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meso-Aryl-3-alkyl-2-oxachlorins

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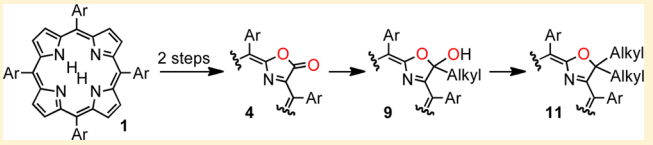
Supporting Information

ABSTRACT: The formal replacement of a pyrrole moiety of *meso*-tetraarylporphyrin **1** by an oxazole moiety is described. The key step is the conversion of porpholactones **4** (prepared by a known two-step oxidation procedure from **1**) by addition of alkyl Grignard reagent to form *meso*-tetraaryl-3-alkyl-2-oxachlorins **9** (alkyloxazolochlorins; alkyl = Me, Et, *i*Pr). Hemiacetal **9** can be converted to an acetal, reduced to an ether, or converted to bis-alkyloxazolochlorins **11**. The optical properties (UV−visible and fluorescence spectroscopy) are described. The chlorin-like optical properties of the alkyloxazolochlorins are compared to regular chlorins, such as 2,3-dihydroxychlorins and nonalkylated oxazolochlorins made by reduction from porpholactone **4**. The conformations of the mono- and bis-alkylated 2-oxachlorins, as determined by single crystal X-ray diffractometry, are essentially planar, thus proving that their optical properties are largely due to their intrinsic electronic properties and not affected by conformational effects. The mono- and bis-3-alkyl-2-oxachlorins are a class of readily prepared and oxidatively stable chlorins.



INTRODUCTION

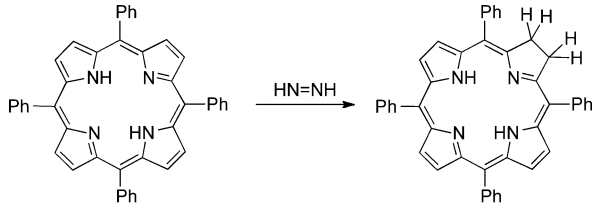
Chlorins, 2,3-dihydroporphyrins, generally possess UV−visible spectra that are red-shifted and endowed with strongly enhanced λ_{max} absorbance bands when compared to the spectra of the corresponding porphyrins.[1,2] It is this property that makes them nature's most prominent photosynthetic pigments.[3,4] Since red wavelengths also penetrate tissue better than shorter ones,[5] chlorins fulfill the photophysical criteria of the ideal photochemotherapeutic drug or photolabeling dye to be used *in vivo* better than porphyrins.[3,6,7] Their broader and more intense absorbance in the visible range of the spectrum makes chlorins also more attractive targets for synthetic light-harvesting applications.[8,9] Thus, the development of the synthesis of chlorins (and bacteriochlorins) is one of the key areas in current synthetic porphyrin chemistry, whereby three principally different approaches toward synthetic chlorins can be distinguished: The manipulation of naturally occurring chlorins, their total syntheses, and the conversion of preformed porphyrins to chlorins.[1,10−12]

The most basic conversion of a porphyrin to a chlorin is the reduction of a porphyrin with diimide (generated *in situ*).[13] Applied to *meso*-tetraphenylporphyrin **1**, this forms chlorin **2** (Scheme 1). However, this reaction is fraught with a number of problems. First, the chlorin is hard to separate from the bacteriochlorin byproducts and the remaining starting material. Second, chlorin **2** is oxidatively unstable and tends to revert back to a porphyrin (or other products).

Thus, a range of alternative irreversible porphyrin-to-chlorin conversion strategies were reported.[1,6,11] Perhaps the most successful and varied strategy entails the removal of a β,β'-double bond by involving it in an electrocyclic addition reaction.[14] One other synthetic method is the osmium tetraoxide-mediated dihydroxylation of porphyrins. Long known for octaalkylporphyrin,[15] this reaction was applied to *meso*-tetraarylporphyrin only more recently.[16−18] Using *meso*-tetraphenylporphyrin **1** (or closely related di- and tetraarylporphyrins), this reaction generates dihydroxychlorin **3** (Scheme 2).[17−21] We reported the use of dihydroxychlorin **3** in the synthesis of a number of chlorin-like chromophores in which one or two pyrroles of a porphyrin were formally replaced by a nonpyrrolic moiety.[17,19,20,22−26]

One such reaction involved the oxidation of **3** to porpholactone **4**,[26,27] which can also be applied to related dihydroxychlorins.[19] Porpholactone **4** was previously known although it was synthesized along differing pathways.[27,28] This oxidation replaces a porphyrin β,β'-carbon double bond by a lactone moiety (or a pyrrole moiety by an oxazolidone moiety). Furthermore, porpholactone **4** could be reduced to porpholactol **5** and the oxazolochlorin **6** possessing chlorin-like

Scheme 1. Diimide Reduction of Porphyrin 1 to Generate Chlorin 2



1
porphyrin-like UV-vis spectrum, λ_{max} = 648 nm

2
chlorin-like UV-vis spectrum, λ_{max} = 652 nm

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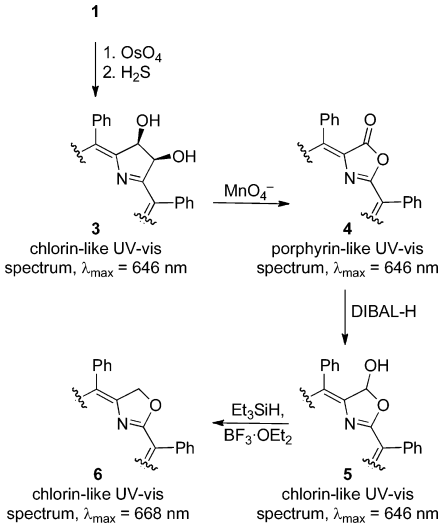
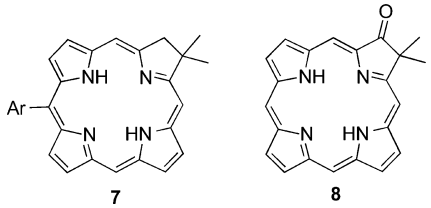
Scheme 2. Literature-known Syntheses of Oxazolochlorins 5 and 6



chromophores with, in part, dramatically enhanced long wavelength absorbances.[26] This enhancement was shown to be due to the presence of the ring oxygen.[26] While the hemiacetal **5** is available through several routes,[24,27,29] the more interesting oxazolochlorin **6** is available only by reduction of **5**.[26] However, this intriguing chlorin analogue proved to be exceedingly unstable with respect to oxidation.[24,26]

Total synthesis approaches to chlorins have been much more rare. Many of them involve a large number of linear steps and operate only on small scales and are thus of diminished practical value. Archetypical of these types of syntheses is the classic Woodward synthesis of chlorophyll *a*.[30] However, the group of Lindsey recently introduced novel methodologies to form chlorins of the types **7** and **8**. Their studies also delineated the structural requirements that result in high extinction coefficients in these chromophores.[12] Notably, both chlorins types **7** and **8** contain *gem*-dimethyl groups at the pyrroline *β*-positions, contributing to their high chemical stability. Despite requiring total syntheses, the generation of various key dipyrromethane precursors to **7** and **8** were optimized to a point where they became available at gram scales.[31] Thus, the limitation of the small-scale syntheses described for most chlorin total syntheses to date that prohibited their application in most applications were substantially mediated or even eliminated.



Lindsey's work inspired the work described here, namely the generation of 2-oxazolochlorins that are mono- and bis-alkyl-substituted *α* to the oxazole oxygen atom to impart greater chemical stability onto the chromophore. We recently provided a preliminary report on this work, namely the conversion of *meso*-tetraphenylporpholactones to *meso*-tetraphenyl-3-alkyl-2-oxachlorins and -dioxabacteriochlorins with tunable optical spectra.[25] Herein, we will expand on this work and report the details of the syntheses of mono- and bis-alkyloxazolochlorins and some of their chemical reactivity. The work by Lindsey challenged us to optimize key alkyloxazolochlorin syntheses to the point that we could make them available in half gram or even full gram scales. We will detail the optical properties of the 3-alkyl-2-oxachlorins (UV−visible and fluorescence spectra). We will also present a structural description of a number of free base and Zn(II) oxazolochlorins using single crystal X-ray diffraction structure elucidation. These investigations allow us to differentiate between direct electronic substituent effects and conformational effects to rationalize their optical properties.

RESULTS AND DISCUSSION

Synthesis of Mono- and Bis-alkyloxazolochlorins. Addition of alkyl (methyl, ethyl, *i*-propyl) Grignard reagents to the zinc(II) complex of porpholactone **4** under anhydrous conditions results in the formation of a more polar product. An aqueous acidic workup using a strong enough acid to demetalate the zinc complexes provided free base porphyrinoids with a chlorin-like UV−visible spectra as the main products in good to satisfactory yields (for a detailed description of the optical spectra of all compound prepared, see below). The HR−MS (ESI+) of these compounds suggested their composition to be derived from the parent porpholactone to which a single equivalent of methane, ethane, and propane was added, respectively. Their ^{1}H, ^{13}C NMR, and IR spectra also confirmed the loss of the lactone functional group and the presence of an alkyl chain attached to the oxazole moiety. These spectroscopic data and their similarity to those of the hemiacetals **5**[26] identified these products as the alkylated hemiketals **9**. The use of 2−3 equivalents of Grignard reagent was found to provide the highest yields of product. The reaction is rapid (5−20 min at ambient temperature), and can be scaled up to 1.5 g of starting porpholactone **4Zn** (2.15 mmol) (or 600 mg of **4^{F}Zn**, 0.62 mmol, whereby the addition of the Grignard reagent at lower temperatures, −78 °C for ^{i}PrMgBr and −45 °C for EtMgCl, was found beneficial for this substrate). The presence of the 'protecting group' zinc(II) is obligatory as the alkylation of free base porpholactones failed.

Even the use of a large excess of Grignard reagent (e.g., a 15-fold molar excess) did not generate more than traces of the corresponding bis-alkylated systems. The use of the more electron-withdrawing *p*-CF_3Ph-derivatives also did not improve the yield of formation of the bisalkylated products. However, reaction of **4Zn**/**4^{F}Zn** with an alkyl-Grignard reagent, followed by reaction of the crude zinc complex of **9** with a Lewis acid and further addition of alkyl-Grignard reagent furnished the dialkyl-derivatives **11** in satisfying yields (Scheme 3). We screened a number of Lewis acids (BF_3·OEt_2, TMSOTf, $Sc(OTf)_3$, $InCl_3$, $Ti(O^{i}Pr)_4$, and $TiCl_4$) for their ability to catalyze this reaction and found TMSOTf to be the best choice. The intermediacy of the TMS-ether of **9Zn** was shown as it could be detected in the reaction mixture by ESI(+) LR-MS.

We have also tested methyl and *i*-propyl lithium as alkylating agents. The reactions formed the expected monoalkylated compounds. However, the experimental conditions (reaction temperatures of −78 °C were required for both reagents) and the precautions associated with using alkyllithium reagents were not offset by higher yields, a larger fraction of bisalkylated products, or cleaner reactions when compared to the Grignard reactions. Thus, we did not develop this route toward alkyloxazolochlorins.

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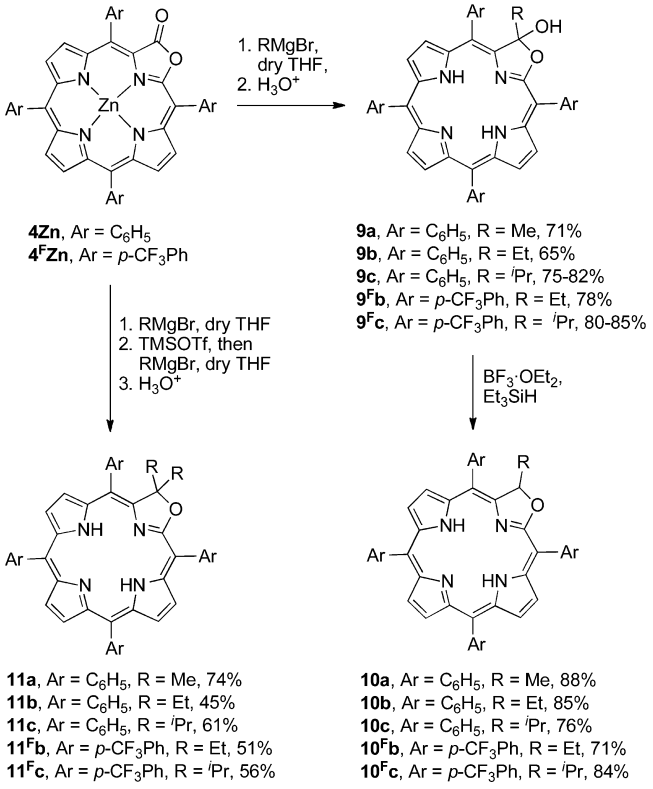
Scheme 3. Synthesis of Mono- and Bis-alkyloxazolochlorins by alkyl-Grignard Addition to Porpholactones 4Zn/4^{F}Zn



4Zn, Ar = C_6H_5
4^{F}Zn, Ar = *p*-CF_3Ph

9a, Ar = C_6H_5, R = Me, 71%
9b, Ar = C_6H_5, R = Et, 65%
9c, Ar = C_6H_5, R = ^{i}Pr, 75-82%
9^{F}b, Ar = *p*-CF_3Ph, R = Et, 78%
9^{F}c, Ar = *p*-CF_3Ph, R = ^{i}Pr, 80-85%

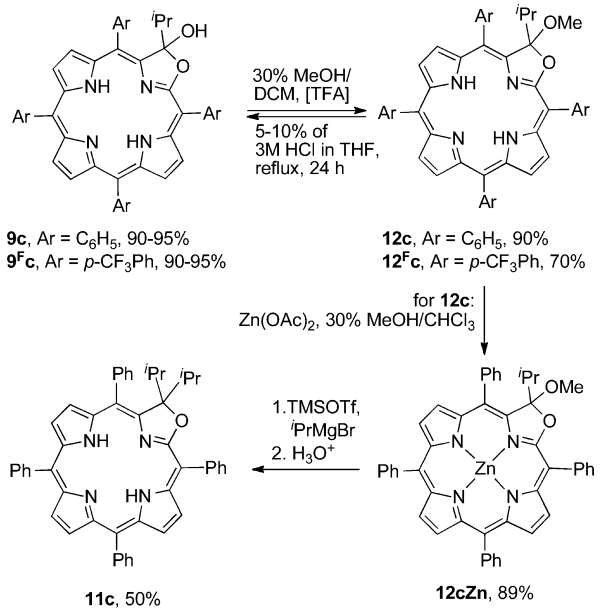
11a, Ar = C_6H_5, R = Me, 74%
11b, Ar = C_6H_5, R = Et, 45%
11c, Ar = C_6H_5, R = ^{i}Pr, 61%
11^{F}b, Ar = *p*-CF_3Ph, R = Et, 51%
11^{F}c, Ar = *p*-CF_3Ph, R = ^{i}Pr, 56%

10a, Ar = C_6H_5, R = Me, 88%
10b, Ar = C_6H_5, R = Et, 85%
10c, Ar = C_6H_5, R = ^{i}Pr, 76%
10^{F}b, Ar = *p*-CF_3Ph, R = Et, 71%
10^{F}c, Ar = *p*-CF_3Ph, R = ^{i}Pr, 84%

Analogously to hemiacetals **5**, their alkylated analogues **9**/**9^{F}** can be hydro-dehydroxylated using triethylsilane in the presence of $BF_3{\cdot}OEt_2$, forming monoalkyloxazolochlorin **10**/**10^{F}**. The success of this reaction is indicated by the loss of one oxygen atom in the composition of the product **10** as determined by HR−MS, the appearance of one hydrogen signal in the pyrroline region of the spectrum (6.1−7.2 ppm) that is coupled with the corresponding alkyl group ($C\underline{H}_3$ of Me, $C\underline{H}_2CH_3$ of Et, and $C\underline{H}(CH_3)_2$ of *i*Pr), and a similar ∼20 nm red-shift of the optical spectrum of alkyloxazolochlorin **10** as observed upon formation of oxazolochlorin **6** by dehydroxylation of hemiacetal **5**.[26] The oxazolochlorins of types **9** and **11** are distinguished by excellent solubilities but the monoalkyloxazolochlorins of type **10** possessed markedly reduced solubilities. Also, the dimethyl-substituted oxazolochlorins possess poor solubility (good quality ^{13}C NMR spectra, for example, could not be recorded over 12 h acquisition times), particularly when compared to the excellent solubility of the bis-ethyl and bis-*i*Pr derivatives. The generally improved solubility of the *p*-CF_3Ph-derivatives was not enough to overcome these solubility issues.

Derivatization of Hemiketals 9. The hydroxy group of hemiketal **9** is susceptible to facile acid-catalyzed ketalization. This reaction is parallel to the reaction of its nonalkylated analogues.[26] Under the right reaction conditions, this reaction is reversible, with no apparent destruction of the macrocycle, providing some evidence for the robust nature of the alkyloxazolochlorins. Interestingly, after zinc(II) insertion into acetal **12c**, a TMSOTf-mediated substitution of the methoxy group with an alkyl group gave rise to, after demetalation, an alternative synthesis of the bisalkylated product **11c** (Scheme 4).

Scheme 4. Ketalization of Hemiketals 9 and Alternate Pathway to Bisalkyloxazolochlorin 11c



9c, Ar = C_6H_5, 90-95%
9^{F}c, Ar = *p*-CF_3Ph, 90-95%

12c, Ar = C_6H_5, 90%
12^{F}c, Ar = *p*-CF_3Ph, 70%

11c, 50%

12cZn, 89%

Structural Aspects of Alkyloxazolochlorins. The crystal structures of mono-*iso*-propyloxazolochlorin hemiketal **9c**, its methyl ketal zinc(II) complex **12cZn**, and of the bis-*iso*-propyloxazolochlorin **11c** were determined by single crystal X-ray diffraction (Figure 1). These structures confirm the connectivity of the oxazolochlorins but more importantly, they prove the conformation of the macrocycles (in the solid state). The conformations of all three macrocycles are essentially planar. The small deviations from planarity that can be observed vary from chromophore to chromophore but are all not large enough to affect the optical properties in any major way. Hydroporphyrins are known to be conformationally somewhat more flexible than the corresponding porphyrins.[32] The conformational analysis of the two halves of an oxazolochlorin dimer also showed small and distinct conformation differences of the two chromophores, suggestive of a somewhat flexible macrocycle.[24] As will be shown below, the optical spectra of all oxazolochlorins do not show any degree of broadening, further allowing us to conclude that the conformational flexibility of oxazolochlorins is not unusually high (as, for instance, observed in the morpholinochlorin that differ from the oxazolochlorins by the presence of an additional sp^3-hybridized carbon atom in the nonpyrrolic moiety).[23]

Unlike many of the structures of the corresponding porpholactones,[26] the structures of **11c** and **12cZn** are not disordered. The structure of **9c** exhibits a small degree of disorder in the oxazole ring, which adopts two orientations within an approximately 80/20 ratio. In all three cases, bond distances, angles and overall porphyrin planarity can be unambiguously observed. The C_β−O bond in the oxazole ring is significantly lengthened in all three compounds (1.4483(18) Å in **11c**, 1.461(5) Å in **12cZn** and 1.457(4) Å for the primary orientation of **9c**) versus a typical C_β−$C_{\beta'}$ bond length of ∼1.36 Å in a normal porphyrin. The C_α−O bond distance is appreciably shorter, however, with distances of (1.3594(17) Å in **11c**, 1.374(4) Å in **12cZn** and 1.351(3) Å for the primary orientation in **9c**), indicative of a significant degree of double bond character. The C_α-C_β bonds in the oxazole rings

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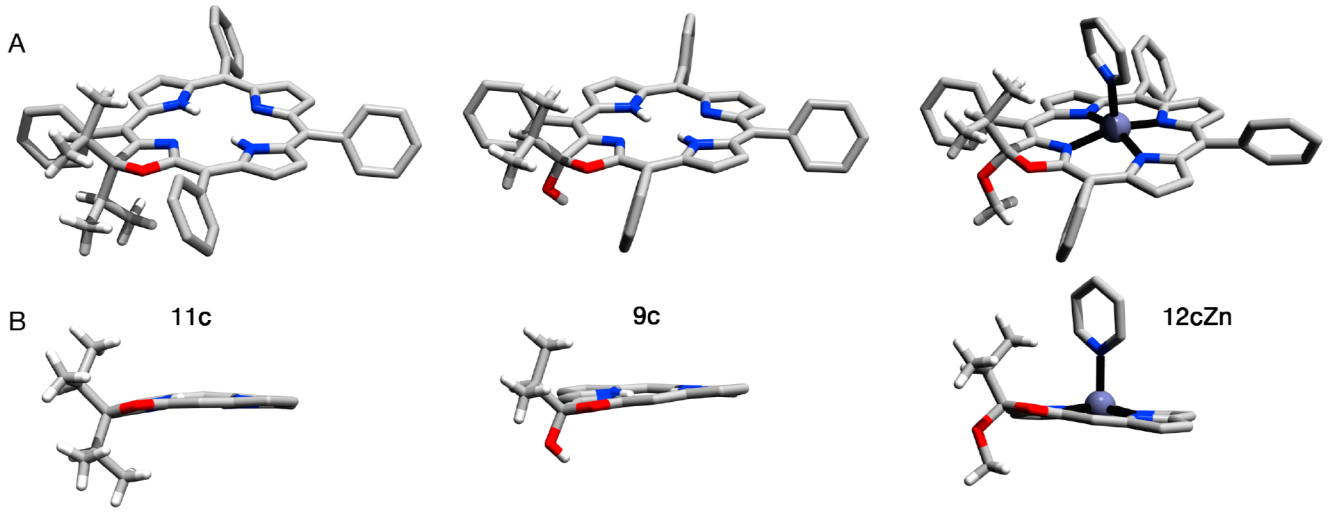

Figure 1. Single crystal X-ray structures of **9c**, **11c**, and **12cZn**. All hydrogen atoms attached to carbon positions and the minor disorder contribution of **9c** have been omitted for clarity.

are clearly single in bond character, with observed bond lengths of 1.545(2) Å in **11c**, 1.518(5) Å in **12cZn** and 1.578(4) Å for the primary orientation in **9c.** In all three compounds, the N−C bonds in the oxazole moiety are asymmetric, with one measuring a typical distance of ∼1.36−1.37 Å, and the second being shorter at ∼1.34 Å.

All three porphyrinoids exhibit primarily planar conformations in the solid state with some small and varying deviations. In **9c**, the largest deviation from the mean 24 atom plane of the porphyrinoid is 0.27 Å, with an average deviation of 0.09 Å. In **11c**, the maximum deviation is 0.23 Å with an average deviation of 0.11 Å. The zinc complex **12cZn** also exhibits a predominantly planar porphyrinoid macrocycle (maximum deviation 0.27 Å, average deviation 0.10 Å); the presence of the zinc ion does not distort the conformation of the ring, although the greatest deviations from planarity are observed in the oxazole unit. The zinc ion is five coordinate with an axial pyridine, and the Zn(II) ion is pulled away from the plane of the porphyrinoid macrocycle by 0.38 Å, as is commonly observed for pentacoordinated zinc porphyrin complexes.[33]

Optical Properties of Alkyloxazolochlorins. Benchmark compound free base porpholactol **5** possesses a chlorin-type UV−visible absorption spectrum (λ_{max} = 646 nm) (Figure 2A; see also ESI). The spectrum of the monoalkylated analogues (**9a**: λ_{max} = 647 nm, **9b**: λ_{max} = 648 nm, **9c**: λ_{max} = 649 nm, **9^{F}b**: λ_{max} = 649 nm, **9^{F}c**: λ_{max} = 650 nm) are nearly indistinguishable from that nonalkylated species **5**. Likewise, the optical spectra of the methyl, ethy, and *i*-propyl derivatives were indistinguishable from each other. On the other hand, the formal replacement of the hemiketal hydroxy group by a hydrogen (as in **6**, λ_{max} = 668 nm) or an alkyl group (as in **10a**: λ_{max} = 667 nm, **10b**: λ_{max} = 667 nm, **10c**: λ_{max} = 668 nm, **10^{F}b**: λ_{max} = 669 nm, **10^{F}c**: λ_{max} = 670 nm) significantly red-shifts the spectrum. The corresponding profound effect of the hydroxy groups located at the chlorin-specific β,β'-bond on the optical properties of the chromophore and a qualitatively similar auxochromic effect upon removal of the hydroxy group was observed for nonalkylated oxazolochlorins and chlorins.[18,26] The bis-alkyloxazolochlorins **11** possess λ_{max} values that are similar to those of the dehydroxylated monoalkyloxazolochlorins **10**. However, the shapes of their Soret bands and the peak positions of the remaining Q-bands are distinctly different.

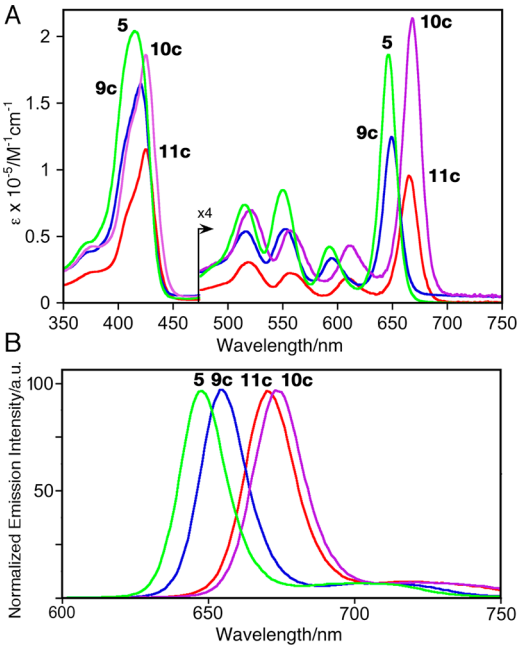

Figure 2. (A) UV−visible and (B) fluorescence spectra of lactol **5** (green trace), *α-i*-propyl lactol **9c** (blue trace), *α-i*-propyl oxazolochlorin **10c** (magenta trace), and *α,α′*-bis-*i*-propyl oxazolochlorin **11c** (red trace) (all in $CHCl_3$ at ambient temperature; $\lambda_{excitation} = \lambda_{Soret}$).

Also, irrespective of whether bis-alkyloxazolochlorins **11a**, **11b** or **11c** are concerned, the UV−visible spectra of the bis-alkyloxazolochlorins possess almost 50% lower extinction coefficients compared to the corresponding monoalkylated species **10a**, **10b** and **10c**.

The fluorescence emission spectra of the alkyloxazolochlorins are all chlorin-type (Figure 2B; see also Supporting Information), with the small Stokes' shift characteristic for porphyrins. The fluorescence yields are in the range of 0.19 to 0.30. A detailed experimental study of the excited state photophysical properties of the oxazolochlorins will be reported in due course.

Comparison to Other Porphyrinoids Containing Oxazole Moieties. We previously discussed the structural parallels between our 2-oxachlorins[26] and the 2-oxa-21-

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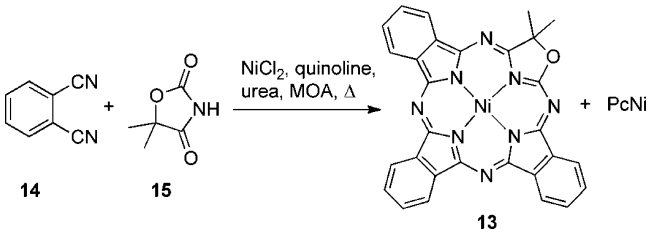
carbachlorin[34] described by Pawlicki and Latos-Grazynski. Recently, an example of a 3,3-dimethyl-oxazole-containing phthalocyanine-analogue, **13**, made by total synthesis, was reported (Scheme 5).[35] Mixed condensation of either

Scheme 5. Synthesis of 2,2-Dimethyl-3-oxa-tri(1,2-benzo)tetraazachlorin (13) According to Dudkin et al.[35]



phthalonitrile (**14**) (or phthalimide) and 5,5-dimethyl-1,3-oxazolidine-2,4-dione (**15**) in the presence of nickel chloride and an ammonium molybdate catalyst (MOA) in quinoline at 250 °C led to a mixture of [phthalocyaninato]Ni(II) (PcNi) as the main product and 2,2-dimethyl-3-oxa-tri(1,2-benzo)-tetraazachlorin (**13**) as a sparingly soluble product in 4.2% yield that required HPLC purification. The optical spectrum of this oxazolotetraazachlorin analogue is qualitatively similar to those of regular tetraazachlorins, albeit the λ_{max} band is 32 nm red-shifted. An increased oxidation stability of the oxazolo-analogues compared to the regular chlorin analogue was also noted. In these respects, the results reported for tetraazachlorin **13** parallel those reported for our oxazolochlorins, highlighting general properties the (alkylated) oxazole moiety impart on porphyrinoids.

CONCLUSIONS

The addition of alkyl-Grignard reagents to the porphyrin-like *meso*-tetraarylporpholactones resulted in the formation of mono- and bis-alkylated oxazolochlorins. The monoalkylated hemiketals can be deoxygenated or converted to ketals. As previously demonstrated for the corresponding hemiacetals **5**,[26] this allows the facile derivatization of these chromophores. The oxazolochlorins possess chlorin-like optical properties that are slightly modulated depending on the nature of the substituents located on the sp^3-hybridized carbon α to the oxazole oxygen. Since porpholactones are readily accessible in gram-scales and the key reactions were demonstrated at gram or half-gram scales, this methodology offers straightforward access to significant quantities of a class of stable chlorin-like chromophores that are endowed with somewhat tunable optical spectra. This tunability, the reasonably high fluorescence quantum yields and the facile derivatization of the chromophores encourage the further study and application of this unique porphyrinoid class. Experiments to test their applicability as light-harvesting devices and in photomedicine are currently underway.

EXPERIMENTAL SECTION

X-ray Single Crystal Diffractometry. X-ray crystallographic analysis: Single crystals of **9c**, **11c**, and **12cZn** were coated in Fomblin oil, mounted on a CryoLoop and placed on the goniometer head under a stream of nitrogen cooled to 100 K. The data were collected on a Bruker APEX2 CCD diffractometer with either IμS microfocus Cu source K_α radiation (λ = 1.54178 Å, **11c**) or IμS microfocus Mo source K_α radiation (λ = 0.71073, **9c** and **12cZn**). The frames were integrated with the Bruker SAINT software package using a narrow-frame algorithm. Data were corrected for absorption effects using the multiscan method (SADABS) and the structure was solved and refined using the Bruker SHELXTL Software Package until the final anisotropic full-matrix, least-squares refinement of F^2 converged. Data collection and structural parameters for the structure elucidations of **9c**, **11c**, and **12cZn** can be found in the ESI.

Materials and Instrumentation. [*meso*-Tetraarylporpholactonato]Zn(II) **4Zn** and **4^{F}Zn** were synthesized as reported in the literature.[26] Flash column chromatography was performed manually in glass columns or on an automated flash chromatography system, on normal-phase silica (solvents used are indicated; isochratic eluation modes).

***meso*-Tetraphenyl-3-hydroxy-3-methyl-2-oxachlorin (9a). General Procedure for the Conversion of Lactone 4Zn to Hemiketal 9.** For a typical reaction, a N_2-flushed, oven-dried 50 mL round-bottom flask was loaded with [*meso*-tetraphenyl-2-oxa-3-oxoporphyrinato]Zn(II) (**4Zn**, 100 mg, 0.145 mmol) dissolved in dry THF (15 mL). Then, 5 equiv of MeMgBr (3 M solution in Et_2O, 0.24 mL) was slowly added at ambient temperature. The reaction progress was monitored using UV−vis spectroscopy (disappearance of the band at ~600 nm and development of a band at ~625 nm). The reaction was completed within 15 min. Upon completion, the reaction was quenched by addition of a saturated aq NH_4Cl solution (2−3 mL). The mixture was transferred into a 250 mL separatory funnel and washed with a saturated aq NH_4Cl, and the chlorin was extracted with CH_2Cl_2. Note: it appears critical to ensure that all Grignard reagent is quenched; repeated aq NH_4Cl washes may be necessary. Crude **9aZn** was dissolved in THF (15 mL) and stirred, and 6 M aq HCl (2−3 mL) is added. The reaction was stirred for ~2 h. The reaction progress was monitored by UV−vis spectroscopy. Upon disappearance of the metallochlorin spectrum of a neutralized aliquot, the green reaction mixture was transferred into a separatory funnel and a saturated aq $NaHCO_3$ solution was added (Caution, foam!). CH_2Cl_2 was added and the organic layer was extracted. The aq $NaHCO_3$ wash was repeated until the organic layer was pure purple in color. The organic phase was isolated and dried over K_2CO_3. The product was isolated by flash chromatography (silica-CH_2Cl_2) to afford product **9a** as a purple solid in good yield (76%, 72 mg). MW = 648.8 g/mol; R_f = 0.55 (silica-CH_2Cl_2); UV−vis ($CHCl_3$) λ_{max} (log ε): 419 (5.29), 516 (4.08), 551 (4.14), 594 (3.86), 647 (4.53) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 420 nm): 652, 704 nm, ϕ = 0.28; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.57 (d, ^3J = 5.0 Hz, 1H), 8.46 (d, ^3J = 5.0 Hz, 1H), 8.41−8.39 (m, 2H), 8.33 (d, ^3J = 4.4 Hz, 1H), 8.15−7.60 (m, 21H), 3.72 (s, 1H), 1.96 (s, 3H), −0.67 (s, 1H), −1.1 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 162.6, 155.1, 153.5, 151.6, 143.1, 142.1, 141.9, 141.8, 139.2,139.1, 137.1, 134.8, 134.7, 134.4, 134.1, 133.9, 133.9, 133.6, 131.6, 129.7, 128.2, 128.0, 127.9, 127.6, 127.5, 127.1, 127.0, 126.9, 126.9, 126.4, 126.3, 125.5, 122.6, 121.2, 111.5, 109.2, 100.3, 27.6 ppm; HR-MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{44}H_{33}N_4O_2$: 649.2604, found 649.2579.

***meso*-Tetraphenyl-3-ethyl-3-hydroxy-2-oxachlorin (9b).** **9b** was prepared from [*meso*-tetraphenyl-2-oxa-3-oxoporphyrinato]Zn(II) (**4Zn**, 100 mg, 0.145 mmol) according to the reaction procedure described for the preparation of **9a**, except the reaction was performed using 5 equiv of EtMgBr (2 M solution in THF, 0.145 mL). The product **9b** was isolated by flash chromatography (silica-CH_2Cl_2) as a purple solid in 65% (61.5 mg) yield. MW = 662.78 g/mol; R_f = 0.55 (silica-CH_2Cl_2); UV−vis ($CHCl_3$) λ_{max} (log ε): 420 (5.59), 516 (4.16), 552 (4.45), 593 (4.19), 648 (4.84) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 420 nm): 652, 710 nm, ϕ = 0.31; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.59 (d, ^3J = 4.4 Hz, 1H), 8.48 (d, ^3J = 3.0 Hz, 1H), 8.43−8.34 (m, 2H), 8.35 (d, ^3J = 4.0 Hz, 1H), 8.17−7.59 (m, 21H), 3.75 (s, 1H), 2.38−2.32 (m, 1H), 1.99−1.94 (m, 1H), 0.75 (t, ^3J = 7.1 Hz, 3H), −0.64 (s, 1H), −1.04 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 163.2, 155.1, 152.1, 151.6, 143.1, 142.1, 141.9, 141.8, 139.4, 138.9, 137.1, 134.9, 134.4, 134.2, 134.1, 133.9, 133.8, 133.6, 131.5, 129.7, 128.3, 128.0, 127.9, 127.9, 127.7, 127.5, 127.1, 126.9, 126.9, 126.8, 126.3, 126.2, 125.5, 122.5, 121.2, 112.2, 111.6, 100.1, 32.5, 8.67 ppm; HR-MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{45}H_{35}N_4O_2$: 663.2760, found 663.2754.

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***meso*-Tetraphenyl-3-hydroxy-3-isopropyl-2-oxachlorin (9c).** **9c** was prepared from [*meso*-tetraphenyl-2-oxa-3-oxoporphyrinato]Zn(II) (**4Zn**, 1.5 g, 2.15 mmol) according to the reaction procedure described for the preparation of **9a**, except the reaction was performed using 2 equiv of *i*-PrMgBr (2 M solution in THF, 2.15 mL). The product **9c** was isolated by flash chromatography (silica-CH_2Cl_2) as a purple solid in 75% yield (1090 mg). MW = 676.80 g/mol; R_f = 0.50 (silica-CH_2Cl_2); UV−vis ($CHCl_3$) λ_{max} (log ε): 420 (5.22), 516 (4.13), 550 (4.14), 592 (3.92), 649 (4.49) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 420 nm): 653, 710 nm, ϕ = 0.35; ^{1}H NMR (300 MHz, $CDCl_3$, δ) 8.59 (d, ^3J = 5.0 Hz, 1H), 8.45−8.47 (m, 3H), 8.34 (d, ^3J = 4.5 Hz, 1H), 7.95−8.17 (m, 7H), 7.85 (m, 1H), 7.65−7.72 (m, 11H), 7.48−7.57 (m, 3H), 2.17−2.26 (m, 1H), 1.28 (d, ^3J = 6.7 Hz, 3H), 0.67 (d, ^3J = 6.7 Hz, 3H), −0.60 (s, 1H), −0.99 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 163.4, 155.2, 153.6, 151.7, 143.2, 142.2, 142.0, 139.4, 139.0, 137.2, 134.9, 134.4, 134.2, 134.1, 133.9, 133.6, 131.6, 131.0, 129.8, 128.9, 128.3, 128.0, 127.9, 127.6, 127.2, 127.0, 126.9, 126.3, 125.6, 122.67, 121.3, 113.6, 111.4, 100.2, 36.4, 30.0, 17.8, 16.1 ppm; LR-MS (ESI+, 30 V, CH_3CN): m/z = 677 (MH^+); HR-MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{46}H_{37}N_4O_2$: 676.2917, found 677.2918.

***meso*-Tetrakis(4-trifluoromethylphenyl)-3-ethyl-3-hydroxy-2-oxachlorin (9^Fb).** 9^F**b** was prepared from [*meso*-tetrakis-(trifluoromethylphenyl)-2-oxa-3oxoporphyrinato]Zn(II) (**4^FZn**, 113 mg, 0.117 mmol) according to the reaction procedure described for the preparation of **9a**, except the reaction was performed at −45 °C using 2 equiv of EtMgBr (2 M solution in THF, 117 μL). For best yield, the reaction should be maintained at −45 °C until it is quenched. The product 9^F**b** was isolated by column chromatography (silica-50% petroleum ether/CH_2Cl_2) as a purple solid in 78% (85 mg) yield. MW = 934.8 g/mol; R_f = 0.26 (silica-50% petroleum ether 30−60/CH_2Cl_2); UV−vis ($CHCl_3$) λ_{max} (log ε): 419 (5.13), 513 (4.00), 548 (3.99), 595 (3.75), 649 (4.45) nm, Fl λ_{max} ($CHCl_3$, λ_{exc} = 419 nm): 654, 702 nm, ϕ = 0.29; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.59 (d, ^3J = 5.1 Hz, 1H), 8.45 (d, ^3J = 3.9 Hz, 1H), 8.42 (d, ^3J = 5.0 Hz, 1H), 8.39 (d, ^3J = 4.6 Hz, 1H), 8.32 (d, ^3J = 4.6 Hz, 1H), 8.18−7.99 (m, 15H), 7.87 (d, ^3J = 8.0 Hz, 1H), 7.77 (d, ^3J = 8.0 Hz, 1H), 3.84 (s, 1H), 2.38−2.29 (m, 1H), 1.92−1.86 (m, 1H), 0.74 (t, ^3J = 7.3 Hz, 3H), −0.63 (s, 1H), −0.99 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 163.2, 154.9, 152.3, 151.4, 145.4, 145.2, 142.9, 142.7, 142.3, 141.6, 136.9, 135.3, 134.2, 134.2, 134.0, 134.0, 133.9, 133.8, 131.8, 130.0, 129.9, 127.7, 126.0, 125.7, 125.1, 125.1, 125.0, 124.3, 124.3, 124.1, 124.1, 124.0, 123.9, 123.9, 123.3, 123.3, 123.3, 123.3, 122.8, 120.1, 112.3, 110.7, 99.2, 32.7, 8.57; HR-MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{49}H_{31}F_{12}N_4O_2$: 935.2255, found 935.2236.

***meso*-Tetrakis(4-trifluoromethylphenyl)-3-hydroxy-3-isopropyl-2-oxachlorin (9^Fc).** 9^F**c** was prepared from [*meso*-tetrakis-(trifluoromethylphenyl)-2-oxa-3-oxoporphyrinato]Zn(II) (**4^FZn**, up to 500 mg scale) according to the reaction procedure described for the preparation of **9a**, except the reaction was performed using *i*-PrMgCl (2 M solution in THF, 0.515 mL for 500 mg scale) maintained at −78 °C. The product 9^F**c** was isolated by chromatography (silica-50% petroleum ether 30−60/CH_2Cl_2) as a purple solid in 80−85% yield (up to 415 mg). MW = 948.8 g/mol; R_f = 0.32 (silica-50% petroleum ether 30−60/CH_2Cl_2); UV−vis ($CHCl_3$) λ_{max} (log ε): 420 (5.24), 513 (4.10), 548 (4.09), 595 (3.88), 650 (4.55) nm; Flλ_{max} ($CHCl_3$, λ_{exc} = 420 nm): 655, 703 nm, ϕ = 0.36; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.57 (d, ^3J = 4.9 Hz, 1H), 8.42 (m, 2H), 8.36 (d, ^3J = 4.5 Hz, 1H), 8.15−7.95 (m, 19H), 3.87 (s, 1H), 2.14−2.08 (m, 1H), 1.28 (d, ^3J = 6.5 Hz, 3H), 0.65 (d, ^3J = 6.7 Hz, 3H), −0.63 (s, 1H), −0.99 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 163.2, 154.8, 153.7, 151.3, 145.4, 145.1, 142.8, 142.7, 142.7, 142.4, 141.8, 136.9, 135.3, 134.2, 134.1, 134.0, 133.9, 133.9, 133.9, 133.7, 131.7, 129.8, 127.7, 125.7, 125.0, 124.3, 124.2, 124.2, 124.1, 124.0,124.0, 123.9, 123.8, 123.3, 123.3, 123.2, 122.8, 120.1, 113.6, 110.4, 99.1, 36.4, 17.5, 15.9; HR-MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{50}H_{33}F_{12}N_4O_2$: 949.2412, found 949.2431.

***meso*-Tetraphenyl-3-methyl-2-oxachlorin (10a). General Procedure for the Conversion of Hemiketal 9 to Monoalkyl Oxazolochlorin 10.** *meso*-Tetraphenyl-3-hydroxy-3-methyl-2-oxachlorin (**9a**, 54 mg, 0.083 mmol), was dissolved in CH_2Cl_2 and stirred at room temperature. To this solution, excess $BF_3{\cdot}OEt_2$ (20 eq, 0.2 mL) and Et_3SiH (20 eq, 0.26 mL) were added slowly. The reaction mixture was left stirring overnight. Reaction progress was monitored using UV−visible spectroscopy (formation of the diagnostic peak at ∼660 nm in a neutralized aliquot). Upon completion, the reaction mixture was quenched by addition of a saturated aq $NaHCO_3$ solution. The mixture was transferred into a separatory funnel. The aq $NaHCO_3$ wash was repeated until the organic layer was purple/green in color. The organic layer was isolated, dried over Na_2SO_4, and the solvent was evaporated by rotary evaporation. The crude product was purified by flash chromatography (silica−CH_2Cl_2) to afford the product **10a** as a purple solid in 88% yield (46 mg). MW = 632.8 g/mol; R_f = 0.89 (silica−CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 424 (5.25), 519 (4.05), 557 (3.94), 610 (3.79), 667 (4.61) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 424 nm): 672, 718 nm, ϕ = 0.29; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.47 (s, 1H), 8.40 (s, 1H), 8.31−8.24 (m, 3H), 8.16−7.95 (m, 10H), 7.71 (s, 12H), 7.10 (d, ^3J = 5.6 Hz, 1H), 1.60 (d, ^3J = 5.4 Hz, 3H), 0.09 (s, 1H), −0.29 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 167.9, 159.7, 154.7, 151.4, 143.9, 142.1, 141.9, 141.8, 140.4, 139.2, 136.7, 134.9, 134.2, 134.0, 133.9, 133.8, 133.7, 132.9, 131.1, 129.8, 129.1, 128.2, 128.1, 128.0, 127.97, 127.91 127.8, 127.6, 127.1, 126.99, 126.94, 126.4, 124.62, 121.61, 121.1, 108.7, 99.3, 83.0, 21.8 ppm; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{44}H_{33}N_4O$: 633.2654, found 633.2646.

***meso*-Tetraphenyl-3-ethyl-2-oxachlorin (10b).** **10b** was prepared from *meso*-tetraphenyl-3-ethyl-3-hydroxy-2-oxachlorin (**9b**, 45 mg, 0.07 mmol) according to the reaction procedure described for the preparation **10a**. The product **10b** was isolated by flash chromatography (silica−CH_2Cl_2) as a purple solid in 85% (38 mg) yield. MW = 646.8 g/mol; R_f = 0.92 (silica−CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 425 (5.36), 520 (4.18), 556 (4.06), 610 (3.92), 667 (4.70) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 424 nm): 673, 718 nm, ϕ = 0.20; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.45 (dd, ^3J = 4.8, ^4J = 0.8 Hz, 1H), 8.38 (dd, ^3J = 4.4, ^4J = 1.2 Hz, 1H), 8.29 (d, ^3J = 4.5 Hz, 1H), 8.23 (m, 2H), 8.15−7.92 (m, 9H), 7.70−7.65 (m, 12H), 7.08 (dd, ^3J = 7.9, ^4J = 3.5 Hz, 1H), 2.06−1.99 (m, 1H), 1.75−1.69 (m, 1H), 0.69 (t, ^3J = 7.4 Hz, 3H), 0.08 (s, 1H), −0.31 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 168.7, 157.9, 154.7, 151.4, 143.9, 142.1, 141.9, 141.8, 140.5, 139.3, 136.7, 134.5, 134.2, 133.99, 133.92, 133.8, 133.75, 133.70, 133.6, 132.9, 131.1, 130.8, 129.8, 129.1, 128.22, 128.18, 128.0, 127.99, 127.96, 127.92, 127.8, 127.7, 127.1, 127.0, 126.9, 126.4, 124.6, 121.6 121.1, 108.9, 99.1, 87.5, 27.7, 8.1 ppm; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{45}H_{35}N_4O$: 647.2811, found 647.2814.

***meso*-Tetraphenyl-3-isopropyl-2-oxachlorin (10c).** **10c** was prepared from *meso*-tetraphenyl-3-hydroxy-3-isopropyl-2-oxachlorin (**9c**, 100 mg, 0.14 mmol) according to the reaction procedure described for the preparation of **10a**. The product **10c** was isolated by flash chromatography (silica−CH_2Cl_2) as a purple solid in 76% (75 mg) yield. MW = 660.8 g/mol; R_f = 0.90 (silica−CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 423 (5.27), 519 (4.14), 556 (4.03), 611 (3.93), 668 (4.63) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 423 nm): 674, 728 nm, ϕ = 0.26; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.45 (dd, ^3J = 4.7, ^4J = 1.5 Hz, 1H), 8.38 (dd, ^3J = 4.7, ^4J = 1.8 Hz, 1H), 8.29 (d, ^3J = 4.5 Hz, 1H), 8.27 (dd, ^3J = 5.0, ^4J = 1.7 Hz, 1H), 8.21 (d, ^3J = 4.5 Hz, 1H), 8.13−8.17 (m, 2H), 7.92−8.02 (m, 6H), 7.64−7.72 (m, 13H), 6.90 (d, ^3J = 2.3 Hz, 1H), 1.95−2.25 (m, 1H), 1.10 (d, ^3J = 6.8 Hz, 3H), 0.50 (d, ^3J = 6.8 Hz, 3H), 0.11 (s, 1H), −0.28 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 168.9, 158.0, 154.6, 151.3, 143.8, 142.0, 141.9, 141.8, 140.5, 139.2, 136.6, 134.5, 134.1, 133.9, 133.8, 133.7, 133.6, 133.3, 132.8, 130.9, 130.6, 129.8, 129.0, 128.1, 127.9, 127.8, 127.7, 127.5, 127.1, 126.9, 126.8, 126.3, 124.6, 121.5, 121.0, 108.9, 98.8, 91.1, 32.9, 31.8, 20.4, 14.4 ppm; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{46}H_{37}N_4O$: 661.2967, found 661.2932.

***meso*-Tetrakis(4-trifluoromethylphenyl)-3-ethyl-2-oxachlorin (10^Fb).** 10^F**b** was prepared from *meso*-tetrakis(4-trifluoromethylphenyl)-3-ethyl-3-hydroxy-2-oxachlorin (9^F**b**, 80 mg, 8.5×10^{-5} mol) according to the reaction procedure described for the preparation of **10a**. The product 10^F**b** was isolated by flash chromatography (silica−

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CH_2Cl_2) as a purple solid in 71% (56 mg) yield. MW = 918.7 g/mol; R_f = 0.93 (silica−50% petroleum ether 30−60/CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 424 (5.12), 518 (3.96), 553 (3.78), 613 (3.71), 669 (4.53) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 424 nm): 675, 720 nm, ϕ = 0.27; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.41 (dd, ^3J = 5.0, ^4J = 1.5 Hz, 1H), 8.33 (dd, ^3J = 4.7, ^4J = 1.7 Hz, 1H), 7.95−8.25 (m, 20H), 7.05−7.07 (m, 1H), 1.99−2.06 (m, 1H), 1.66−1.73 (m, 1H), 0.70 (t, ^3J = 7.4 Hz, 3H), 0.09 (s, 1H), −0.29 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 168.6, 158.1, 154.4, 151.1, 145.4, 145.2, 143.9, 143.7, 142.7, 141.5, 136.5, 134.7, 134.0, 133.9, 133.8, 133.7, 133.1, 131.3, 131.2, 130.9, 130.7, 130.4, 130.28, 130.17, 129.9, 129.8, 128.1, 126.3, 126.2, 126.1, 126.0, 125.8, 125.3, 125.28, 125.22, 125.17, 125.14, 125.10, 125.06, 125.0, 124.9, 124.3, 124.27, 124.24, 124.20, 124.1, 124.09, 124.0, 123.4, 123.3, 123.1, 121.2, 120.5, 107.9, 98.2, 87.5, 27.9, 8.1 ppm; HR-MS (DART$^+$, 100% CH_3CN, orifice voltage 20 V, TOF, of MH$^+$): m/z calcd for $C_{49}H_{31}F_{12}N_4O$: 919.2306, found 919.2331.

***meso*-Tetrakis(4-trifluoromethylphenyl)-3-isopropyl-2-oxachlorin (10^Fc).** 10^Fc was prepared from *meso*-tetrakis(4-trifluoromethylphenyl)-3-hydroxy-3-isopropyl-2-oxachlorin (9^Fc, 52 mg, 6.0 × 10^{-5} mol) according to the reaction procedure described for the preparation of **10a**. The product 10^Fc was isolated by flash chromatography (silica−CH_2Cl_2) as a purple solid in 84% (43 mg) yield. MW = 932.8 g/mol; R_f = 0.93 (silica−50% petroleum ether 30−60/CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 425 (5.14), 519 (3.98), 555 (3.81), 615 (3.74), 670 (4.54) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 424 nm): 676, 722 nm, ϕ = 0.24; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.41 (d, ^3J = 4.7 Hz, 1H), 8.32 (d, ^3J = 4.8 Hz, 1H), 8.07 (m, 20H), 6.95 (s, 1H), 1.90−1.95 (m, 1H), 1.11 (d, ^3J = 6.6 Hz, 3H), 0.48 (d, ^3J = 6.0 Hz, 3H), 0.10 (s, 1H), −0.27 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 168.9, 158.2, 154.4, 151.1, 145.4, 145.2, 144.1, 143.7, 142.7, 141.6, 135.6, 134.7, 133.9, 133.8, 133.7, 133.1, 131.2, 130.9, 130.6, 130.4, 130.3, 130.1, 139.9, 128.1, 126.2, 126.1, 126.0, 125.3, 125.2, 125.1, 124.9, 124.3, 124.2, 124.1, 123.3, 121.2, 120.4, 107.9, 98.0, 91.3, 33.3, 20.4, 14.4 ppm; HR−MS (ESI+ of MH$^+$, 100% CH_3CN, TOF): m/z calcd for $C_{50}H_{33}F_{12}N_4O$: 933.2463, found 933.2433.

***meso*-Tetraphenyl-3,3-dimethyl-2-oxachlorin (11a). General Procedure for the Conversion of Porpholactone 4Zn to Bisalkyloxazolochlorin 11.** Step 1: Lactone zinc(II) complex **4Zn** (103 mg, 0.15 mmol) was dissolved in dry THF and stirred under N_2 at room temperature and 3 equiv of MeMgBr (3 M solution in THF, 0.15 mL) were added. The reaction progress was monitored using UV−visible spectroscopy (development of an intense peak at ∼625 nm indicates the formation of the acetal moiety). Upon completion (∼30 min), the reaction was quenched and washed with distilled H_2O in a separatory funnel. The organic phase was extracted with CH_2Cl_2, the organic phase isolated, and reduced to dryness using a rotary evaporator. The residue was then dissolved in dry THF (10 mL), and passed through a plug of Na_2SO_4 and dried using rotary evaporation. Step 2: The round-bottom flask containing the dried residue from part 1 was purged with N_2 prior to adding dry THF (10 mL). Under N_2, 2.5 equiv of TMSOTf (0.067 mL) was added and stirred for 5−10 min, followed by 5 equiv of MeMgBr (0.25 mL of a 3 M solution in THF). In order to avoid incomplete reaction, the molar equiv of alkyl-Grignard should double that of TMSOTf in this step. The reaction progress was monitored by UV−visible spectroscopy (a small aliquot is being treated with drops of 6 M HCl and neutralizing with aq $NaHCO_3$, the formation of a peak at ∼665 nm indicates the formation of the product). Step 3: Upon completion, the reaction was quenched with water (1−2 mL), then 6 M HCl (10 mL) was added to the reaction mixture to affect demetalation. The reaction mixture was stirred until the demetalation was complete (as monitored by UV−visible spectroscopy; formation of a free-base chlorin spectrum upon neutralization indicates the formation of the product). Once demetalation was achieved, the mixture was neutralized with a saturated aq $NaHCO_3$ solution in a separatory funnel. CH_2Cl_2 (10 mL) were added and the organic phase was isolated and dried using rotary evaporator. Product **11a** was isolated and purified by column chromatography (silica−CH_2Cl_2) as a purple solid in 74% yield (71 mg). MW = 646.8 g/mol; R_f = 0.96 (silica−CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 424 (5.10), 519 (3.93), 556 (3.87), 607 (3.75), 666 (4.42) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 425 nm): 668, 715 nm, ϕ = 0.19; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.42 (dd, ^3J = 5.2, ^4J = 1.4 Hz, 1H), 8.28 (dd, ^3J = 4.5, ^4J = 1.9 Hz, 1H), 8.25 (d, ^3J = 4.5, 1H), 8.22−8.20 (m, 1H), 8.18 (d, ^3J = 4.5, 1H), 8.06−7.58 (m, 21H), 1.85 (s, 6H), 0.06 (s, 1H), −0.33 (s, 1H) ppm; due to its poor solubility, high-quality ^{13}C NMR spectra could not be obtained; HR−MS (ESI+ of M$^+$, 100% CH_3CN, TOF): m/z calcd for $C_{45}H_{34}N_4O$: 646.2733, found 646.2729.

***meso*-Tetraphenyl-3,3-diethyl-2-oxachlorin (11b).** Prepared from [*meso*-tetraphenyl-2-oxa-3-oxoporphyrinato]Zn(II) (**4Zn**, 103 mg, 0.15 mmol) and EtMgCl according to the reaction procedure described for the preparation of **11a** except for the following: In Step 1, 1.5 equiv of EtMgCl (3 M solution in THF, 0.075 mL) was used with the reaction time of ∼5 min at room temperature. In Step 2, 2 equiv of TMSOTf (0.054 mL) were added at room temperature and stirred for ∼5 min, then 4 equiv of EtMgCl (3 M solution in THF, 0.198 mL) were added and the solution stirred for additional ∼5 min at room temperature. (Note: increased reaction time does not result in better yield, in fact, the opposite effect was noticed.) The product **11b** was isolated by flash chromatography (silica−CH_2Cl_2) as a purple solid in 45% (45 mg) yield. MW = 674.8 g/mol; R_f = 0.9 (silica-CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 425 (5.10), 517 (3.87), 556 (3.76), 608 (3.66), 664 (4.45) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 425 nm): 669, 719 nm, ϕ = 0.30; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.43 (d, ^3J = 4.9 Hz, 1H), 8.30 (d, ^3J = 4.2 Hz, 1H), 8.27 (d, ^3J = 4.4 Hz, 1H), 8.20 (d, ^3J = 4.4 Hz, 2H), 8.06 (d, ^3J = 6.1 Hz, 4H) 7.96−7.91 (m, 4H), 7.69−7.56 (m, 14H), 2.15−2.04 (m, 4H), 0.78 (t, ^3J = 7.2 Hz, 6H), 0.11 (s, 1H), −0.32 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 167.6, 157.9, 154.8, 150.9, 143.8, 142.8, 142.2, 141.8, 139.9, 139.4, 137.0, 133.9, 133.8, 133.7, 133.6, 133.5, 132.9, 130.6, 129.6, 128.4, 127.9, 127.8, 127.5, 127.4, 127.1, 126.8, 126.6, 126.5, 125.0, 121.5, 120.9, 109.0, 99.1, 97.4, 34.0, 8.3; HR−MS (ESI+ of MH$^+$, 100% CH_3CN, TOF): m/z calc'd for $C_{47}H_{38}N_4O$: 674.3046, found 674.3031.

***meso*-Tetraphenyl-3,3-diisopropyl-2-oxachlorin (11c).** Prepared from [*meso*-tetraphenyl-2-oxa-3-oxoporphyrinato]Zn(II) (**4Zn**, 250 mg, 0.36 mmol) and *i*-PrMgCl according to the reaction procedure described for the preparation of **11a** except for the following: In Step 1, 2 equiv *i*-PrMgCl (2 M solution in THF, 0.36 mL) were added slowly and stirred for 5 min at r.t. In Step 2, 2 equiv of TMSOTf (0.13 mL) were added at r.t. and stirred for 5 min, then 4 equiv of *i*-PrMgCl (2 M solution in THF, 0.72 mL) were added and stirred for ∼5 min. Product **11c** was isolated by flash chromatography (silica−CH_2Cl_2) as a purple solid in 61% (152 mg) yield. MW = 702.3 g/mol; R_f = 0.9 (silica−CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 424 (5.06), 516 (3.88), 554 (3.75), 609 (3.66), 667 (4.38) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} 425 nm): 670, 726 nm, ϕ = 0.31; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.43 (d, ^3J = 4.8 Hz, 1H), 8.24−8.27 (m, 3H), 8.17 (m, 1H), 8.03−8.06 (m, 4H), 7.91−7.96 (m, 4H), 7.57−7.69 (m, 13H), 2.55−2.59 (m, 2H), 1.07 (d, ^3J = 6.6 Hz, 6H), 0.66 (d, ^3J = 6.8 Hz, 6H), 0.08 (s, 1H), −0.30 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 167.6, 161.1, 154.8, 150.8, 143.5, 142.4, 141.8, 140.3, 140.1, 137.1, 134.8, 134.1, 133.9, 133.7, 133.6, 133.4, 132.9, 130.5, 129.5, 128.4, 127.9, 127.8, 127.7, 127.5, 127.4, 127.2, 126.9, 126.8, 126.7, 126.4, 125.1, 122.1, 120.7, 108.9, 100.9, 99.2, 36.9, 19.3, 18.9; HR−MS (ESI+ of MH$^+$, 100% CH_3CN, TOF): m/z calcd for $C_{49}H_{43}N_4O$: 703.3437, found 703.3459.

***meso*-Tetrakis(4-trifluoromethylphenyl)-3,3-diethyl-2-oxachlorin (11^Fb).** 11^Fb was prepared from [*meso*-tetrakis(4-trifluoromethylphenyl)-2-oxa-3-oxoporphyrinato]Zn(II) (4^F**Zn**, 40 mg, 4.1 × 10^{-5} mol) and EtMgCl according to the reaction procedure described for the preparation of **11a**, except for the following: In Step 1, 2 equiv of EtMgCl (2 M solution in THF, 0.041 mL) were added at −45 °C. In Step 2, 3 equiv of TMSOTf (0.022 mL) were added and the solution was stirred for ∼90 min at −45 °C. Into the reaction mixture, 10 equiv of EtMgCl (2 M solution in THF, 0.205 mL) were added at −45 °C. The reaction was then stirred for ∼4 h at −45 °C while the progress was closely monitored as described in the preparation of **11a**. The product 11^Fb was isolated by chromatography (silica−60%

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petroleum ether 30−60/CH_2Cl_2) as a purple solid in 51% (20 mg) yield. MW = 946.8 g/mol; R_f = 0.97 (silica−50% petroleum ether 30−60/CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 423 (5.15), 516 (3.99), 553 (3.86), 609 (3.82), 666 (4.56) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 424 nm): 671, 721 nm, ϕ = 0.29; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.41 (d, ^3J = 4.29 Hz, 1H), 8.26 (d, ^3J = 3.40 Hz, 1H), 8.2−7.08 (m, 19H), 7.61 (d, ^3J = 3.60 Hz, 1H), 2.20−2.17(m, 2H), 2.01−1.97 (m, 2H), 0.79 (t, ^3J = 7.18 Hz, 6H), 0.10 (s, 1H), −0.31 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 167.4, 158.2, 154.6, 150.7, 145.5, 145.5, 143.6, 143.26, 143.25, 142.98, 142.97, 142.5, 136.9, 134.0, 133.9, 133.71, 133.66, 133.5, 133.2, 130.9, 129.8, 127.7, 125.33, 125.29, 124.34, 124.31, 124.27, 124.1, 124.04, 124.01, 123.8, 123.7, 121.8, 119.8, 108.0, 98.2, 97.7, 34.1, 8.2 ppm; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{51}H_{35}F_{12}N_4O$: 947.2619, found 947.2603.

***meso*-Tetrakis(4-trifluoromethylphenyl)-3,3-diisopropyl-2-oxachlorin (11^Fc).** 11^Fc was prepared from [*meso*-tetrakis(4-trifluoromethylphenyl)-2-oxa-3-oxo-porphyrinato]Zn(II) (**4^FZn**, 53 mg, 5.5 × 10^{-5} mol) and *i*-PrMgCl according to the reaction procedure described for the preparation of **11a** except for the following: In Part 1, 3 equiv of *i*-PrMgCl (2 M solution in THF, 0.083 mL) were added and the solution stirred for ∼1 h at −78 °C. In Step 2, 3 equiv of TMSOTf (0.03 mL) were added and the reaction was stirred for ∼1 h at −78 °C. Next, 6 equiv of *i*-PrMgCl (2 M solution in THF, 0.164 mL) was added at −78 °C, then the reaction was stirred for about ∼1 h at this temperature. The product 11^Fc was isolated by column chromatography (silica−60% petroleum ether 30−60/CH_2Cl_2) as a purple solid in 56% (30 mg) yield. MW = 974.3 g/mol; R_f = 0.97 (silica-50% petroleum ether 30−60/CH_2Cl_2); λ_{max} (log ε): 425 (5.29), 517 (4.11), 554 (3.95), 610 (3.92), 668 (4.67) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 425 nm): 673, 718 nm, ϕ = 0.27; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.41 (d, ^3J = 4.4 Hz, 1H), 8.22−7.88 (m, 20H), 7.53 (d, ^3J = 2.5 Hz, 1H), 2.55−2.48 (m, 2H), 1.09 (d, ^3J = 6.2 Hz, 6H), 0.67 (d, ^3J = 6.6 Hz, 6H), 0.08 (s, 1H), −0.03 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 167.5, 161.4, 154.6, 150.5, 145.6, 145.0, 143.9, 143.5, 143.3, 143.0, 136.9, 134.2, 134.0, 133.7, 133.6, 133.4, 133.2, 130.9, 130.7, 129.7, 127.7, 125.3, 125.2, 124.98, 124.95, 124.33, 124.30, 124.0, 123.9, 123.8, 123.7, 122.3, 119.7, 107.9, 101.4, 98.2, 37.0, 19.3, 19.0; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{53}H_{39}F_{12}N_4O$: 975.2932, found 975.2901.

***meso*-Tetraphenyl-3-isopropyl-3-methoxy-2-oxachlorin (12c). General Procedure for the Conversion of Hemiketals 9 to Ketals 12.** Hemiacetal *meso*-tetraphenyl-3-hydroxy-3-isopropyl-2-oxachlorin (**9c**, 190 mg, 0.28 mmol) was dissolved with 30% MeOH in THF (v/v), and stirred at r.t. A catalytic amount (few small drops) of TFA was added. Reaction progress was monitored using TLC and complete conversion typically required overnight stirring (15−18 h). Upon completion, the reaction was quenched by addition of Et_3N (∼2−3 mL, added dropwise until solution turns to pink/red). The neutralized solution was evaporated by rotary evaporation. The bright pink, nonpolar product **12c** was isolated by column chromatography (silica−CH_2Cl_2) as a purple solid in excellent yield (181 mg, 93%). MW = 690.83 g/mol; R_f = 0.88 (silica-CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 421 (4.94), 516 (3.76), 551 (3.77), 595 (3.52), 650 (4.19) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 420 nm): 653, 702 nm, ϕ = 0.36; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.61 (d, ^3J = 4.9 Hz, 1H), 8.49 (d, ^3J = 4.9 Hz, 1H), 8.45 (d, ^3J = 5.0 Hz, 1H), 8.43 (d, ^3J = 4.5 Hz, 1H), 8.36 (d, ^3J = 4.5 Hz, 1H), 8.18−7.99 (m, 8H), 7.86−7.55 (m, 13H), 3.04 (s, 3H), 2.19 (m, 1H), 1.22 (d, ^3J = 6.5 Hz, 3H), 0.67 (d, ^3J = 6.5 Hz, 3H), −0.56 (s, 1H), −0.99 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 164.1, 155.1, 151.6, 150.9, 143.0, 142.2, 142.0, 141.8, 139.4, 138.8, 137.0, 134.2, 134.1, 133.9, 133.8, 133.5, 133.4, 131.5, 129.7, 128.2, 128.0, 127.9, 127.6, 127.5, 127.1, 126.9, 126.2, 126.1, 125.5, 122.6, 121.2, 117.5, 111.4, 99.8, 50.9, 35.8, 17.4, 16.5, ppm; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{47}H_{39}N_4O_2$: 691.3073, found 691.3062.

General Procedure for the Reversion of Ketals 12 to Hemiketals 9. Ketal **12c** (100 mg, 0.145 mmol) was dissolved in 10% 3 M HCl in THF (v/v) and stirred overnight at 45 °C. The reaction was washed with aq. $NaHCO_3$ solution and the organic layer was extracted using CH_2Cl_2. The organic layer was evaporated by rotary evaporation and the product was isolated by flash chromatography (CH_2Cl_2) as a purple solid in 90−95% yield (88−93 mg).

***meso*-Tetrakis(4-trifluoromethylphenyl)-3-isopropyl-3-methoxy-2-oxachlorin (12^Fc).** 12^Fc was prepared from *meso*-tetrakis(4-trifluoromethylphenyl)-3-hydroxy-3-isopropyl-2-oxachlorin (**9^Fc**, 51 mg, 5.4 × 10^{-5} mol) according to the procedure described for the preparation **12c**. The product 12^Fc was isolated by flash chromatography (silica-CH_2Cl_2) as a purple solid in 70% (36 mg) yield. MW = 962.8 g/mol; R_f = 0.88 (silica−30% petroleum ether 30−60/CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 420 (5.22), 514 (4.11), 548 (4.11), 595 (3.60), 652 (4.54) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} 420 nm): 655, 703 nm, ϕ = 0.35; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.56 (d, ^3J = 3.8 Hz, 1H), 8.42 (t, ^3J = 3.9 Hz, 2H), 8.34 (d, ^3J = 4.5 Hz, 1H), 7.85−8.28 (m, 18H), 3.04 (s, 3H), 2.04−2.09 (m, 1H), 1.19 (d, ^3J = 6.4 Hz, 3H), 0.63 (d, ^3J = 6.8 Hz, 3H), −0.62 (s, 1H), −1.02 (s, 1H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 164.0, 154.8, 151.4, 151.3, 145.4, 145.1, 142.9, 142.8, 142.3, 141.7, 136.9, 134.2, 133.95, 133.92, 133.88, 133.81, 133.7, 133.6, 131.7, 130.6, 130.4, 130.3, 129.9, 127.8, 126.1, 125.7, 125.2, 125.1, 125.05, 125.00, 124.98, 124.96, 124.4, 124.3, 124.2, 124.1, 123.4, 123.3, 123.2, 122.8, 120.1, 117.7, 110.4, 98.8, 51.0, 36.0, 17.3, 16.5 ppm; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calc'd for $C_{51}H_{35}F_{12}N_4O_2$: 963.2568, found 963.2539.

[*meso*-Tetraphenyl-3-isopropyl-3-methoxy-2-oxachlorinate]Zn(II) (12cZn). *meso*-Tetraphenyl-3-isopropyl-3-methoxy-2-oxachlorin (**12c**, 67 mg, 9.7 × 10^{-5} mol), was dissolved in 30% MeOH/$CHCl_3$ (v/v) and heated to reflux. A solution of $Zn(OAc)_2{\cdot}H_2O$ (∼5−7 equiv, 100−150 mg) in MeOH (5−10 mL) was added and the mixture was stirred and heated overnight. The reaction progress was monitored by TLC (silica−CH_2Cl_2; the bright pink nonpolar starting material is converted to a more polar green spot). Upon completion, the product was isolated by rotary evaporation, followed by flash chromatography (silica−CH_2Cl_2). The material was obtained as crystalline material by crystallization using a slow solvent exchange from CH_2Cl_2 to MeOH or pentane as a green crystalline solid (65%, 47 mg). MW = 754.2 g/mol; R_f = 0.50 (silica−CH_2Cl_2); UV−visible ($CHCl_3$) λ_{max} (log ε): 417 (5.36), 455 (4.07), 516 (3.76), 581 (3.88), 622 (4.58) nm; Fl λ_{max} ($CHCl_3$, λ_{exc} = 420 nm): 626, 679 nm, ϕ = 0.19; ^{1}H NMR (300 MHz, $CDCl_3$, δ): 8.58 (d, ^3J = 4.7 Hz, 1H), 8.49 (d, ^3J = 3.3 Hz, 1H), 8.41−8.33 (m, 3H), 8.13−7.88(m, 9H), 7.78−7.58 (m, 12H), 3.1 (s, 3H), 2.26−2.17 (m, 1H), 1.25 (d, ^3J = 6.4 Hz, 3H), 0.75 (d, ^3J = 6.6 Hz, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$, δ): 162.2, 156.0, 155.1, 149.9, 147.9, 146.6, 145.3, 145.2, 142.4, 139.6, 139.3, 134.2, 133.9, 133.8, 133.7, 133.65, 133.60, 133.5, 133.1, 132.0, 130.3, 128.5, 128.4, 128.1, 128.0, 127.98, 127.87, 127.82, 127.7, 127.3, 127.0, 126.9, 126.8, 126.3, 126.2, 122.9, 117.6, 112.5, 98.5, 50.9, 36.1, 17.5, 16.2 ppm; HR−MS (ESI+ of MH^+, 100% CH_3CN, TOF): m/z calcd for $C_{47}H_{36}N_4O_2Zn$: 752.2130, found 752.2120.

■ ASSOCIATED CONTENT

Supporting Information

^{1}H, ^{13}C NMR, and IR spectra of all obtained compounds and experimental details to the crystal structure determination of **9c**, **11c**, and **12cZn**, including the cif files. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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