Stereoselective Epoxidation of Allylic Carbamates with *m*-Chloroperbenzoic Acid: The Role of Cooperative Coordination

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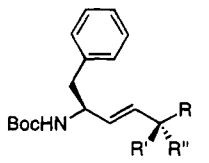
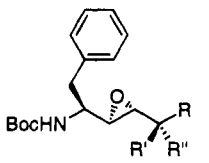
Stereoselective epoxidations of a series of allylic carbamate methyl esters **1a–d**, homoallylic alcohols **1e–h**, and acetates **1i–l** have been performed using *m*-chloroperbenzoic acid (*m*-CPBA) as epoxidizing agent. Throughout, the formation of the *threo* epoxides was favored. This selectivity is probably due to a directing effect of the carbamate group which forms a hydrogen bond to the peracid. However, the *threo/erythro* isomeric ratio is also dependent on steric interactions and on the possibility of cooperative coordination of the peracid to other suitably positioned functionalities such as allylic methyl ester, homoallylic alcohol, and acetate groups. The results of the present study indicate that the methyl ester is a weaker directing group than the carbamate. However, the directing effect of the methyl ester is stronger than that of the homoallylic alcohol and acetate groups. A thermodynamic study of the epoxidation of two epimeric carbamate esters giving considerably different isomeric product ratios (9:1 compared to 2:1) indicates that the order in the transition state structure influences the isomeric ratios.

Introduction

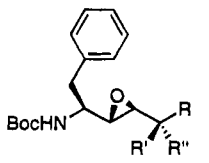
The allylic carbamates **1a–d** are stereoselectively converted into *threo* epoxides **2a–d** by treatment with *m*-chloroperbenzoic acid (*m*-CPBA).[1a] This stereoselectivity has been suggested to emanate from a cooperative coordination of the incoming peracid by the carbamate group and the more weakly coordinating allylic ester function.[1a,2–4] In the present study, we have studied further the phenomenon of cooperative coordination by comparing the stereoselectivity of epoxidation of **1a–d** with that of the closely related homoallylic alcohols **1e–h** and acetates **1i–l**. In addition, we have prepared and studied the reactivity of the allylic carbamate **1m** which lacks a second functional group. To gain more insight into the factors underlying the stereoselectivity, we have also undertaken a thermodynamic study of the epoxidation of **1b** and **1c**.



1a-m



2a-m



3a-m

	R	R'	R"
a:	COOMe	H	H
b:	COOMe	H	CH_2Ph
c:	COOMe	CH_2Ph	H
d:	COOMe	CH_2Ph	CH_2Ph
e:	CH_2OH	H	H
f:	CH_2OH	H	CH_2Ph
g:	CH_2OH	CH_2Ph	H
h:	CH_2OH	CH_2Ph	CH_2Ph
i:	CH_2OAc	H	H
j:	CH_2OAc	H	CH_2Ph
k:	CH_2OAc	CH_2Ph	H
l:	CH_2OAc	CH_2Ph	CH_2Ph
m:	H	CH_2Ph	H

Results and Discussion

Synthesis of Allylic Carbamates. The allylic methyl esters **1a–d** and the homoallylic alcohols **1e–h** have been synthesized previously.[1a] Acetates **1i–l** were obtained from **1e–h** by treatment with acetic anhydride and triethylamine in CH_2Cl_2. The allylic carbamate **1m** was synthesized by a Julia reaction of 3-phenylpropanal with sulfone **4**; this afforded an 86:14 ratio of *E* and *Z* isomers from which pure **1m** was isolated by flash chromatography in 64% yield (Scheme 1).

Epoxidation Reactions with *m*-Chloroperbenzoic Acid (*m*-CPBA). Each of the allylic carbamates was

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(1) (a) Jenmalm, A.; Berts, W.; Li, Y.-L.; Luthman, K.; Csöregh, I.; Hacksell, U. *J. Org. Chem.* **1994**, *59*, 1139–1148. For other studies on the directing effect of allylic amides see: (b) Hasegawa, A.; Sable, H. Z. *J. Org. Chem.* **1966**, *31*, 4154–4161. (c) Ohfune, Y.; Kurokawa, N. *Tetrahedron Lett.* **1984**, *25*, 1587–1590. (d) Shaw, K. J.; Luly, J. R.; Rapoport, H. *J. Org. Chem.* **1985**, *50*, 4515–4523. (e) Hauser, F. M.; Ellenberger, S. R.; Glusker, J. P.; Smart, C. J.; Carrel, H. L. *J. Org. Chem.* **1986**, *51*, 50–57. (f) Kogen, H.; Nishi, T. *J. Chem. Soc., Chem. Commun.* **1987**, 311–312. (g) Luly, J. R.; Dellaria, J. F.; Plattner, J.; Soderqvist, J. L.; Yi, N. *J. Org. Chem.* **1987**, *52*, 1487–1492. (h) Roush, W. R.; Straub, J. A.; Brown, R. J. *J. Org. Chem.* **1987**, *52*, 5127–5136. (i) Hori, K.; Ohfune, Y. J. *J. Org. Chem.* **1988**, *53*, 3886–3888. (j) Rotella, D. P. *Tetrahedron Lett.* **1989**, *30*, 1913–1916. (k) Cambell, M. M.; Floyd, A. J.; Lewis, T.; Mahon, M. F.; Oglivie, R. J. *Tetrahedron Lett.* **1989**, *30*, 1993–1996. (l) Kocóvský, P.; Starý, I. *J. Org. Chem.* **1990**, *55*, 3236–3243. (m) Pettersson, H.; Gogoll, A.; Bäckvall, J.-E. *J. Org. Chem.* **1992**, *57*, 6025–6031. (n) Li, Y.-L.; Luthman, K.; Hacksell, U. *Tetrahedron Lett.* **1992**, 33, 4487–4490. (o) Romeo, S.; Rich, D. H. *Tetrahedron Lett.* **1993**, *34*, 7187–7190. (p) Albeck, A.; Persky, R. *J. Org. Chem.* **1994**, *59*, 653–657.

(2) In the proposed transition state, the NH of the carbamate is hydrogen bonding to a peracid oxygen and the proton of the peracid is hydrogen bonding to the carbonyl oxygen of the ester function.

(3) For other examples of cooperative coordination to *m*-CPBA, see: (a) Johnson, M. R.; Kishi, Y. *Tetrahedron Lett.* **1979**, 4347–4350. (b) Clayden, J.; Collington, E. W.; Egert, E.; McElroy, A. B.; Warren, S. *J. Chem. Soc., Perkin Trans. 1* **1994**, 2801–2810 and ref 1f.

(4) It has been shown earlier that carbonyl groups can direct the attack of *m*-CPBA. See: (a) Kocóvský, P. *Tetrahedron Lett.* **1988**, 2475–2478. (b) Mohamadi, F.; Spees, M. M. *Tetrahedron Lett.* **1989**, *30*, 1309–1310. (c) Armstrong, A.; Barsanti, P. A.; Clarke, P. A. *Tetrahedron Lett.* **1994**, *35*, 6155–6158 and ref 11.

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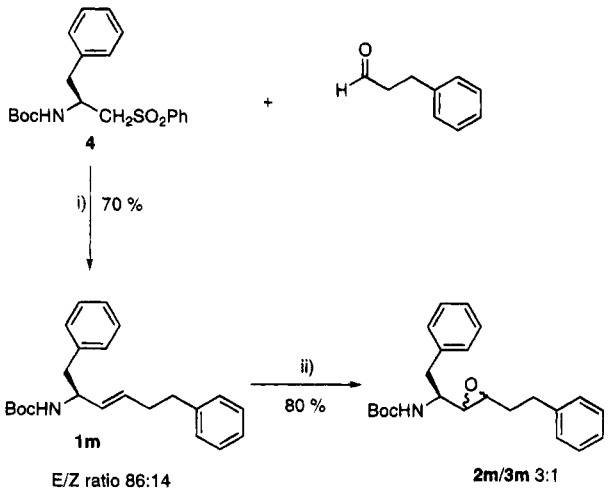
Scheme 1[a]



[a] Key: (i) (a) THF, BuLi (2.0 equiv); (b) Na(Hg) (6%), Na_2HPO_4, MeOH; (ii) *m*-CPBA, CH_2Cl_2.

Table 1. Epoxidation Reactions on 1a–1m with *m*-CPBA[a]

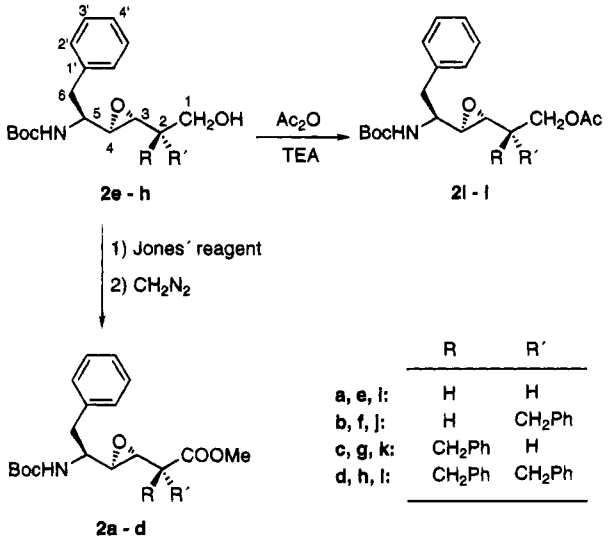
entry	substrate	ratio *threo/erythro*	yield (%)	time (h)
1	**1a**	8:1	75	48
2	**1b**	2:1	80	44
3	**1c**	9:1	77	40
4	**1d**	9:1	90	24
5	**1e**	7:1	68	12
6	**1f**	2:1	89	6
7	**1g**	8:1	89	5
8	**1h**	4:1	94	5
9	**1i**	5:1	87	12
10	**1j**	2:1	84	45
11	**1k**	6:1	84	24
12	**1l**	4:1	80	48
13	**1m**	3:1	80	29

[a] The relative ratio of epoxide isomers has been determined by HPLC and NMR spectroscopy on the crude reaction product.

treated with *m*-CPBA (1.5 equiv) in CH_2Cl_2[5] at room temperature. The resulting epoxides were isolated by flash chromatography.

The results from the epoxidation of methyl esters **1a–1d** (entries 1–4; Table 1) with *m*-CPBA have been described previously,[1a] but the stereoselectivity of the epoxidation of **1a** is now revised.[6] With the exception of **1b**, which gave a 2:1 ratio of *threo/erythro* epoxides, the stereoselectivity was pronounced, producing the *threo* isomers in large excess. Epoxidation of homoallylic alcohols **1e**, **1g**, and **1h** proceeded with a slightly lower stereoselectivity than the corresponding esters whereas the epoxidation of **1f** gave the same *threo/erythro* ratio as **1b** (entries 5–8; Table 1). The stereoselectivity of epoxidation of the homoallylic acetates **1i** and **1k** was even less pronounced whereas that of **1j** and **1l** was identical to that of the corresponding alcohols (entries 9–12; Table 1).

Scheme 2



The epoxidation of **1m**, which lacks a methyl ester, alcohol, or acetate function, gave a 3:1 mixture of **2m** and **3m** (the *threo* and *erythro* isomers, respectively).[7]

As confirmed by competition experiments, the rate of epoxidation of the homoallylic alcohols was much faster than that of the homoallylic acetates which reacted somewhat faster than the allylic methyl esters. In addition, the reactivity of **1m** was considerably higher than that of the methyl esters under the standardized reaction conditions. It may also be noted that **1c** reacted faster than **1b**, the $k_{1c}(4.4 \times 10^{-2}\ h^{-1})/k_{1b}(2.9 \times 10^{-2}\ h^{-1})$ ratio being 1.5.[8]

Configurational Assignment of the Epoxides. The stereochemistries of epoxides **2a–c** and **3a–c** have been established rigorously.[9] Hence, the absolute configuration of the compounds resulting from epoxidation of alcohols **1e–g** and acetates **1i–k** could be determined by chemical correlation (Scheme 2); epoxide alcohols

(5) The influence of other solvents on the epoxidation reaction has been investigated. Compounds **1b** and **1c** have been treated with 1.5 equiv of *m*-CPBA in either THF, DMF, or MeOH. However, in these solvents the conversion of starting material to products was slow. After 72 h less than 25% of products had formed and the ratios of the epoxide isomers seemed to be unaffected by the solvent used.

(6) The previously reported ratio of epoxide isomers formed from **1a** with *m*-CPBA (19:1) was determined on a mixture of isomers obtained after column chromatography.[1a] However, we have noticed that when the crude product mixture is purified on silica gel, the *erythro* isomer is converted into an allylic alcohol by ring opening of the epoxide. The same ring opening reaction occurs also with the *threo* isomer, but the reaction rate is considerably slower. In a recent paper the high *threo/erythro* ratio of allylic amide epoxide isomers (190:1)[1o] was shown to be due to a lower stability of the *erythro* isomer leading to the formation of byproducts. The initial epoxide isomer ratio was later determined to 5:1 and seemed to be independent of the nature of the *N*-protecting group. See: (b) Romeo, S.; Rich, D. H. *Tetrahedron Lett.* **1994**, *35*, 4939–4942. Previously, Roush *et al.*[1h] and Luly *et al.*[1g] have suggested that the stereoselectivity is dependent on the nature of the *N*-protecting group.

(7) Although the *threo/erythro* ratio was determined to 3:1 in the crude product, the *erythro* isomer could only be isolated in minute amount. The decrease in yield seems to occur during column chromatography on silica gel. We therefore performed an experiment in which the crude mixture of **2m/3m** (3.1:1) (19 mg) was stirred with silica gel (60 mg) in CH_2Cl_2 (1 mL) at room temperature. The reaction was monitored by HPLC, and (*S*)-1-benzyl-*N*-(*tert*-butoxycarbonyl)-5-phenyl-(*Z*)-2-pentenylamine (3 mg) was used as an internal standard. Aliquots (5 μL) were analyzed by HPLC after dilution with CH_2Cl_2 to 50 μL. After 40 h all **3m** had decomposed whereas 76% of **2m** remained.

(8) This relative rate is based on a first-order kinetics approximation. Data were plotted from an experiment in which a 1:1 mixture of **1b** and **1c** was treated with 1.5 equiv of *m*-CPBA at room temperature, consistent with either first- (ln [**1b**, **1c**] vs *t*) or second- (1/[**1b**, **1c**] vs *t*) order kinetic conditions. A straight line was obtained only for the first-order plot which indicates first-order kinetics. However, in a recent study of *m*-CPBA epoxidations, second order kinetics were observed with substrates lacking a directing group. See: Shea, K. J.; Kim, J.-S. *J. Am. Chem. Soc.* **1992**, *114*, 3044–3051.

(9) The configurational assignments of **2a** and **3a** were made by chemical conversion of **2a** into an allylic alcohol of known structure.[1n] X-ray crystallographic analysis established the configuration of **3b**. Consequently, the configuration of isomer **2b** could be assigned. The configuration of **2c** and **3c** could then be established by chemical correlation.[1a]

Table 2. Selected ^1H and ^{13}C NMR Spectral Data Used for Assignments of Relative Stereochemistries of the Epoxides

	δ (ppm)				
compd	H-3	H-5	C-3	C-5	C-6
2a	3.17	4.12	51.64	50.46	39.60
3a	3.33	*a*	53.85	*a*	37.29
2b	3.04	4.05	55.80	50.58	39.26
3b	3.29	3.59	58.43	52.26	37.44
2c	3.08	3.94	55.46	50.05	39.39
3c	3.20	3.69	57.98	52.17	37.52
2d	2.98	4.02	57.65	50.01	39.36
3d	3.08	3.78	59.52	51.95	37.04
2e	2.90	4.04	58.71	50.63	38.89
3e	*a*	3.48	*a*	53.46	37.61
2f	2.78	4.02	59.10	50.91	37.68
3f	3.13	3.52	61.04	52.83	37.45
2g	2.83	3.90	57.56	50.08	38.96
3g	2.83	3.36	63.83	53.76	37.22
2h	2.89	4.02	56.59	49.83	38.39
3h	3.03	3.38	65.45	53.32	37.04
2i	2.83	4.13	53.26	50.62	39.57
3i	2.88	3.66	55.89	52.31	37.40
2j	2.85	4.06	57.04	50.62	39.34
3j	3.01	3.56	59.26	52.54	37.59
2k	2.39	3.90	58.35	49.83	39.30
3k	2.98	3.64	59.93	52.65	37.49
2l	2.70	4.02	58.85	49.65	39.21
3l	2.84	3.76	61.48	52.31	36.99

[a] Not determined.

2e–g were oxidized into the carboxylic acids using Jones' reagent, and subsequent treatment with diazomethane afforded the corresponding methyl esters **2a–c**. The previous assignment of the configuration of **2d** and **3d** relied on diagnostic differences in ^1H and ^{13}C NMR spectral data.[1a] The consistent chemical shift differences between *threo* and *erythro* isomers are illustrated in Table 2. An unambiguous determination of the configuration of **2h** was obtained by X-ray crystallography (Figure 1).[10] This also established the absolute configuration of **3h.** The stereochemistries of **1d, 2d, 2l,** and **3l** were established by chemical correlation; **2d** was prepared from alcohol **2h** by oxidation of the alcohol to the carboxylic acid followed by treatment with dimethyl sulfate and K_2CO_3 in acetone. The assignment of the configurations of the acetate epoxides **2j–l** and **3j–l** was secured by acetylation of the corresponding alcohols (Scheme 2).

In order to unambiguously establish the stereochemistries of the two epoxide stereoisomers lacking an additional substituent (**2m** and **3m**) we performed an X-ray crystallographic determination of the structure of the major isomer (**2m**). As expected, **2m** is the *threo* isomer (Figure 2).[10]

A Thermodynamic Study of the Epoxidation of Allylic Esters 1b and 1c. In order to obtain information about the relative energies of activation for the epoxidation of stereoisomers **1b** and **1c** with *m*-CPBA, we investigated the temperature dependence of the stereoselectivity.[11] Thus, equimolar mixtures of **1b** and **1c** were treated with *m*-CPBA at different temperatures (Figure 3), and $\Delta\Delta G^{\ddagger}$, $\Delta\Delta H^{\ddagger}$, and $\Delta\Delta S^{\ddagger}$ values were calculated.[12]

The **2c/3c** ratio increased with a decrease in the temperature, the enthalpy term being the major determinant of the *threo/erythro* ratio (Figure 3, entries 5–8; Table 3). In contrast, the **2b/3b** ratio increased with increasing temperature, and thus, the entropy term seems to determine the *threo/erythro* ratio (entries 1–4; Table 3); that is, the transition state leading to **2b** is favored in terms of entropy.

Conclusions. All substrates studied herein produce predominantly the *threo* epoxides on treatment with

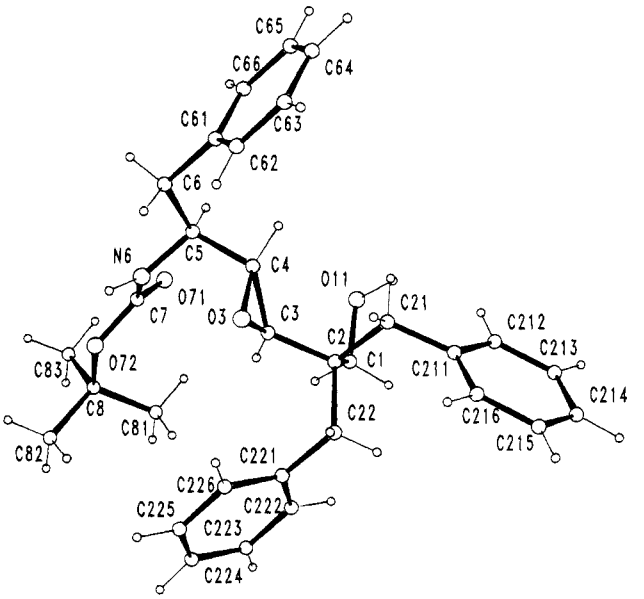


Figure 1. Perspective view of **2h** with crystallographic labeling of the atoms.

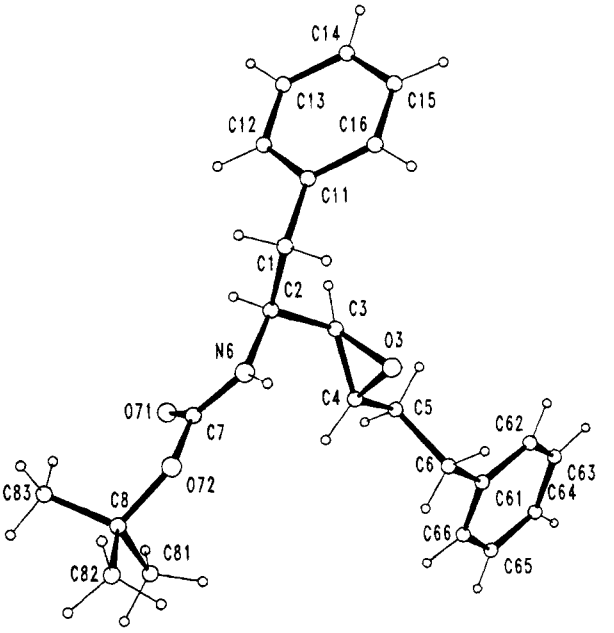


Figure 2. Perspective view of **2m** with crystallographic labeling of the atoms.

(10) The authors have deposited atomic coordinates for **2h** and **2m** with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

(11) Izumi, Y.; Tai, A. *Stereodifferentiating Reactions*; Kodansha-Academic Press: Tokyo, 1977; Chapter 7.

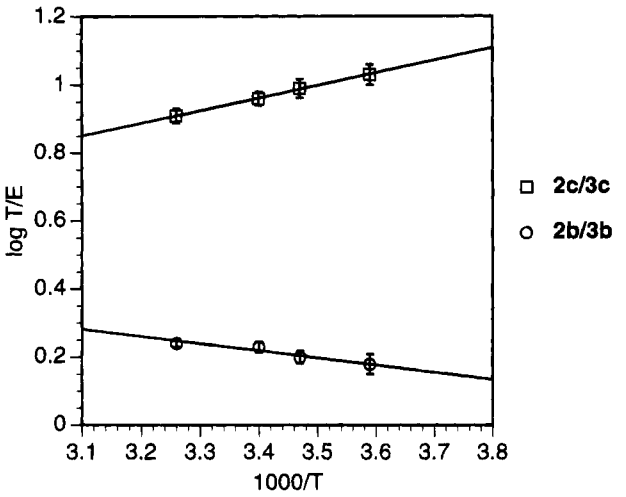


Figure 3. Influence of temperature on the *threo/erythro* ratio in the epoxidation of **1b** and **1c** with *m*-CPBA.

Table 3. Epoxidation of Equimolar Mixtures of 1b and 1c at Different Temperatures

entry	*threo/erythro*	temp (°C)	T/E ratio[a]	n[b]	$\Delta\Delta G^{\ddagger}$ (kcal/mol)	$\Delta\Delta H^{\ddagger}$ (kcal/mol)	$\Delta\Delta S^{\ddagger}$ (cal/deg·mol)
1	**2b/3b**	4.5	1.53 ± 0.11	4	−0.24	0.85	3.91
2		15	1.60 ± 0.05	6	−0.27		3.88
3		21	1.71 ± 0.06	5	−0.31		3.96
4		34	1.75 ± 0.07	2	−0.34		3.88
5	**2c/3c**	4.5	10.7 ± 0.7	4	−1.31	−1.73	−1.52
6		15	9.8 ± 0.7	6	−1.31		−1.47
7		21	9.2 ± 0.4	5	−1.30		−1.47
8		34	8.0 ± 0.5	2	−1.27		−1.49

[a] The *threo/erythro* (T/E) ratios were determined by HPLC on the crude product. The ratios are the averages ± sd. [b] Number of determinations.

m-CPBA, indicating that the allylic carbamate function is the major determinant of stereochemistry; most likely, the carbamate hydrogen forms a hydrogen bond to the incoming peracid, thus preferably directing the oxidizing agent to the β face (Figure 4) of the double bond.[1,13]

We have previously suggested that the differences in stereoselectivity of epoxidation of **1a–d** might be rationalized in qualitative terms by taking into account the relative stabilities of cooperatively coordinating conformers.[1a] However, the thermodynamic data indicate that the transition state giving **2b** is less ordered than that producing **2c**. Thus, it is likely that the low stereoselectivity of epoxidation of **1b** (2:1), and by analogy, that of **1f** and **1j** (2:1), should be related to low energy conformers of **1b** in which only one substituent coordinates the peracid (Figure 4).[15] The slightly higher stereoselectivity of epoxidation of **1m** (3:1) might then be due to the absence of a weakly coordinating allylic methyl ester, homoallylic acetate, or alcohol group which may partly counteract the directing effect of the more strongly allylic carbamate group in **1b**, **1f**, and **1j**. In the epoxidation of the homoallylic alcohol **1f**, the selectivity was somewhat lower at −20 °C (1:1.3) as compared to the same reaction at room temperature (1:1.5). This indicates that similar mechanistic factors determine the different stereoselectivities in the epoxidation of epimers **1b** and **1f** as compared to **1c** and **1g**. Most likely this mechanistic rationale may explain also the higher stereoselectivity of epoxidation of acetate **1k** as compared to **1j**.

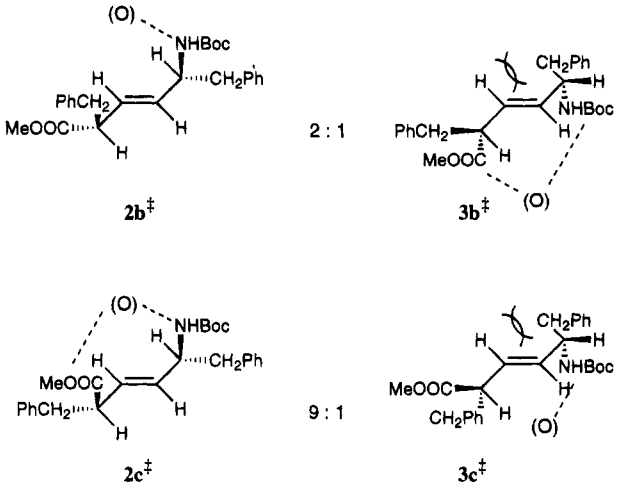


Figure 4. Proposed conformations of transition states for **1b** and **1c** in which the peracid is directed either to the β-face (left) or to the α-face (right) of the alkene. As confirmed by thermodynamic data, transition states forming **2b** and **3c** are less ordered compared to those forming **2c** and **3b**. Therefore, the transition states denoted **2b‡** and **3c‡** are formulated with a single coordination to the peracid by the carbamate function. In contrast, transition states **2c‡** and **3b‡** are thought to involve a cooperative coordination by both the carbamate and the ester functions.[14]

The stereochemical results obtained with the homoallylic alcohols **1e**, **1g**, and **1h** and acetates **1i**, **1k**, and **1l** indicate that these substituents may also direct the attack of the peracid although the coordination appears to be slightly less effective than that from an allylic methyl ester group.

Experimental Section

General.[1a] The numbering of the atoms is given in Scheme 2. The elemental analyses were carried out by MikroKemi AB, Uppsala, Sweden, or Analytische Laboratorien, Gummersbach, Germany. The epoxidations of **1a–1d** have been described elsewhere.[1a]

Transformation of the Alcohol Epoxides 2e–2h to Ester Epoxides 2a–2d. A solution of the alcohol epoxide in acetone was treated with Jones' reagent (0.67 M) at 0 °C and stirred for 30 min. Water was added, and the acetone was

(12) The difference in free energy of activation, $\Delta\Delta G^{\ddagger}$, was calculated for the four diastereomeric epoxides on the basis of observed product ratios. $\Delta\Delta G^{\ddagger}$ values for **2c/3c** and **2b/3b** were obtained from eq 1 where Q is the ratio of the diastereomeric products.

$$\Delta\Delta G^{\ddagger} = -RT \ln Q \quad (1)$$

$\Delta\Delta H^{\ddagger}$ values were obtained from a plot of log Q versus $1/T$ (Figure 3) using eq 2 where ϱ is the slope of the line.

$$-\Delta\Delta H^{\ddagger} = 2.303R\varrho \quad (2)$$

Finally, $\Delta\Delta S^{\ddagger}$ was obtained from eq 3.

$$\ln Q = \Delta\Delta S^{\ddagger}/R - \Delta\Delta H^{\ddagger}/RT \quad (3)$$

(13) Different transition states have been suggested to explain the stereoselectivity of epoxidations of allylic amides (refs 1h and 1l) and alcohols: (a) Henbest, H. B.; Wilson, R. A. L. *J. Am. Chem. Soc.* **1957**, 1958–1965. (b) Sharpless, K. B.; Verhoeven, T. R. *Aldrichim. Acta* **1979**, *12*, 63–74.

(14) Compare with Figure 3 in ref 1a.

(15) Although there is considerable literature precedent[3] for the role of cooperative coordination in epoxidations with *m*-CPBA, we have not unambiguously established its presence in the transition state. Therefore, we have not excluded the less likely possibility, suggested by one of the reviewers, that the entropic data might reflect, e.g., a difference in conformational equilibria of **1b** and **1c**.

removed before extraction with ether. The ether phase was dried over $MgSO_4$ and concentrated in vacuo. The crude product was treated with 10 equiv of diazomethane in ether at room temperature overnight. Acetic acid was added, and the mixture was concentrated. Column chromatography afforded the pure ester epoxide.

Epoxidation Reactions Using *m*-CPBA. *m*-CPBA (1.5 equiv) was added to a solution of the substrate in CH_2Cl_2. After being stirred at room temperature for 5–48 h (see Table 1) the reaction mixture was extracted with saturated aqueous Na_2SO_3, 1 M aqueous HCl, saturated aqueous $NaHCO_3$, and brine. The combined aqueous layers were extracted with CH_2Cl_2. The organic layers were dried ($MgSO_4$), filtered, and concentrated. Purification as indicated below gave the products.

Epoxidation of 1e. (3*R*,4*R*,5*S*)-5-((*tert*-Butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexanol (2e). Recrystallization ($CHCl_3$/hexane) afforded pure **2e**: HPLC (4% EtOH in hexane), 1.5 mL/min, t_R 15.7 min; mp 73–74 °C; $[\alpha]_D$ +9.5° (*c* = 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.35–7.20 (m, 5H), 4.60 (br s, 1H), 4.04 (m, 1H), 3.72 (app t, 2H), 2.98–2.81 (m, 4H), 2.34 (br s, 1H), 1.75 (m, 2H), 1.40 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 156.0, 137.3, 129.3, 128.6, 126.7, 79.8, 59.8, 58.7, 54.8, 50.6, 38.9, 34.0, 28.3; IR (KBr) 3380, 3320, 1695, 1520 cm^{-1}. Anal. Calcd for $C_{17}H_{25}NO_4$: C, 66.4; H, 8.2; N, 4.6. Found: C, 66.3; H, 8.0; N, 4.5.

Epoxidation of 1f. (2*R*,3*R*,4*R*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexanol (2f) and (2*R*,3*S*,4*S*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexanol (3f). Flash chromatography [$CHCl_3$/MeOH/hexane (4:1:10)] afforded pure **2f** and **3f**.

2f: HPLC (3% EtOH in hexane), 1.5 mL/min, t_R 8.4 min; mp 71–73 °C (CH_2Cl_2/hexane); $[\alpha]_D$ −0.6° (*c* = 0.9, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.33–7.14 (m, 10H), 4.69 (app br d, 1H), 4.06–3.99 (m, 1H), 3.56–3.35 (m, 2H), 3.02 (br s, 1H), 2.99–2.97 (m, 1H), 2.86 (app d, 2H), 2.82–2.75 (m, 2H), 2.60 (dd, 1H, *J* = 8.8, −13.7 Hz), 1.77–1.72 (m, 1H), 1.37 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 156.0, 138.9, 137.1, 129.2, 129.1, 128.5, 128.3, 126.6, 126.1, 79.9, 62.4, 59.1, 58.9, 50.9, 44.7, 37.7, 34.9, 28.2; IR (KBr) 3374, 1696, 1518, 1169 cm^{-1}. Anal. Calcd for $C_{24}H_{31}NO_4 \cdot 0.25H_2O$: C, 71.7; H, 7.9; N, 3.5. Found: C, 71.6; H, 7.8; N, 3.2.

3f: HPLC (3% EtOH in hexane), 1.5 mL/min, t_R 15.7 min; mp 120–122 °C (CH_2Cl_2/hexane); $[\alpha]_D$ −53.8° (*c* = 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.34–7.14 (m, 10H), 4.43–4.37 (s, 1H), 3.76–3.58 (m, 2H), 3.55–3.48 (m, 1H), 3.15–3.11 (m, 1H), 2.97–2.88 (m, 1H), 2.79–2.71 (m, 1H), 2.68–2.57 (m, 1H), 2.63 (m, 2H), 2.52 (br s, 1H), 1.88–1.81 (m, 1H), 1.39 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 155.6, 139.4, 136.6, 129.3, 129.0, 128.6, 128.4, 126.7, 126.2, 79.9, 63.1, 61.0, 57.8, 52.8, 44.5, 37.4, 32.9, 28.2; IR (KBr) 3372, 1682, 1526, 1173 cm^{-1}. Anal. Calcd for $C_{24}H_{31}NO_4 \cdot 0.25H_2O$: C, 71.7; H, 7.9; N, 3.5. Found: C, 72.0; H, 7.6; N, 3.3.

Epoxidation of 1g. (2*S*,3*R*,4*R*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexanol (2g) and (2*S*,3*S*,4*S*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexanol (3g). Flash chromatography [$CHCl_3$/MeOH/hexane (4:1:10)] afforded pure **2g** and **3g**.

2g: HPLC (3% EtOH in hexane), 1.5 mL/min, t_R 15.0 min; $[\alpha]_D$ +46.8° (*c* = 1.3, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.29–7.11 (m, 10H), 4.54 (br d, 1H), 3.93–3.88 (m, 1H), 3.73–3.61 (m, 2H), 2.83 (app br d, 1H, *J* = 6.9 Hz), 2.75–2.64 (m, 3H), 2.60–2.52 (m, 2H), 2.36 (br s, 1H), 1.69–1.61 (m, 1H), 1.38 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 155.3, 139.2, 137.1, 129.2, 128.9, 128.4, 126.4, 126.2, 79.5, 63.5, 58.1, 57.6, 50.1, 44.9, 39.0, 34.2, 28.2; IR (neat) 3427, 1694, 1496, 1169 cm^{-1}. Anal. Calcd for $C_{24}H_{31}NO_4 \cdot 0.25H_2O$: C, 71.7; H, 7.9; N, 3.5. Found: C, 71.7; H, 7.7; N, 3.2.

3g: HPLC (3% EtOH in hexane), 1.5 mL/min, t_R 8.4 min; $[\alpha]_D$ −36.2° (*c* = 1.2, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.39–7.14 (m, 10H), 4.61 (app br d, 1H), 3.56–3.51 (m, 2H), 3.16 (br s, 1H), 3.14–3.10 (m, 1H), 3.08–3.06 (m, 1H), 2.96 (dd, 1H, *J* = 4.7, −13.6 Hz), 2.89–2.77 (m, 2H), 2.71 (dd, 1H, *J* = 9.4, −13.6 Hz), 1.67–1.59 (m, 1H), 1.38 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 156.6, 139.2, 136.3, 129.3, 129.2, 128.9, 128.4, 127.0, 126.1, 80.5, 63.8, 62.7, 59.4, 53.8, 46.1, 37.2, 35.3, 28.2.

Epoxidation of 1h. (3*R*,4*R*,5*S*)-2,2-Dibenzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexanol (2h) and (3*S*,4*S*,5*S*)-2,2-Dibenzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexanol (3h). Flash chromatography [pentane/ether (2:1)] afforded pure **2h** and **3h**.

2h: HPLC (1% EtOH in hexane), 1.5 mL/min, t_R 8.5 min; mp 133–135 °C (CH_2Cl_2/hexane); $[\alpha]_D$ +34.7° (*c* = 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.29–7.04 (m, 15H), 4.44 (br s, 1H), 4.06–3.98 (m, 1H), 3.36–3.33 (m, 2H), 3.02 (d, 1H, *J* = −13.1 Hz), 2.90–2.88 (m, 1H), 2.82–2.76 (m, 3H), 2.71–2.65 (br s, 1H), 2.68 (d, 1H, *J* = −13.5 Hz), 2.60 (d, 1H, *J* = −13.1 Hz), 2.37 (d, 1H, *J* = −13.5 Hz), 1.27 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 155.7, 137.0, 136.9, 136.7, 131.0, 130.4, 129.1, 128.5, 128.1, 128.0, 126.6, 126.3, 79.7, 63.6, 61.3, 56.6, 49.8, 41.7, 39.5, 38.4, 38.3, 28.1; IR (KBr) 3422, 1708, 1495, 1158 cm^{-1}. Anal. Calcd for $C_{31}H_{37}NO_4$: C, 76.4; H, 7.6; N, 2.9. Found: C, 76.2; H, 7.4; N, 2.7.

3h: HPLC (1% EtOH in hexane), 1.5 mL/min, t_R 9.0 min; $[\alpha]_D$ −76.3° (*c* = 1.5, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.37–7.07 (m, 15H), 4.57–4.53 (s, 1H), 3.54–3.38 (m, 2H), 3.42–3.33 (m, 1H), 3.08–2.94 (m, 4H), 2.85 (app br dd, 1H), 2.75 (d, 1H, *J* = −13.5 Hz), 2.41 (d, 1H, *J* = −12.4 Hz), 2.33 (d, 1H, *J* = −13.5 Hz), 1.36 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 156.5, 137.2, 136.9, 136.4, 131.2, 130.7, 129.3, 128.8, 128.0, 127.0, 126.29, 126.26, 80.5, 65.4, 63.8, 57.4, 53.3, 42.3, 39.9, 37.0, 36.0, 28.3; IR (neat) 3432, 1694, 1495, 1168 cm^{-1}. Anal. Calcd for $C_{31}H_{37}NO_4$: C, 76.4; H, 7.6; N, 2.9. Found: C, 76.6; H, 7.6; N, 2.8.

Preparation of the Acetates 1i–1l. To a solution of **1e–1h** and triethylamine in CH_2Cl_2 were added acetic anhydride and a catalytic amount of 4-(dimethylamino)pyridine (DMAP) at room temperature. The reaction was stirred overnight. The organic phase was extracted with 1 M aqueous HCl and saturated aqueous $NaHCO_3$, dried ($MgSO_4$), and concentrated in vacuo. The crude product was purified by column chromatography as indicated below.

(*S*)-5-((*tert*-Butoxycarbonyl)amino)-6-phenyl-(*E*)-3-hexenyl Acetate (1i). Flash chromatography [pentane/ether (3:1)] afforded pure **1i**: HPLC (1% EtOH in hexane), 1.5 mL/min, t_R 9.9 min; $[\alpha]_D$ +5.9° (*c* = 1.6, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.39–7.22 (m, 5H), 5.56–5.49 (m, 2H), 4.49 (br, 1H), 4.45 (m, 1H), 4.11 (app t, 2H), 2.89 (m, 2H), 2.39 (m, 2H), 2.09 (s, 3H), 1.49 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.8, 155.1, 137.5, 132.7, 129.5, 128.2, 126.4, 79.3, 63.6, 53.7, 42.3, 31.5, 28.4, 20.8; IR (neat) 3350, 2964, 1740, 1708, 1510 cm^{-1}. Anal. Calcd for $C_{19}H_{27}NO_4$: C, 68.44; H, 8.16; N, 4.20. Found: C, 68.31; H, 8.18; N, 4.07.

(2*R*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-6-phenyl-(*E*)-3-hexenyl Acetate (1j). Flash chromatography [pentane/ether (7:3)] afforded pure **1i**: HPLC (14% EtOAc in hexane), 1.5 mL/min, t_R 13.1 min; mp 68–69 °C (CH_2Cl_2/hexane); $[\alpha]_D$ −28.2° (*c* = 0.9, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.20–6.98 (m, 10H), 5.34–5.17 (m, 2H), 4.34–4.18 (m, 2H), 3.86 (d, 2H), 2.75–2.44 (m, 5H), 1.92 (s, 3H), 1.34 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.8, 154.9, 139.1, 137.4, 131.8, 130.5, 129.4, 129.2, 128.2, 126.3, 126.1, 79.2, 66.4, 53.0, 43.0, 41.8, 37.9, 28.3, 20.8; IR (KBr) 3396, 1737, 1689, 1508, 1238, 1170 cm^{-1}. Anal. Calcd for $C_{26}H_{33}NO_4$: C, 73.7; H, 7.8; N, 3.3. Found: C, 74.0; H, 7.8; N, 3.2.

(2*S*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-6-phenyl-(*E*)-3-hexenyl Acetate (1k). Flash chromatography [pentane/ether (3:1)] afforded pure **1i**: HPLC (14% EtOAc in hexane), 1.5 mL/min, t_R 14.0 min; $[\alpha]_D$ +10.6° (*c* = 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.21–6.96 (m, 10H), 5.36–5.20 (m, 2H), 4.37–4.19 (m, 2H), 3.87 (app d, 2H), 2.67–2.47 (m, 5H), 1.93 (s, 3H), 1.33 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.8, 154.9, 139.0, 137.2, 132.0, 130.6, 129.5, 129.2, 128.21, 128.16, 126.3, 126.1, 79.2, 66.4, 52.8, 43.0, 41.6, 37.9, 28.3, 20.8; IR (neat) 3359, 1738, 1713, 1495, 1244, 1169 cm^{-1}. Anal. Calcd for $C_{26}H_{33}NO_4$: C, 73.7; H, 7.8; N, 3.3. Found: C, 73.6; H, 7.8; N, 3.2.

(*S*)-2,2-Dibenzyl-5-((*tert*-butoxycarbonyl)amino)-6-phenyl-(*E*)-3-hexenyl Acetate (1l). Flash chromatography [pentane/ether (7:3)] afforded pure **1i**: HPLC (10% EtOAc in hexane), 1.5 mL/min, t_R 17.0 min; mp 79–82 °C (CH_2Cl_2/hexane); $[\alpha]_D$ −26.2° (*c* = 1.1, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.17–6.88 (m, 15H), 5.43 (d, 1H, *J* = 16.2 Hz), 4.77 (dd, 1H, *J* = 5.1, 16.2 Hz), 4.37–4.28 (m, 2H), 3.66 (app s, 2H), 2.85–2.61 (m,

6H), 2.06 (s, 3H), 1.35 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.6, 154.9, 137.3, 136.9, 134.4, 130.6, 129.4, 129.2, 128.2, 127.85, 127.76, 126.34, 126.29, 79.2, 65.7, 53.4, 43.5, 43.3, 43.1, 41.6, 28.3, 21.0; IR (KBr) 3527, 3377, 1728, 1690, 1509, 1238, 1168 cm^{-1}. Anal. Calcd for $C_{33}H_{39}NO_4 \cdot 0.25H_2O$: C, 76.5; H, 7.7; N, 2.7. Found: C, 76.4; H, 7.6; N, 2.6.

Epoxidation of 1i. (3*R*,4*R*,5*S*)-5-((*tert*-Butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (2i) and (3*S*,4*S*,5*S*)-5-((*tert*-Butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (3i). Flash chromatography [pentane/ether (3:1)] afforded pure **2i** and **3i**.

2i: HPLC (1% EtOH in hexane), 1.5 mL/min, t_R 18.0 min; $[\alpha]_D$ +21.8° (c = 1.9, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.34–7.20 (m, 5H), 4.57 (br, 1H), 4.15–4.11 (m, 3H), 2.97 (dd, 1H), 2.87–2.79 (m, 3H), 2.02 (s, 3H), 1.89 (m, 1H), 1.71 (m, 1H), 1.40 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.8, 155.3, 137.2, 129.3, 128.5, 126.6, 79.5, 61.1, 58.5, 53.3, 50.6, 39.6, 30.8, 28.2, 20.8; IR (KBr) 2977, 1740, 1717, 1506 cm^{-1}. Anal. Calcd for $C_{19}H_{27}NO_5$: C, 65.31; H, 7.79; N, 4.00. Found: C, 65.29; H, 7.75; N, 4.00.

3i: HPLC (1% EtOH in hexane), 1.5 mL/min, t_R 20.5 min; ^{1}H NMR ($CDCl_3$) δ 7.35–7.20 (m, 5H), 4.42 (br, 1H), 4.17 (app dt, 2H), 3.66 (m, 1H), 3.10–2.67 (m, 4H), 2.05 (s, 3H), 1.83 (m, 2H), 1.39 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.8, 155.1, 136.5, 129.4, 128.5, 126.6, 79.6, 61.2, 59.1, 55.9, 52.3, 37.4, 31.1, 28.2, 20.8.

Epoxidation of 1j. (2*R*,3*R*,4*R*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (2j) and (2*R*,3*S*,4*S*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (3j). Flash chromatography [pentane/ether (7:3)] afforded pure **2j** and **3j**.

2j: HPLC (14% EtOAc in hexane), 1.5 mL/min, t_R 19.2 min; mp 94–95 °C (CH_2Cl_2/hexane); $[\alpha]_D$ +28.4° (c = 0.9, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.33–7.12 (m, 10H), 4.53 (br d, 1H), 4.10–4.01 (m, 1H), 3.96–3.84 (m, 2H), 2.93-2.77 (m, 5H), 2.63 (dd, 1H, J = 8.9 Hz), 1.93 (s, 3H), 1.94–1.83 (m, 1H), 1.38 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.7, 155.3, 138.3, 137.3, 129.3, 129.0, 128.6, 128.5, 126.6, 126.4, 79.6, 63.6, 58.4, 57.0, 50.6, 41.8, 39.3, 34.9, 28.3, 20.6; IR (KBr) 3350, 1734, 1680, 1526, 1234, 1167 cm^{-1}. Anal. Calcd for $C_{26}H_{33}NO_5$: C, 71.0; H, 7.6; N, 3.2. Found: C, 71.2; H, 7.4; N, 2.8.

3j: HPLC (14% EtOAc in hexane), 1.5 mL/min, t_R 24.2 min; $[\alpha]_D$ −39.4° (c = 1.4, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.34–7.08 (m, 10H), 4.25–4.20 (br s, 1H), 4.16–4.06 (m, 2H), 3.61–3.50 (m, 1H), 3.01 (app br d, 1H, J = 7.2 Hz), 2.87 (dd, 1H, J = 4.2, −14.1 Hz), 2.78–2.71 (m, 1H), 2.74 (dd, 1H, J = 7.6, −13.8 Hz), 2.65 (dd, 1H, J = 7.6, −13.8 Hz), 2.48 (dd, 1H, J = 1.8, 7.0 Hz), 2.08 (s, 3H), 1.84–1.75 (m, 1H), 1.39 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.9, 155.0, 138.6, 136.7, 129.4, 128.9, 128.5, 126.6, 126.5, 79.6, 64.5, 59.2, 59.0, 52.5, 42.8, 37.6, 34.5, 28.3, 20.9; IR (neat) 3362, 1742, 1714, 1496, 1244, 1169 cm^{-1}. Anal. Calcd for $C_{26}H_{33}NO_5$: C, 71.04; H, 7.57; N, 3.19. Found: C, 71.32; H, 7.63; N, 3.25.

Epoxidation of 1k. (2*S*,3*R*,4*R*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (2k) and (2*S*,3*S*,4*S*,5*S*)-2-Benzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (3k). Flash chromatography [pentane/ether (7:3)] afforded pure **2k** and **3k**.

2k: HPLC (14% EtOAc in hexane), 1.5 mL/min, t_R 19.5 min; $[\alpha]_D$ +46.9° (c = 1.3, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.30–7.09 (m, 10H), 4.40 (br d, 1H), 4.17–4.06 (m, 2H), 3.96–3.84 (m, 1H), 2.80–2.64 (m, 4H), 2.58 (dd, 1H, J = 8.9, −13.5 Hz), 2.41–2.37 (m, 1H), 2.07 (s, 3H), 1.81–1.69 (m, 1H), 1.40 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.9, 155.3, 138.5, 137.1, 129.2, 128.9, 128.5, 128.4, 126.5, 79.4, 64.8, 58.4, 56.1, 49.8, 42.7, 39.3, 34.8, 28.2, 20.9; IR (neat) 3356, 1739, 1714, 1496, 1243, 1169 cm^{-1}. Anal. Calcd for $C_{26}H_{33}NO_5$: C, 71.0; H, 7.6; N, 3.2. Found: C, 71.0; H, 7.6; N, 3.2.

3k: HPLC (14% EtOAc in hexane), 1.5 mL/min, t_R 22.4 min; mp 120–121 °C (CH_2Cl_2/hexane); $[\alpha]_D$ −35.6° (c = 0.8, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.35–7.11 (m, 10H), 4.42 (br d, 1H), 3.98 (dd, 1H, J = 5.1, −11.2 Hz), 3.91 (dd, 1H, J = 7.2, −11.2 Hz), 3.69–3.59 (m, 1H), 3.01–2.96 (m, 1H), 2.97 (dd, 1H, J = 9.5, −13.9 Hz), 2.95 (dd, 1H, J = 9.5, −13.9 Hz), 2.82 (dd, 1H, J = 7.8, −13.9 Hz), 2.77 (dd, 1H, J = 2.0, 7.1 Hz), 2.69 (dd, 1H, J = 8.8, −13.9 Hz), 1.99 (s, 3H), 1.91–1.78 (m, 1H), 1.36 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.7, 155.1, 138.4, 136.6, 129.4, 129.1, 128.6, 128.5, 126.7, 126.4, 79.7, 63.8, 59.9, 59.2, 52.6, 42.4, 37.5, 35.1, 28.2, 20.8; IR (KBr) 3370, 1740, 1684, 1521, 1249, 1172 cm^{-1}. Anal. Calcd for $C_{26}H_{33}NO_5 \cdot 0.25H_2O$: C, 70.3; H, 7.6; N, 3.2. Found: C, 70.4; H, 7.3; N, 3.0.

Epoxidation of 1l. (3*R*,4*R*,5*S*)-2,2-Dibenzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (2l) and (3*S*,4*S*,5*S*)-2,2-Dibenzyl-5-((*tert*-butoxycarbonyl)amino)-3,4-epoxy-6-phenylhexyl Acetate (3l). Flash chromatography [pentane/ether (3:1)] afforded pure **2l** and **3l**.

2l: HPLC (10% EtOAc in hexane), 1.5 mL/min, t_R 17.3 min; $[\alpha]_D$ +9.2° (c = 0.9, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.32–7.04 (m, 15H), 4.35 (br d, 1H), 4.07–3.96 (m, 1H), 3.82–3.68 (AB q, 2H), 2.83–2.57 (m, 8H), 2.05 (s, 3H), 1.29 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.6, 155.2, 137.2, 136.3, 130.7, 130.4, 129.2, 128.4, 128.2, 126.6, 126.5, 79.3, 64.9, 58.8, 55.9, 49.6, 40.6, 40.0, 39.2, 39.0, 28.1, 20.9; IR (neat) 3413, 1742, 1713, 1495, 1237, 1168 cm^{-1}. Anal. Calcd for $C_{33}H_{39}NO_5$: C, 74.8; H, 7.4; N, 2.6. Found: C, 74.8; H, 7.3; N, 2.5.

3l: HPLC (10% EtOAc in hexane), 1.5 mL/min, t_R 28.8 min; $[\alpha]_D$ −30.1° (c = 0.8, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.24–6.87 (m, 15H), 4.29–4.22 (br d, 1H), 3.96–3.56 (m, 3H), 2.85–2.83 (m, 1H), 2.75 (dd, 1H, J = 2.3, 6.1 Hz), 2.71–2.55 (m, 5H), 2.47 (d, 1H, J = −13.7 Hz), 1.96 (s, 3H), 1.26 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 170.6, 155.0, 136.9, 136.4, 136.3, 130.8, 130.4, 129.4, 128.4, 128.2, 126.65, 126.63, 126.58, 79.6, 65.1, 61.5, 56.5, 52.3, 40.7, 39.3, 37.0, 28.3, 20.9; IR (neat) 3362, 1739, 1714, 1496, 1238, 1169 cm^{-1}. Anal. Calcd for $C_{33}H_{39}NO_5$: C, 74.83; H, 7.42; N, 2.64. Found: C, 74.77; H, 7.56; N, 2.72.

Julia Olefination. (*S*)-1-Benzyl-*N*-(*tert*-butoxycarbonyl)-5-phenyl-(*E*)-2-pentenylamine (1m) and (*S*)-1-Benzyl-*N*-(*tert*-butoxycarbonyl)-5-phenyl-(*Z*)-2-pentenylamine. A suspension of sulfone **4**[1a] (1.0 g, 2.7 mmol) in THF (50 mL) was refluxed until a clear solution was obtained. The solution was cooled to −78 °C, and *n*-butyllithium (1.6 M in hexane) (3.7 mL) was added dropwise. The solution was stirred for 30 min at −78 °C. In a separate flask, a solution of 3-phenylpropanal (0.7 g, 5.3 mmol) in THF (3 mL) was treated with DIBAL methoxide [prepared by the addition of MeOH (0.3 mL, 6.4 mmol) and THF (3 mL) to DIBAL (20% in toluene) (4.5 mL, 6.4 mmol) at −78 °C]. The solution of the aluminum complex was transferred via cannula to the solution of the sulfone dianion, and the mixture was stirred for 30 min at −78 °C. The reaction was quenched at −78 °C with saturated aqueous NH_4Cl and was extracted with CH_2Cl_2. The organic layer was dried ($MgSO_4$) and concentrated. MeOH (50 mL) was added, and undissolved sulfone was filtered off. The MeOH solution was cooled to 0 °C and treated with Na_2HPO_4 (2.1 g, 5.6 mmol) and 6% Na(Hg) (21 g). The mixture was stirred overnight at 0 °C, diluted with water, and extracted with CH_2Cl_2. The organic phase was dried ($MgSO_4$) and concentrated. Flash chromatography [pentane/ether (9:1)] and recrystallization (1% EtOH in hexane) afforded 0.61 g of **1m** (64%).

1m: HPLC (5% EtOAc in hexane), 1.5 mL/min, t_R 12.7 min; mp 66 °C; $[\alpha]_D$ −6.9° (c = 0.77, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.42–7.23 (m, 10H), 5.64 (dt, 1H), 5.52 (dd, 1H), 4.51 (br s, 1H), 4.46 (m, 1H), 2.91 (dd, 2H), 2.73 (app t, 2H), 2.42 (dt, 2H), 1.47 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 155.1, 141.6, 137.6, 130.42, 130.37, 129.6, 128.4, 128.23, 128.18, 126.3, 125.8, 79.2, 53.1, 41.9, 35.6, 34.0, 28.3; IR (KBr) 3360, 1680, 1525 cm^{-1}. Anal. Calcd for $C_{23}H_{29}NO_2$: C, 78.6; H, 8.3; N, 4.0. Found: C, 78.5; H, 8.2; N, 4.0.

***(Z)*-Isomer.** Preparative HPLC (2% EtOAc in hexane) afforded pure compound: HPLC (5% EtOAc in hexane), 1.5 mL/min, t_R 12.4 min; mp 88–89 °C; $[\alpha]_D$ +2.1° (c = 1.0, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 7.31–7.09 (m, 10H), 5.44 (dt, 1H), 5.21 (dd, 1H), 4.56 (br, 1H), 4.41 (m, 1H), 2.83 (dd, 1H), 2.62 (dd, 1H), 2.55–2.16 (m, 4H), 1.42 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 155.0, 141.6, 137.7, 131.4, 129.7, 128.4, 128.2, 126.3, 125.8, 79.3, 49.4, 41.9, 35.4, 29.4, 28.4; IR (KBr) 3384, 1686, 1516 cm^{-1}. Anal. Calcd for $C_{23}H_{29}NO_2$: C, 78.6; H, 8.3; N, 4.0. Found: C, 78.3; H, 8.3; N, 4.0.

Epoxidation of 1m. (1*S*,2*R*,3*R*)-1-Benzyl-*N*-(*tert*-butoxycarbonyl)-2,3-epoxy-5-phenyl-2-pentylamine (2m) and (1*S*,2*S*,3*S*)-1-Benzyl-*N*-(*tert*-butoxycarbonyl)-2,3-epoxy-

5-phenylpentylamine (3m). Recrystallization (1% EtOH in hexane) afforded pure **2m**: HPLC (10% EtOAc in hexane) 1.5 mL/min, t_R 9.0 min; mp 71–72 °C; $[\alpha]_D$ +45.6° (c = 0.29, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.34–7.14 (m, 10H), 4.50 (br, 1H), 4.02 (m, 1H), 2.96–2.59 (m, 6H), 1.80 (dt, 2H), 1.39 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 155.3, 141.0, 137.3, 129.4, 128.5, 128.4, 128.3, 126.6, 126.0, 79.5, 59.0, 55.6, 50.6, 39.7, 33.2, 32.1, 28.3; IR (KBr) 3394, 2983, 1693, 1516 cm^{-1}. Anal. Calcd for $C_{23}H_{29}NO_3$: C, 75.2; H, 8.0; N, 3.8. Found: C, 75.1; H, 8.1; N, 3.5.

3m. Preparative HPLC (3% EtOAc in hexane) afforded **3m**: HPLC (10% EtOAc in hexane), 1.5 mL/min, t_R 13.5 min; ^1H NMR ($CDCl_3$) δ 7.28–7.06 (m, 10H), 4.30 (br, 1H), 3.58 (m, 1H), 2.95–2.55 (m, 6H), 1.75 (dt, 2H), 1.31 (s, 9H).

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Supplementary Material Available: ^1H and ^{13}C NMR spectral assignments for all new compounds. Crystal data and selected experimental details from the determination of the crystal structure of **2h** and **2m** (13 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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