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Synthesis of novel 1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]-quinolines via benzotriazole methodology

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Abstract—Pyrroloquinolines have been synthesized reacting 1-(benzotriazol-1(2)-ylmethyl)indolines with unactivated and electron-rich alkenes in the presence of *p*-toluenesulfonic acid catalyst. Mixtures of the expected diastereomers were obtained and some of them separated in their respective components. X-Ray diffraction along with two-dimensional NMR experiments was needed to assist the determination for both the structures of the precursors and products. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Synthesis of highly hydrogenated polyheterocyclic systems is an interesting tool since many of them are contained in the framework of naturally occurring products or in important compounds for practical applications. Thus, 1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline **1** known as lilolidine (Fig. 1),[1] is present in the structure of the pyroquilone **2**[2] and its derivatives[3,4] which have shown potent antifungal properties against rice blast disease. Additionally, the lilolidinic system has been found as part of the structure of some phenanthridine alkaloids **3** (**3a** Assoanine, R, R^1=OMe, R^2, R^3=H; **3b** Oxoassoanine, R, R^1=OMe, CR^2R^3=O and **3c** Anhydrolycorine, R+R^1=OCH_2O, R^2, R^3=H) isolated initially from *Narcissus pseudonarcissus* bulbs and aerial parts of *N. assoanus*.[5,6]

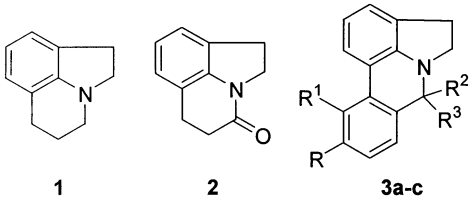

Figure 1. Structures of lilolidine and related pyrroloquinolines.

Benzotriazole has been widely used as a synthetic auxiliary in organic synthesis,[7] and recently it has been found that *N*,*N*-disubstituted-benzotriazol-1-yl-methylamines react with electron-rich olefins under acid catalysis, which provided useful routes to the synthesis of tetrahydroquinolines[8] and related compounds.[9]

This work is part of our ongoing program concerning the synthesis of novel hydroquinoline-analogue systems with potential biological and pharmacological properties. This approach is based on the benzotriazole methodology, where the reaction of benzotriazolyl-derivatives of the indolines **5a**,**b** with terminal alkenes and *p*-toluenesulfonic acid as catalyst afforded the expected products (**6**–**10**)**a**,**b** in good yields.

2. Results and discussion

Using previous results as a starting point, the reaction was carried out starting with **5a** in CH_2Cl_2 at room temperature using $ZnBr_2$ as catalyst, but with poor results. Recently, these conditions were successfully used by us,[9] but in this case, an insoluble yellow solid was formed, corresponding to the complex **5a**·$\mathbf{ZnBr_2}$[10] and the expected product was not obtained. In a further experiment, the reaction was tried in THF at room temperature in the presence of $ZnBr_2$, obtaining the expected products with low yields of 15–25%. Some of that insoluble complex was also formed but slowly. Finally, the reaction of compound **5a** and 1-vinyl-2-pyrrolidinone (2 equiv.) was carried out in methanol in the presence of catalytic amount of *p*-toluenesulfonic acid

Keywords: indolines; benzotriazole; alkenes; cyclization; 1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinolines; lilolidine.
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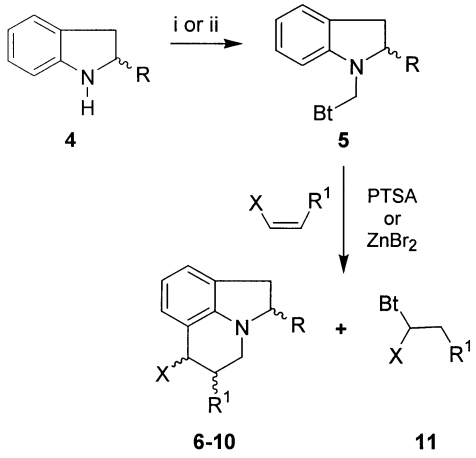


Scheme 1. General procedure for the preparation of the novel pyrroloquinoline derivatives.

(10%) at room temperature, giving the expected 6-(*N*-pyrrolid-2-onyl)-1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline **6a** in 66% isolated yield. A variety of other activated alkenes were also combined with **5a** and **b** under the above reaction conditions to give the novel tricyclic and tetracyclic pyrroloquinolines (**6**–**10**)**a**,**b** which would be difficult to synthesize by other methods. The reaction sequence and the structures of products **6**–**10** are shown in Scheme 1 and Fig. 2, respectively. All the compounds (**6**–**10**)**a**,**b** were characterized by ^{1}H, ^{13}C NMR, mass or HRMS spectroscopies and CHN analyses. Excepting for compounds **6a** and **12** all the rest are pale yellow oils, which are slowly turning dark by exposure to the air and the light. The key

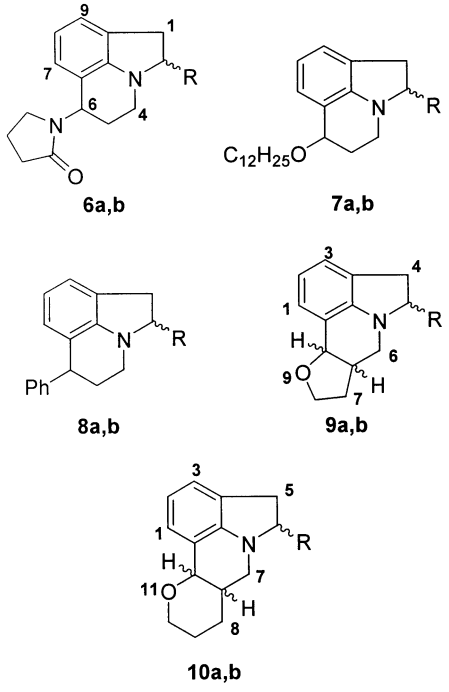
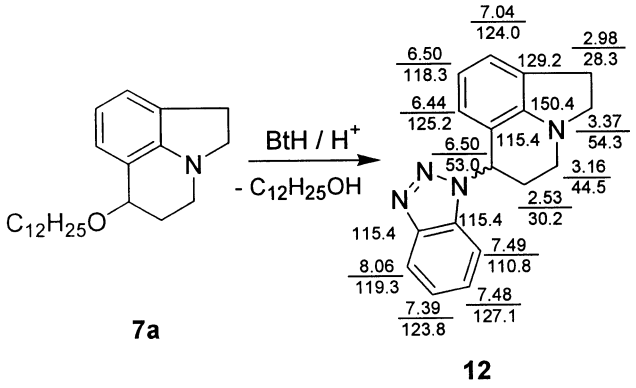


Figure 2. Structures of the novel pyrroloquinolines prepared.



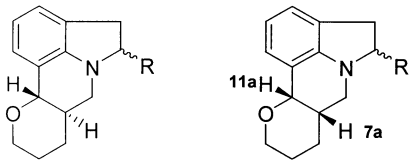
Scheme 2. Formation of 6-(1-benzotriazolyl)-1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline **12** from compound **7a**.

benzotriazolyl derivatives **5a**,**b** were previously prepared from the respective indolines **4a**,**b** by two approaches (Section 4) and also characterized by spectroscopic techniques.

In all cases, an additional equivalent of the alkene was necessary to trap the leaving benzotriazolyl moiety in form of the stable compound **11**, as previously has been shown.[9] When one equivalent of dodecyl vinyl ether was used, a mixture of 210 (32%) and 160 mg (29%) of both compounds **7a** and **12**, respectively, was obtained. The same experiment with two equivalents of the alkene yielded compound **7a** as unique product. Compound **12** was completely characterized and its protons and carbon atoms were fully assigned by DEPT-135, HSQC, H,H-COSY-DQF, NOESY and HMBC experiments and its structure was confirmed by X-ray diffraction.[11] We suggest that this compound was generated in situ from compound **7a** by nucleophilic substitution of benzotriazole over the dodecyloxyl moiety (Scheme 2). This behavior of the benzotriazole in acidic conditions has been well documented.[12–14]

In general, the ^{1}H NMR spectra of compounds (**6**–**10**)**a**,**b** and **12** show a relatively complicated spin pattern at δ=0.80–4.15 ppm owing to aliphatic protons and the mixtures of diastereomers. However, extended NMR study including DEPT and two-dimensional (COSY, NOESY and ^{13}C, ^{1}H shift correlation) measurements for these compounds confirm the proposed structures.

The formation of two stereogenic carbon atoms in the molecules (**6**–**8**)**b** gives the possibility of two stereoisomeric racemates (i.e. *trans* and *cis*). In all three cases, an unseparable mixture of both racemates was obtained. Equally, the presence of two stereogenic carbon atoms in the molecules **9a** and **10a** also give the possibility of two stereoisomeric racemates (*trans* and *cis*). For compounds **9a**, an unseparable mixture (ratio 31:69, ^{1}H NMR) of both racemates was obtained with the *cis* isomer extensively predominating, which was determined by ^{1}H NMR (integrals and coupling constants, J=0 and 4.5 Hz, for *cis* and *trans* isomers, respectively) and by ^{13}C NMR where double sets of resonances for several carbon atoms can be observed. While, for mixture of compounds **10a** (Fig. 3), it was possible to separate the pure racemic diastereomers from the original mixture, in this case, with the *trans* isomer



10'a,b 10''a,b

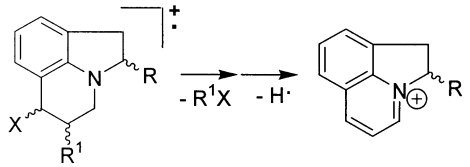
Figure 3. Structures for stereoisomers separated from **10a**,**b**.

10′a slightly predominating versus *cis* isomer **10″a** (molar ratio **10′a/10″a**=59/41, 65% total yield, column chromatography), determined by ^{1}H NMR (a larger vicinal coupling constant J=6.2 Hz for 11a-H in **10′a**, compared with J=3.2 Hz for the same proton in **10″a**).

On the other hand, the presence of three stereogenic carbon atoms in the molecules **9b** and **10b** make possible four stereoisomeric racemates: *trans–trans*, *trans–cis*, *cis–trans* and *cis–cis*. Like **9a**, an unseparable stereoisomeric mixture was obtained for compounds **9b**. ^{13}C NMR was especially useful for this finding, because, it is possible to observe four sets of NMR resonances belonging to the same type of carbon atom, for some carbons of the framework, which confirms that all four racemates are present in the mixture. Despite, it was impossible to quantify each one of them. Just like **10a**, for mixture of compounds **10b**, it was possible to separate in two parts. One of them corresponding to both racemic diastereomers *trans*-**10′b** in 40% yield and the other to both racemic diastereomers *cis*-**10″b** in 35% yield (75% total yield), structures of which were determined by NMR experiments.

Chemical shift of 6-H for compounds **6**–**8**, 9a-H for compounds **9** and 11a-H for compounds **10** (δ=4.10–5.44 ppm) are all characteristic, and were useful in some cases to determine the presence of diastereomeric mixtures and their quantification.

Both tricyclic and tetracyclic systems show the same fragmentation pattern in mass spectra, as shown in Scheme 3. This is confirmed by the presence of a common base peak (i.e. m/z=156 for (**6**–**10**)**a** and **12** and m/z=170 for (**6**–**10**)**b**), corresponding to a stable dihydropyrroloquinolinium ion.



Scheme 3. Fragmentation pattern for compounds (**6**–**10**)**a**,**b** and **12**.

3. Conclusions

Reactions of 1-(benzotriazol-1(2)-ylmethyl)indolines **5a**,**b** with alkenes provide a simple method for the preparation of novel tricyclic and tetracyclic tetrahydropyrroloquinoline derivatives (**6**–**10**)**a**,**b** and **12** which are of potential interest in pharmaceutical chemistry.

4. Experimental

4.1. General methods

All melting points were determined on a Büchi melting point apparatus and are uncorrected. The ^{1}H, ^{13}C and ^{1}H–^{13}C NMR spectra were recorded on Varian Gemini 200, Bruker DPX 300 and Bruker 500 instruments, chemical shifts (δ) are reported in ppm relative to internal tetramethylsilane and coupling constants in Hz, $CDCl_3$ and DMSO-d_6 as solvent. Silica gel plates (Merck F_{254}) were used for analytical TLC. The mass spectra were run on a Varian Model MAT MS-311 spectrometer at 70 eV. Microanalyses were performed with a Perkin Elmer Model 240 C Elemental Analyser and values are within ±0.4% of the theoretical values.

4.2. General procedure for preparing the benzotriazolylmethylindolines 5a,b

Method A. A mixture of indoline **4a** or **b** (8.4 mmol), benzotriazole (8.4 mmol) and formaldehyde (37% w/w solution, 12.6 mmol) in 10 mL of ethyl ether, was stirred at room temperature for 30 min and the resulting precipitate was filtered and recrystallized from ethanol.

Method B. A mixture of 1-hydroxymethylbenzotriazol[15] (1.25 g, 8.39 mmol) and equimolar amount of indoline **4a** or **b** in 5 mL of ethanol, was heated at 50°C for 5–10 min. After cooling, the resulting precipitate was filtered and recrystallized from ethanol. From both methods, a mixture of 1-Bt and 2-Bt isomers were obtained with an approximate ratio of 2:1 for **5a** and 4:1 for **5b**, respectively.

4.2.1. 1-(Benzotriazol-1(2)-ylmethyl)-indoline (5a). White crystals, 80% yield (method A), 85% yield (method B); mp 148–149°C. Some NMR peaks corresponding to the 2-Bt isomer are given in square brackets, the others are overlapped with 1-Bt signals; ^{1}H NMR ($CDCl_3$): δ 2.97 (t, J=8.2 Hz, 2H), 3.55 (t, J=8.3 Hz, 2H) [3.78 (t, J=8.2 Hz, 2H)], 6.02 (s, 2H) [6.08 (s, 2H)], 6.74 (t, J=7.3 Hz, 1H), 6.93 (d, J=7.8 Hz, 1H), 7.01–7.22 (m, 2H), 7.35 (brt, 1H), 7.46 (t, J=6.8 Hz, 1H), 7.58 (d, J=7.7 Hz, 1H), [7.83 (dd, J=6.4, 3.5 Hz, 2H)], 8.05 (d, J=8.2 Hz, 1H); ^{13}C NMR ($CDCl_3$): 29.5, 52.6 [54], 62.4 [69], [108.5], 108.8 [109.5], 111.2 [119.3], [119.7], [120.4], 120.7, 121.3, 125.3 [126.2], 126.5 [127.8], [128.5], 128.7, 128.9, 131.0, 134.2 [145.7], 147.5, 150.3; MS m/z (%): 250 (28) [$M^{+\cdot}$], 132 (100) [M−(BtH)]; Anal. calcd for $C_{15}H_{14}N_4$ (250.11): C, 71.98; H, 5.64; N, 22.38. Found: C, 71.95; H, 5.64; N, 22.37.

4.2.2. 1-(Benzotriazol-1(2)-ylmethyl)-2-methylindoline (5b). White crystals, 86% yield (method A), 82% yield (method B); mp 70°C. Some NMR peaks corresponding to the 2-Bt isomer are given in square brackets, the others are overlapped with 1-Bt signals; ^{1}H NMR ($CDCl_3$): δ 1.39 (d, J=5.8 Hz, 3H) [1.53 (d, J=6.0 Hz, 3H)], 2.64 (dd, J= 15.6, 9.2 Hz, 1H), 3.10 (dd, J=15.8, 9.2 Hz, 1H), 3.70–3.83 (m, 1H) [3.96–4.15 (m, 1H)], [5.94 (d, J=14.2 Hz, 1H)], 5.97 (d, J=14.6 Hz, 1H), 6.09 (d, J=14.6 Hz, 1H), [6.21 (d, J=14.0 Hz, 1H)], 6.74 (t, J=7.3 Hz, 1H), 6.90 (d, J=7.8 Hz, 1H), 6.98–7.23 (m, 2H), 7.28–7.44 (m, 2H), 7.54 (d, J=7.6 Hz, 1H), [7.83 (dd, J=6.7, 3.1 Hz, 2H)],

8.03 (d, J=7.6 Hz, 1H); ^{13}C NMR ($CDCl_3$): [20.1], 20.8, 38.5, 59.3, 61.0 [66.2], 109.0 [109.7], 111.5, 119.7 [120.6], 121.3, 125.4 [126.1], 126.4 [127.8], 129.0, 130.1, 134.3 [145.6], 147.6, 150.7; MS *m/z* (%): 264 (35) [M^{+}], 146 (100) [M−(BtH)]; Anal. calcd for $C_{16}H_{16}N_4$ (264.12): C, 72.70; H, 6.10; N, 21.20. Found: C, 72.73; H, 6.08; N, 21.17.

4.3. General procedure for preparing the pyrroloquinoline derivatives (6–10)a and (6–10)b

A mixture of **5a** or **b** (1.99 mmol), alkene (4.00 mmol) and *p*-toluenesulfonic acid (50 mg) in anhydrous methanol (15 ml) was stirred at room temperature for 1–3 h, TLC control. The solvent was removed under reduced pressure and the residue was dissolved in ethyl acetate and washed with aq. NaOH solution (5%, 20 mL), followed by water and dried with anhydrous Na_2SO_4. The solvent was removed under vacuum and the residue was purified by column chromatography (gradient hexane/ethyl acetate). For the mixtures of compounds **10a** and **b**, it was possible to recover two fractions of products with different R_f.

4.3.1. (±)-6-(*N*-Pyrrolidin-2-onyl)-1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline (6a). This compound was obtained from 1-vinyl-2-pyrrolidinone as white crystal, 66% yield; mp 111°C; ^{1}H NMR ($CDCl_3$): 1.90–2.04 (m, 2H), 2.10–2,19 (m, 2H), 2.46 (t, J=7.8 Hz, 2H), 2.88–3.25 (m, 6H), 3.27–3.42 (m, 2H), 5.44 (t, J=7.8 Hz, 1H, 6-H), 6.63 (t, J=7.3 Hz, 1H, 8-H), 6.72 (d, J=7.0 Hz, 1H, 7-H), 7.02 (d, J=6.8 Hz, 1H, 9-H); ^{13}C NMR ($CDCl_3$): δ 18.1, 27.5, 28.9, 31.3, 43.2, 45.9, 46.5, 54.9 (6-C), 116.9 (6a-C), 118.9 (8-C), 123.2 (9-C), 124.9 (7-C), 129.2 (9a-C), 151.0 (3a-C), 175.3 (C=O); MS *m/z* (%): 242 (54) [M^{+}], 157 (52) [M−C_4H_7NO], 156 (100) [M−(C_4H_7NO+H)]; Anal. calcd for $C_{15}H_{18}N_2O$ (242.10): C, 74.35; H, 7.49; N, 11.56. Found: C, 74.32; H, 7.51; N, 11.55.

4.3.2. (±)-6-Dodecyloxy-1,2,5,6-tetrahydro-4*H*-pyrrolo-[3,2,1-*ij*]quinoline (7a). This compound was obtained from dodecyl vinyl ether as pale yellow oil, 60% yield; ^{1}H NMR ($CDCl_3$): 0.80(m, 5H), 1.01–1.56 (brs, 20H), 2.10–2.52 (m, 2H), 2.82–3.02 (m, 1H), 3.35–3.58 (m, 4H), 3.61–3.92 (m, 1H), 4.57 (brd, 1H, 6-H), 6.65 (t, J=7.1 Hz, 1H, 8-H), 6.94 (d, J=7.2 Hz, 1H, 7-H), 7.10 (d, J=7.0 Hz, 1H, 9-H); ^{13}C NMR ($CDCl_3$): δ 13.6, 22.2, 28.6, 28.8, 29.3, 31.5, 32.4, 37.6, 49.2, 54.7, 62.8, 65.4, 73.8, 76.8 (6-C), 118.2 (6a-C), 119.1 (8-C), 123.4 (9-C), 127.0 (7-C), 128.8 (9a-C), 150.7 (3a-C); MS *m/z* (%): 343 (35) [M^{+}], 157 (52) [M−$C_{12}H_{25}OH$], 156 (100) [M−($C_{12}H_{25}OH$+H)]; Anal. calcd for $C_{23}H_{37}NO$ (343.24): C, 80.41; H, 10.86; N, 4.08. Found: C, 80.45; H, 10.85; N, 4.06.

4.3.3. (±)-6-Phenyl-1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline (8a). This compound was obtained from styrene as pale yellow oil, 70% yield; ^{1}H NMR ($CDCl_3$): 1.51–1.80 (m, 2H), 2.05–2.55 (m, 1H), 2.70–3.65 (m, 5H), 4.10 (t, J=7.4 Hz, 1H, 6-H), 6.40 (brt, 1H), 6.70 (brt, 1H), 6.95–7.50 (m, 6H); ^{13}C NMR ($CDCl_3$): δ 29.4, 35.0, 41.4, 46.3, 55.5 (6-C), 121.4, 122.9, 126.0, 127.3, 128.3, 128.8, 129.1, 132.9, 146.4, 148.2 (3a-C); MS *m/z* (%): 235 (68) [M^{+}], 157 (52) [M−C_6H_6], 156 (100) [M−(C_6H_6+H)]; Anal. calcd for $C_{17}H_{17}N$ (235.11): C, 86.77; H, 7.28; N, 5.95. Found: C, 86.74; H, 7.29; N, 5.93.

4.3.4. 4,5,6a,7,8,9a-Hexahydro-6*H*-9-oxa-5a-aza-cyclopenta[*e*]acenaphthylene (mixture of the two racemic diastereomers 9a). These compounds were obtained from 2,3-dihydrofuran as pale yellow oil, 67% yield. Some NMR peaks corresponding to the *trans* isomer are given in square brackets, the others are overlapped with the *cis* isomer signals; ^{1}H NMR ($CDCl_3$): 1.68–1.74 (m, 1H, 7-H) [1.85–1.91 (m, 1H, 7-H)], [2.10–2.13 (m, 1H, 7′-H)], 2.20–2.27 (m, 1H, 7′-H), [2.44–2.55 (m, 1H, 6a-H)], 2.57–2.63 (m, 1H, 6a-H), 2.92 (dd, J=13.2, 7.4 Hz, 1H, 6-H), 3.00–3.05 (m. 1H, 4-H), 3.12 (dd, 1H, J=13.2, 9.1 Hz, 6′-H), [3.18 (dd, J=13.1, 7.5 Hz, 1H, 6-H)], 3.32–3.45 (m, 2H, 4′H, 5-H), 3.48–3.53 (m, 1H, 5′-H), [3.94–3.97 (m, 1H, 8-H)], 3.98–4.03 (m, 1H, 8-H), 4.06–4.10 (m, 1H, 8′-H), 4.91 (s, 1H, 9a-H) [4.95 (d, J=4.5 Hz, 1H, 9a-H)], 6.54 (d, J=7.8 Hz, 1H, 1-H) [6.58 (d, J=8.1 Hz, 1H, 1-H)], [6.69 (t, J=7.3 Hz, 1H, 2-H)], 6.72 (t, J=7.3 Hz, 1H, 2-H), 7.14 (brd, 1H, 3-H); ^{13}C NMR ($CDCl_3$): δ 28.5, 30.0 [43.5], 45.2 [48.5], 52.2, 53.9, 55.2, 66.5 (6-C), [104.4], 106.7 [107.8], [117.2], [117.8], 124.2, 124.5, 127.3, 129.5, 152.5 (br) (9c-C); MS *m/z* (%): 201 (59) [M^{+}], 157 (17) [M−C_2H_4O], 156 (100) [M− (C_2H_4O+H)]; Anal. calcd for $C_{13}H_{15}NO$ (201.12): C, 77.58; H, 7.51; N, 6.96. Found: C, 77.62; H, 7.49; N, 6.94.

4.3.5. (±)-(7a*R,11a*S**)-5,6,7a,9,10,11a-Hexahydro-4*H*,7*H*,8*H*-11-oxa-6a-azabenzo[*de*]antracene (10′a).** This compound was obtained from 2,3-dihydropyran as pale yellow oil, 38% yield, R_f=0.31 (CH_2Cl_2); ^{1}H NMR ($CDCl_3$): 1.25–1.45 (m, 1H, 9H), 1.57–1.92 (m, 2H, 9′-H, 8-H), 2.05–2.39 (m, 1H, 8′-H), 2.45–2. 78 (m, 2H, 7a-H, 5-H), 2.82–3.35 (m, 4H, 5′H, 6-H, 7,7′-H), 3.41–3.62 (m, 1H, 6′-H), 3.69–4.15 (m, 2H, 10-H), 4.66 (d, J=6.2 Hz, 1H, 11a-H), 6.73 (t, J=7.2 Hz, 1H, 2-H), 7.05 (d, J=7.4 Hz, 1H, 1-H), 7.15 (d, J=7.0 Hz, 1H, 3-H); ^{13}C NMR ($CDCl_3$): δ 29.4 (9-C), 30.1 (br, 5-C, 8-C), 38.2 (7a-C), 49.8 (7-C), 55.5 (6-C), 66.3 (10-C), 74.5 (11a-C), 119.2 (2-C), 120.5 (4-C), 124.0 (3-C), 127.2 (1-C), 127.6 (11b-C), 150.0 (11c-C); MS *m/z* (%): 215 (63) [M^{+}], 157 (24) [M−C_3H_6O], 156 (100) [M− (C_3H_6O+H)]; Anal. calcd for $C_{14}H_{17}NO$ (215.15): C, 78.10; H, 7.96; N, 6.51. Found: C, 78.05; H, 7.94; N, 6.54.

4.3.6. (±)-(7a*S,11a*S**)-5,6,7a,9,10,11a-Hexahydro-4*H*,7*H*,8*H*-11-oxa-6a-azabenzo[*de*]antracene (10″a).** This compound was obtained from 2,3-dihydropyran as pale yellow oil, 27% yield, R_f=0.43 (CH_2Cl_2); ^{1}H NMR (DMSO-d_6): 1.32–1.44 (m, 1H, 9-H), 1.52–1.68 (m, 1H, 9′-H), 1.71–1.79 (m, 1H, 8-H), 1.83–1.98 (m, 1H, 8′-H), 2.02–2.12 (m, 1H, 7a-H), 2.80–3.08 (m, 5H, 5,5′-H, 6-H, 7,7′-H), 3.38–3.47 (m, 1H, 6′-H), 3.55 (td, J=10.9, 2.7 Hz, 1H, 10-H), 3.72–3.81 (m, 1H, 10′-H), 4.37 (d, J=3.2 Hz, 1H, 11a-H), 6.54 (t, J=7.40 Hz, 1H, 2-H), 6.88 (d, J=7.5 Hz, 1H, 1-H), 6.95 (d, J=7.1 Hz, 1H, 3-H); ^{13}C NMR (DMSO-d_6): δ 22.3 (9-C), 25.6 (8-C), 28.3 (5-C), 33.5 (7a-C), 47.1 (7-C), 54.0 (6-C), 66.8 (10-C), 71.3 (11a-C), 117.5 (2-C), 118.5 (4-C), 123.5 (3-C), 126.7 (1-C), 128.3 (11b-C), 149.9 (11c-C); MS *m/z* (%): 215 (61) [M^{+}], 157 (18) [M−C_3H_6O], 156 (100) [M−(C_3H_6O+H)]; Anal. calcd for $C_{14}H_{17}NO$ (215.15): C, 78.10; H, 7.96; N, 6.51. Found: C, 78.06; H, 7.93; N, 6.53.

4.3.7. 2-Methyl-6-(*N*-pyrrolidin-2-onyl)-1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline (mixture of the two racemic diastereomers 6b). This compound was obtained from 1-vinyl-2-pyrrolidinone as pale yellow oil, 62% yield. Some NMR peaks corresponding to the secondary isomer are given in square brackets, the others are overlapped with the main isomer signals; ^{1}H NMR ($CDCl_3$): [1.10 (d, J=5.9 Hz, 3H)], 1.26 (d, J=5.8 Hz, 3H), 1.72–2.10 (m, 2H), 2.15–2.32 (m, 2H), 2.38–2.79 (m, 4H), 2.92–3.65 (m, 5H), [4.15 (t, J=7.3 Hz, 1H, 6-H)], 5.35 (t, J=7.5 Hz, 1H, 6-H), 6.62 (t, J=7.4 Hz, 1H, 8-H), 6.81 (d, J=7.2 Hz, 1H, 7-H), 6.95 (d, J=7.3 Hz, 1H, 9-H), [7.40 (d, J=7.2 Hz, 1H, 9-H)]; ^{13}C NMR ($CDCl_3$): δ 17.6, 18.3 [27.4], 29.0 [29.5], 31.4, 37.2 [40.0], 42.3 [43.8], 44.5, 44.8 [46.6], 62.1 (6-C), 116.4 [116.5] (6a-C), 118.5 [118.7] (8-C), 123.4 (9-C), [124.2], 125.8 (7-C), [126.0], 128.5 (9a-C), 150.8 (3a-C), 175.3 [175.5] (C=O); MS *m/z* (%): 256 (58) [$M^{+\cdot}$], 171 (58) [$M-C_4H_7NO$], 170 (100) [$M-(C_4H_7NO+H)$]; Anal. calcd for $C_{16}H_{20}N_2O$ (256.14): C, 74.97; H, 7.86; N, 10.93. Found: C, 75.00; H, 7.85; N, 10.94.

4.3.8. 6-Dodecyloxy-2-methyl-1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline (mixture of the two racemic diastereomers 7b). This compound was obtained from dodecyl vinyl ether as pale yellow oil, 58% yield. Some NMR peaks corresponding to the secondary isomer are given in square brackets, the others are overlapped with the main isomer signals; ^{1}H NMR ($CDCl_3$): 1.00 (brt, 3H), 1.21–1.82 (brs, 25H), 1.85–2.18 (m, 1H), 2.41–2.86 (m, 1H), 3.02–3.91 (m, 5H), 4.65 (t, J=6.8 Hz, 1H, 6-H) [4.75 (t, J=7.0 Hz, 1H, 6-H)], 6.53 (brd, 1H, 7-H), 6.70 (brt, 1H, 8-H), 7.13 (d, J=7.5 Hz, 1H, 9-H) [7.30 (d, J=7.6 Hz, 1H, 9-H)]; ^{13}C NMR ($CDCl_3$): δ 15.2 [20.3], 20.8, 23.9, 27.6, 30.1, 30.3, 30.8, 31.0, 32.0, 33.1, 38.6, 43.2 [53.2], [53.5], 53.7, 61.3, 66.4, 66.8 [67.2] (6-C)], [101.4], [103.2], 107.5, 118.3, 125.2, 128.5, 129.8, 153.5 (3a-C); MS *m/z* (%): 357 (39) [$M^{+\cdot}$], 171 (54) [$M-C_{12}H_{25}OH$], 170 (100) [$M-(C_{12}H_{25}OH+H)$]; Anal. calcd for $C_{24}H_{39}NO$ (357.28): C, 80.62; H, 10.99; N, 3.92. Found: C, 80.66; H, 10.97; N, 3.90.

4.3.9. 2-Methyl-6-phenyl-1,2,5,6-tetrahydro-4*H*-pyrrolo-[3,2,1-*ij*]quinoline (mixture of the two racemic diastereomers 8b). This compound was obtained from styrene as pale yellow oil, 58% yield. Some NMR peaks corresponding to the secondary isomer are given in square brackets, the others are overlapped with the main isomer signals; ^{1}H NMR ($CDCl_3$): 1.28 (brd, 3H), 1.55–2.08 (m, 2H), 2.15–2.78 (m, 3H), 2.82–3.46 (m, 2H), 3.50–3.78 (m, 1H), 4.10 (brt, 1H, 6-H), 6.38 (brt, 1H), 6.71 (brd, 1H), 6.82–7.08 (m, 4H), 7.14–7.32 (brd, 2H); ^{13}C NMR ($CDCl_3$): δ 18.1, 18.8, 29.4, 29.7, 32.7, 34.3, 37.2, 37.8, 40.3, 41.3, 62.8 [63.2] (6-C), 107.2, 120.1, 122.0, 123.1 (br), 124.1, 124.8 (br), 126.0, 126.3, 127.1, 127.5 (br), 128.2, 128.5, 128.9, 129.4, 132.7, 148.0 [148.3] (3a-C); MS *m/z* (%): 249 (72) [$M^{+\cdot}$], 171 (25) [$M-C_6H_6$], 170 (100) [$M-(C_6H_6+H)$]; Anal. calcd for $C_{18}H_{19}N$ (249.14): C, 86.70; H, 7.68; N, 5.62. Found: C, 86.64; H, 7.71; N, 5.63.

4.3.10. 5-Methyl-4,5,6a,7,8,9a-hexahydro-6*H*-9-oxa-5a-aza-cyclopenta[*e*]acenaphthylene (mixture of the four racemic diastereomers 9b). These compounds were obtained from 2,3-dihydrofuran as pale yellow oil, 67% yield. Some NMR peaks corresponding to the secondary isomers are given in square brackets, the others are overlapped with the main isomer signals; ^{1}H NMR ($CDCl_3$): 1.27 (brd, 3H), [1.35 (brd, 3H)], 1.51–1.87 (m, 1H), 1.91–2.38 (m, 1H), 2.41–2.78 (m, 2H), 2.87–3.24 (m, 2H), 3.27–3.34 (m, 2H), 3.51–3.87 (m, 1H), 4.10 (brt, 1H), 4.85 (brd, J=4.0 Hz, 1H, 9a-H), 6.52 (brd, 1H, 1-H), 6.68 (brt, 1H, 2-H), 7.05 (brd, 1H, 3-H) [7.20 (brd, 1H, 3-H)]; ^{13}C NMR ($CDCl_3$): δ 19.1 [19.3], [19.5], [19.7], [27.4], 27.8 [28.0], [28.2], 37.3 (br), 43.1 [43.3], 44.8 [45.3], [45.7], 49.3 [49.9], [54.2], 54.4 (br), 60.5 (br), [60.7], [61.4], 66.1 (br), [66.2], [66.4] (9a-C), 104.2, 106.1 (br), [106.2], 107.5 [107.7], [116.8], [117.1], 117.3 (br), 124.1 (br), 127.3 (br), 128.5 (br), [152.1], 152.5 (br), [152.8] (9c-C); HRMS (FAB): *m/z* calcd for $C_{14}H_{17}NO$ (215.1354). Found (215.1372); MS *m/z* (%): 215 (58) [$M^{+\cdot}$], 157 (29) [$M-C_2H_4O$], 156 (100) [$M-(C_2H_4O+H)$].

4.3.11. [6(*R*,*S*)*,7a*R**,11a*S**]-5,6,7a,9,10,11a-Hexahydro-7-methyl-4*H*,7*H*,8*H*-11-oxa-6a-azabenzo[*de*]antracene (mixture of two racemic diastereomers 10′b). These compounds were obtained from 2,3-dihydropyran as pale yellow oil, 37% yield, R_f=0.58 (light petroleum/ethyl acetate, 90:10). Some NMR peaks corresponding to the secondary isomer are given in square brackets, the others are overlapped with the main isomer signals; ^{1}H NMR ($CDCl_3$): [1.25 (d, 3H)], 1.35 (d, 3H), 1.38–1.75 (m, 2H), 1.78–2.15 (m, 2H), 2.41–2.83 (m, 2H), 3.02 (dd, 2H), 3.21–4.05 (m, 4H), [4.30 (brd, J=6.5 Hz, 1H, 11a-H)], 4.36 (brd, J=6.4 Hz, 1H, 11a-H), 6.45 (brt, 1H, 2-H), 6.66 (brd, 1H, 1-H), 7.01 (brd, 1H, 3-H) [7.15 (brd, 1H, 3-H)]; ^{13}C NMR ($CDCl_3$): δ [20.9], 21.1, 24.3 [24.5], [25.4], 25.5 [38.9], 40.5 [50.1], 50.5, 56.7 [56.9], [62.6], 63.3, 63.7 [63.9] (11a-C), 103.6 [104.1], 107.6 [107.9], 118.5, 125.5, 128.8 br, [129.9], 130.1, 154.3 (br) (11c-C); MS *m/z* (%): 229 (57) [$M^{+\cdot}$], 171 (24) [$M-C_3H_6O$], 170 (100) [$M-(C_3H_6O+H)$]; Anal. calcd for $C_{15}H_{19}NO$ (229.13): C, 78.56; H, 8.35; N, 6.11. Found: C, 78.60; H, 8.33; N, 6.10.

4.3.12. [6(*R*,*S*)*,7a*S**,11a*S**]-5,6,7a,9,10,11a-Hexahydro-7-methyl-4*H*,7*H*,8*H*-11-oxa-6a-azabenzo[*de*]antracene (mixture of two racemic diastereomers 10″b). These compounds were obtained from 2,3-dihydropyran as pale yellow oil, 30% yield, R_f=0.67 (light petroleum/ethyl acetate, 90:10). Some NMR peaks corresponding to the secondary isomer are given in square brackets, the others are overlapped with the main isomer signals; ^{1}H NMR (DMSO-d_6): 1.25 (brd, 3H) [1.32 (d, 3H)], 1.41–1.71 (m, 4H), 1.74–2.15 (m, 1H), 2.37–2.74 (m, 1H), 2.77–3.16 (m, 1H), 3.18–3.45 (m, 3H), 3.47–3.73 (m, 2H), [4.32 (brt, 1H)], 4.62 (brs, 1H, 11a-H), 6.43 (brt, J=7.3 Hz, 1H, 2-H), 6.65 (brd, J=7.5 Hz, 1H, 1-H), 7.01 (brd, J=7.2 Hz, 1H, 3-H); ^{13}C NMR (DMSO-d_6): δ 20.6 [21.3], 24.3 br, 26.8, [27.0], 31.1, 38.7 (br), 40.8 [41.2], [50.9], 51.6, 55.8 [56.1], 60.6 [60.9], 62.5 [63.3] (11a-C), 100.5 [100.9], 107.7 [107.9], [118.5], 118.8, 125.4 [128.6], 128.8, 130.2, 154.5 (br) (11c-C); MS *m/z* (%): 229 (55) [$M^{+\cdot}$], 171 (20) [$M-C_3H_6O$], 170 (100) [$M-(C_3H_6O+H)$]; Anal. calcd for $C_{15}H_{19}NO$ (229.13): C, 78.56; H, 8.35; N, 6.11. Found: C, 78.59; H, 8.32; N, 6.09.

4.3.13. (±)-6-(1-Benzotriazolyl)-1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline (12). White crystal, 29% yield;

mp 149–150°C; ^{1}H NMR (DMSO-d$_6$): δ 2.53 (m, 2H, 5-H), 2.98 (m, 2H, 1-H), 3.16 (m, 2H, 4-H), 3.37 (m, 2H, 2-H), 6.40 (t, 1H, 6.5 Hz, 6-H), 6.44 (brd, 1H, J=7.8 Hz, 7-H), 6.50 (t, 1H, J=7.8 Hz, 8-H), 7.04 (brd, 1H, J=6.6 Hz, 9-H), 7.49 (td, 1H, J=5.8, 2.2 Hz, 5′-H), 7.48 (td, 1H, J=8.4, 1.5 Hz, 6′-H), 7.49 (brd, 1H, 7′-H), 8.06 (dd, 1H, J=8.3, 1.8 Hz, 4′-H); ^{13}C NMR (DMSO-d$_6$): δ 28.3 (1-C), 30.2 (5-C), 44.5 (4-C), 53.0 (6-C), 54.3 (2-C), 110.8 (7′-C), 115.4 (6a-C), 118.3 (8-C), 119.3 (4′-C), 123.8 (5′-C), 124.0 (9-C), 125.2 (7-C), 127.1 (6′-C), 129.2 (9a-C), 132.3 (7a′-C), 145.2 (3a′-C), 150.4 (3a-C); MS *m/z* (%): 276 (46) [$M^{+\cdot}$], 158 (41) [M−Bt$^{\cdot}$], 157 (48) [M−BtH], 156 (100) [M−(BtH+H)]; Anal. calcd for $C_{17}H_{16}N_4$ (276.34): C, 73.89; H, 5.84; N, 20.27. Found: C, 73.87; H, 5.87; N, 20.23.

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