Tellurapyrylium dye **1** reacts with singlet oxygen[13] in the presence of water to give oxidized dye **2** with a second-order rate constant that varies from 9×10^6 M^{-1} s^{-1} in 99% methanol to 8×10^8 M^{-1} s^{-1} in water at ambient temperature.[14] The stoichiometry for the reaction of singlet oxygen with **1** was determined from studies employing an oxygen electrode. For five independent runs, the concentration of oxygen was lowered $(4.0 \pm 0.3) \times 10^{-5}$ M in air-saturated aqueous solutions of **1** (9.3×10^{-5} M) upon irradiation with filtered light (630–850 nm) from a quartz–halogen source. After 100 s of irradiation, no further decrease in oxygen concentration and complete oxidation of **1** to **2** were observed. The observed loss of oxygen corresponds to 2.3 ± 0.2 molecules of **1** oxidized for each oxygen molecule consumed.

In 99% methanol at 310 K, $\leq 10^{-7}$ M **2** is detected following irradiation (630–850 nm) of air-saturated, 1.0×10^{-5} M solutions of **1** for 900 s (**1** is depleted). However, following 2-fold dilution with an aqueous solution of leucodye **3a** (10^{-3} M) and addition of horseradish peroxidase to a concentration of 10^{-12} M, 3.7×10^{-5} M dye **4a** (ϵ 45 000 L mol^{-1}) was formed. Thus, 7.4 mol of hydrogen peroxide was produced from each mole of **1** in solution.

The catalytic cycle for the production of hydrogen peroxide from singlet oxygen and water with **1** is summarized in Scheme I. Catalyst lifetime is determined by chemical and photochemical reactions of the catalyst. For **1** at 1.0×10^{-5} M in 99% methanol, the quantum yield for self-sensitized scavenging of singlet oxygen was measured to be 1.1×10^{-4} while the quantum yield for photochemical loss of **1** was measured to be 1.5×10^{-5}. The rate constant for hydrolysis of **1**, $k(H_2O)$, was measured to be $\leq 5 \times 10^{-7}$ s^{-1} at 310 K in 99% methanol. Similarly, the rate constant, k_3, for other thermal reactions of **2** was measured to be $\leq 6 \times 10^{-5}$ s^{-1} at 310 K in 99% methanol by monitoring the thermal recovery of **1** (≈99%). Under pseudo-first-order conditions, **1** (1.0×10^{-5} M) reacts with hydrogen peroxide (1×10^{-3} M or 1×10^{-4} M) to give **2** with a second-order rate constant, k_2, of $(1.29 \pm 0.06) \times 10^{-2}$ M^{-1} s^{-1} at 310 K in 99% methanol. In 50% aqueous methanol and in water, k_2 is larger, with values of 0.33 M^{-1} s^{-1} and 2.0 M^{-1} s^{-1}, respectively, at 298 K.[14]

At 298 K in distilled water, **3b** (10^{-3} M) is oxidized by **2** (1×10^{-5} M) with a second-order rate constant of (44.1 ± 2.0) M^{-1} s^{-1}, producing **4b** and **1**. This suggests that **1** should function as a catalyst for the two-electron oxidation of **3** to **4** with either singlet oxygen or hydrogen peroxide as shown in Scheme II.

As illustrated in Figure 1 in 99% methanol, an initial concentration of **1** of 3.0×10^{-6} M will oxidize 1.56×10^{-4} M **3a** (initially 10^{-3} M) to **4a** in air-saturated 99% methanol upon irradiation (630–850 nm) before the catalyst is consumed (≈900 s). Similarly, 5.13×10^{-5} M **3b** (initially 10^{-3} M) is oxidized to **4b** upon irradiation of air-saturated, 99% methanol solutions containing 1.0×10^{-6} M **1** for 900 s. These numbers represent turnovers of ≥50 for the catalyst **1**. In rigorously degassed 99% methanol solutions of **1** and **3**, no oxidation is observed upon irradiation.

In aqueous solutions (pH 6.8) containing 1×10^{-4} M leucodye **3** and 0.01 M hydrogen peroxide, dyes **4** are formed with pseudo-first-order rate constants of 7.04×10^{-8} s^{-1} for **3a** and 1.57×10^{-7} s^{-1} for **3b** at 298 K. The addition of 1.0×10^{-6} M **1** (1 mol %) gave accelerated (>2000-fold larger) pseudo-first-order rate constants of $(1.74 \pm 0.02) \times 10^{-4}$ s^{-1} for oxidation of **3a** at 298 K and $(3.34 \pm 0.03) \times 10^{-4}$ s^{-1} for oxidation of **3b** at 298 K. In both cases, concentrations of **4** approached 10^{-4} M with catalyst turnover numbers of 100.

Analogues of **1** containing either two sulfur atoms or two selenium atoms in place of tellurium do not catalyze the conversion of singlet oxygen and water to hydrogen peroxide and do not catalyze the oxidation of leucodyes **3** to **4** with hydrogen peroxide. We are currently investigating other tellurapyrylium dyes as catalysts to optimize hydrogen peroxide production and catalyst lifetime and to increase the scope of oxidations with species such as **2**.

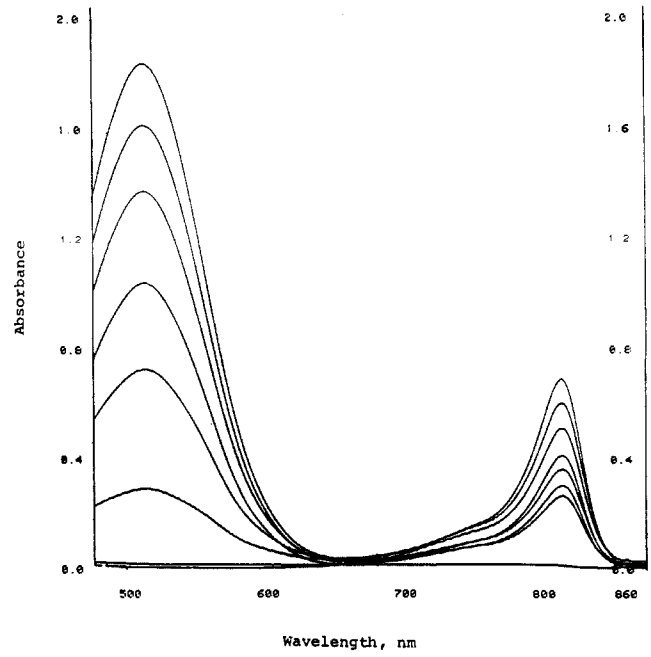

Figure 1. Photochemical oxidation of **3a** (5×10^{-3} M) to **4a** (λ_{max} 515 nm) in 99% aqueous methanol upon irradiation of **1** (λ_{max} 810 nm, 3.0×10^{-6} M) with filtered (630–850-nm) light from a quartz–halogen source. The irradiation was stopped every 60 s to generate the absorption curves shown (0–360 s). After 900 s, the optical density was 7.02 (measured by 10-fold dilution, curve not shown). The blank trace was for the leucodye **3** in air-saturated 90% aqueous methanol irradiated for 20 min without catalyst.

(13) This reaction was observed with singlet oxygen generated from irradiation of a variety of sensitizers in air-saturated aqueous methanol including rose bengal [$\Phi(^1O_2) = 0.76$; Gollnick, K.; Schenck, G. O. *Pure Appl. Chem.* **1964**, *9*, 507], methylene blue [$\Phi(^1O_2) = 0.52$; Nemoto, M.; Kokubun, H.; Koizumi, M. *Bull. Chem. Soc. Jpn.* **1969**, *42*, 1223, 2464], and self-sensitized generation of singlet oxygen from **1** [$\Phi(^1O_2) = 0.12$, ref 14].

(14) (a) Detty, M. R.; Merkel, P. B.; Powers, S. K. *J. Am. Chem. Soc.* **1988**, *110*, 5920. (b) Detty, M. R.; Merkel, P. B. *J. Am. Chem. Soc.*, in press.

General Approach to the Synthesis of Macroline-Related Alkaloids. Stereospecific Total Synthesis of (−)-Alstonerine

L. H. Zhang and J. M. Cook*

Department of Chemistry
University of Wisconsin—Milwaukee
Milwaukee, Wisconsin 53201

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In the last several years, approximately 30 macroline-related alkaloids have been isolated from *Alstonia macrophylla* Wall, *Alstonia muelleriana* Domin, and other species of *Alstonia*;[1-3] macralstonine (**1**),[1a,b] alstonerine (**2a**),[2a] and alstophylline (**2b**)[2b] serve as representative examples. The recent biomimetic interconversions by LeQuesne et al.[3] have served to establish that the absolute configurations of alstonerine (**2a**), alstophylline (**2b**) and macroline **4** (**3a** → **4**)[3a] are identical with those of N_a-methylsarpagine, the non-macroline portion of the bisindole alkaloid macralstonidine.[3] Moreover, macroline (**4**) and alstophylline (**2b**) have been condensed to provide the hypotensive

(1) (a) Kishi, T.; Hesse, M.; Vetter, W.; Gemenden, C. W.; Taylor, W. I.; Schmid, H. *Helv. Chim. Acta* **1966**, *49*, 946. (b) Burke, D. E.; DeMarkey, C. A.; LeQuesne, P. W.; Cook, J. M. *J. Chem. Soc., Chem. Commun.* **1972**, 1346.

(2) (a) Cook, J. M.; LeQuesne, P. W.; Elderfield, R. C. *J. Chem. Soc. D* **1969**, 1306. (b) Kishi, T.; Hesse, M.; Gemenden, C. W.; Taylor, W. I.; Schmid, H. *Helv. Chim. Acta* **1965**, *48*, 1349.

(3) (a) Garnick, R. L.; LeQuesne, P. W. *J. Am. Chem. Soc.* **1978**, *100*, 4213. (b) Esmond, R. W.; LeQuesne, P. W. *J. Am. Chem. Soc.* **1980**, *102*, 7117 and references cited therein.

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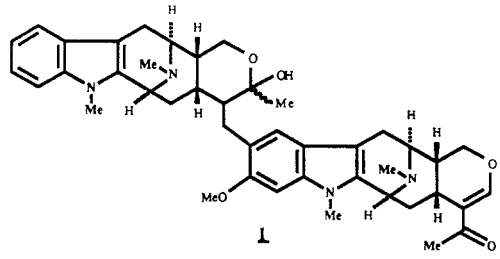
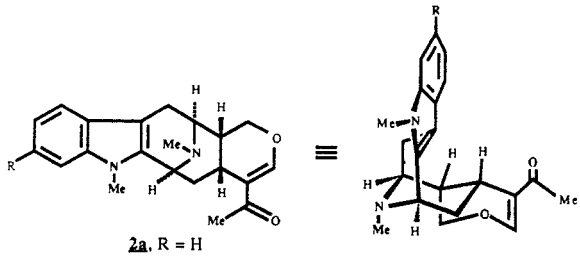
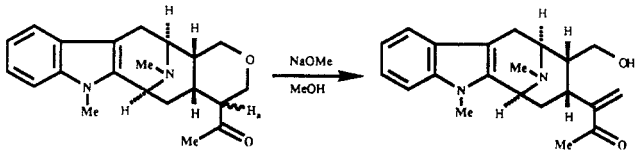


1



2a, R = H
2b, R = OMe



3a, $H_a = \beta$
3b, $H_a = \alpha$

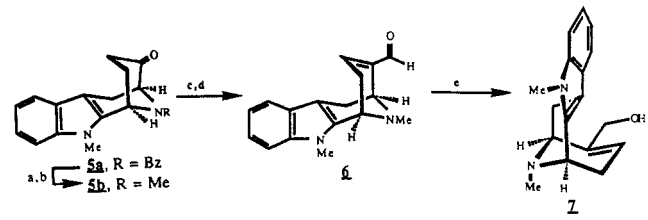
4

bisindole alkaloid **1**.[2a] The total synthesis of **1** then reverts to the synthesis of **2b** and **4** in optically active form. In this regard, we report the stereospecific synthesis of (−)-alstonerine (**2a**) via a route amenable to preparation of **2b**. In addition, the synthesis of (−)-dihydroalstonerine (**3b**) has been completed, the epimer **3a** of which has been converted into macroline (**4**) by LeQuesne and Garnick.[3a] The strategy developed in the stereospecific synthesis of **2a** and **3b** can be employed for the enantiospecific synthesis of other members of the macroline/sarpagine family of indole alkaloids.

The optically pure (−)-tetracyclic ketone **5a** was prepared from D-(+)-tryptophan in seven steps by a stereospecific method developed in these laboratories on a 100-g scale in the optically active series[4a,c] and a kilogram scale in the (±) series.[4b] The conversion of the N_b-benzyl tetracyclic ketone **5a** into the N_b-methyl tetracyclic ketone **5b** $\{[\alpha]^{22}_D$ −129.6° (*c* 0.52, $CHCl_3$)$\}$ was achieved by methylation of **5a** with methyl trifluoromethanesulfonate, followed by catalytic debenzylation (84% overall yield) as illustrated in Scheme I. The optically active carbonyl compound (−)-**5b** was transformed into the α,β-unsaturated aldehyde (−)-**6** via a two-step process[5,6] in 80% overall yield under conditions analogous to those reported by Trudell[4b] for conversion of (±)-**5b** into (±)-**6**. Chemoselective reduction of the carbonyl group of aldehyde **6** with lithium aluminum hydride (−20 °C) provided the allylic alcohol (−)-**7** in greater than 90% yield.

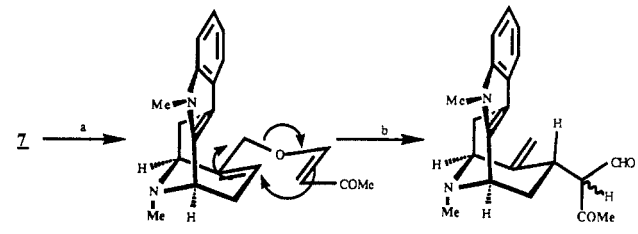
Numerous attempts to alkylate **5a**[7a] or to add nucleophilic carbon to **6** were uniformly unsuccessful.[7b,c] Consequently, an intramolecular approach for functionalization of C-15 via a Claisen rearrangement was pursued. Michael addition of butyn-3-one[8a] to allylic alcohol **7** gave the desired enone **8** in 90% yield (Scheme II). Previous studies in our laboratory had shown that execution of the ortho ester Claisen rearrangement in this system occurred

Scheme I[a]



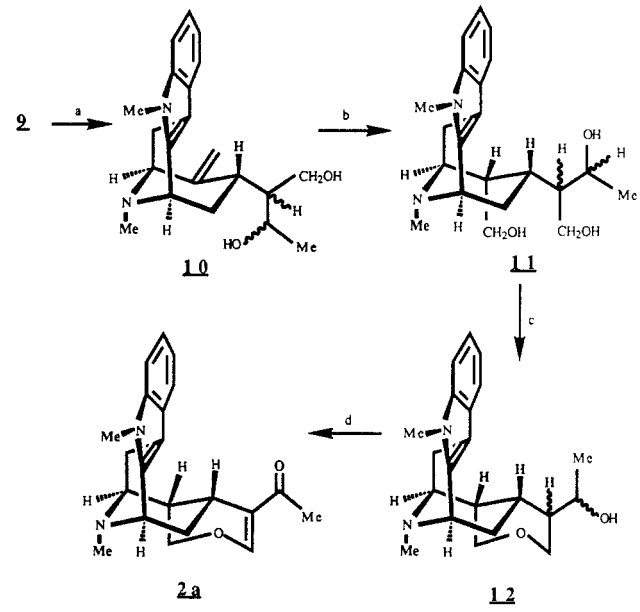
[a] (a) $MeSO_3CF_3/CH_2Cl_2$; (b) H_2/Pd/C; (c) $PhSOCH_2Cl$/LDA/THF; KOH; (d) $LiClO_4/PO(Bu)_3$/toluene; (e) $LiAlH_4/Et_2O$.

Scheme II[a]



[a] (a) $HC{\equiv}CCOCH_3$, dioxane, Et_3N in dark; (b) PhH, sealed tube, 145 °C.

Scheme III[a]



[a] (a) $NaBH_4$, EtOH; (b) 9-BBN/THF, 22 °C, 20 h; 3 N NaOH, H_2O_2, 40 °C, 2 h; (c) TsCl, pyridine, 22 °C; Et_3N; (d) $(COCl)_2$, DMSO, CH_2Cl_2, −78 °C → −10 °C; Et_3N.

with a stereofacial selectivity of 13:1 from the β-face of the double bond;[8b] however, when enol ether **8** was heated in benzene (sealed tube, 145 °C), the desired β-dicarbonyl compound **9** was obtained as a single diastereomer at C-15 (65% yield). As illustrated in Scheme II, the Claisen rearrangement has occurred stereospecifically from the desired α-face of the double bond to provide optically active **9**, presumably via a chair transition state.[8b] This has important implications for the enantiospecific synthesis of the macroline/sarpagine/ajmaline alkaloids, since intermediate **9** has been functionalized at C-15 with the absolute configuration common to all three families of alkaloids.

The β-dicarbonyl intermediate **9** was reduced to the diol (−)-**10** (86%) on treatment with sodium borohydride, as illustrated in

(4) (a) Zhang, L.-H.; Cook, J. M. *Heterocycles* **1988**, *27*, 1357, 2795. (b) Trudell, M.; Cook, J. M. *J. Am. Chem. Soc.* **1989**, *111*, 7504. (c) For a related synthesis of this tetraketone, see: Magnus, P.; Mugrage, B.; DeLuca, M.; Cain, G. A. *J. Am. Chem. Soc.* **1989**, *111*, 786.

(5) Reutrakul, V.; Kanghee, W. *Tetrahedron Lett.* **1977**, 1377.

(6) Satoh, T.; Itoh, M.; O'Hara, T.; Yamakawa, K. *Bull. Chem. Soc. Jpn.* **1987**, *60*, 1939.

(7) (a) Weber, R. W. Ph.D. Thesis, University of Wisconsin—Milwaukee, Milwaukee, WI, 1985. (b) Hollinshead, S. Ph.D. Thesis, York University, United Kingdom, 1987. (c) Trudell, M. L. Ph.D. Thesis, University of Wisconsin—Milwaukee, Milwaukee, WI, 1989.

(8) (a) Rackur, G. E.; Stahl, M.; Walkowiak, M.; Winterfeldt, E. *Chem. Ber.* **1976**, *109*, 3817. (b) Zhang, L.-H.; Trudell, M.; Hollinshead, S.; Cook, J. M. *J. Am. Chem. Soc.* **1989**, *111*, 8263.

Scheme III. Hydroboration of the exocyclic methylene function (C-16) with 9-BBN occurred stereospecifically from the β-face of the double bond and on oxidative workup (3 N NaOH/H_2O_2/40 °C/2 h) provided the triol **11** in 85% yield. Direct hydroboration of the β-dicarbonyl compound **9** with 9-BBN furnished the triol **11**; however, the yield was somewhat lower. As shown in Scheme III (structure **11**), 9-BBN has attacked the β-face of the exocyclic methylene function in order to minimize steric repulsion (1,3) between the axial N_b-methyl function and the incoming hydroboration reagent. This is opposite to the stereochemical outcome of the hydroboration at C-16 observed during the synthesis of (±)-suaveoline.[4b]

The optically active triol (−)-**11** was regioselectively cyclized to the desired (−)-tetrahydroalstonerine monol **12** on stirring with tosyl chloride (1 equiv) in pyridine followed by the addition of either triethylamine or potassium hydroxide. This process gave (−)-**12** in 60% yield, accompanied by starting triol **11** (33%), which could be recycled to provide additional quantities of (−)-tetrahydroalstonerine **12**. When monol **12** was stirred with pyridinium dichromate, an 86% yield of (−)-dihydroalstonerine (**3b**) was realized; however, treatment of **12** under modified Swern[9] conditions [$(COCl)_2$/DMSO/CH_2Cl_2/−78 °C → −10 °C/1.5 h; Et_3N] gave (−)-alstonerine (**2a**) (mp 171–172 °C) in 51% yield, accompanied by dihydroalstonerine (**3b**) (31%). The spectral data for (−)-**2a** (^1H NMR, ^{13}C NMR,[10] IR, UV, MS)[2a] were in complete agreement with those published for natural (−)-alstonerine (mp 172–173 °C); moreover, the optical rotation {$[\alpha]^{25}_D$ −190° (*c* 0.32, EtOH)} of synthetic **2a** indicates that it has been prepared in at least 98% ee.

The synthesis described above represents the first chirally controlled preparation of a member of the macroline-related alkaloids.[11] The stereospecific preparation of tetracyclic ketone **5a**,[4a,b] coupled with the execution of both the Claisen rearrangement (C-15) and the hydroboration process (C-16) in the desired fashion, provides a route for the enantiospecific synthesis of the macroline/sarpagine alkaloids. Further work is in progress to extend this approach to the synthesis of alstophylline (**2b**), as well as a number of bisindole alkaloids,[1-3] including the hypotensive bisindole alkaloid macralstonine (**1**).[1a,b]

Note Added in Proof. Recently, base-catalyzed (NaOMe, CH_3OH, Δ) epimerization of synthetic **3b** gave the epimeric **3a** which had been previously converted into macroline **4** by LeQuesne et al.[3a] Consequently, the synthesis of (−)-**3b** also constitutes a formal total synthesis of **4**, although the yield of this conversion has not been maximized.

(9) Mancuso, A. J.; Huang, S.-L.; Swern, S. *J. Org. Chem.* **1978**, *43*, 2480.

(10) Ratnayake, C.; Lakshimi, S. R.; Arambewela, K. T.; Silva, D.; Rahman, A.; Alvi, K. A. *Phytochemistry* **1987**, *26*, 868.

(11) The optical purity (>97% ee) of **5a** as well as other intermediates was proven by the use of chiral shift reagents as detailed in the following: Campbell, J. *Aldrichimica Acta* **1972**, *5*, 2. All compounds including (−)-**2a** gave satisfactory NMR, IR, and mass spectral data.

Additions and Corrections

Phosphate Ester and Phosphinate Binding to the (μ-Oxo)diiron(III) Core: Synthesis and Characterization of $[Fe_2O(O_2P(OC_6H_5)_2)_2(HBpz_3)_2]$ and $[Fe_2O(O_2P(C_6H_5)_2)_2(HBpz_3)_2]$ [*J. Am. Chem. Soc.* **1990**, *112*, 681–690]. PETRA N. TUROWSKI, WILLIAM H. ARMSTRONG, MARY E. ROTH, and STEPHEN J. LIPPARD*

Page 687: The minus sign in eq 2 should be a plus sign. This change does not affect any results of the paper, for which the correct equation was used.

Characterization of (Methylcyclopentadienyl)trimethylplatinum and Low-Temperature Organometallic Chemical Vapor Deposition of Platinum Metal [*J. Am. Chem. Soc.* **1989**, *111*, 8779]. ZILING XUE, M. JANE STROUSE, DAVID K. SHUH, CAROLYN B. KNOBLER, HERBERT D. KAESZ,* ROBERT F. HICKS, and R. STANLEY WILLIAMS

Page 8780: We have learned of new evidence from NOESY spectra that suggests that the assignment of H_a and H_b (Figure 1) and C_a and C_b (Figure 2) in (MeCp)$PtMe_3$ should be *reversed* (private communication from Richard A. Newmark, Larry D. Boardman, and Allen R. Siedle, 3M Corporate Research Laboratories, Bldg. 201-BS-05, Box 33221, St. Paul, MN 55144-1000). Arguments and supporting data that involve a series of compounds including the one mentioned above are being prepared for publication.

X-ray Structures of Cubylcubane and 2-*tert*-Butylcubylcubane: Short Cage–Cage Bonds [*J. Am. Chem. Soc.* **1988**, *110*, 7232]. R. GILARDI,* M. MAGGINI, and P. E. EATON

Page 7232, footnote 3: the *c* dimension should be 13.431 (1) Å rather than 13.341 (1) Å.

Mechanism of Grignard Reagent Formation. The Surface Nature of the Reaction [*J. Am. Chem. Soc.* **1989**, *111*, 1896]. H. M. WALBORSKY* and JANUSZ RACHON

Page 1896: The label for structure **4** should read (*S*)-(+)-**4**.

Evidence for a 1,2-Fluoride Shift in a Gaseous Cation [*J. Am. Chem. Soc.* **1989**, *111*, 6868]. THOMAS A. SHALER and THOMAS HELLMAN MORTON*

Page 6869, Table I: The first entry should be −216.227 24 au for ion **5**. Footnote *b* should refer to the following reference: Stams, D. A.; Thomas, T. D.; Maclaren, D. C.; Ji, D.; Morton, T. H. *J. Am. Chem. Soc.* **1990**, *112*, 1427–1434.

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