Stereoselective Epoxidations and Electrophilic Additions to Partial Ergot Alkaloids and Conformationally-Fixed Styrenes. Experimental and Theoretical Modeling Evidence for the Importance of Torsional Steering as a Stereocontrol Element

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Partial ergot alkaloid substrates and related conformationally-fixed styrenes undergo epoxidation, osmium tetraoxide dihydroxylation, and hydrobromination with a level of stereoselectivity which cannot be explained by steric control but is consistent with electrophilic attack to minimize torsional strain. Force-field modeling is consistent with the importance of torsional steering as the dominant stereochemical control element.

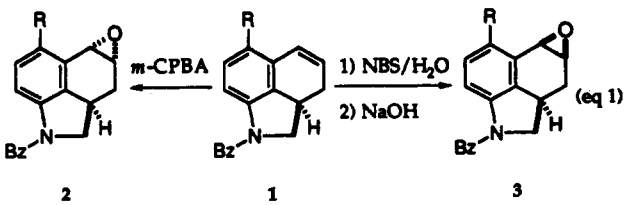
Introduction

The lively discussion of the origin of π-facial stereocontrol has recently focused on torsional,[1] electrostatic,[2] and hyperconjugative[3] effects. In the absence of charged or highly polar groups, torsional effects can provide a remarkably high influence on stereoselectivity.[1] Torsional effects in electrophilic additions to hydrocarbons have primarily been recognized in additions to rigid polycyclic systems such as norbornene derivatives.[4] The importance of staggered arrangements with respect to forming bonds was recognized by Felkin for nucleophilic additions.[5] The Felkin–Anh model is now believed to be generally applicable in nucleophilic and radical additions, but this has been controversial.[1,3] We report here experimental results and theoretical modeling which establishes the role of torsional effects in stereoselectivity control for aryl-fused cycloalkenes containing a styrene moiety. The magnitude of the stereoelectronic, or torsional, factors controlling stereoselectivity has not heretofore been quantified. These results demonstrate an unprecedented degree of stereoselectivity in a sterically nonbiased system.

We have reported the epoxidations, hydroxybrominations, and osmium tetraoxide dihydroxylations of tricyclic partial ergot alkaloid substrates.[6] A remarkably high, unprecedented diastereofacial selectivity was observed using these oxidation protocols. We have now prepared several alkyl derivatives of the parent compounds and simple hydrocarbon (deaza) analogues and have further investigated the stereoselectivities of these substrates. We have discovered a general, highly stereocontrolling element in these systems. We have also performed computational studies on simple model systems with empirical force field calculations. The results indicate that torsional effects can efficiently steer attack to one face of the reacting π-system. The scope of these reactions suggests wide applicability of the general principle of torsional steering in stereoselectivity.

Experimental Results

The results of our experimental studies on tricyclic partial ergots are summarized in Figure 1. The stereochemical descriptors *zu* and *en* are used for these cyclic systems, where *zu* indicates the epoxide resides on the same side of the ring relative to an alkyl branch. *En* refers to these two high priority groups being on opposite sides of the ring. Epoxidation (*m*-CPBA) of 1 (racemic, Bz = PhCO) is *en* selective to give an anti epoxide 2 in 97% yield with 98:2 diastereofacial selectivity (HPLC, eq 1).



2 1 3

The complementary syn epoxide 3 was formed by a two step procedure, via the bromohydrin (NBS/H_2O/DMSO), followed by intramolecular displacement (NaOH, toluene) with equally high diastereoselectivity (2:98, HPLC). In this reaction, bromine attack is also *en* selective. The bromonium ion intermediate formed is attacked from the backside by water. Subsequent elimination of HBr with cyclization gives the *zu* epoxide. Osmylation of 1 followed

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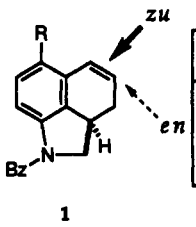
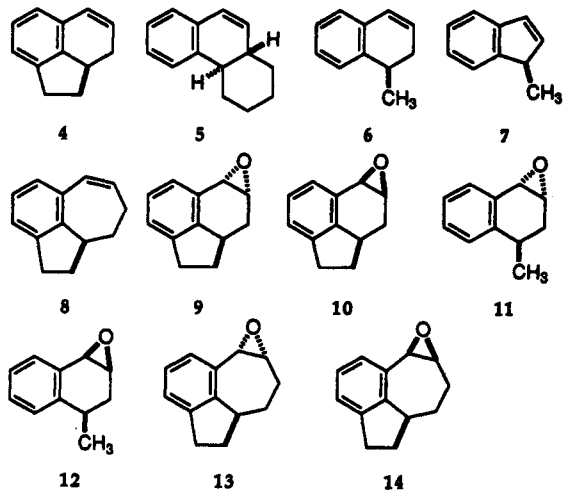


1

[O] / R	H	Br	CN	OCH_3
m-CPBA	2/98[a]	3/97	7/93	1/99
NBS/H_2O	2/98	3/97	7/93	1/99

([a]10/90 in refluxing $CHCl_3$)

Figure 1. *Zu/en* ratios observed in the epoxidation (0 °C, CH_2Cl_2) and hydroxybromination (NBS, H_2O; NaOH) reactions of partial ergot alkaloids.



[O] / R	4	5	6	7	8
m-CPBA	1/99	>1/99	15/85	50/50	82/18
NBS/H_2O	1/99	>1/99	15/85	—	98/2

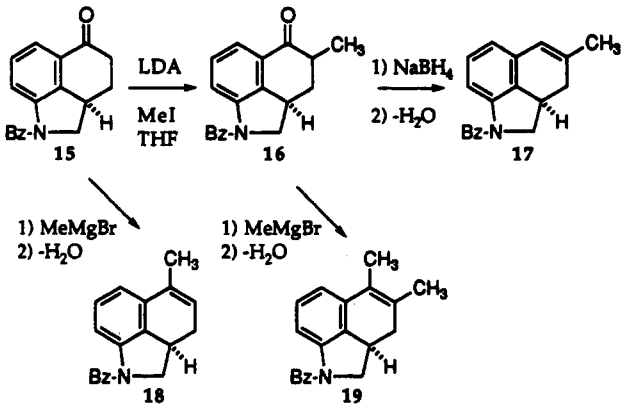
Figure 2. *Zu/en* ratios observed in the reactions of all carbon (deaza) constrained styrene derivatives.

the same trend as these epoxidations, forming only the anti diol which results from *en* attack.[6]

Structure proofs were based upon epoxide magnetic anisotropic shifts in the ^{1}H-NMR spectra[7] and X-ray analyses of the osmylation product as well as an epoxide derivative.[8] The oxidation stereoselectivity was not sensitive to solvent effects (CH_2Cl_2, $CHCl_3$, toluene, THF, *n*-BuOH, aqueous *n*-BuOH, DMSO)[9] or reagent variations (*m*-CPBA, NBS, OsO_4, MMPP). Compared to the parent compound (1, R = H), the stereoselectivity and reaction rate both decrease slightly when R is electron-withdrawing (Br, CN), and both increase when R is electron-donating (OCH_3, Figure 1). The ratios were determined by HPLC analyses of the crude reaction mixtures.

A variety of all-carbon (deaza) analogues were prepared and subjected to the same oxidation protocols (Figure 2). When 4[10] was oxidized with *m*-CPBA (yielding epoxide **9**) or by the NBS/H_2O method (yielding **10** after NaOH), remarkably high stereoselectivities were observed. While the rigid compound **5** was reported by Jerina to give high

Scheme 1



stereoselectivity with *m*-CPBA, NBA, and OsO_4,[11] we found that the dihydronaphthalene 6[12] provided somewhat reduced stereoselectivity (epoxides **11** and **12**). Ring size has an important influence: epoxidation of 3-methylindene (**7**)[13] occurs equally from both faces, while the benzosuberone 8[14] afforded the opposite stereoselectivity (providing epoxides **13** and **14**) compared to **1**.

In these examples, the complementary epoxidation procedures (*m*-CPBA or MMPP *vs* NBS/H_2O/NaOH) provided equal diastereoselectivities, except for compound **8**. That the oxidation of **8** with *m*-CPBA was not as selective as with NBS suggests reversible formation of the bromonium ion intermediate. Reitz and Liotta[15] investigated the selectivities of electrophile-promoted cyclizations of γ-hydroxyalkenes and found higher selectivities with onium ion intermediates. The reversible formation of the onium ion intermediate from reaction of **8** with NBS may permit higher stereocontrol, since the torsional effects described below stabilize the *zu* bromonium ion even more so than the transition state that leads to this intermediate.

The influence of alkene substitution was also investigated in the partial ergot series. The required alkenes were synthesized according to Scheme 1. Kornfeld's ketone **15**[16] was converted to **16** (LDA, CH_3I, THF, 92%) followed by reduction ($NaBH_4$, EtOH) and dehydration (Amberlyst IRA resin, toluene, reflux) to afford **17** (84%, two steps, mp 142–3 °C). Additionally, ketone **15** was reacted with CH_3MgBr in toluene at 5 °C to afford the corresponding carbinol which was dehydrated with $TsOH\cdot H_2O$ to afford **18** (78% overall yield, mp 137 °C). α-Methyl ketone **16** was similarly converted to tetrasubstituted olefin **19** (77% overall yield, mp 163–4 °C).

The two epoxidation protocols were applied to the methyl olefins, and the *zu/en* ratios of the reaction mixtures, determined by HPLC, are given in Figure 3. Epoxidation of the 4-methyl olefin **17** proceeded without difficulty to afford high diastereoselectivity (2/98 *zu/en*) in 98% yield. The corresponding hydroxybromination protocol provided equally high diastereoselectivity in 76% (two steps overall). However, oxidation of the 5-methyl

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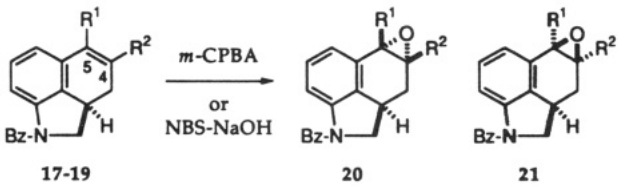

17-19 20 21

cmpd	R_1	R_2	m-CPBA	NBS/H_2O
17	H	CH_3	2/98	2/98
18	CH_3	H	>1/99	>1/99
19	CH_3	CH_3	>1/99	>1/99

Figure 3. *Zu/en* ratios observed in the reactions of alkyl-substituted tricyclic partial ergot alkaloids.

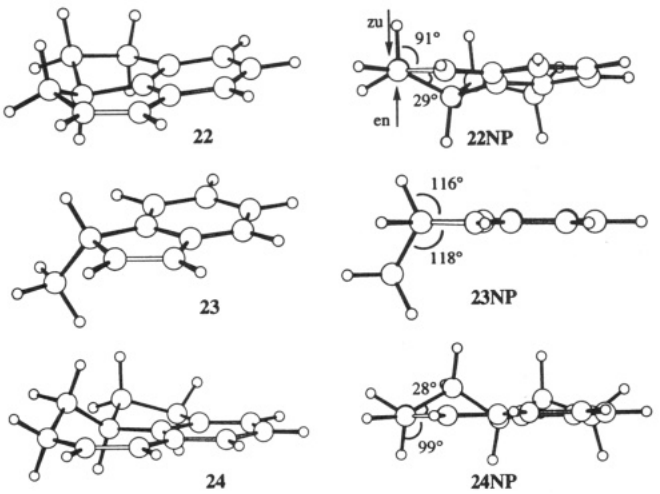

Figure 4. Structures **22**, **23**, and **24**: MM2-optimized structures of compounds **4**, **7**, and **8**. Structures **22–24NP** are Newman projections.

or 4,5-dimethyl olefins **18** or **19**, respectively, revealed greater sensitivity of the epoxide products towards acid-catalyzed pinacol rearrangement (to the 4-ketone byproduct) and solvolysis (to the diols). Furthermore, undesired allylic bromination with NBS of the 5-methyl moiety resulted in lower overall yields of the *endo*-epoxides. Careful workup, however, provided the desired epoxides formed with high stereocontrol. Thus, epoxidations of **18** and **19** afforded the diastereoenriched epoxides in 84% and 59% yield, respectively. The corresponding hydroxybrominations were also highly diastereoselective, with overall yields to the epoxides **21** of 50% and 44%, respectively. Furthermore, in the oxidations of **18** and **19**, none of the corresponding complementary diastereomer was observed by HPLC.

Theoretical Results

How can the direction of attack be influenced by the apparently minor differences between the two faces of these alkenes? Figure 4 shows MM2[17] calculated structures of compounds **4**, **7**, and **8**. The cyclohexadiene ring of structure **4** is shown in **22**. It is quite flat as shown more clearly by the Newman projection, **22NP**. The C=C–C–C dihedral angle is approximately 29°, and the C=C–C–H_{ax} dihedral angle is 91°. Attack from the bottom face (*en*) leads to a staggered transition structure, while attack from the top face (*zu*) suffers from torsional strain and is disfavored.[18] The bottom face is more crowded, in general, than the top face due to the position of the methine CH. Nevertheless, this significant steric difference does not disuade the steering of attack to the more crowded bottom face, in order to minimize torsional strain involving a forming bond and the α-CH bond. The same effects operate in the partial ergot alkaloids in Figures 1 and 3 as well as the hydrocarbons **5** and **6**. Stereoselectivity in **6** is reduced because the partially saturated ring may adopt two half-chair conformations, and staggered attack on the minor conformer gives a larger percentage of the minor isomer observed in the final reaction product. Stereoselectivity from either oxidation protocol drops dramatically in the indene **7**. The ring in methylindene (**7**) is flat as shown in the MM2 structures **23/23NP**. There is little difference in the torsional effect of an allylic CH and an allylic CC, since both steer attack to the anti face to minimize torsional strain in the transition state. Consequently, the two cancel each other out and there is no facial selectivity: steric differences in this case are unimportant, and torsional effects are the same on both faces.[19]

The seven-membered ring of **8** adopts the envelope conformation shown in **24**. The allylic bonds are partially staggered, but in an opposite direction to **22**. Thus, the top face (*zu*) attack gives a staggered transition structure, but bottom attack (*en*) suffers from eclipsing interactions. The homoallylic CH_2 in **8** would appear to block top side attack sterically, but this is more than overcome by torsional factors which favor top side attack. In all of these cases, torsional steering causes attack to occur in a staggered fashion.

Approximate transition state model calculations support this analysis. In order to provide approximate energetic information about the importance of torsional effects on the control of π-facial stereoselectivity, we constructed models for the transition states of epoxidation and osmium tetraoxide reactions. The purpose here was not to provide a quantitative force field as we have developed for other reactions[20] but rather to determine whether the qualitative rationale given here has merit.

Structures **25** and **26** are the two model transition structures for the epoxidation of olefin **4** (Figure 5). The transition structure geometry was based on the position of the transferring O in the calculated transition structure for the reaction of ethylene with peroxyformic acid.[21] The alkene moiety is nearly unchanged from the reactant conformation. Structure **25** is calculated to be more stable than **26** by 1.2 kcal/mol. This energy difference is due mainly to the torsional destabilization of structure **26**. The torsional effect also exists in the epoxide products. MM2 calculations using Raber's epoxide parameters[22] gave a 1.6 kcal/mol preference for the major product. These

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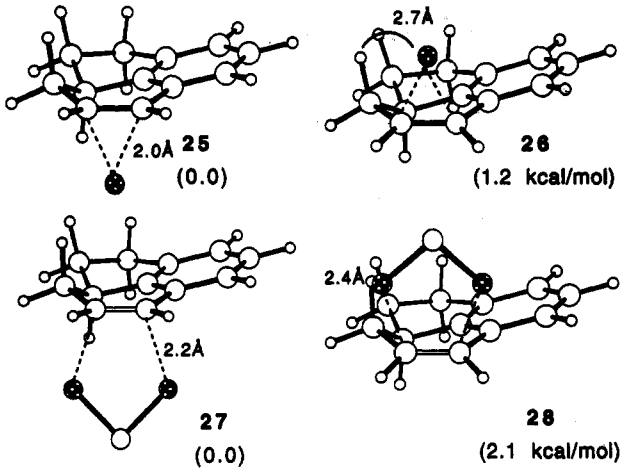

Figure 5. MM2 transition structures with epoxide models (**25** and **26**) and dihydroxylation models (**27** and **28**) for the reaction of **4**.

energy differences of 1.2–1.6 kcal/mol are adequate to explain about a 10:1 ratio of products at 25 °C. However, the experimental ratios are generally much higher, on the order of 99:1 for most of the cases given. An experimental $\Delta\Delta G^{\ddagger}$ of 2.7 kcal/mol is necessary in order to provide a 99:1 ratio. The underestimate of this difference in the model calculations is due to the assumption of a symmetrical transition-state geometry. The epoxidation of a styrenoid substrate, however, has an unsymmetrical geometry, as described below, and this magnifies the torsional effects.

The same model calculations give no facial preference for epoxidation of **7** and a 1.4 kcal/mol preference for the *zu* epoxidation on **8**. These model calculations show that torsional effects alone are adequate to rationalize which attack is *en* and *zu* selective in **4** and **8**, respectively, but not selective in **7**.

We also applied an approximate dihydroxylation transition structure model, which was developed for the modeling of enantioselective dihydroxylation of alkenes by osmium tetraoxide mediated by chiral amines.[23] In the current model, only the O–Os–O unit was included in the calculation. This permits assessment of the torsional effects involving the forming O–C bonds without steric effects due to other ligands which may be present on Os. A 2.1 kcal/mol preference is calculated for **28** over **27**. The larger stereoselectivity is reflected by the shorter O/H_{ax} distance in **28** (2.4 Å) than in **26** (2.7 Å). These distances are too long to result in any appreciable difference in van der Waals interaction energies, but they reflect the fact that **28** has considerable eclipsing, making it highly unfavorable as compared to **27**, while the eclipsing in **26** is smaller, and its energy difference with respect to **25** is smaller as well.

Discussion

The magnitude of the face selectivities for the oxidations of these conformationally-locked styrenoid substrates is extraordinary when compared to cyclohexenoid substrates. For example, as a matter of reference, the following olefin epoxidations[24] are presented for comparison (Figure 6):

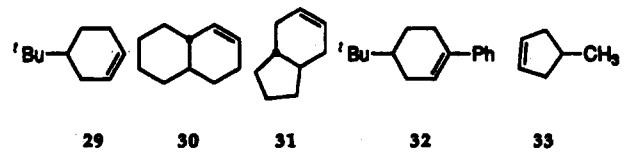

Figure 6. Cycloalkene epoxidation substrates.

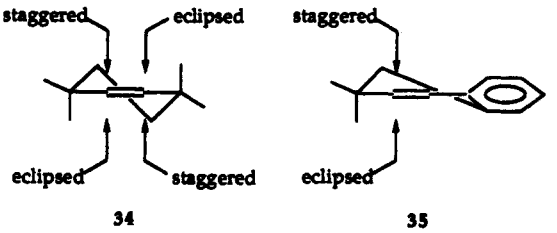

Figure 7. Torsional interactions involving forming bonds in cyclohexene, **34**, and dihydronaphthalene, **35**.

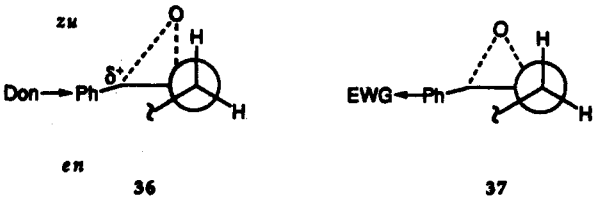

Figure 8. Epoxidation transition states: unsymmetrical transition state **36** with an electron-donating group in the aromatic ring; symmetrical transition state **37** with an electron-withdrawing group.

tert-butylcyclohexene (**29**) with *m*-CPBA afforded a 40:60 ratio of epoxides, *trans*-decalene (**30**) with *p*-NPBA afforded a 45:55 ratio, *trans*-tetrahydroindane (**31**) with *p*-NPBA afforded a 40:60 ratio, 4-phenyl-*tert*-butylcyclohexene (**32**)[25] afforded a 50:50 ratio, and the Henbest olefin (**33**)[26] with peroxylauric acid afforded a 76:24 ratio.

In these cycloalkenoid olefins, the double bond is flanked by two axial/pseudoaxial hydrogen substituents, as shown in **34** (Figure 7). Concerted attack at both alkene carbons, as in epoxidations, experiences one favorable and one unfavorable torsional effect. Therefore, the stereoselectivities are significantly less. The conformationally-fixed styrenoid olefinic center, however, is substituted with only one axial hydrogen and an adjacent aromatic ring, shown in **35**. Styrenoid **32** has the counterbalancing hydrogens as in **34**; it undergoes epoxidation equally from both faces, thereby demonstrating the importance of only one axial hydrogen substituent to enhance the torsional effect.

Kinetic deuterium isotope effects on the epoxidations of styrene derivatives suggest an unsymmetrical transition structure, with more extended C_β–O bond formation due to cation stabilization by the phenyl group.[27] The observed variation of stereoselectivity for **1** with substituents agrees with such assessment and can be also rationalized by the torsional strain argument. Electron-donating substituents (**1**, R = OCH_3) cause larger asymmetry in the transition state, due to enhanced partial positive character stabilization, but disfavor the *zu* face attack depicted in **36** (Figure 8). In this case, the *en* face attack predominates, yielding 99:1 diastereoselectivity ($\Delta\Delta G^{\ddagger}$ = 2.7 kcal). However, a more symmetrical transition state, resulting from destabilization of the β-partial positive character

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adjacent to the ring substituted with an electron-withdrawing group (1, R = CN, Br), possesses a relatively longer O–H_{ax} distance (37, Figure 8). For 1 (R = CN) the facial selectivity decreases to 93:7 ($\Delta\Delta G^{\ddagger}$ = 1.5 kcal), and for 1 (R = Br) the facial selectivity decreases to 97:3 ($\Delta\Delta G^{\ddagger} \approx$ 2.0 kcal).

These results provide powerful examples of the magnitude of torsional steering upon the stereoselectivities of additions to π-bonds. It also produces the large axial preference for additions of nucleophiles to 2-cyclohexenones[28] and is applicable to other reactions such as electrophilic additions to cyclic enolates.[29] Hyperconjugation effects cannot explain these observations.[3] For example, if attack anti to CH rather than CC were preferred, there would be a preference for *zu* addition to 7, providing an unequal, if not predominant epoxide mixture, which is a contradiction to experimental data. Steric effects also do not provide an alternative explanation. Examples 4-8 indicate that the steric bulk of substituents does not alter stereoselectivity. In the reactions of nonpolar styrene derivatives, the conformation of the reactant—which is manifest in the transition state—and the preference for a staggered conformation with respect to forming bonds control stereoselectivity.

Experimental Section

General Procedure for the Oxidation with *m*-CPBA. *trans*-4-Methyl-1,2-epoxytetralin (11). *m*-CPBA (2.39 g, 13.9 mmol) was dissolved in $CHCl_3$ (5 mL) and stirred at 0 °C under N_2. 4-Methyl-1,2-dihydrotetralin (2.0 g, 13.9 mmol) in $CHCl_3$ (12 mL) was added to the reaction flask. The mixture was stirred at 0 °C for 15 min and then at ambient temperature for 1.5–2 h. The reaction mixture was filtered, and the filtrate was washed with $NaHCO_3$ solution (4 × 30 mL) and brine (1 × 30 mL), dried (Na_2SO_4), and concentrated to a clear yellow oil (2.25 g, 100%). Flash chromatography on SiO_2 (200 g) eluting with hexane–EtOAc (10:1) afforded 4-methyl-1,2-epoxytetralin (1.4 g, 63%): R_f 0.59 (SiO_2, 4:1 hexanes/EtOAc); ^1H NMR ($CDCl_3$) δ 1.35 (d, 3H, J = 8.1 Hz), 1.45 (t, 1H, J = 11.7 Hz), 2.33–2.50 (m, 1H), 2.9 (m, 1H), 3.68 (m, 1H), 3.85 (d, 1H, J = 4.5), 7.15–7.4 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 17.1, 26.6, 31.1, 54.1, 54.2, 124.5, 125.6, 128.3, 129.4, 132.2, 134.1; MS m/z 161 (M + 1); IR ($CHCl_3$) 3021, 2934, 1491, 1218 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 204 (12 500); HRMS calcd for $C_{11}H_{13}O$: 161.0966, found 161.0977; GC analysis, *zu*:*en* = 15:85.

General Procedure for the Oxidation with NBS. *cis*-4-Methyl-1,2-epoxy tetralin (12). 4-Methyl-1,2-dihydrotetralin (300 mg, 2.1 mmol) was dissolved in DMSO (1.5 mL) at ambient temperature under nitrogen. Water (163 mL, 9.0 mmol) was then added at rt followed by NBS (411 mg, 2.3 mmol). The reaction mixture was stirred at rt for 1 h. The mixture was diluted with EtOAc (10 mL), washed with water (30 mL) and brine (20 mL), dried (Na_2SO_4), and concentrated to yield an intermediate 2-bromo-1-hydroxy-4-methyltetralin (470 mg, 94%). This crude intermediate bromohydrin was dissolved in toluene (2 mL) at rt and added dropwise to a slurry of freshly powdered NaOH (100 mg, 2.5 mmol) and toluene (2 mL). The mixture was stirred at rt for 2.5 h. The reaction mixture was diluted with EtOAc, then washed with water (3 × 30 mL) and brine (30 mL), dried (Na_2SO_4), and concentrated to yield a dark yellow oil (330 mg, 99%). Flash chromatography of this oil on SiO_2 (30 mg) eluting with hexanes/EtOAc (10:1) afforded the desired epoxy product (150 mg, 45%); R_f 0.5 (SiO_2, 9:1:0.1 hexanes/EtOAc/MeOH); ^1H NMR ($CDCl_3$) δ 1.34 (d, 3H, J = 8.1 Hz), 2.04 (dd, 1H, J = 6.9, 5.9 Hz), 2.2 (m, 1H), 2.94 (m, 1H), 3.74 (m,1H), 3.84 (d, 1H, J = 5.0 Hz), 7.12 (t, 1H, J = 8.9 Hz), 7.16 (d, 1H, J = 7.9 Hz), 7.26 (t, 1H, J = 8.9 Hz), 7.42 (d, 1H, J = 7.9 Hz); MS m/z 161 (M + 1); IR ($CHCl_3$) 3021, 2929, 1493, 1219 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 203 (12 800); HRMS calcd for $C_{11}H_{13}O$ 161.0966, found 161.0976; GC analysis *zu*:*en* = 85:15.

1-Benzoyl-4,5-*exo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]-indole (2, R = H) (97%): mp 109–110 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.40–7.60 (m, 7H), 7.10 (br s, 1H), 4.38 (br s, 1H), 3.86 (d, 1H, J = 3.9 Hz), 3.70 (m, 2H), 3.36 (m, 1H), 2.68 (m, 1H), 1.28 (dd, 1H, J = 12.0, 13.8 Hz); IR (KBr) 1640, 1614, 1475, 1409, 1392 cm^{-1}; MS m/z 278 (25), 277 (85); UV (EtOH) λ nm (ϵ): 295 (7100), 265 (11 700), 216 (29 700). Anal. Calcd for $C_{18}H_{15}NO_2$: C, 77.96; H, 5.45; N, 5.05. Found: C, 77.79; H, 5.20; H, 4.98.

1-Benzoyl-4,5-*endo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]-indole (3, R = H) (65%): mp 147–149 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.40–7.61 (m, 6H), 7.19 (m, 2H), 4.24 (br s, 1H), 3.78 (d, 1H, J = 3.4 Hz), 3.60 (m, 3H), 2.62 (m, 1H), 1.79 (m, 1H); IR (KBr) 3019, 1642, 1615, 1471, 1404, 1391 cm^{-1}; MS m/z 278 (30), 277 (98); UV (EtOH) λ nm (ϵ): 297 (7740), 265 (11 100), 215 (26 700). Anal. Calcd for $C_{18}H_{15}NO_2$: C, 77.96; H, 5.45; N, 5.05. Found: C, 77.74; H, 5.23; N, 4.80.

6-Bromo-1-benzoyl-4,5-*exo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (2, R = Br) (99%): mp 136.5–138 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.39–7.60 (m, 6H), 7.22 (m, 1H), 4.26 (br s, 1H), 4.22 (d, 1H, J = 3.4 Hz), 3.75 (m, 2H), 3.39 (m, 1H), 2.66 (m, 1H), 1.49 (dd, 1H, J = 12.5, 13.3 Hz); IR ($CHCl_3$) 1643, 1602, 1471, 1459, 1382 cm^{-1}; MS m/z 355, 357; UV (EtOH) λ nm (ϵ) 271 (15 800), 221 (28 800). Anal. Calcd for $C_{18}H_{14}BrNO_2$: C, 60.69; H, 3.96; N, 3.93. Found: C, 60.75; H, 3.95; N, 3.86.

6-Bromo-1-benzoyl-4,5-*endo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (3, R = Br) (71%): mp 196–198 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.23–7.66 (m, 7H), 4.28 (br s, 1H), 3.39 (d, 1H, J = 3.5 Hz), 3.52–3.75 (m, 3H), 3.65 (m, 1H),1.78 (m, 1H); IR (KBr) 1655, 1466, 1453, 1372 cm^{-1}; MS m/z 357 (25), 355 (26), 105 (95), 77 (79). Anal. Calcd for $C_{18}H_{14}BrNO_2$: C, 60.69; H, 3.96; N, 3.93. Found: C, 59.95; H, 3.67; N, 3.40.

6-Cyano-1-benzoyl-4,5-*exo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (2, R = CN) (95%): mp 172–173 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.41–7.62 (m, 7H), 4.43 (m, 1H), 4.21 (d, 1H, J = 2.8 Hz), 3.84 (m, 1H), 3.77 (t, 1H, J = 8.5 Hz), 3.41 (m, 1H), 3.76 (m, 1H), 1.55 (m, 1H); IR ($CHCl_3$) 3020, 2223, 1654, 1616, 1471, 1459, 1376, 1350 cm^{-1}; UV (EtOH) λ nm (ϵ) 309 (14 100), 285 (17 300), 230 (23 700). Anal. Calcd for $C_{19}H_{14}N_2O_2$: C, 75.48; H, 4.67; N, 9.27. Found: C, 75.25; H, 4.76; N, 9.12.

6-Cyano-1-benzoyl-4,5-*endo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (3, R = CN) (55%): mp 186–188 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.21–7.70 (m, 7H), 4.26 (br s, 1H), 3.40 (m, 1H), 3.57 (m, 3H), 3.01 (m, 1H), 1.80 (m, 1H); IR (KBr) 3020, 2203, 1654, 1616, 1472, 1376 cm^{-1}; UV (EtOH) λ nm (ϵ) 309 (15 700), 285 (19 000), 230 (26 000), 202 (21 600); MS m/z 303 (26), 105 (95), 77 (79); HRMS calcd for $C_{19}H_{15}N_2O_2$: 303.1133, found 303.1117.

6-Methoxy-1-benzoyl-4,5-*exo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (2, R = OCH_3) (89%): mp 182–184 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.20–7.60 (m, 7H), 4.26 (d, 1H, J = 2.8 Hz), 4.22 (br s, 1H), 3.85 (br s, 3H), 3.58–3.75 (m, 2H), 3.33 (m, 1H), 2.66 (br s, 1H), 1.47 (dd, 1H, J = 10.6, 13.0 Hz); MS m/z 308 (M^+); IR ($CHCl_3$) 1634, 1494, 1476, 1401 cm^{-1}; UV (EtOH) λ nm (ϵ) 315 (sh), 274 (10 200), 219 (22 000), 202 (21 600); HRMS calcd for $C_{19}H_{18}NO_3$ 308.1287, found 308.1281.

6-Methoxy-1-benzoyl-4,5-*endo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (3, R = OCH_3) (64%): oil; ^1H NMR ($CDCl_3$, 300 MHz) 7.20–7.60 (m, 7H), 4.18 (m, 1H), 3.98 (d, 1H, J = 3.6 Hz), 3.92 (br s, 3H), 3.63 (m, 3H), 2.68 (m, 1H), 1.78 (m, 1H); IR ($CHCl_3$) 1638, 1495, 1480 cm^{-1}; UV (EtOH) λ nm (ϵ) 275 (10 200), 220 (22 100), 204 (21 600); HRMS calcd for $C_{19}H_{18}NO_3$ 308.1287, found 308.1294.

1-(Toluenesulfonyl)-4,5-*exo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (2, R = H, Bz = Ts) (83%): 148–150 °C; ^1H NMR ($CDCl_3$, 300 MHz) 7.66 (d, 2H, J = 10 Hz), 7.53 (d, 1H, J = 8 Hz), 7.25 (m, 3H), 7.10 (d, 1H, J = 8 Hz), 4.30 (dd, 1H, J = 9.5, 10 Hz), 3.78 (d, 1H, J = 3 Hz), 3.64 (dd, 1H, J = 3, 3 Hz), 3.33 (dd, 1H, J = 11.5, 13 Hz), 3.07 (m, 1H), 2.60 (ddd, 1H, J = 3, 7, 16 Hz), 2.36 (s, 3H), 1.31 (dd, 1H, J = 15, 16 Hz); MS m/z 327 (84), 172 (99), 144 (100), 115 (99), 91 (98); IR ($CHCl_3$) 1610, 1596, 1349, 1168 cm^{-1}; UV (EtOH) λ nm (ϵ) 212 (32 600), 252

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(7200). Anal. Calcd for $C_{18}H_{20}NO_3$: C, 66.04; H, 5.25; N, 4.28. Found: C, 66.31; H, 5.10; N, 4.21.

1-(Toluenesulfonyl)-4,5-*exo*-epoxy-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (3, R = H, Bz = Ts) (62%): 147–150 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) 7.64 (d, 2H, J = 10 Hz), 7.50 (d, 1H, J = 8 Hz), 7.25 (m, 4H), 4.25 (dd, 1H, J = 10, 10 Hz), 3.69 (d, 1H, J = 4 Hz), 3.56 (m, 1H), 3.39 (m, 1H), 3.07 (dd, 1H, J = 10, 13 Hz), 2.60 (ddd, 1H, J = 3, 3, 13 Hz), 2.38 (s, 3H), 1.58 (m, 1H); MS m/z 327 (100), 172 (66), 144 (55); IR ($CHCl_3$) 1600, 1458, 1335, 1345, 1165, 1088, 811 cm^{-1}; UV (EtOH) λ nm (ϵ) 212 (24 800), 252 (7400). Anal. Calcd for $C_{18}H_{20}NO_3$: C, 66.04; H, 5.25; N, 4.28. Found: C, 66.31; H, 5.10; N, 4.21.

***endo*-Epoxy-1,2,2a,3,4,5-hexahydroacenaphthene (9)** (92%): R_f 0.53 (SiO_2, 5:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.40 (m, 1H), 1.62 (m, 1H), 2.44 (m, 1H), 2.73 (dq, 1H, J = 2.8,7.1 Hz), 2.8–3.12 (m, 3H), 3.74 (t, 1H, J = 3.1 Hz), 3.87 (d, 1H, J = 3.9 Hz), 7.16–7.29 (m 3H); ^{13}C NMR ($CDCl_3$) δ 28.7, 31.8, 34.3, 35.8, 50.9 , 55.9, 124.2, 125.2, 126.7, 130.5, 142.7, 143.0; MS m/z 173 (M + 1); IR ($CHCl_3$) 3011, 2960, 1468 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 278 (1000); HRMS calcd for $C_{12}H_{13}O$ 173.0966, found 173.0968.

***exo*-Epoxy-1,2,2a,3,4,5-hexahydroacenaphthene (10)** (57%): R_f 0.47 (SiO_2, 5:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.44–1.59 (m, 1H), 1.66–1.75 (m, 1H), 2.30–2.39 (m, 1H), 2.68 (dt, 1H, J = 6.6, 14.4 Hz), 2.88–2.93 (m, 2H), 3.18–3.31 (m, 1H), 3.62–3.66 (m, 1H), 3.78 (d, 1H, J = 3.9 Hz), 7.16–7.22 (m, 2H), 7.31–7.36 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 32.3, 32.6, 34.3, 37.8, 49.8, 52.6, 124.5, 126.9, 130.1, 142.4, 144.9; MS m/z 172 (M + 1); IR ($CHCl_3$) 2960, 1706, 1462 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 256 (3300); HRMS calcd for $C_{12}H_{13}O$ 173.0966, found 173.0969.

Epoxidation of 8 with *m*-CPBA to form epoxide 13 (52%): R_f 0.43 (SiO_2, 9:1 hexanes/EtOAC); ^{1}H NMR ($CDCl_3$) δ 1.52–1.75 (m, 3H), 2.07–2.27 (m 2H), 2.52 (dq, 1H, J = 3.7, 15.7 Hz), 2.77–2.84 (m, 2H), 2.90 (dq, 1H, J = 7.0, 11.4 Hz), 3.65–3.68 (m, 1H), 3.88 (d, 1H, J = 4.2 Hz), 7.13–7.24 (m, 2H), 7.33–7.36 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 28.7, 29.1, 31.8, 34.2, 48.3, 60.1, 61.2, 124.8, 126.5, 131.3, 131.6, 145.3, 146.9; MS m/z 187 (M + 1); IR ($CHCl_3$) 2925, 1457, 1049 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 272 (1100); HRMS calcd for $C_{13}H_{15}O$ 187.1123, found 187.1126.

Epoxidation of 8 with NBS to form epoxide 14 (55%): R_f 0.43 (SiO_2, 9:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.41–1.64 (m, 2H), 1.80–1.88 (m, 1H), 2.24–2.32 (m, 1H), 2.35 (q, 1H, J = 4.7 Hz), 2.42–2.54 (m, 1H), 2.76–2.85 (m, 2H), 3.32-3.42 (m, 1H), 3.45–3.49 (m, 1H), 3.77 (d, 1H, J = 4.1 Hz), 7.11–7.17 (m, 2H), 7.22–7.25 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 27.1, 30.7, 31.8, 34.3, 43.0, 57.1, 60.2, 124.7, 126.4, 129.6, 131.9, 144.8, 145.9; MS m/z 187 (M + 1); IR ($CHCl_3$) 2926, 2860, 1465, 1235, 1048 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 272 (1100); HRMS calcd for $C_{13}H_{15}O$ 187.1123, found 187.1125.

4-Methyl-1-benzoyl-1,2,2a,3-tetrahydrobenz[*c,d*]indole (17). Ketone **15** (5.0 g, 0.018 mol) dissolved in THF (50 mL) was added dropwise to sodium bis(trimethylsilyl)amide (18 mL, 0.018 mol, 1M in THF) at 0 °C under N_2. After the mixture was stirred at 0 °C for 30 min, the enolate was added to MeI (7.5 mL, 0.12 mol) in THF (30 mL) at −78 °C. Upon complete addition, the cooling bath was removed and the reaction mixture stirred at rt for 2 h. The reaction mixture was then partitioned between NH_4Cl solution (saturated aqueous) and EtOAc. The organic phase was rinsed with brine, dried (Na_2SO_4), and concentrated. The crude ketone was dissolved directly in EtOH (40 mL), treated with $NaBH_4$ (0.76 g, 0.02 mol), and stirred under reflux for 2.5 h. After the solution was cooled to rt, the solvent was removed and the residue partitioned between 1 N HCl (40 mL) and extracted with CH_2Cl_2 (3 × 20 mL). The organic phase was rinsed with brine, dried (Na_2SO_4), and concentrated. The crude carbinol was next heated under reflux in toluene (100 mL) containing Amberlyst IR-15A resin (3.0 g) for 2 h. After the mixture was cooled the mixture to rt and the resin filtered, the solution was concentrated to dryness. Recrystallization from EtOAc/hexanes afforded 3.72 g (71%, three steps) of methyl olefin **17**. mp 142–3 °C; R_f 0.73 (SiO_2, 1:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.93 (s, 3H), 2.24 (m, 2H), 3.55 (m, 1H), 3.78 (t, 1H, J = 10.8 Hz), 4.32 (m, 1H), 6.31 (s, 1H), 6.76 (m, 1H), 7.47 (m, 5H), 7.59 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 23.8, 33.8, 34.7, 58.7, 119.0, 121.1, 127.3, 127.2, 128.5, 130.5, 132.4, 136.9, 138.7, 140.3, 168.7 (two C's not resolved); MS m/z 275 (M$^+$); IR ($CHCl_3$) 3011, 1645, 1631, 1468, 1398 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 202 (20 500), 224 (15 000), 267 (19 200); HRMS calcd for $C_{19}H_{17}NO$ 276.1388, found 276.1367.

4-Methyl-4,5-*exo*-epoxy-1-benzoyl-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (20, R_1 = H, R_2 = CH_3) (98%): R_f 0.77 (SiO_2, 1:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.55 (s, 3H), 1.57 (m, 1H), 2.47 (m, 1H), 3.42 (m, 1H), 3.64 (s, 1H), 3.68 (t, 1H, J = 10.7 Hz), 4.40 (m, 1H), 7.08 (m, 1H), 7.46 (m, 4H), 7.54 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 21.9, 31.9, 33.0, 57.4, 58.0, 61.6, 116.9, 122.8, 127.3, 128.0, 128.6, 130.6, 132.0, 136.3, 168.7 (two C's not resolved); MS m/z 291 (M$^+$); IR ($CHCl_3$) 3019, 1640, 1614, 1476, 1392 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 220 (26 000), 266 (11 600), 296 (7000). Anal. Calcd for $C_{19}H_{17}NO_2$: C, 78.33; H, 5.88; N, 4.81. Found: C, 78.03; H, 5.88; N, 4.59.

4-Methyl-4,5-*endo*-epoxy-1-benzoyl-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (21, R_1 = H, R_2 = CH_3) (76%): R_f 0.66 (SiO_2, 1:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.55 (s, 3H), 1.86 (m, 1H), 2.37 (m, 1H), 3.57 (m, 1H), 3.60 (s, 1H), 4.25 (m, 1H), 7.16 (m, 1H), 7.43 (m, 4H), 7.53 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 24.5, 34.5, 36.4, 56.3, 58.5, 58.6, 124.6, 125.3, 127.3, 128.2, 128.6, 129.0, 129.9, 130.8, 136.5, 141.2, 168.7; MS m/z 291 (M$^+$); IR ($CHCl_3$) 3012, 1641, 1615, 1473, 1392 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 216 (21 900), 265 (10 000), 295 (6600); HRMS calcd for $C_{19}H_{18}NO_2$ 292.1388, found 292.1316. Anal. Calcd for $C_{19}H_{17}NO_2$: C, 78.33; H, 5.88; N, 4.81. Found: C, 77.95; H, 5.98; N, 4.49.

5-Methyl-1-benzoyl-1,2,2a,3-tetrahydrobenz[*c,d*]indole (18). Ketone **15** (50.0 g, 0.18 mol) in toluene (1000 mL) was treated with MeMgBr (99 mL, 0.198 mol, 2 M in THF) at −78 °C. After being stirred at −78 °C for 1 h and warmed to rt overnight, the reaction mixture was worked up as above. The crude carbinol was next heated under reflux in toluene (1500 mL) containing *p*-TsOH·H_2O (0.25 g) for 4 h under a Dean Stark trap. After the solution was cooled to rt, the organic phase was washed with $NaHCO_3$ (3 × 250 mL) and brine, dried (Na_2SO_4), and concentrated. The crude material was purified by HPLC (SiO_2, toluene, gradient to 25% EtOAc/75% toluene). Recrystallization from EtOAc afforded 38.48 g (73.9%, two steps) of methyl olefin **18**: mp 137 °C; R_f 0.35 (SiO_2, 3:1 hexanes/EtOAc); mp 136–7 °C; ^{1}H NMR ($CDCl_3$) δ 2.08 (s, 3H), 2.14 (m, 1H), 2.52 (m, 1H), 3.49 (m, 1H), 3.79 (t, 1H, J = 10.6 Hz), 4.28 (m, 1H), 5.77 (m, 1H), 6.90 (m, 1H), 7.48 (m, 4H), 7.60 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 18.1, 28.3, 34.6, 59.9, 117.2, 124.0, 127.3, 128.1, 128.6, 130.5, 131.8, 134.0, 136.7, 139.8, 140.5, 141.7, 168.6; MS m/z 275 (M$^+$); IR ($CHCl_3$) 3011, 1644, 1629, 1603, 1579, 1494, 1397 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 202 (21 000), 228 (16 000), 263 (20 400), 306 (4600). Anal. Calcd for $C_{19}H_{17}NO$: C, 82.88; H, 6.22; N, 5.09. Found: C, 82.67; H, 6.33; N, 5.08.

5-Methyl-4,5-*exo*-epoxy-1-benzoyl-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (20, R_1 = CH_3, R_2 = H) (84%): R_f 0.35 (SiO_2, 3:1 hexanes/EtOAc); mp 146–7 °C; ^{1}H NMR ($CDCl_3$) δ 1.57 (m, 1H), 1.77 (s, 3H), 2.66 (m, 1H), 3.41 (m, 1H), 3.51 (br d, 1H, J = 2.9 Hz), 3.70 (t, 1H, J = 10.6 Hz), 4.36 (m, 1H), 7.16 (m, 1H), 7.48 (m, 4H), 7.58 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 18.3, 26.7, 32.5, 54.3, 57.9, 62.2, 121.3, 127.3, 127.9, 128.6, 130.6, 131.6, 133.8, 136.4, 141.4, 168.6 (three C's not observed); MS m/z 291 (M$^+$); IR ($CHCl_3$) 3012, 1640, 1613, 1474, 1395 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 203 (19 200), 217 (21 800), 266 (8900), 296 (5700). Anal. Calcd for $C_{19}H_{17}NO$: C, 78.33; H, 5.88; N, 4.81. Found: C, 78.61; H, 5.98; N, 5.10.

5-Methyl-4,5-*endo*-epoxy-1-benzoyl-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (21, R_1 = CH_3, R_2 = H) (50%): R_f 0.42 (SiO_2, 1:1 hexanes/EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.74 (s, 3H), 1.81 (m, 1H), 2.67 (m, 1H), 3.43 (m, 1H), 3.61 (m, 2H), 4.28 (m, 1H), 7.22 (m, 3H), 7.58 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 19.5, 31.0, 34.0, 54.7, 58.3, 59.4, 121.9, 127.3, 128.2, 128.4, 128.5, 128.6, 129.0, 130.6, 136.3, 141.3, 168.6; MS m/z 292 (M + 1); IR ($CHCl_3$) 3012, 1641, 1614, 1472, 1392 cm^{-1}; UV (EtOH) λ_{max} (ϵ) 203 (21 300), 214 (21 600), 266 (9400), 295 (6700); HRMS calcd for $C_{19}H_{17}NO$ 292.1339, found: 292.1338.

4,5-Dimethyl-1-benzoyl-1,2,2a,3-tetrahydrobenz[*c,d*]indole (19). Ketone **15** (5.55 g, 0.020 mol) dissolved in THF (40 mL) was added dropwise to sodium bis(trimethylsilyl)amide (20 mL, 0.020 mol, 1 M in THF) at 0 °C under N_2. After the solution was stirred at 0 °C for 30 min, the enolate was added to MeI (7.5 mL, 0.12 mol) in THF (30 mL) at −78 °C. Upon complete addition, the cooling bath was removed, and the reaction mixture was stirred at rt for 2 h. The reaction mixture was then partitioned

between NH_4Cl solution (saturated aqueous) and EtOAc. The organic phase was rinsed with brine, dried (Na_2SO_4), and concentrated. The crude ketone was dissolved directly in toluene and treated with MeMgBr (10 mL, 0.030 mol, 3 M in Et_2O) at −10 °C. After being stirred at −10 °C for 1 h and rt for 2 h, the reaction mixture was worked up as above. The crude carbinol was next heated under reflux in toluene (100 mL) containing Amberlyst IR-15A resin (5.0 g) for 2 h. After cooling to rt and filtration of the resin, the solution was concentrated to dryness. Recrystallization from EtOAc afforded 4.46 g (77.0%, three steps) of the dimethyl olefin **19**. mp 163–4 °C; R_f 0.44 (SiO_2, 3:1 hexanes/EtOAc); ^1H NMR ($CDCl_3$) δ 1.91 (s, 3H), 2.08 (s, 3H), 2.23 (m, 1H), 2.34 (m, 1H), 3.45 (m, 1H), 3.75 (t, 1H, J = 10.6 Hz), 4.25 (m, 1H), 6.86 (m, 1H), 7.46 (m, 4H), 7.54 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 13.3, 20.5, 34.1, 35.7, 59.4, 116.8, 125.0, 127.4, 128.0, 128.6, 130.4, 131.0, 135.0, 136.6, 140.3, 168.7 (two C's not observed); MS m/z 290 (M + 1); IR ($CHCl_3$) 3025, 1642, 1629 cm^{-1}; UV (EtOH) λ_{max} (ε) 269 (20 700). Anal. Calcd for $C_{20}H_{19}NO$: C, 83.01; H, 6.62; N, 4.84. Found: C, 82.21; H, 6.55; N, 4.78.

4,5-Dimethyl-4,5-*exo*-epoxy-1-benzoyl-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (20, $R_1 = CH_3$, $R_2 = CH_3$) (59%): mp 175–6 °C; R_f 0.42 (SiO_2, 3:1 hexanes/EtOAc); ^1H NMR ($CDCl_3$) δ 1.56 (s, 3H), 1.65 (m, 1H), 1.77 (s, 3H), 2.49 (m, 1H), 3.47 (m, 1H), 3.68 (t, 1H, J = 10.6 Hz), 4.36 (m, 1H), 7.14 (m, 1H), 7.46 (m, 4H), 7.56 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 14.8, 19.0, 32.8, 33.9, 57.7, 58.7, 65.2, 121.3, 127.4, 127.7, 127.8, 127.8, 128.6, 130.6, 134.5, 134.6, 136.4, 136.4, 141.4, 168.7; MS m/z 305 (M^+); IR ($CHCl_3$) 3012, 1640, 1474, 1461, 1386 cm^{-1}; UV (EtOH) λ_{max} (ε) 203 (23 600), 219 (27 500), 265 (11 200), 296 (7200). Anal. Calcd for $C_{20}H_{19}NO_2$: C, 78.66; H, 6.27; N, 4.59. Found: C, 78.88; H, 6.44; N, 4.79.

4,5-Dimethyl-4,5-*endo*-epoxy-1-benzoyl-1,2,2a,3,4,5-hexahydrobenz[*c,d*]indole (21, $R_1 = CH_3$, $R_2 = CH_3$) (44%): R_f 0.53 (SiO_2, 1:1 hexanes/EtOAc); ^1H NMR ($CDCl_3$) δ 1.55 (s, 3H), 1.72, (s, 3H), 1.89 (m, 1H), 2.39 (m, 1H), 3.58 (m, 2H),4.20 (m, 1H), 7.10–7.60 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 15.8, 21.5, 34.0, 38.3, 58.5, 58.9, 62.6, 122.2, 127.3, 128.0, 128.6, 130.6, 134.0, 135.3, 136.4, 141.1, 141.2, 168.6; MS m/z 306 (M + 1); IR ($CHCl_3$) 3010, 1641, 1469, 1455, 1395 cm^{-1}; UV (EtOH) λ_{max} (ε) 220 (19 800), 255 (14 500); HRMS calcd for $C_{20}H_{20}NO_2$ 306.1494, found 306.1514.

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