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A FACILE AND EFFICIENT SYNTHESIS OF MONO- AND BIS-FUNCTIONALIZED *meso*-SUBSTITUTED PORPHYRINS *VIA* PALLADIUM-CATALYZED NEGISHI CROSS-COUPLING

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Abstract – A series of mono- and bis-functionalized *meso*-substituted porphyrins bearing chemically reactive functional groups such as -COOR, -Cl, and –CN in the alkyl substituents at the *meso* positions were efficiently synthesized by the reactions of *meso*-brominated precursors with alkylzinc reagents *via* palladium-catalyzed Negishi cross-coupling.

INTRODUCTION

Porphyrins and related tetrapyrrolic macrocycles are widespread in nature and have found a range of useful applications in various fields, such as catalysis, molecular recognition/sensing, enzymatic mimicry, medicine, and materials.[1,2] It is also well documented that the physical, chemical, and biological properties of porphyrins strongly depend on the electronic and steric environments of their peripheral substituents.[1] Consequently, intensive efforts have been made to develop new synthetic strategies and intermediates for preparing porphyrin derivatives bearing a diverse variety of peripheral substituents.[3–6] The *meso*-functionalized porphyrins **1** and **2**, of which alkyl substituents at the *meso* positions have chemically reactive functionalities such as esters, halogens, and pseudohalogens, would serve as a potential precursor for subsequent transformations to synthesize more complicated porphyrin derivatives (Figure 1). However, their synthetic utility is still limited, partly because of the lack of practical and facile access to such compounds; classically, these porphyrins **1** and **2** have been prepared *via* either tedious multi-step total syntheses or acid-mediated one-pot mixed condensation of pyrroles with aldehydes, which usually meets difficulty in separation and often provides low yields.[1,7] Recently, the research group

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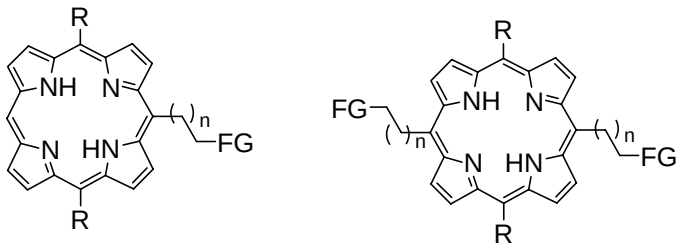
This paper is dedicated to Professor Dr. Ryoji Noyori on the occasion of his 70th birthday.



1 **2** FG = -CO_2R, -Cl, -CN, *etc.*

Figure 1. Mono- and bis-functionalized porphyrins.

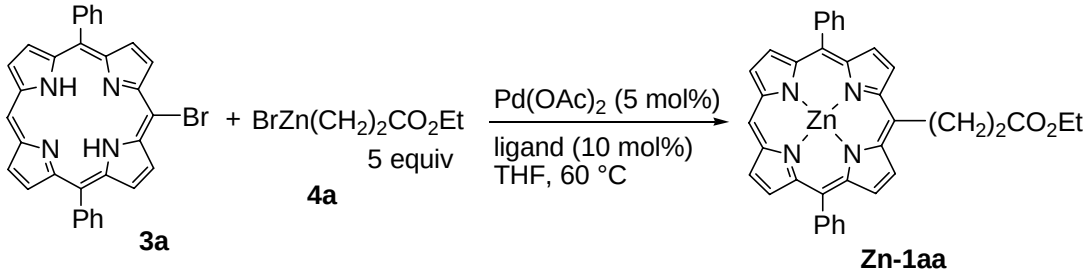
of Senge reported an efficient access to the mono-functionalized porphyrins, e.g. **1**, through a sequential reaction under basic conditions, which involves nucleophilic addition (S_NAr reaction) of alkyl- or aryllithium reagents to 5,15-disubstituted porphyrins followed by trapping of the resulting anions with alkyl iodides having functional groups and then oxidation with DDQ.[5b] While highly significant, this study was limited in scope (it included only examples using two substrates, Ni(II) complexes of 5,15-diphenyl- and 5,15-di-*n*-butylporphyrins), and should hardly be applied to the direct preparation of the bis-functionalized porphyrins **2**, because the use of organolithium reagents limits the tolerance toward chemically reactive groups such as esters. Thus, there still remains a need to develop an alternative approach to preparing the functionalized porphyrins **1** and **2**, with higher generality and practicality.

Herein, we report a general and convenient method for synthesizing the mono- and bis-functionalized porphyrins **1** and **2** via the palladium-catalyzed Negishi cross-coupling reactions of *meso*-bromoporphyrins with alkylzinc reagents containing chemically reactive functional groups, such as -COOEt, -Cl, and -CN.[8,9] The reaction can be carried out under mild conditions with a variety of bromoporphyrins, including their Zn(II), Ni(II), and Cu(II) complexes as well as the free bases, allowing the synthesis of mono- and bis-functionalized metalloporphyrins **1** and **2** in good to high yields.

RESULTS AND DISCUSSION

We initiated our studies by examining the catalytic activities of different phosphine ligands (10 mol%) for the model reaction between 5-bromo-10,20-diphenylporphyrin **3a** and (3-ethoxy-3-oxopropyl)zinc(II) bromide **4a** (5 equiv) in the presence of $Pd(OAc)_2$ (5 mol %) in THF at 60 °C (Table 1). Although the reaction failed to produce any product with bisphosphine ligands (entries 7and 8), the use of monophosphines as ligand could effectively promote the coupling reaction. Ultimately, tricyclohexylphosphine (Cy_3P) proved to be the most efficient ligand among those screened, providing complete conversion of the free base bromoporphyrin **3a** within 1 h and an excellent yield of the desired Zn(II) complex of functionalized porphyrin **Zn-1aa** (entry 2). An equally good result was achieved using *t*-Bu_3P, albeit a slightly prolonged reaction time was required to complete the reaction (entry 3). It is of note that *t*-Bu_3P could be introduced as the air-stable tetrafluoroboric acid adduct. Further optimization revealed that THF was the

Table 1. Negishi reactions of *meso*-bromoporphyrin **3a**: effect of the phosphine ligand.



entry	ligand	time (h)	yield (%)[a]
1	Ph_3P	1	72
2	Cy_3P[b]	1	80
3	*t*-$Bu_3P{\cdot}HBF_4$	2	80
4	(*o*-tol)$_3$P	2	61
5	*t*-$BuPh_2P$	1	45
6	(2,6-$(MeO)_2C_6H_3)_3P$	18	30
7	*rac*-BINAP[c]	18	trace
8	DPPP[d]	18	6

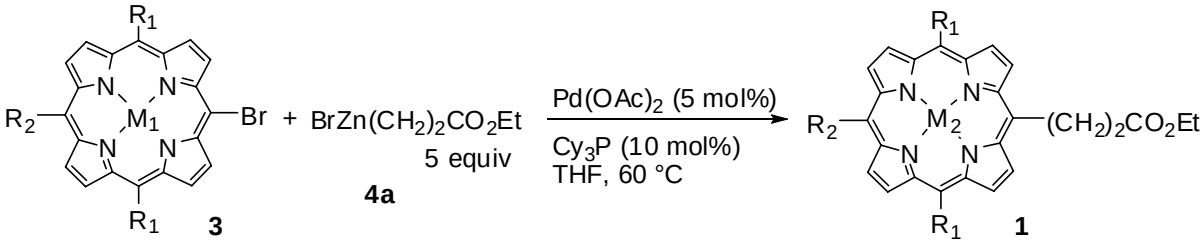
a) Isolated yield. b) Cy_3P: tricyclohexylphosphine.
c) BINAP: 2,2'-bis(diphenylphosphino)-1,1'-binaphthalene.
d) DPPP: 1,3-bis(diphenylphosphino)propane.

optimal solvent.

Having identified a reasonable set of conditions, we then explored the coupling of various *meso*-bromoporphyrins with 5 equiv of the organozinc compound **4a**. Thus, the reactions were carried out under the optimal conditions with $Pd(OAc)_2$ (5 mol%) as the catalyst and Cy_3P as the ligand in THF at 60 °C. The reaction works well with diaryl-substituted free base *meso*-bromoporphyrins **3b**–**e**, of which substituents on the phenyl ring are Me, vinyl, OMe, and *t*-Bu, producing the corresponding Zn(II) complexes bearing an ester functionality in good yields (entries 2–5). This coupling proved to be less sensitive to steric hindrance, as the functionalization of the substrate **3f** possessing ortho-substituted phenyl rings proceeds smoothly to provide the Zn(II) complex **Zn-1fa** in 72% yield (entry 6). Likewise, other free bases, including 10,20-dialkyl- and 10,15,20-trisubstituted bromoporphyrins, afford the desired Zn(II) complexes in good yields (entries 7–11). The utility of this $Pd(OAc)_2/Cy_3P$ catalyst is not limited to the functionalization of free base porphyrins. Thus, without modification, the method can be applied to couplings of metalloporphyrin complexes, such as Zn(II), Ni(II), and Cu(II) complexes of **3a**, leading to the formation of the corresponding metal-containing, functionalized porphyrins in good yields (entries 12–14).

The reaction scope was also investigated with respect to the alkylzinc coupling partner (Table 3). As expected, ester-containing alkylzinc compounds **4a**–**c** with different length of the carbon chain could be

Table 2. Palladium-catalyzed reaction of alkylzinc reagent **4a** with various bromoporphyrins.



entry	R_1	R_2	M_1	M_2	substrate	product	time (h)	yield (%)[a]
1	Ph	H	2H	Zn	**3a**	**Zn-1aa**	1	80
2	*p*-tolyl	H	2H	Zn	**3b**	**Zn-1ba**	0.5	70
3	3-(CH_2=CH)C_6H_4	H	2H	Zn	**3c**	**Zn-1ca**	1	76
4	3-(MeO)C_6H_4	H	2H	Zn	**3d**	**Zn-1da**	1	74
5	3,5-(*t*-Bu)$_2C_6H_3$	H	2H	Zn	**3e**	**Zn-1ea**	0.5	68
6	2,4,6-$Me_3C_6H_2$	H	2H	Zn	**3f**	**Zn-1fa**	2	72
7	*n*-Bu	H	2H	Zn	**3g**	**Zn-1ga**	3	72
8	*i*-Bu	H	2H	Zn	**3h**	**Zn-1ha**	5	73
9	Ph	*n*-Bu	2H	Zn	**3i**	**Zn-1ia**	1	72
10	Ph	*i*-Bu	2H	Zn	**3j**	**Zn-1ja**	1	80
11	Ph	Ph	2H	Zn	**3k**	**Zn-1ka**	18	59
12	Ph	H	Zn	Zn	**Zn-3a**	**Zn-1aa**	2	68
13	Ph	H	Cu	Cu	**Cu-3a**	**Cu-1aa**	2	70
14	Ph	H	Ni	Ni	**Ni-3a**	**Ni-1aa**	2	70

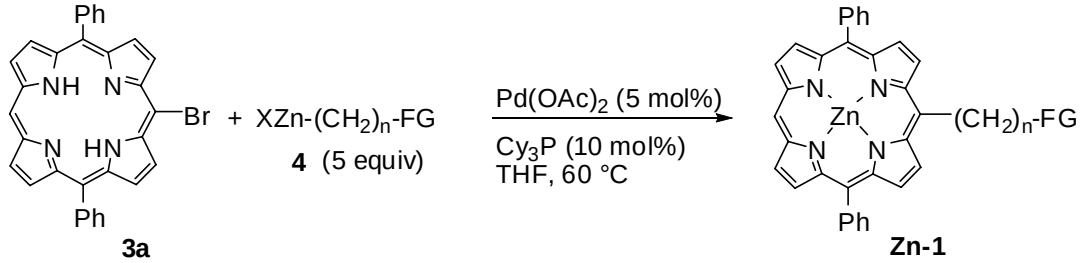
a) Isolated yield.

employed as the coupling partner (entries 1–3). In addition to esters, other functional groups, such as chlorides and nitliles, can be present in the organozinc (entries 4 and 5). The method is also applicable to alkylzinc compounds **4f** and **4g** bearing aromatic rings, affording the desired Zn(II) porphyrins **Zn-1af** and **Zn-1ag** with benzylic substituents in good yields (entries 6 and 7).

Overall, the data shown in Table 2 and Table 3 demonstrate that there is broad substrate scope in these coupling reactions. We note that these reactions can easily be scaled up if needed, although most of the reactions were carried out in a 0.1 mmol scale (see Experimental). For example, the reaction of porphyrin **3a** with the organozinc reagent **4a** could be carried out in a 2 mmol scale under similar conditions, the desired Zn(II) complex **Zn-1aa** being obtained as the sole isolable product at 977 mg and in 78% yield.

We next turned our attention to developing a direct method for introducing two alkyl substituents with chemically reactive functional groups into the porphyrin core, which has scarcely been achieved by known methods (Table 4).[9] Thus we examined the direct conversion of dibromoporphyrin **5a** to the bis-functionalized porphyrin Zn(II) complex **Zn-2aa**. Although the standard reaction conditions using as

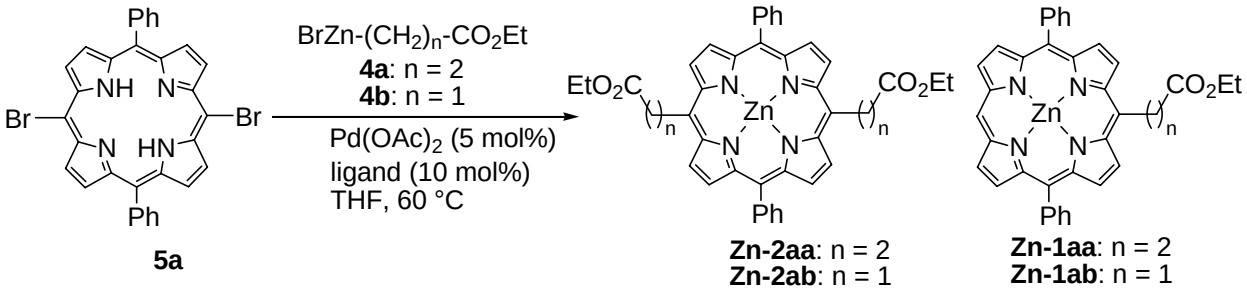
Table 3. Palladium-catalyzed reaction of *meso*-brominated diphenylporphyrin **3a** with alkylzinc reagents **4**.



entry	$XZn-(CH_2)_n-FG$	product	time (h)	yield (%)[a]
1	BrZn CO_2Et (**4a**)	**Zn-1aa**	1	80
2	BrZn CO_2Et (**4b**)[b]	**Zn-1ab**	2	73
3	BrZn CO_2Et (**4c**)	**Zn-1ac**	1.5	60
4	BrZn CN (**4d**)	**Zn-1ad**	2	62
5	BrZn Cl (**4e**)	**Zn-1ae**	2	90
6	ClZn Cl (**4f**)	**Zn-1af**	2	100
7	MeO, ClZn (**4g**)	**Zn-1ag**	2	91

a) Isolated yield. b) 50 equiv of the reagent was used.

Table 4. Palladium-catalyzed bis-functionalization of dibromoporphyrin **5a**.



entry	alkylzinc (equiv)	ligand	product (yield)[a]
1	**4a** (10)	Cy_3P	**Zn-2aa** (46%) + **Zn-1aa** (24%)
2	**4a** (10)	t-$Bu_3P{\cdot}HBF_4$	**Zn-2aa** (80%) + **Zn-1aa** (trace)
3	**4b** (50)	t-$Bu_3P{\cdot}HBF_4$	**Zn-2ab** (73%) + **Zn-1ab** (trace)

a) Isolated yield.

a phosphine ligand provided only 46% yield of the desired product **Zn-2aa** along with a substantial amount of the mono-functionalized Zn(II) complex **Zn-1aa** (entry 1), *t*-Bu_3P was found to be an efficient ligand. Under these conditions, the bis-functionalized Zn(II) complex **Zn-2aa** was obtained as the sole isolable product in 80% yield (entry 2). A similar result was observed with the Reformatsky reagent **4b** as a coupling partner in the reaction to afford the corresponding Zn(II) complex **Zn-2ab** in 73% yield (entry 3).

CONCLUSION

In summary, we have developed a new, general and practical method for synthesizing mono- and bis-functionalized porphyrins **1** and **2**, of which *meso*-alkyl substituents contain chemically reactive groups such as -COOR, -Cl, and -CN, from easily available brominated precursors via palladium-catalyzed Negishi cross-coupling. This catalytic method is distinguished by its operational simplicity as well as its mild conditions, showing wide functional group tolerance while affording the desired products in good yields. In addition, these functionalized porphyrins obtained could be used as a versatile precursor in subsequent transformations to produce complex porphyrin systems with special chemical and physical properties. Utilizing the synthetic method, we are currently working to construct libraries of porphyrin systems for potential applications in catalysis, medicine, and molecular recognition/sensing.

EXPERIMENTAL

General ^{1}H- and ^{13}C-NMR spectra were recorded on a JEOL JNM-EX270, JNM-AL300, or JNM-AL400 spectrometer. The chemical shifts were reported in ppm relative to $CHCl_3$ (δ = 7.24) for ^{1}H-NMR and relative to the central resonance of $CDCl_3$ (δ = 77.0) for ^{13}C-NMR. IR spectra were recorded on a JASCO FT/IR-7000 or JASCO FT/IR-4100 spectrophotometer. The mass spectroscopic data were obtained on a JEOL JNM-DX302 spectrometer. UV-visible absorption spectra were measured with a Hitachi U-3210 spectrophotometer.

All the palladium-catalyzed coupling reactions were carried out under an argon atmosphere in oven-dried glassware following standard Schlenk techniques. Tetrahydrofuran (THF) was distilled under argon from sodium benzophenone ketyl. Kanto Kagaku Silica Gel 60 (spherical) and Merck kiesel-gel 60 F_{254} were employed for silica gel column and thin layer chromatography, respectively.

5-Bromo-10,20-diphenylporphyrin (**3a**),[8b] 5-bromo-10,20-di(*p*-tolyl)porphyrin (**3b**),[6b] 5,15-bis(3-vinylphenyl)-10-bromoporphyrin (**3c**),[6b] 5,15-bis(3-methoxyphenyl)-10-bromoporphyrin (**3d**),[6b] 10-bromo-5,15-bis[3,5-di(*tert*-butyl)phenyl]porphyrin (**3e**),[10] 5-bromo-15-(*n*-butyl)-10,20-diphenylporphyrin (**3i**),[6b] 5-bromo-10,15,20-triphenylporphyrin (**3k**),[6b] 5,15-dibromo-10,20-diphenylporphyrin (**5a**,)[8b] [10-bromo-

5,15-diphenylporphyrinato]zinc(II) (**Zn-3a**),[11] and [10-bromo-5,15-diphenylporphyrinato]nickel(II) (**Ni-3a**)[12] were prepared as described in the literature.

(3-Ethoxy-3-oxopropyl)zinc(II) bromide (**4a**), (4-ethoxy-4-oxobutyl)zinc(II) bromide (**4c**), (3-cyanopropyl)zinc(II) bromide (**4d**), (4-chlorobutyl)zinc(II) bromide (**4e**), (2-methoxybenzyl)zinc(II) chloride (**4f**), and (3-chlorobenzyl)zinc(II) chloride (**4g**) were purchased from Aldrich Chemical Co. Other simple chemicals were purchased and used as such, unless otherwise stated.

Preparation of *meso*-bromoporphyrins 3f–h and 3j

To a solution of a porphyrin (1.0 mmol) in CH_2Cl_2/MeOH (9:1 vol/vol, 250 mL) was added NBS (196 mg, 1.1 mmol) at rt. The reaction mixture was stirred for 5 min and quenched with acetone (25 mL). The solvent was evaporated to dryness. Column chromatography on silica gel (hexane/toluene 4:1) followed by recrystallization from CH_2Cl_2/MeOH gave the pure compound. The starting 5,15-di- and 5,10,15-tri-substituted porphyrins were prepared as described in the literature.[6,13]

5,15-Bis(2,4,6-trimethylphenyl)-10-bromoporphyrin (3f) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.08 (s, 1H), 9.66 (d, J = 4.8 Hz, 2H), 9.22 (d, J = 4.8 Hz, 2H), 8.78 (d, J = 4.8 Hz, 4H), 7.30 (s, 4H), 2.64 (s, 6H), 1.82 (s, 12H), -2.87 (s, 2H); HRMS-FAB ($[M+H]^+$): calcd for $C_{38}H_{34}BrN_4$: 625.1967, found: 625.1967

10-Bromo-5,15-di(*n*-butyl)porphyrin (3g) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.93 (s, 1H), 9.74 (d, J = 4.8 Hz, 2H), 9.42 (d, J = 4.6 Hz, 4H), 9.23 (d, J = 4.6 Hz, 2H), 4.86 (t, J = 8.1 Hz, 4H), 2.47–2.44 (m, 4H), 1.79–1.77 (m, 4H), 1.11 (t, J = 7.3 Hz, 6H), -3.04 (s, 2H); HRMS-FAB ($[M+H]^+$): calcd for $C_{28}H_{30}BrN_4$: 501.1654, found: 501.1656.

10-Bromo-5,15-di(isobutyl)porphyrin (3h) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.90 (s, 1H), 9.69 (d, J = 4.8 Hz, 2H), 9.35 (d, J = 4.8 Hz, 4H), 9.18 (d, J = 4.8 Hz, 2H), 4.67 (d, J = 7.1 Hz, 4H), 2.70–2.61 (m, 2H), 1.11 (d, J = 6.6 Hz, 12H), -3.06 (s, 2H); HRMS-FAB ($[M+H]^+$): calcd for $C_{28}H_{30}BrN_4$: 501.1654, found: 501.1651.

5-Bromo-10,20-diphenyl-15-isobutylporphyrin (3j) ^{1}H NMR ($CDCl_3$, 300MHz): δ 9.55 (d, J = 4.8 Hz, 4H), 8.82–8.80 (m, 4H), 8.17–8.15 (m, 4H), 7.82–7.71 (m, 6H), 5.35–5.27 (m, 1H), 2.96–2.71 (m, 2H), 2.37 (d, J = 7.1 Hz, 3H), 1.03 (t, J = 7.4 Hz, 3H), -2.64 (s, 2H); HRMS-FAB ($[M+H]^+$): calcd for $C_{36}H_{30}BrN_4$: 597.1654, found: 597.1652.

Preparation of [10-bromo-5,15-diphenylporphyrinato]copper(II) (Cu-3a)

To a solution of 10-bromo-5,15-diphenylporphyrin **3a** (49.1 mg, 0.1 mmol) in $CHCl_3$/MeOH (2:1 vol/vol, 9 mL) was added $Cu(OAc)_2 \cdot H_2O$ (300 mg, 1.5 mmol) at rt. The reaction mixture was stirred for 2.5 h, and concentrated under a reduced pressure. The resulting solid was recrystallized from THF/H_2O to afford the product **Cu-3a** in a quantitative yield. HRMS (EI) m/z: calcd for $C_{32}H_{19}BrN_4Cu$: 601.0089, found: 601.0084. Neither ^{1}H-NMR nor ^{13}C-NMR data are available owing to the poor solubility of the compound.

General procedure for the palladium-catalyzed reaction of *meso*-bromoporphyrins 3 with alkylzinc reagents 4a and 4c–g

An oven-dried 50 mL sealable Schlenk flask equipped with a magnetic stirring bar and a reflux condenser was charged with a *meso*-bromoporphyrin **3** (0.1 mmol), $Pd(OAc)_2$ (1.1 mg, 5 mol%), and Cy_3P (2.8 mg, 10 mol%). The reaction vessel was evacuated and flushed with argon (three times), and absolute THF (20 mL) was added. To the solution was added a 0.5 M THF solution of an alkylzinc reagent **4** (1 mL, 0.5 mmol) at rt. The mixture was heated under argon at 60 °C for several hours (0.5–2 hr), and then allowed to reach rt. The reaction mixture was diluted with THF/Et_2O (2:1 vol/vol, 20 mL), and washed with aqueous NH_4Cl and brine. The organic layer was dried over anhydrous $MgSO_4$, and concentrated in vacuo. Column chromatography on silica gel (CH_2Cl_2) followed by recrystallization from CH_2Cl_2/hexane gave the product.

[5,15-Diphenyl-10-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1aa) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.07 (s, 1H), 9.58 (d, *J* = 4.8 Hz, 2H), 9.27 (d, *J* = 4.6 Hz, 2H,), 9.03 (2H, d, *J* = 4.8 Hz), 9.00 (2H, d, *J* = 4.6 Hz), 8.21–8.18 (m, 4H), 7.79–7.77 (m, 6H), 5.36 (t, *J* = 8.2 Hz, 2H), 4.20 (q, *J* = 7.1 Hz, 2H), 3.50 (t, *J* = 8.2 Hz, 2H), 1.23 (t, *J* = 7.1 Hz, 3H,); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.3, 149.4, 149.2, 148.8, 142.2, 134.1, 132.1, 132.1, 131.2, 128.1, 127.1, 126.2, 119.7, 118.2, 105.1, 60.4, 42.1, 30.7, 14.1; IR (KBr): 3051, 3019, 1691, 1323, 994, 842, 784, 746, 699 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 416 (5.6), 549 (4.3) nm; HRMS (EI) m/z: calcd for $C_{37}H_{28}N_4O_2Zn$: 624.1502, found: 624.1503.

[5,15-Di(*p*-tolyl)-10-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1ba) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.09 (s, 1H), 9.59 (d, *J* = 4.7 Hz, 2H), 9.28 (d, *J* = 4.4 Hz, 2H), 9.07 (d, *J* = 4.7 Hz, 2H), 9.03 (d, *J* = 4.4 Hz, 2H), 8.08 (d, *J* = 7.9 Hz, 4H), 7.57 (d, *J* = 7.9 Hz, 4H), 5.39 (t, *J* = 8.2 Hz, 2H), 4.22 (q, *J* = 7.2 Hz, 2H), 3.52 (t, *J* = 8.2 Hz, 2H), 2.73 (s, 6H), 1.24 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (CDCl3, 100 MHz): δ 172.6, 149.8, 149.7, 149.6, 149.0, 139.5, 136.9, 134.2, 132.4, 132.4, 131.3, 128.2, 127.1, 120.1, 118.3, 105.3, 60.7, 42.4, 31.0, 21.0, 14.3; IR (KBr): 3024, 2982, 2916, 1728, 1503, 1379, 1321, 1180, 1061, 998, 849, 793 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 415 (5.7), 544 (4.1) nm; HRMS (EI) m/z: calcd for $C_{39}H_{32}N_4O_2Zn$: 652.1817, found: 652.1813.

[5,15-Bis(3-vinylphenyl)-10-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1ca) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.10 (s, 1H), 9.59 (d, *J* = 4.8 Hz, 2H), 9.29 (d, *J* = 4.5 Hz, 2H), 9.06 (d, *J* = 4.8, 2H), 9.03 (d, *J* = 4.5, 2H), 8.25 (d, *J* = 1.8 Hz, 2H), 8.09 (dd, *J* = 7.4 and 1.6 Hz, 2H), 7.85 (d, *J* = 7.9 Hz, 2H), 7.72 (t, *J* = 7.6 Hz, 2H), 7.00 (dd, *J* = 17.6 and 10.8 Hz, 2H), 5.96 (d, *J* = 17.6 Hz, 2H), 5.40 (d, *J* = 10.8 Hz, 2H), 5.37 (t, *J* = 8.3 Hz, 2H), 4.20 (q, *J* = 7.1 Hz, 2H), 3.50 (t, *J* = 8.3 Hz, 2H), 1.24 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.5, 149.8, 149.7, 149.5, 149.2, 142.7, 136.7, 135.6, 133.8, 132.4, 132.3, 132.2, 131.5, 128.4, 126.6, 125.2, 119.7, 118.5, 114.5, 105.5, 60.7, 42.4, 31.0, 24.9, 14.3; IR (KBr): 2976, 1695, 1476, 1321, 995, 854, 790, 713 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 415 (5.7), 543

(4.3) nm; HRMS (EI) m/z: calcd for $C_{41}H_{32}N_4O_2Zn$: 676.1817, found: 676.1818.

[5,15-Bis(3-methoxyphenyl)-10-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1da) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.15 (s, 1H), 9.63 (d, *J* = 4.8 Hz, 2H), 9.33 (d, *J* = 4.6 Hz, 2H), 9.10 (d, *J* = 4.8 Hz, 2H), 9.07 (d, *J* = 4.6 Hz, 2H), 7.81–7.77 (m, 4H), 7.65 (t, *J* = 7.8 Hz, 2H), 7.33 (dd, *J* = 7.8 and 2.2 Hz, 2H), 5.43 (t, *J* = 8.3 Hz, 2H), 4.22 (q, *J* = 7.1 Hz, 2H), 3.98 (s, 6H), 3.54 (t, *J* = 8.4 Hz, 2H), 1.24 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.5, 157.6, 149.9, 149.4, 149.2, 143.8, 132.5, 132.4, 131.5, 128.4, 127.5, 127.4, 120.3, 119.8, 118.6, 113.2, 105.5, 60.7, 55.5, 42.4, 37.5, 31.1, 14.4; IR (KBr): 2940, 1730, 1599, 1461, 1284, 997, 786, 700 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 414 (5.7), 543 (4.3) nm; HRMS (EI) m/z: calcd for $C_{39}H_{32}N_4O_4Zn$: 684.1715, found: 684.1713.

{5,15-Bis[3,5-di(*tert*-butyl)phenyl]-10-(3-ethoxycarbonylpropyl)porphyrinato}zinc(II) (Zn-1ea) ^{1}H NMR ($CDCl_3$, 300 MHz) δ 10.18 (s, 1H), 9.66 (d, *J* = 4.8 Hz, 2H), 9.35 (d, *J* = 4.4 Hz, 2H), 9.12 (d, *J* = 4.8 Hz, 2H), 9.10 (d, *J* = 4.4 Hz, 2H), 8.09 (d, *J* = 1.8 Hz, 4H), 7.82 (dd, *J* = 1.8 and 1.8 Hz, 2H), 5.46 (t, *J* = 8.2 Hz, 2H), 4.24 (q, *J* = 7.1 Hz, 2H), 3.58 (t, *J* = 8.2 Hz, 2H), 1.55 (s, 36H), 1.26 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.7, 150.1, 149.9, 149.8, 149.1, 148.4, 141.5, 132.8, 132.7, 131.4, 129.6, 128.3, 121.5, 120.7, 118.3, 105.4, 60.7, 42.5, 35.1, 31.9, 31.2, 14.4; IR (KBr): 2962, 1678, 1589, 1475, 1294, 997, 787, 717 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 416 (5.7), 545 (4.3) nm; HRMS-FAB ($[M]^+$): calcd for $C_{53}H_{60}N_4O_2Zn$: 848.4008, found: 848.4003.

[5,15-Bis(2,4,6-trimethylphenyl)-10-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1fa) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.08 (s, 1H), 9.58 (d, *J* = 4.8 Hz, 2H), 9.28 (d, *J* = 4.6 Hz, 2H), 8.89 (d, *J* = 4.8 Hz, 2H), 8.86 (d, *J* = 4.6 Hz, 2H), 7.29 (s, 4H), 5.42 (t, *J* = 8.3 Hz, 2H), 4.23 (q, *J* = 7.1 Hz, 2H), 3.58 (t, *J* = 8.3 Hz, 2H), 2.64 (s, 6H), 1.80 (s, 12H), 1.24 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.7, 149.8, 149.5, 149.3, 149.1, 139.1, 138.7, 137.3, 131.9, 131.2, 131.1, 128.8, 127.5, 118.2, 117.7, 104.8, 60.7, 42.4, 31.0, 21.7, 21.6, 14.4; IR (KBr): 2971, 2915, 1706, 1610, 1440, 1377, 1191, 1059, 997, 843, 787, 720 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 414 (5.7), 545 (3.8) nm; HRMS (EI) m/z: calcd for $C_{43}H_{40}N_4O_2Zn$: 708.2443, found: 708.2440.

[5,15-Di(*n*-butyl)-10-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1ga) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.43 (s, 1H), 9.14 (d, *J* = 4.4 Hz, 2H), 9.13 (d, *J* = 4.4 Hz, 2H), 9.09 (d, *J* = 4.7 Hz, 2H), 8.91 (d, *J* = 4.7 Hz, 2H), 4.97 (t, *J* = 8.3 Hz, 2H), 4.49 (t, *J* = 8.2 Hz, 4H), 4.24 (q, *J* = 7.2 Hz, 2H), 3.31 (t, *J* = 8.3 Hz, 2H), 2.38–2.27 (m, 4H), 1.79–1.74 (m, 4H), 1.25 (*t*, J = 7.2 Hz, 3H), 1.11 (*t*, J = 7.4 Hz, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.7, 149.1, 148.8, 148.3, 147.5, 131.1, 128.6, 128.4, 127.9, 119.0, 116.5, 103.9, 60.6, 42.3, 40.9, 34.9, 30.8, 25.0, 23.8, 14.4, 14.3; IR (KBr): 3100, 2955, 1733, 1473, 1176, 1070, 994, 842, 783, 698 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 414 (5.7), 548 (3.9) nm; HRMS (EI) m/z: calcd for $C_{33}H_{36}N_4O_2Zn$: 584.2130, found: 584.2130.

[5,15-Di(isobutyl)-10-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1ha) ^{1}H NMR ($CDCl_3$, 300

MHz): δ 9.58 (s, 1H), 9.25 (d, *J* = 4.6 Hz, 2H), 9.24 (d, *J* = 4.8 Hz, 2H), 9.20 (d, *J* = 4.8 Hz, 2H), 9.00 (d, *J* = 4.6 Hz, 2H), 5.04 (t, *J* = 8.3 Hz, 2H), 4.51 (d, *J* = 7.1 Hz, 4H), 4.23 (q, *J* = 7.1 Hz, 2H), 3.37 (t, *J* = 8.3 Hz, 2H), 2.62–2.58 (m, 2H), 1.25 (t, *J* = 7.2 Hz, 4H), 1.11 (d, *J* = 6.6 Hz, 12H,); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.7, 149.9, 149.5, 148.5, 147.7, 131.9, 129.4, 129.2, 127.8, 118.1, 116.5, 104.1, 60.6, 43.5, 42.3, 36.8, 30.9, 23.4, 14.4; IR (KBr): 3124, 2961, 1734, 1465, 1380, 1280, 1174, 993, 844, 781, 716 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 414 (5.5), 546 (3.4) nm; HRMS (EI) m/z: calcd for $C_{33}H_{36}N_4O_2Zn$: 584.2130, found: 584.2136.

[5-(*n*-Butyl)-10,20-diphenyl-15-(3-ethoxycarbonylpropyl)porphyrinato]zinc(II) (Zn-1ia) ^{1}H NMR ($CDCl_3$, 400 MHz): δ 9.47 (d, *J* = 4.6 Hz, 2H), 9.46 (d, *J* = 4.6 Hz, 2H), 8.93 (d, *J* = 4.6 Hz, 2H), 8.91 (d, *J* = 4.6 Hz, 2H), 8.17–8.12 (m ,4H), 7.81–7.72 (m, 6H), 5.25 (dd, *J* = 9.0 and 7.3 Hz, 2H), 4.90 (t, *J* = 7.9 Hz, 2H), 4.19 (q, *J* = 7.2 Hz, 2H), 3.46 (t, *J* = 8.2 Hz, 2H), 2.53–2.46 (m, 2H), 1.83–1.79 (m, 2H), 1.22 (t, *J* = 7.1 Hz, 3H), 1.11 (t, *J* = 7.3 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.6, 150.0, 149.6, 149.2, 149.2, 142.7, 134.2, 132.4, 132.0, 128.6, 128.1, 127.2, 126.3, 121.1, 119.9, 117.2, 60.6, 42.2, 41.1, 35.4, 30.8, 23.8, 14.3; IR (KBr): 2952, 1713, 1346, 1202, 1075, 1006, 937, 789, 699 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 420 (5.7), 549 (3.8) nm; HRMS (EI): m/z calcd for $C_{41}H_{36}N_4O_2Zn$: 680.2130, found: 680.2133.

[5,15-Diphenyl-10-(3-ethoxycarbonylpropyl)-20-isobutylporphyrinato]zinc(II) (Zn-1ja) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.70 (brd, *J* = 4.5 Hz, 2H), 9.54 (br d, *J* = 4.9 Hz, 2H), 8.95 (br d, *J* = 4.5 Hz, 4H), 8.18 (br d, *J* = 4.9 Hz, 4H), 7.76–7.74 (m, 6H), 5.47–5.32 (m, 3H), 4.21 (q, *J* = 7.2 Hz, 2H), 3.51 (t, *J* = 8.2 Hz, 2H), 3.00–2.75 (m, 2H), 2.42 (d, *J* = 7.1 Hz, 3H), 1.23 (t, *J* = 7.1 Hz, 3H), 1.03 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 67.8 MHz): δ 172.9, 149.9, 149.3, 143.1, 134.3, 132.5, 131.8, 128.4, 127.4, 126.4, 126.2, 120.0, 117.4, 67.5, 60.6, 42.8, 42.4, 35.9, 30.7, 27.4, 25.3, 14.3, 14.2; IR (KBr): 2965, 1699, 1007, 787 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 419 (5.7), 551 (4.3) nm; HRMS (EI) m/z: calcd for $C_{41}H_{36}N_4O_2Zn$: 680.2130, found: 680.2133.

[5-(3-Ethoxycarbonylpropyl)-10,15,20-triphenylporphyrinato]zinc(II) (Zn-1ka) ^{1}H NMR ($CDCl_3$, 400 MHz): δ 9.54 (br d, *J* = 4.6 Hz, 2H), 9.00 (br d, *J* = 4.9 Hz, 2H), 8.90 (br s, 4H), 8.20–8.17 (m, 6H), 7.80–7.70 (m, 9H), 5.32 (t, *J* = 8.3 Hz, 2H), 4.20 (q, *J* = 7.2 Hz, 2H), 3.50 (t, *J* = 8.3 Hz, 2H), 1.23 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.5, 150.1, 149.8, 149.6, 149.5, 142.6, 142.5, 134.2, 134.2, 132.5, 131.8, 131.7, 128.4, 127.3, 126.4, 120.6, 118.1, 60.7, 42.3, 30.9, 14.3; IR (KBr): 3052, 1703, 1595, 1486, 1440, 1342, 1289, 1073, 1003, 794, 753, 701 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 419 (5.7), 548 (4.2) nm; HRMS (EI) m/z: calcd for $C_{43}H_{32}N_4O_2Zn$: 700.1817, found: 700.1815.

[5,15-Diphenyl-10-(3-ethoxycarbonylpropyl)porphyrinato]copper(II) (Cu-1aa) IR (KBr): 2980, 1736, 1177, 1002, 852, 797, 701 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 410 (5.6), 535 (4.0) nm; HRMS (EI) m/z: calcd for $C_{37}H_{28}N_4O_2Cu$: 623.1508, found: 623.1501. Neither ^{1}H-NMR nor ^{13}C-NMR data are available

owing to the poor solubility of the compound.

[5,15-Diphenyl-10-(3-ethoxycarbonylpropyl)porphyrinato]nickel(II) (Ni-1aa) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.70 (s, 1H), 9.37 (d, *J* = 4.9 Hz, 2H), 9.05 (d, *J* = 4.9 Hz, 2H), 8.84 (d, *J* = 4.9 Hz, 2H), 8.82 (d, *J* = 4.9 Hz, 2H), 8.02–7.97 (m, 4H), 7.73–7.67 (m, 6H), 5.01 (t, *J* = 8.3 Hz, 2H), 4.19 (q, *J* = 7.1 Hz, 2H), 3.34 (t, *J* = 8.2 Hz, 2H), 1.23 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.6, 142.8, 142.3, 141.7, 140.8, 133.7, 132.7, 132.6, 132.1, 128.9, 127.7, 126.8, 118.2, 116.1, 104.2, 60.7, 41.1, 29.6, 14.2; IR (KBr): 2976, 1735, 1338, 1177, 1072, 1002, 852, 795, 750, 700 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 408 (4.5), 523 (3.2) nm; HRMS (EI) m/z: calcd for $C_{37}H_{28}N_4O_2Ni$: 618.1566, found: 618.1567.

[5,15-Diphenyl-10-(4-ethoxycarbonylbutyl)porphyrinato]zinc(II) (Zn-1ac) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.07 (s, 1H), 9.60 (d, *J* = 4.8 Hz, 2H), 9.27 (d, *J* = 4.4 Hz, 2H), 9.02 (d, *J* = 4.6 Hz, 2H), 9.00 (d, *J* = 4.6 Hz, 2H), 8.21–8.19 (m, 4H), 7.79–7.75 (m, 6H), 5.06 (t, *J* = 7.9 Hz, 2H), 4.18 (q, *J* = 7.1 Hz, 2H), 2.90–2.80 (m, 2H), 2.68 (t, *J* = 6.9 Hz, 2H), 1.29 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 173.3, 149.7, 149.6, 149.5, 149.4, 142.6, 134.3, 132.3, 132.1, 131.4, 128.6, 127.3, 126.4, 120.1. 119.9, 105.2, 60.5, 35.0, 34.5, 33.2, 14.4; IR (KBr): 2942, 1717, 1438, 1253, 1062, 997, 844, 783, 700 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 414 (5.7), 543 (4.1) nm; HRMS (EI) m/z: calcd for $C_{38}H_{30}N_4O_2Zn$: 638.1660, found: 638.1668.

[5,15-Diphenyl-10-(3-cyanopropyl)porphyrinato]zinc(II) (Zn-1ad) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.04 (s, 1H), 9.49 (d, *J* = 4.6 Hz, 2H), 9.25 (d, *J* = 4.6 Hz, 2H), 9.03 (d, *J* = 4.6 Hz, 2H), 8.99 (d, *J* = 4.6 Hz, 2H), 8.19–8.17 (m, 4H), 7.80–7.73 (m, 6H), 5.11 (t, *J* = 7.6 Hz, 2H), 2.90–2.80 (m, 2H), 2.56 (t, *J* = 6.9 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 149.8, 149.8, 149.5, 149.1, 142.4, 134.3, 132.5, 128.1, 127.4, 126.4, 120.1, 117.6, 105.5, 34.1, 33.2, 17.5; IR (KBr): 3056, 2968, 2247, 1594, 1384, 1320, 1175, 1065, 994, 850, 789, 699 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 414 (5.7), 544 (4.3) nm; HRMS (EI) m/z: calcd for $C_{36}H_{25}N_5Zn$: 591.1401, found: 591.1407.

[10-(4-Chlorobutyl)-5,15-diphenylporphyrinato]zinc(II) (Zn-1ae) IR (KBr): 3051, 1439, 1391, 1062, 995, 854, 784, 724, 700 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 408 (5.7), 538 (4.3) nm; HRMS (EI) m/z: calcd for $C_{36}H_{27}ClN_4Zn$: 614.1216, found: 614.1218. Neither ^{1}H-NMR nor ^{13}C-NMR data are available owing to the poor solubility of the compound.

{10-[(3-Chlorophenyl)methyl]-5,15-diphenylporphyrinato}zinc(II) (Zn-1af) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.10 (s, 1H), 9.44 (d, *J* = 4.6 Hz, 2H), 9.29 (d, *J* = 4.6 Hz, 2H), 9.01 (d, *J* = 4.6 Hz, 2H), 8.98 (d, *J* = 4.6 Hz, 2H), 8.22–8.17 (m, 4H), 7.81–7.71 (m, 6H), 7.27 (s, 1H), 7.16–7.12 (m, 1H), 7.06–7.03 (m, 2H), 6.35 (s, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 150.0, 149.9, 149.8, 149.5, 146.9, 142.4, 134.3, 134.2, 132.5, 132.4, 132.4, 131.5, 129.4, 129.1, 128.4, 127.3, 126.5, 126.4, 125.8, 120.2, 116.1, 105.7, 40.4; IR (KBr): 3051, 1594, 1068, 998, 854, 787, 700 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 415 (5.7), 544 (4.3) nm; HRMS (EI) m/z: calcd for $C_{39}H_{25}ClN_4Zn$: 648.1059, found: 648.1055.

{5,15-Diphenyl-10-[(2-methoxyphenyl)methyl]porphyrinato}zinc(II) (Zn-1ag) ^{1}H NMR ($CDCl_3$, 300 MHz): δ 10.05 (s, 1H), 9.46 (d, *J* = 4.6 Hz, 2H), 9.26 (d, *J* = 4.6 Hz, 2H), 8.99 (d, *J* = 4.6 Hz, 2H), 8.95 (d, *J* = 4.6 Hz, 2H), 8.21–8.14 (m, 4H), 7.80–7.69 (m, 6H), 7.06–7.02 (m, 2H), 6.43–6.31 (m, 4H), 4.22 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 154.9, 150.6, 149.7, 149.6, 149.5, 142.5, 134.3, 132.3, 131.3, 131.2, 129.6, 127.2, 126.4, 120.3, 119.9, 117.7, 109.6, 105.4, 55.7, 33.6; IR (KBr): 2940, 1489, 1240, 997, 784, 749 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 415 (5.7), 544 (4.2) nm; HRMS (EI) m/z: calcd for $C_{40}H_{28}N_4OZn$: 644.1555, found 644.1552.

Palladium-catalyzed reaction of *meso*-bromoporphyrin 3a with zinc enolate 4b: **preparation of [5,15-Diphenyl-10-(2-ethoxycarbonylethyl)porphyrinato]zinc(II) (Zn-1ab)**

An oven-dried 50 mL sealable two-necked flask equipped with a reflux condenser, a magnetic stirring bar and rubber septa was charged with Zn dust (1.3 g, 20 mmol) and CuCl (188 mg, 2 mmol). The reaction vessel was evacuated and flushed with argon (three times), and absolute THF (8 mL) was added. The suspension was refluxed for 1 h using an oil-bath. During this activation period, another oven-dried 5 mL sealable flask was evacuated and flushed with argon (three times) and then charged absolute THF (4 mL) and ethyl bromoacetate (560 μL, 5 mmol). The reaction vessel containing Zn(Cu) couple was removed from the oil-bath. To initiate the reaction, ca. 1/10 of the THF solution of ethyl bromoacetate was added via a syringe to the stirred Zn(Cu) couple suspension while the suspension was still hot. The rest of the solution was added in such a rate as to maintain a gentle reflux (ca. 5 min). The reaction mixture was stirred and refluxed until its color turned to green (ca. 3 h). To the resulting ca. 0.4 M THF solution of the zinc enolate **4b** was added dropwise a mixture of *meso*-bromoporphyrin **2a** (54.1 mg, 0.1 mmol), $Pd(OAc)_2$ (1.1 mg, 5 mol%), and Cy_3P (2.8 mg, 10 mol%) in THF (20 mL) over a period of 5 min. The reaction mixture was heated under argon at 60 °C for 1 h, and then allowed to reach rt. The reaction mixture was filtered through a filter paper, diluted with THF/Et_2O (2:1 vol/vol, 20 mL), and washed with aqueous NH_4Cl and brine. The organic layer was dried over anhydrous $MgSO_4$, and concentrated in vacuo. Column chromatography on silica gel (CH_2Cl_2) followed by recrystallization from CH_2Cl_2/hexane gave the product **Zn-1ab**. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.98 (s, 1H), 9.48 (d, *J* = 4.6 Hz, 2H), 9.21 (d, *J* = 4.4 Hz, 2H), 9.00 (d, *J* = 4.6 Hz, 2H), 8.96 (d, *J* = 4.6 Hz, 2H), 8.21–8.15 (m, 4H), 7.83–7.72 (m, 6H), 5.87 (s, 2H), 4.13 (q, *J* = 7.1 Hz, 2H), 1.16 (t, *J* = 7.1 Hz, 3H); ^{13}C-NMR ($CDCl_3$, 100 MHz) δ 173.4, 150.6, 150.5, 150.3, 150.2, 143.2, 135.1, 133.1, 133.0, 132.1, 129.5, 128.0, 127.1, 120.8, 111.6, 106.3, 61.6, 41.1, 14.4; IR (KBr): 3047, 2980, 1726, 1385, 1320, 1171, 1061, 996, 784, 702 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 414 (5.6), 544 (4.0) nm; HRMS (EI) m/z: calcd for $C_{36}H_{26}N_4O_2Zn$: 610.1347, found: 610.1353.

Palladium-catalyzed conversion of 5,15-dibromo-10,20-diphenylporphyrin (5a) into [5,15-bis-(3-ethoxycarbonylpropyl)-10,20-diphenylporphyrinato]zinc(II) (Zn-2aa)

An oven-dried 50 mL sealable Schlenk flask equipped with a magnetic stirring bar was charged with a dibromoporphyrin **5a** (54.1 mg, 0.1 mmol), $Pd(OAc)_2$ (1.1 mg, 5 mol%), and *t*-$Bu_3P{\cdot}HBF_4$ (2.9 mg, 10 mol%). The reaction vessel was evacuated and flushed with argon (three times), and absolute THF (20 mL) was added. To the solution was added 3-ethoxy-3-oxopropylzinc bromide **4a** (2 mL, 0.5 M solution in THF, 1.0 mmol) at rt. The mixture was heated under argon at 60°C for 2 h, and then allowed to reach rt. The reaction mixture was diluted with THF/Et_2O (2:1 vol/vol, 20 mL), and washed with aqueous NH_4Cl and brine. The organic layer was dried over anhydrous $MgSO_4$, and concentrated in vacuo. Column chromatography on silica gel (THF/hexane 1:10 → 1:3) followed by recrystallization from CH_2Cl_2/hexane gave the product **Zn-2aa**. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.52 (d, *J* = 4.8 Hz, 4H), 8.95 (d, *J* = 4.8 Hz, 4H), 8.19–8.14 (m, 4H), 7.83–7.70 (m, 6H), 5.32 (t, *J* = 8.3 Hz, 4H), 4.21 (q, *J* = 7.1 Hz, 4H), 3.49 (t, *J* = 8.3 Hz, 4H), 1.23 (t, *J* = 7.1 Hz, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.5, 149.7, 149.4, 142.6, 134.2, 132.6, 128.4, 127.3, 126.4, 120.2, 117.8, 60.7, 42.3, 30.9, 14.3; IR (KBr): 2972, 1709, 1325, 1008, 794, 704 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 419 (5.7), 550 (4.3) nm; HRMS (EI) m/z: calcd for $C_{42}H_{36}N_4O_4Zn$: 724.2028, found: 724.2029.

Palladium-catalyzed conversion of 5,15-dibromo-10,20-diphenylporphyrin (5a) into [5,15-bis-(2-ethoxycarbonylethyl)-10,20-diphenylporphyrinato]zinc(II) (Zn-2ab)

An oven-dried 50 mL sealable two-necked flask equipped with a reflux condenser, a magnetic stirring bar and rubber septa was charged with Zn dust (1.3 g, 20 mmol) and CuCl (188 mg, 2 mmol). The reaction vessel was evacuated and flushed with argon (three times), and absolute THF (8 mL) was added. The suspension was refluxed for 1 h using an oil-bath. During this activation period, another oven-dried 5 mL sealable flask was evacuated and flushed with argon (three times) and then charged absolute THF (4 mL) and ethyl bromoacetate (560 μL, 5 mmol). The reaction vessel containing Zn(Cu) couple was removed from the oil-bath. To initiate the reaction, ca. 1/10 of the THF solution of ethyl bromoacetate was added via a syringe to the stirred Zn(Cu) couple suspension while the suspension was still hot. The rest of the solution was added in such a rate as to maintain a gentle reflux (ca. 5 min). The reaction mixture was stirred and refluxed until its color turned to green (ca. 3 h). To the resulting ca. 0.4 M THF solution of the zinc enolate **4b** was added dropwise a mixture of dibromoporphyrin **5a** (54.1 mg, 0.1 mmol), Pd(OAc)2 (1.1 mg, 5 mol%), and t-$Bu_3P{\cdot}HBF_4$ (2.9 mg, 10 mol%) in THF (20 mL) over a period of 5 min. The reaction mixture was heated under argon at 60 °C for 1 h, and then allowed to reach rt. The reaction mixture was filtered through a filter paper, diluted with THF/Et_2O (2:1 vol/vol, 20 mL), and washed with aqueous NH_4Cl and brine. The organic layer was dried over anhydrous $MgSO_4$, and concentrated in vacuo. Column chromatography on silica gel (THF/hexane 1:10 → 1:3) followed by recrystallization from CH_2Cl_2/hexane gave the product **Zn-1ab**. ^{1}H-NMR ($CDCl_3$, 300 MHz) δ: 9.56 (d, *J* = 4.8 Hz, 4H), 8.99 (d, *J* = 4.8 Hz, 4H), 8.20–8.15 (m, 4H,), 7.79–7.70 (m, 6H,), 6.01 (s, 4H), 4.19 (q, *J* = 7.1 Hz, 4H,),

1.19 (t, J = 7.1 Hz, 6H); IR (KBr): 2994, 2976, 2951, 1717, 1595, 1490, 1443, 1348, 1265, 1209, 1183, 1089, 1026, 10024, 946, 798, 7594 cm^{-1}; UV/vis (CH_2Cl_2): λ_{max} (log ε): 419 (5.6), 552 (4.4) nm; HRMS (EI) m/z: calcd for $C_{40}H_{32}N_4O_4Zn$: 696.1715, found: 696.1716. ^{13}C-NMR data are not available owing to the poor solubility of the compound.

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REFERENCES AND NOTES

1. 'The Porphyrin Handbook, Vol. 1–20,' ed. by K. M. Kadish, K. M. Smith, and R. Guilard, Academic Press, San Diego, 1999–2003.
2. We have developed porphyrin-based Lewis acid catalysts that can promote regio- and stereoselective isomerization of epoxides to carbonyl compounds and Claisen rearrangement of allyl vinyl ethers, see: (a) K. Suda, K. Baba, S. Nakajima, and T. Takanami, *Chem. Commun.*, 2002, 2570. (b) K. Suda, T. Kikkawa, S. Nakajima, and T. Takanami, *J. Am. Chem. Soc.*, 2004, **126**, 9554. (c) T. Takanami, M. Hayashi, and K. Suda, *Tetrahedron Lett.*, 2005, **46**, 2893. (d) T. Takanami, M. Hayashi, K. Iso, H. Nakamoto, and K. Suda, *Tetrahedron*, 2006, **62**, 9467.
3. For a review, see: A. Satake, *J. Synth. Org. Chem. Jpn.*, 2007, **65**, 298.
4. For some examples of leading works on functionalization reactions of porphyrins, see: (a) H. Hata, H. Shinokubo, and A. Osuka, *J. Am. Chem. Soc.*, 2005, **127**, 8264. (b) A. K. Sahoo, S. Mori, H. Shinkubo, and A. Osuka, *Angew. Chem. Int. Ed.*, 2006, **45**, 7972. (c) S. Yamaguchi, T. Katoh, H. Shinkubo, and A. Osuka, *J. Am. Chem. Soc.*, 2007, **129**, 6392. (d) Y. Chen and X. P. Zhang, *J. Org. Chem.*, 2003, **68**, 4432. (e) G. Y. Gao, A. J. Colvin, Y. Chen, and X. P. Zhang, *Org. Lett.*, 2003, **5**, 3261. (f) G. Y. Gao, Y. Chen, and X. P. Zhang, *Org. Lett*., 2004, **6**, 1837. (g) G. Y. Gao, A. J. Colvin, Y. Chen, and X. P. Zhang, *J. Org. Chem.*, 2004, **69**, 8886.
5. Senge et al. have developed a useful method for the preparation of *meso*-substituted porphyrins utilizing S_NAr reaction with organolithium reagents, see: (a) M. O. Senge, *Acc. Chem. Res.*, 2005, **38**, 733. (b) X. Feng and M. O. Senge, *Tetrahedron*, 2000, **56**, 587. (c) M. O. Senge, S. S. Hatscher, A. Wiehe, K. Dahms, and A. Kelling, *J. Am. Chem. Soc.*, 2004, **126**, 13634. (d) K. Dahms, M. O. Senge, and M. B. Bakar, *Eur. J. Org. Chem.*, 2007, 3833, and references cited therein.
6. We have reported amination, cyanation, and formylation of porphyrins: (a) T. Takanami, M. Hayashi, F. Hino, and K. Suda, *Tetrahedron Lett.*, 2003, **44**, 7353. (b) T. Takanami, M. Hayashi, H. Chijimatsu, W. Inoue, and K. Suda, *Org. Lett.*, 2005, **7**, 3937. (c) T. Takanami, A. Wakita, A.

Sawaizumi, K. Iso, H. Onodera, and K. Suda, *Org. Lett.*, 2008, **10**, 685.

7. See for example: (a) M. Tanaka, S. Hayashi, S. Eu, T. Umeyama, Y. Matano, and H. Imahori, *Chem. Commun.*, 2007, 2069. (b) M. Ptaszek, Z. Yao, D. Savithri, P. D. Boyle, and J. S. Lindsey, *Tetrahedron*, 2007, **63**, 12629. (c) S. Matile, N. Berova, and K. Nakanishi, *J. Am. Chem. Soc.*, 1995, **117**, 7021. (d) L. Sun, J. Gersdorff, D. Niethammer, P. Tian, and H. Kurreck, *Angew. Chem., Int. Ed. Engl.*, 1994, **33**, 2318. (e) A. Osuka, R. P. Zhang, K. Maruyama, I. Yamazaki, and Y. Nishimura, *Bull. Chem. Soc. Jpn.*, 1992, **65**, 2807.
8. For pioneering studies on palladium-catalyzed Negishi cross-coupling of *meso*-bromoporphyrins with simple alkylzinc reagents, see: (a) S. G. DiMagno, V. S. -Y. Lin, and M. J. Therien, *J. Am. Chem. Soc.*, 1993, **115**, 2513. (b) S. G. DiMagno, V. S. -Y. Lin, and M. J. Therien, *J. Org. Chem.*, 1993, **58**, 5983.
9. Very recently, Chen and coworkers reported synthesis of mono- and bis-functionalized porphyrins via nickel-catalyzed coupling of *meso*-brominated precursors with malonate-type carbon nucleophiles. However, the low to moderate yields of bis-functionalized porphyrins and the limitation of substrates to the Ni(II) complexes preclude this method from being generally applicable, see: C. Liu, D. -M. Shen, and Q. -Y. Chen, *J. Org. Chem.*, 2007, **72**, 2732.
10. R. Shediac, M. H. B. Gray, H. T. Uyeda, R. C. Johnson, J. T. Hupp, P. J. Angiolillo, and M. J. Therien, *J. Am. Chem. Soc.*, 2000, **122**, 7017.
11. X. Shi, Sk. R. Amin, and L. S. Liebeskind, *J. Org. Chem.*, 2000, **65**, 1650.
12. M. Yeung, A. C. H. Ng, M. G. B. Drew, E. Vorpagel, E. M. Breitung, R. J. McMahon, and D. K. P. Ng, *J. Org. Chem.*, 1998, **63**, 7143.
13. C. Brückner, J. J. Posakony, C. K. Johnson, R. W. Boyle, B. R. James, and D. Dolphin, *Porphyrins Phthalocyanines*, 1998, **2**, 455.