A solution of (*p*-toluoyl)pyridyl thioester (**2a**) (2.29 g, 10.0 mmol) in THF (10 mL) was then added over 1 min. The solution was maintained at −78 °C for 10 min, and then the cooling bath was removed. TLC [silica; CH_2Cl_2/ethyl acetate (25:1)] showed complete consumption of the pyridyl thioester after 15 min, so the reaction was quenched with saturated aqueous NH_4Cl. The mixture was allowed to warm to room temperature, poured into CH_2Cl_2, washed with water, and then dried (Na_2SO_4) and the solvent removed to afford a dark foam. Purification by flash column chromatography [silica; neat CH_2Cl_2 to CH_2Cl_2/ethyl acetate (100:3)] afforded a golden amorphous solid (2.79 g, 82%). Analytical data were identical to those previously reported.[6]

1-(4-Iodobenzoyl)-5-phenyldipyrromethane (3b). A solution of **1a** (1.11 g, 5.00 mmol) in THF (80 mL) was treated with EtMgBr (10 mL, 10 mmol, 1.0 M in THF) and a solution of **2f** (1.70 g, 5.00 mmol) in THF (10 mL) as described for **3a**. The reaction was quenched for 1 h after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/:hexanes (1:4)] followed by precipitation from ether/hexanes afforded a tan solid (1.70 g, 74%): mp 138 °C; ^{1}H NMR δ 5.54 (s, 1 H), 5.98 (m, 1 H), 6.09 (m, 1 H), 6.15 (m, 1 H), 6.67 (m, 1 H), 6.76 (m, 1 H), 7.18−7.33 (m, 5 H), 7.51 (d, J = 9.0 Hz, 2 H), 7.80 (d, J = 9.0 Hz, 2 H), 8.14 (br s, 1 H), 9.76 (br s, 1 H). Anal. Calcd for $C_{22}H_{17}IN_2O$: C, 58.42; H, 3.79; N, 6.19. Found: C, 58.56; H, 3.77; N, 6.14.

1-(4-Iodobenzoyl)-5-(4-methoxyphenyl)dipyrromethane (3c). A solution of **1b** (1.26 g, 5.00 mmol) in THF (80 mL) was treated with EtMgBr (10 mL, 10 mmol, 1.0 M in THF) and a solution of **2f** (1.70 g, 5.00 mmol) in THF (10 mL) as described for **3a**. The reaction was quenched for 1 h after

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removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] afforded a pale brown foamlike solid (1.82 g, 75%): mp 68 °C; ^{1}H NMR δ 3.79 (s, 3 H), 5.48 (s, 1 H), 5.97 (m, 1 H), 6.08 (m, 1 H), 6.17 (m, 1 H), 6.70 (m, 1 H), 6.76 (m, 1 H), 6.85 (m, 2 H), 7.12 (m, 2 H), 7.55 (m, 2 H), 7.81 (m, 2 H), 8.04 (br s, 1 H), 9.50 (br s, 1 H). Anal. Calcd for $C_{22}H_{17}IN_2O$: C, 57.28; H, 3.97; N, 5.81. Found: C, 57.16; H, 3.96; N, 5.75.

1-(4-Iodobenzoyl)-5-(pentafluorophenyl)dipyrromethane (3d). A solution of **1c** (0.94 g, 3.0 mmol) in THF (50 mL) was treated with EtMgBr (6.0 mL, 6.0 mmol, 1.0 M in THF) and a solution of **2f** (1.02 g, 3.00 mmol) in THF (6 mL) as described for **3a**. The reaction was quenched for 1 h after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] afforded a tan solid (1.14 g, 70%): mp 208 °C; ^{1}H NMR δ 5.92 (s, 1 H), 6.18 (m, 1 H), 6.20−6.25 (m, 2 H), 6.76−6.80 (m, 2 H), 7.58 (m, 2 H), 7.84 (m, 2 H), 8.25 (br s, 1 H), 9.33 (br s, 1 H). Anal. Calcd for $C_{22}H_{12}F_5IN_2O$: C, 48.73; H, 2.23; N, 5.17. Found: C, 49.15; H, 2.45; N, 5.04.

1-(4-Iodobenzoyl)-5-mesityldipyrromethane (3e). A solution of **1d** (0.79 g, 3.0 mmol) in THF (50 mL) was treated with EtMgBr (6.0 mL, 6.0 mmol, 1.0 M in THF) and a solution of **2f** (1.02 g, 3.00 mmol) in THF (6 mL) as described for **3a**. The reaction was quenched for 1 h after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] afforded an off-white solid (1.12 g, 71%): mp 163 °C; ^{1}H NMR δ 2.08 (s, 6 H), 2.29 (s, 3 H), 5.94 (s, 1 H), 6.13 (m, 2 H), 6.69 (m, 1 H), 6.79 (m, 1 H), 6.89 (s, 2 H), 7.57 (m, 2 H), 7.83 (m, 3 H), 9.25 (br s, 1 H). Anal. Calcd for $C_{25}H_{23}IN_2O$: C, 60.74; H, 4.69; N, 5.67. Found: C, 60.43; H, 4.53; N, 5.42.

1-[4-[2-(Trimethylsilyl)ethynyl]benzoyl]-5-phenyldipyrromethane (3f). A solution of **1a** (0.89 g, 4.0 mmol) in THF (65 mL) was treated with EtMgBr (8.0 mL, 8.0 mmol, 1.0 M in THF) and a solution of **2g** (1.25 g, 4.00 mmol) in THF (8 mL) as described for **3a**. The reaction was quenched for 1 h after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] followed by precipitation from ether/hexanes afforded a yellowish foamlike solid (1.10 g, 65%): mp 168 °C; ^{1}H NMR δ 0.26 (s, 9 H), 5.54 (s, 1 H), 5.98 (m, 1 H), 6.08 (m, 1 H), 6.15 (m, 1 H), 6.70 (m, 1 H), 6.77 (m, 1 H), 7.20−7.35 (m, 5 H), 7.53 (d, J = 8.1 Hz, 2 H), 7.76 (d, J = 8.1 Hz, 2 H), 8.05 (br s, 1 H), 9.45 (br s, 1 H). Anal. Calcd for $C_{27}H_{26}N_2OSi$: C, 76.74; H, 6.20; N, 6.63. Found: C, 76.73; H, 6.23; N, 6.65.

1-[4-[2-(Trimethylsilyl)ethynyl]benzoyl]-5-(4-methoxyphenyl)dipyrromethane (3g). A solution of **1b** (1.0 g, 4.0 mmol) in THF (65 mL) was treated with EtMgBr (8.0 mL, 8.0 mmol, 1.0 M in THF) and a solution of **2g** (1.25 g, 4.00 mmol) in THF (8 mL) as described for **3a**. The reaction was quenched for 1 h after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] afforded a yellow solid (1.31 g, 72%): mp 150 °C; ^{1}H NMR δ 0.26 (s, 9 H), 3.79 (s, 3 H), 5.49 (s, 1 H), 5.97 (s, 1 H), 6.07 (m, 1 H), 6.17 (m, 1 H), 6.71 (m, 1 H), 6.77 (m, 1 H), 6.87 (m, 2 H), 7.13 (m, 2 H), 7.53 (d, J = 8.1 Hz, 2 H), 7.77 (d, J = 8.1 Hz, 2 H), 8.01 (br s, 1 H), 9.45 (br s, 1 H). Anal. Calcd for $C_{28}H_{28}N_2O_2Si$: C, 74.30; H, 6.24; N, 6.19. Found: C, 74.36; H, 6.28; N, 6.18.

1-(Pentafluorobenzoyl)-5-(4-methoxyphenyl)dipyrromethane (3h). A solution of **1b** (1.0 g, 4.0 mmol) in THF (4 mL) was treated with EtMgBr (10 mL, 10 mmol, 1.0 M in THF) and a solution of **2c** (1.22 g, 4.00 mmol) in THF (4 mL) as described for **3a**. The reaction was quenched for 30 min after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] afforded an off-white amorphous solid (0.80 g, 65%): mp 50 °C; ^{1}H NMR δ 3.79 (s, 3 H), 5.49 (s, 1 H), 5.98 (m, 1 H), 6.10 (m, 1 H), 6.17 (m, 1 H), 6.64 (m, 1 H), 6.72 (m, 1 H), 6.86 (d, J = 8.1 Hz, 2 H), 7.10 (d, J = 8.1 Hz, 2 H), 8.04 (br s, 1 H), 9.64 (br s, 1 H). Anal. Calcd for $C_{23}H_{15}F_5N_2O_2$: C, 61.89; H, 3.39; N, 6.28. Found: C, 62.17; H, 3.63; N, 6.17.

1-Benzoyl-5-(4-methoxyphenyl)dipyrromethane (3i). A solution of **1b** (1.26 g, 5.00 mmol) in THF (5 mL) was treated with EtMgBr (12.5 mL, 12.5 mmol, 1.0 M in THF) and a solution of **2b** (1.08 g, 5.00 mmol) in THF (5 mL) as described for **3a**. The reaction was quenched for 30 min after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:3)] afforded a pink amorphous solid (1.26 g, 76%): mp 147 °C dec; ^{1}H NMR δ 3.75 (s, 3 H), 5.53 (s, 1 H), 5.99 (m, 1 H), 6.13 (m, 2 H), 6.63 (m, 1 H), 6.76 (d, J = 8.1 Hz, 2 H), 6.81 (m, 1 H), 7.08 (d, J = 8.1 Hz, 2 H), 7.43−7.55 (m, 3 H), 7.78 (m, 2 H), 8.57 (br s, 1 H), 10.43 (br s, 1 H). Anal. Calcd for $C_{23}H_{20}N_2O_2$: C, 77.51; H, 5.66; N, 7.86. Found: C, 77.79; H, 5.65; N, 7.92.

1-Benzoyl-5-(pentafluorophenyl)dipyrromethane (3j). A solution of **1c** (1.28 g, 4.00 mmol) in THF (4 mL) was treated with EtMgBr (10 mL, 10 mmol, 1.0 M in THF) and a solution of **2b** (0.86 g, 4.0 mmol) in THF (4 mL) as described for **3a**. The reaction was quenched for 30 min after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:3)] followed by precipitation from ether/hexanes afforded a brown amorphous solid (1.26 g, 71%): mp 148 °C; ^{1}H NMR δ 5.93 (s, 1 H), 6.06−6.07 (m, 2 H), 6.12 (m, 1 H), 6.67 (m, 1 H), 6.79 (m, 1 H), 7.43−7.58 (m, 3 H), 7.82 (d, J = 6.3 Hz, 2 H), 8.51 (br s, 1 H), 10.31 (br s, 1 H). Anal. Calcd for $C_{22}H_{13}F_5N_2O$: C, 63.47; H, 3.15; N, 6.73. Found: C, 63.62; H, 3.15; N, 6.68.

1-(4-Methoxybenzoyl)-5-(pentafluorophenyl)dipyrromethane (3k). A solution of **1c** (1.28 g, 4.00 mmol) in THF (4 mL) was treated with EtMgBr (10 mL, 10 mmol, 1.0 M in THF) and a solution of **2d** (1.0 g, 4.0 mmol) in THF (4 mL) as described for **3a**. The reaction was quenched for 30 min after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] afforded a pink amorphous solid (1.30 g, 73%): mp 67 °C; ^{1}H NMR δ 3.87 (s, 3 H), 5.92 (s, 1 H), 6.04−6.15 (m, 3 H), 6.70 (m, 1 H), 6.78 (m, 1 H), 6.97 (m, 2 H), 7.87 (m, 2 H), 8.48 (br s, 1 H), 10.23 (br s, 1 H). Anal. Calcd for $C_{23}H_{15}F_5N_2O_2$: C, 61.89; H, 3.39; N, 6.28. Found: C, 61.60; H, 3.41; N, 6.26.

1-(3-Iodobenzoyl)-5-(4-*tert*-butylphenyl)dipyrromethane (3l). A solution of **1e** (279 mg, 1.00 mmol) in THF (1.0 mL) was treated with EtMgBr (2.5 mL, 2.5 mmol, 1.0 M in THF) and a solution of **2e** (341 mg, 1.00 mmol) in THF (1.0 mL) as described for **3a**. The reaction was quenched for 20 min after removal of the cooling bath. Purification of the crude reaction product by flash column chromatography [silica; CH_2Cl_2/hexanes (2:1) to neat CH_2Cl_2] afforded a pale yellow amorphous solid (360 mg, 71%): mp 79 °C dec; ^{1}H NMR δ 1.30 (s, 9 H), 5.52 (s, 1 H), 6.01 (m, 1 H), 6.12 (m, 1 H), 6.17 (q, J = 2.9 Hz, 1 H), 6.71 (m, 1 H), 6.78 (dd, J = 3.7 and 2.2 Hz, 1 H), 7.13 (d, J = 8.1 Hz, 2 H), 7.17−7.22 (m, 1 H), 7.33 (d, J = 8.1 Hz, 2 H), 7.76 (m, 1 H), 7.86 (m, 1 H), 8.08 (br s, 1 H), 8.14 (m, 1 H), 9.57 (br s, 1 H). Anal. Calcd for $C_{26}H_{25}IN_2O$: C, 61.42; H, 4.96; N, 5.51. Found: C, 61.35; H, 4.93; N, 5.43.

1-(3-Iodobenzoyl)-5-[4-[2-(trimethylsilyl)ethoxycarbonyl]phenyl]dipyrromethane (3m). A solution of **1f** (3.66 g, 10.0 mmol) in THF (10 mL) was treated with EtMgBr (25 mL, 25 mmol, 1.0 M in THF) and a solution of **2e** (3.41 g, 10.0 mmol) in THF (15 mL) as described for **3a**. The reaction was quenched for 30 min after removal of the cooling bath. Purification by flash column chromatography [silica; ethyl acetate/hexanes (1:3)] followed by precipitation from ether/hexanes afforded a tan solid (4.05 g, 68%): mp 146−147 °C; ^{1}H NMR δ 0.08 (s, 9 H), 1.12 (t, J = 9.0 Hz, 2 H), 4.41 (m, 2 H), 5.59 (s, 1 H), 5.97 (m, 1 H), 6.06 (m, 1 H), 6.18 (m, 1 H), 6.74 (m, 1 H), 6.79 (m, 1 H), 7.18−7.30 (m, 3 H), 7.78 (d, J = 8.1 Hz, 1 H), 7.87 (d, J = 8.1 Hz, 1 H), 8.00 (d, J = 8.1 Hz, 2 H), 8.10 (br s, 1 H), 8.15 (s, 1 H), 9.51 (br m, 1 H). Anal. Calcd for $C_{28}H_{29}IN_2O_3Si$: C, 56.38; H, 4.90; N, 4.70. Found: C, 56.33; H, 4.86; N, 4.84.

1-[4-[2-(Trimethylsilyl)ethynyl]benzoyl]-5-(4-*tert*-butylphenyl)dipyrromethane (3n). A solution of **1e** (2.79 g, 10.0 mmol) in THF (10 mL) was treated with EtMgBr (25.0 mL, 25.0 mmol, 1.0 M in THF) and a solution of **2g** (3.11 g, 10.0 mmol) in THF (10 mL, 1.0 M) as described for **3a**. The reaction was quenched for 5 min after removal of the cooling bath. Purification of the crude reaction product by flash column chromatography [silica; CH_2Cl_2 (neat)] a pale yellow amor-

phous solid (3.63 g, 76%): mp 99 °C dec; ^{1}H NMR δ 0.27 (s, 9 H), 1.30 (s, 9 H), 5.52 (s, 1 H), 6.00 (m, 1 H), 6.12 (m, 1 H), 6.16 (m, 1 H), 6.68 (m, 1 H), 6.77 (m, 1 H), 7.12 (d, J = 8.1 Hz, 2 H), 7.32 (d, J = 8.1 Hz, 2 H), 7.53 (d, J = 8.1 Hz, 2 H), 7.74 (d, J = 8.1 Hz, 2 H), 8.16 (br s, 1 H), 9.73 (br m, 1 H). Anal. Calcd for $C_{31}H_{34}N_2OSi$: C, 77.78; H, 7.16; N, 5.85. Found: C, 77.83; H, 7.16; N, 5.92.

1-(4-Ethynylbenzoyl)-5-{4-[2-(trimethylsilyl)ethoxycarbonyl]phenyl}dipyrromethane (3o). A solution of **1f** (1.46 g, 3.98 mmol) in THF (10 mL) was treated with EtMgBr (8.0 mL, 8.0 mmol, 1.0 M in THF) and a solution of **2h** (0.96 g, 4.0 mmol) in THF (4 mL, 1.0 M) as described for **3a**. The reaction was quenched for 30 min after removal of the cooling bath. Purification of the crude reaction product by flash column chromatography [silica; ethyl acetate/hexanes (1:4)] furnished a grayish amorphous solid (1.3 g, 66%): mp 173−174 °C; ^{1}H NMR δ 0.08 (s, 9H), 1.13 (m, 2 H), 3.22 (s, 1 H), 4.41 (t, J = 8.1 Hz, 2 H), 5.59 (s, 1 H), 5.97 (m, 1 H), 6.05 (m, 1 H), 6.18 (m, 1 H), 6.73 (m, 1 H), 6.79 (m, 1 H), 7.28 (d, J = 8.1 Hz, 2 H), 7.57 (d, J = 8.1 Hz, 2 H), 7.78 (m, 2 H), 7.99 (m, 2 H), 8.09 (br s, 1 H), 9.55 (br s, 1 H). Anal. Calcd for $C_{30}H_{30}N_2O_3Si$: C, 72.84; H, 6.11; N, 5.66. Found: C, 72.79; H, 6.11; N, 5.53.

General Procedure for Porphyrin Formation: 5,15-Di-*p*-tolyl-10,20-diphenylporphyrin (4a). A sample of $NaBH_4$ (18.9 g total, 0.50 mol, 25 molar equiv) was carefully added in small portions (~5 g each every 5 min) to a stirred solution of 1-(*p*-toluoyl)-5-phenyldipyrromethane (**3a**, 6.81 g, 20.0 mmol) in THF/methanol (3:1, 400 mL). The progress of the reduction was followed by TLC [alumina, hexanes/ethyl acetate (9:1)]. The reaction was complete after 20 min, so the reaction mixture was quenched with water (800 mL) and then poured into CH_2Cl_2 (800 mL). The organic phase was isolated, washed with water (2 × 800 mL), and then dried (K_2CO_3) and the solvent removed to afford the carbinol as an orange oil.

The carbinol (~20.0 mmol) was immediately dissolved in 4.00 L of acetonitrile, and TFA (9.24 mL, 120 mmol, 30 mM) was added. The solution instantly darkened and the reaction was monitored by UV spectroscopy. After 3 min, the spectroscopic yield of porphyrin had essentially leveled off, and then DDQ (9.08 g, 40.0 mmol) was added and the mixture stirred at room temperature for 1 h. Then triethylamine (16.7 mL, 120 mmol) was added, and the entire reaction mixture was then filtered through a pad of alumina (eluted with CH_2Cl_2) until the eluant was no longer dark. Removal of the solvent gave a dark solid that was fully redissolved in CH_2Cl_2 (~500 mL) and filtered through a pad of silica (eluted with CH_2Cl_2) to afford a purple solid (1.28 g, 20% from **3a**): $C_{46}H_{34}N_4$ calcd mass 642.3, obsd 643.8 (LD-MS). ^{1}H NMR data were identical to those previously reported.[3]

5,10-Bis(4-methoxyphenyl)-10,20-bis(pentafluorophenyl)porphyrin (4b). Monoacyldipyrromethane **3h** (223 mg, 0.499 mmol) was reduced and then self-condensed as described for **4a** to afford a purple solid (60 mg, 28%): ^{1}H NMR δ −2.81 (br s, 2 H), 4.10 (s, 6 H), 7.31 (d, J = 8.7 Hz, 4 H), 8.13 (d, J = 8.7 Hz, 4 H), 8.79 (d, J = 5.1 Hz, 4 H), 8.92 (d, J = 5.1 Hz, 4 H); $C_{46}H_{24}F_{10}N_4O_2$ calcd mass 854.2, obsd 854.9 (LD-MS); calcd exact mass 855.1818 (MH^+), obsd 855.1794 (MH^+) (FAB-MS). Similarly, monoacyl dipyrromethane **3k** (223 mg, 0.499 mmol) afforded **4b** (33 mg, 16%).

5,10-Bis(4-methoxyphenyl)-10,20-diphenylporphyrin (4c). Monoacyldipyrromethane **3i** (0.18 g, 0.50 mmol) was reduced and then self-condensed as described for **4a** to afford a purple solid (41 mg, 26%): ^{1}H NMR δ −2.76 (br s, 2 H), 4.09 (s, 6 H), 7.28 (d, J = 8.7 Hz, 4 H), 7.72−7.78 (m, 6 H), 8.13 (d, J = 8.7 Hz, 4 H), 8.21 (m, 4 H), 8.85 (m, 8 H); $C_{46}H_{34}N_4O_2$ calcd mass 674.3, obsd 674.7 (LD-MS); calcd exact mass 675.2760 (MH^+), obsd 675.2768 (MH^+) (FAB-MS).

5,10-Bis(pentafluorophenyl)-10,20-diphenylporphyrin (4d). Monoacyldipyrromethane **3j** (208 mg, 0.500 mmol) was reduced and then self-condensed as described for **4a** to afford a purple solid (43 mg, 22%): ^{1}H NMR δ −2.84 (br s, 2 H), 7.80 (m, 6 H), 8.21 (dd, J = 7.2 and 1.5 Hz, 4 H), 8.80 (d, J = 4.5 Hz, 4 H), 8.95 (d, J = 4.5 Hz, 4 H); $C_{44}H_{20}F_{10}N_4$ calcd mass 794.2, obsd 794.5 (LD-MS); calcd exact mass 795.1607 (MH^+), obsd 795.1627 (MH^+) (FAB-MS).

5,15-Bis(4-*tert*-butylphenyl)-10,20-bis(3-iodophenyl)-porphyrin (4e). Monoacyldipyrromethane **3l** (5.08 g, 10.0 mmol) was reduced and then self-condensed as described for **4a** to afford a purple solid (1.21 g, 25%): ^{1}H NMR δ −2.80 (br s, 2 H), 1.63 (s, 18 H), 7.48−7.53 (m, 2 H), 7.79 (d, J = 8.1 Hz, 4 H), 8.13−8.22 (m, 8 H), 8.61 (m, 2 H), 8.83 (m, 4 H), 8.93 (m, 4 H); $C_{52}H_{44}I_2N_4$ calcd mass 978.2, obsd 980.5 (LD-MS); calcd exact mass 979.1734 (MH^+), obsd 979.1734 (MH^+) (FAB-MS).

5,15-Bis(3-iodophenyl)-10,20-bis[4-[2-(trimethylsilyl)-ethoxycarbonyl]phenyl]porphyrin (4f). Monoacyldipyrromethane **3m** (3.9 g, 6.5 mmol) was reduced and then self-condensed as described for **4a** to afford a purple solid (0.90 g, 24%): ^{1}H NMR δ −2.86 (br s, 2 H), 0.18 (s, 18 H), 1.30 (t, J = 7.8 Hz, 4 H), 4.61 (t, J = 7.8 Hz, 4 H), 7.49 (m, 2 H), 8.15 (m, 4 H), 8.28 (d, J = 7.8 Hz, 4 H), 8.45 (d, J = 7.8 Hz, 4 H), 8.58 (s, 2 H), 8.84 (m, 8 H); $C_{56}H_{52}I_2N_4O_4Si_2$ calcd mass 1154.2, obsd 1157.9 (LD-MS); calcd exact mass 1155.1695 (MH^+), obsd 1155.1699 (MH^+) (FAB-MS).

5,15-Bis(4-*tert*-butylphenyl)-10,20-bis(4-ethynylphenyl)-porphyrin (4g). Monoacyldipyrromethane **3n** (3.83 g, 8.00 mmol) was reduced and then self-condensed as described for **4a** to afford a purple solid (0.80 g). The ^{1}H NMR spectrum of the porphyrin product indicated partial loss of the TMS group. Consequently, the sample was suspended in THF (600 mL) and treated with Bu_4NF on silica (1.5 g) overnight to completely deprotect the ethynyl moieties. The suspension was suction-filtered, and the residue was washed with $CHCl_3$ (300 mL). The filtrate was concentrated to dryness, and the residue was suspended in ethyl alcohol (50 mL). After 5 min of sonication, the suspension was filtered to obtain **4g** as a bright purple solid (0.63 g, 20% overall yield): ^{1}H NMR δ −2.79 (s, 2 H), 1.55 (s, 18 H), 3.32 (s, 2 H), 7.76 (d, J = 7.8 Hz, 4 H), 7.89 (d, J = 8.1 Hz, 4 H), 8.13 (d, J = 8.1 Hz, 4 H), 8.18 (d, J = 7.8 Hz, 4 H), 8.80 (d, J = 4.5 Hz, 4 H), 8.90 (d, J = 4.5 Hz, 4 H); $C_{56}H_{46}N_4$ requires 774.9, obsd 775.7 (LD-MS), calcd exact mass 774.3722 (M^+), obsd 774.3693 (M^+) (FAB-MS).

5,15-Bis(4-ethynylphenyl)-10,20-bis[4-(2-(trimethylsilyl)ethoxycarbonyl)phenyl]porphyrin (4h). Monoacyldipyrromethane 3o (1.30 g, 2.63 mmol) was reduced and then self-condensed as described for **4a** to afford **4h** as a purple solid (0.245 g, 20%): ^{1}H NMR δ −2.85 (s, 2 H), 0.18 (s, 18 H), 1.29 (t, J = 8.1 Hz, 4 H), 3.32 (s, 2 H), 4.61 (t, J = 8.1 Hz, 4 H), 7.90 (d, J = 8.1 Hz, 4 H), 8.17 (d, J = 8.1 Hz, 4 H), 8.29 (d, J = 8.1 Hz, 4 H), 8.44 (d, J = 8.1 Hz, 4 H), 8.83 (m, 8 H); $C_{60}H_{54}N_4O_4Si_2$ requires 951.2, obsd 953.4 (LD-MS), calcd exact mass 950.3684 (M^+), obsd 950.3705 (M^+) (FAB-MS).

Acknowledgment. This work was funded by the NIH (GM36238). Mass spectra were obtained at the Mass Spectrometry Laboratory for Biotechnology. Partial funding for the Facility was obtained from the North Carolina Biotechnology Center and the National Science Foundation. We thank Dr. Daniel Gryko for preparation of **1f** and Dr. Jon-Paul Strachan for the preparation of **2a** and **2c**.

Supporting Information Available: The determination of the limits of detection of scrambled porphyrins by LD-MS analysis; ^{1}H NMR spectra and LD-MS spectra of porphyrins **4a**−**h**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO9915473