JOC Article

8-Endo versus 7-Exo Cyclization of α-Carbamoyl Radicals. A Combination of Experimental and Theoretical Studies

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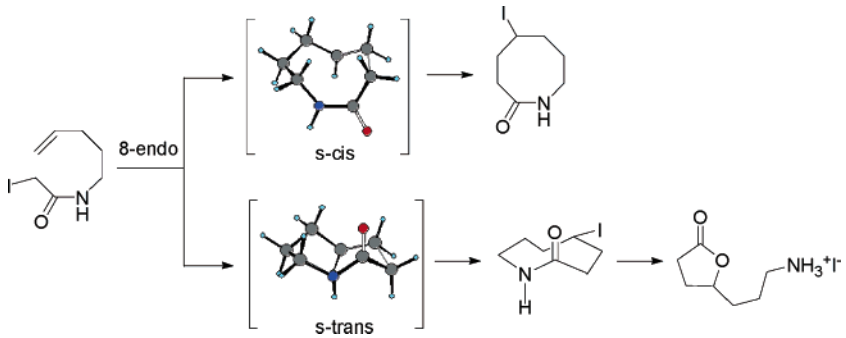
Received October 22, 2004



Atom transfer radical cyclization reactions of *N*-(4-pentenyl)iodoacetamides were investigated. The reactions were efficiently promoted by BF_3·OEt_2. For *N*-alkenyl-substituted iodoamides, excellent regioselectivity in favor of 8-endo cyclization was observed, while both 7-exo and 8-endo cyclization products were formed with the 8-endo cyclization preferred in the cases of *N*-(2-allylphenyl)-substituted iodoamides. Density functional theory calculations at the B3LYP/6-31G* level revealed that both the s-trans and the s-cis conformational transition structures were feasible for the 8-endo cyclization of *N*-alkenyl-substituted α-carbamoyl radicals while 7-exo transition structures were much less stable. For the cyclization of *N*-(2-allylphenyl)-substituted α-carbamoyl radicals, the transition structures for 8-endo and 7-exo cyclizations were of comparable energy. These results were in excellent agreement with the experimental observations.

Introduction

The past 2 decades have witnessed a rapid progress in radical chemistry toward organic synthesis.[1] Radical cyclizations, in particular, have received enormous attention.[1,2] Among them, cyclization of α-carbamoyl radicals has been demonstrated to be a viable means for the construction of lactam skeletons and thus of great potential in organic synthesis.[1,3] However, most of the studies were concentrated on the cyclization in a 5-exo mode, while little is known of the 8-endo or 7-exo cyclization. The only examples were the Bu_3SnH/AIBN-initiated cyclization reactions of haloamides **1** reported by Ikeda and co-workers, which showed that the ratios of 7-exo and 8-endo products **2** and **3** depended strongly on the types of radical precursors (Scheme 1).[4] For example, the dichloroamide **1** (X = Y = Cl) generated exclusive 7-exo cyclization product **2**, while the bisthiophenylamide **1** (X = Y = PhS) furnished the corresponding 8-endo cyclization product **3**.

Owing to the significance of seven- and eight-membered lactams in organic synthesis,[5] we looked into these reactions in detail. We report here that the atom transfer

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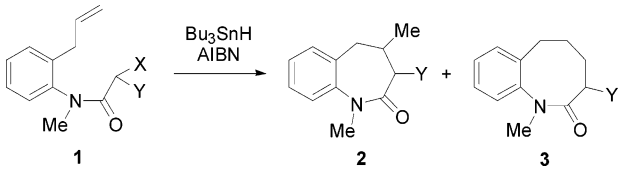
(1) For review articles, see: (a) Giese, B. *Radicals in Organic Synthesis: Formation of Carbon−Carbon Bonds*; Pergamon: Oxford, UK, 1986. (b) Curran, D. P. *Synthesis* **1988**, 417 and 489. (c) Jasperse, C. P.; Curran, D. P.; Fevig, T. L. *Chem. Rev.* **1991**, *91*, 1237. (d) Melikyan, G. G. *Synthesis* **1993**, 833. (e) Iqbal, J.; Bhatia, B.; Nayyar, N. K. *Chem. Rev.* **1994**, *94*, 519. (f) Snider, B. B. *Chem. Rev.* **1996**, *96*, 339. (g) Curran, D. P.; Porter, N. A.; Giese, B. *Stereochemistry of Radical Reactions*; VCH: Weinheim, Germany, 1996. (h) Gansauer, A.; Bluhm, H. *Chem. Rev.* **2000**, *100*, 2771. (i) *Radicals in Organic Synthesis*; Renaud, P., Sibi, M. P., Eds.; Wiley-VCH: Weinheim, Germany, 2001. (j) Sibi, M. P.; Manyem, S.; Zimmerman, J. *Chem. Rev.* **2003**, *103*, 3263.

(2) (a) Giese, B.; Kopping, B.; Gobel, T.; Dickhaut, J.; Thoma, G.; Kulicke, K. J.; Trach, F. In *Organic Reactions*; Wiley: New York, 1996; Vol. 48, p 301. (b) Bowman, W. R.; Fletcher, A. J.; Potts, G. B. S. *J. Chem. Soc., Perkin Trans. 1* **2002**, 2747.

10.1021/jo0481349 CCC: $30.25
Published on Web 01/26/2005

SCHEME 1

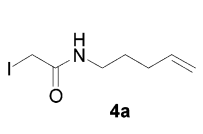
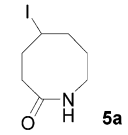
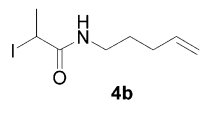
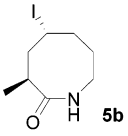
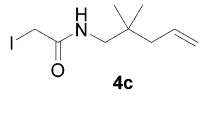
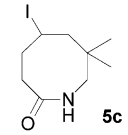
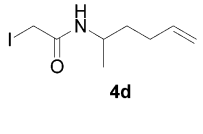
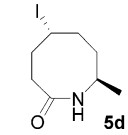
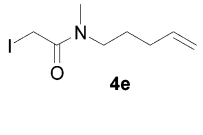
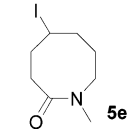


radical cyclization reactions of *N*-(4-pentenyl)iodoacetamides (**4** and **6**) could be efficiently promoted by BF_3·OEt_2. Furthermore, density functional calculations at the B3LYP/6-31G* level were employed to locate the possible transition structures for the cyclizations, which in turn provided a detailed understanding of the mechanism of the α-carbamoyl radical cyclization.

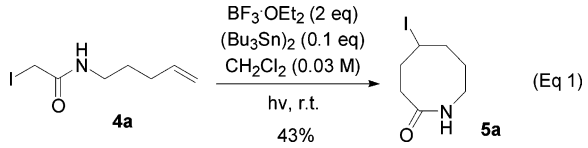
Results

Halogen atom transfer methods with $(Bu_3Sn)_2$ or BEt_3 as the initiator developed by Curran et al. have been well demonstrated to be a unique and effective method for the cyclizations of α-carbonyl radicals.[6] Thus, we prepared *N*-(4-pentenyl)iodoacetamide (**4a**) as the model substrate for the investigation of 7-exo or 8-endo cyclization of α-carbamoyl radicals. For the ease of comparison, the substrate concentration was set at 0.03 M. Direct photostimulation of **4a** with $(Bu_3Sn)_2$ (10 mol %) in benzene or CH_2Cl_2 at room temperature did not give any expected cyclization product while the starting material remained unchanged. When the reaction was carried out at refluxing temperature of benzene (80 °C), the reaction proceeded very slowly, and the initiator $(Bu_3Sn)_2$ was consumed within a few hours. Photostimulation of **4a** with 50 mol % of $(Bu_3Sn)_2$ at 80 °C for 1 day gave the cyclized product **5a** in only 26% yield along with a significant amount of unidentified decomposition products. To accelerate the cyclization, we turned to Lewis acids for help as they have recently been widely used in promoting radical reactions.[7] Among the Lewis acids screened, BF_3·OEt_2 gave the best results. With the addition of 2 equiv of BF_3·OEt_2 at room temperature, the solution became cloudy immediately and within 30 min the mixture turned to clear again while some precipitate was formed at the bottom of the flask. ^{1}H NMR montoring indicated that the starting material **4a** was all consumed. After filtration, the filtrate was checked by ^{1}H NMR, which showed that only the 8-endo cyclization product **5a** was formed while no corresponding 7-exo cyclization product could be detected. After removal of the tin-containing residue, **5a** was achieved in 43% isolated yield (eq 1).

TABLE 1. 8-Endo Cyclization of Iodoamides 4a−e

substrate	product	yield(%)[a]
 **4a**	 **5a**	43
 **4b**	 **5b**	51
 **4c**	 **5c**	59
 **4d**	 **5d**	34
 **4e**	 **5e**	49

[a] Isolated yield based on **4**.



(Eq 1)

Other Lewis acids such as $Mg(OTf)_2$, $Zn(OTf)_2$ or $Yb(OTf)_3$ did not show a significant effect on the reaction. This is probably because of their poor solubility in solvents such as CH_2Cl_2 or benzene.[8]

Thus, a number of unsaturated iodoamides **4a−e** were photostimulated in the presence of BF_3·OEt_2 (2 equiv) and $(Bu_3Sn)_2$ (0.1 equiv) in CH_2Cl_2 at room temperature and the results are summarized in Table 1. In all the cases, only the 8-endo cyclization products **5a−e** were obtained, indicating a high regioselectivity in these cyclization reactions.

We also prepared phenyl-containing iodoamides **6a−c** and subjected them to the above reaction conditions as shown in eq 1. The results are presented in Table 2. In contrast to the reactions of **4a−e**, both 7-exo cyclization products **7a−c** and 8-endo cyclization products **8a−c**

(3) For recent selected examples, see: (a) Attenni, B.; Cerreti, A.; D'Annibale, A.; Resta, S.; Trogolo, C. *Tetrahedron* **1998**, *54*, 12029. (b) Davies, D. T.; Kapur, N.; Parsons, A. F. *Tetrahedron Lett.* **1999**, *40*, 8615. (c) Clark, A. J.; Duncalf, D. J.; Filik, R. P.; Haddleton, D. M.; Thomas, G. H.; Wongtap, H. *Tetrahedron Lett.* **1999**, *40*, 3807. (d) Clark, A. J.; Filik, R. P.; Haddleton, D. M.; Radigue, A.; Sanders, C. J.; Thomas, G. H.; Smith, M. E. *J. Org. Chem.* **1999**, *64*, 8954. (e) Davies, D. T.; Kapur, N.; Parsons, A. F. *Tetrahedron* **2000**, *56*, 3941. (f) Cerreti, A.; D'Annibale, A.; Trogolo, C.; Umani, F. *Tetrahedron Lett.* **2000**, *41*, 3261. (g) Bryans, J. S.; Chessum, N. E. A.; Parsons, A. F.; Ghelfi, F. *Tetrahedron Lett.* **2001**, *42*, 2901. (h) Clark, A. J.; Battle, G. M.; Bridge, A. *Tetrahedron Lett.* **2001**, *42*, 4409.

(4) Sato, T.; Ishida, S.; Ishibashi, H.; Ikeda, M. *J. Chem. Soc., Perkin Trans. 1* **1991**, 353.

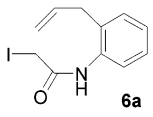
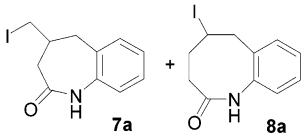
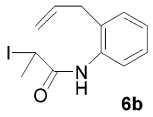
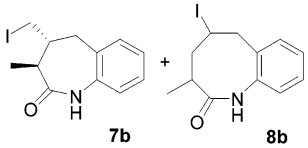
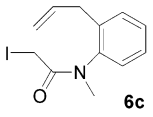
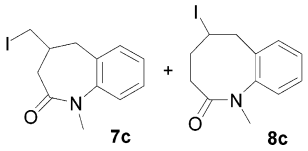
(5) For recent reviews, see: (a) Kidwai, M.; Sapra, P.; Bhushan, K. R., *Curr. Med. Chem.* **1999**, *6*, 195. (b) Ghosh, A.; Koltun, E.; Bilcer, G. *Synthesis* **2001**, 1281. (c) Nubbemeyer, U. *Top. Curr. Chem.* **2001**, *216*, 125.

(6) (a) Curran, D. P.; Chang, C.-T. *Tetrahedron Lett.* **1987**, *28*, 2477. (b) Curran, D. P.; Chang, C.-T. *J. Org. Chem.* **1989**, *54*, 3140. (c) Curran, D. P.; Chen, M.-H.; Kim, D. *J. Am. Chem. Soc.* **1989**, *111*, 6265. (d) Curran, D. P.; Chang, C.-T. *Tetrahedron Lett.* **1990**, *31*, 933. (e) Curran, D. P.; Tamine, J. *J. Org. Chem.* **1991**, *56*, 2746.

(7) For review articles, see: (a) Renaud, P.; Gerster, M. *Angew. Chem., Int. Ed.* **1998**, *37*, 2562. (b) Guerin, B.; Ogilvie, W. W.; Guindon, Y. In *Radicals in Organic Synthesis*; Renaud, P., Sibi, M. P., Eds; Wiley-VCH: Weinheim, 2001; Vol. 1, p 441.

(8) For similar discussions, see: (a) Wang, J.; Li, C. *J. Org. Chem.* **2002**, *67*, 1271. (b) Fang, X.; Xia, H.; Yu, H.; Dong, X.; Chen, M.; Wang, Q.; Tao, F.; Li, C. *J. Org. Chem.* **2002**, *67*, 8481.

TABLE 2. 8-Endo/7-Exo Cyclization of Iodoamides 6a−c

substrate	product	yield (%)[a] (**7** : **8**)
 **6a**	 **7a** + **8a**	70 (28:72)
 **6b**	 **7b** + **8b**	100 (39:61)[b]
 **6c**	 **7c** + **8c**	73 (27:73)

[a] Isolated yield based on **6**. [b] cis:trans = 2.5:1 for **8b**.

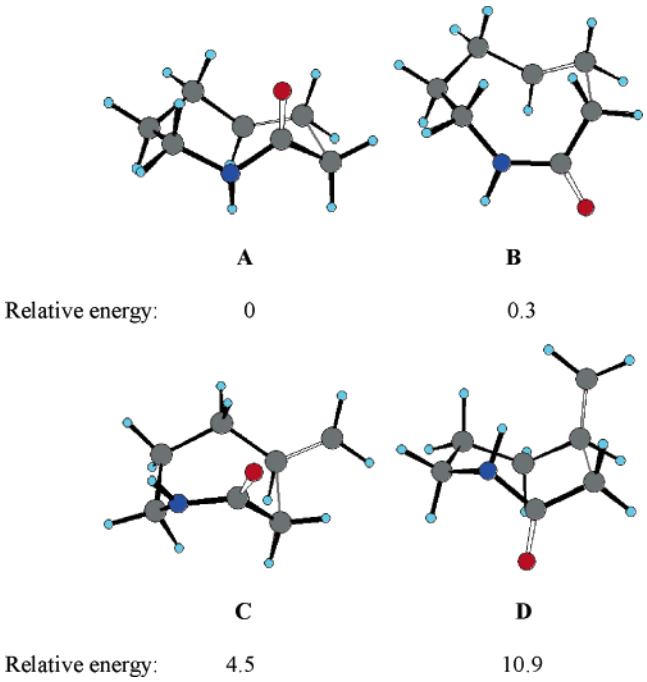


FIGURE 1. Calculated structures of the transition structures for the cyclization of **4a** with relative free energies in kcal/mol.

were formed. The ratios of **7** to **8** were about 1:2 with the 8-endo cyclization products preferred. Moreover, the overall yields in the reactions of **6a**−**c** were much higher than in the cases of **4a**−**e**. The configurations of the cyclization products **5b**, **5d** and **7b** were unambiguously established by their NOESY spectra. The NOESY spectra of **5b** and **5d** also showed strong NOE between H-3 and H-8 protons, indicating that s-cis conformations were preferred for the eight-membered lactams in the solution. Moreover, the X-ray crystal structures of eight-membered lactams **5a** and **8a**, shown in Scheme 2, both possess the s-cis boat-chair-like conformations.

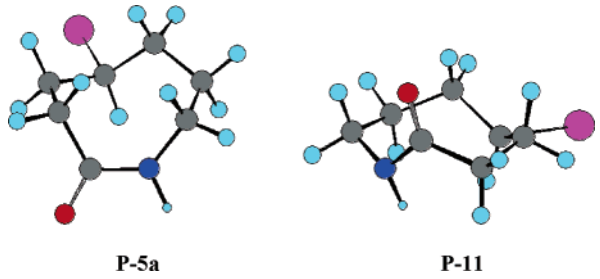
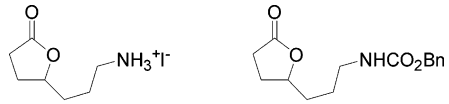


FIGURE 2. Calculated structures of **5a** and **11**.

The difference in cyclization yield between Tables 1 and 2 prompted us to recheck the reactions of **4**. We noticed that, while there was always some precipitate formed in the reactions of **4a**−**e**, no precipitate was observed in the reactions of **6a**−**c**. Initially we thought that the precipitate might be the radical oligomers of **4a**−**e**. However, when the precipitate formed in the reaction of **4a** was collected and treated with water at room temperature, it quickly dissolved and the ^{1}H NMR analysis showed that compound **9** was formed. The formation of **9** was further confirmed by its reaction with benzyl chloroformate in the presence of triethylamine as the base to afford the expected product **10**, which was unambiguously characterized. Compound **10** was thus obtained in 26% yield based on the original substrate **4a**. This result clearly indicated that the precipitate formed in the reactions of **4** was not the radical oligomers because the hydrolysis of the oligomers of **4a** required elevated temperature in hydrochloric acid.[9]



9 **10**

Calculations and Discussion

The different reaction phenomena between substrates **4** and **6** remained to be explained. To gain more insight into the cyclization behavior of α-carbamoyl radicals, we turned to quantum mechanics calculations for help, which have been shown to be an increasingly important tool in modeling radical reactions and mechanisms.[10,11]

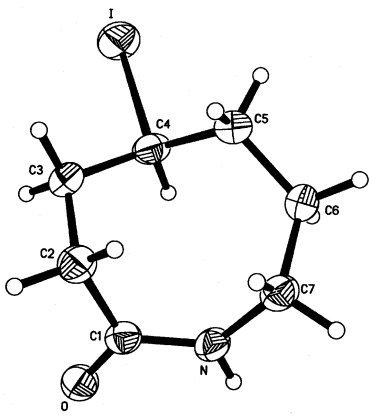
All calculations were carried out with the Gaussian98 programs.[12] The structures of the transition structures were searched and optimized with Becke's three-parameter hybrid exchange functional and the Lee−Yang−Parr correlation functional (B3LYP)[13] and the 6-31G* basis sets.[14] Vibration frequency calculations were also performed to characterize the transition structures, having

(9) Liu, L.; Wang, X.; Li, C. *Org. Lett.* **2003**, *5*, 361.

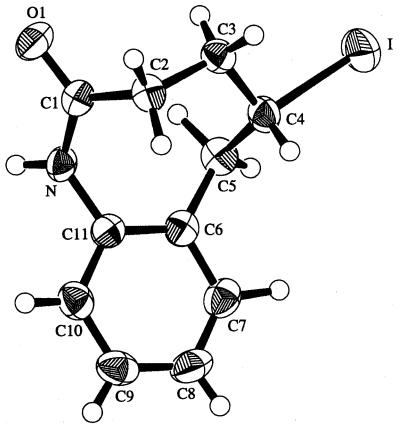
(10) For review articles on use of calculations in radical reactions, see: (a) Eksterowicz, J. E.; Houk, K. N. *Chem. Rev.* **1993**, *93*, 2439. (b) Schiesser, C. H.; Skidmore, M. A. In *Radicals in Organic Synthesis*; Renaud, P.; Sibi, M. P., Eds.; Wiley-VCH: Weinheim, 2001, Vol. 1, p 337.

(11) For recent examples, see: (a) Hartung, J.; Kneuer, R.; Rummey, C.; Bringmann, G. *J. Am. Chem. Soc.* **2004**, *126*, 12121. (b) Shanks, D.; Berlin, S.; Besev, M.; Ottosson, H.; Engman, L. *J. Org. Chem.* **2004**, *69*, 1487. (c) Leach, A. G.; Wang, R.; Wohlhieter, G. E.; Khan, S. I.; Jung, M. E.; Houk, K. N. *J. Am. Chem. Soc.* **2003**, *125*, 4271. (d) Croft, A. K.; Easton, C. J.; Radom, L. *J. Am. Chem. Soc.* **2003**, *125*, 4119. (e) Sung, K.; Wang, Y. Y. *J. Org. Chem.* **2003**, *68*, 2771. (f) Falzon, C. T.; Ryu, I.; Schiesser, C. H. *Chem. Commun.* **2002**, 2338. (g) See ref 8b.

SCHEME 2. ORTEP Diagrams of 5a and 8a



5a



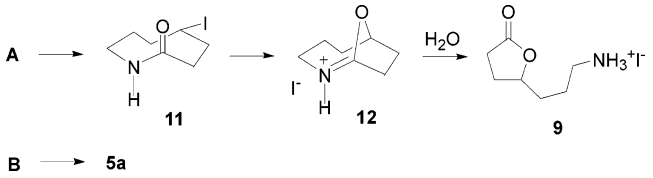
8a

only one imaginary frenquency. In the following dicussions all energies are in terms of free energy.

The calculated transition structures for the cyclization of **4a** are listed in Figure 1. The optimized transition structures for 8-endo cyclization are shown as **A** and **B**. Conformation **A** is in an s-trans chair-chair-like conformation, while **B** is in an s-cis boat-chair-like conformation. **A** is calculated to be about 0.3 kcal/mol more stable than **B**. This implies that both s-cis and s-trans 8-endo cyclization products can be formed. The two optimized transition structures for 7-exo cyclization are presented as **C** and **D**. Stucture **C** in an s-cis conformation has a boat-boat-like conformation and is at least 4 kcal/mol higher in erergy than structures **A** and **B**. Structure **D**, which is in an s-trans conformation, is found to be very unstable and is about 10.9 kcal/mol less stable than A. The C(3)−C(2)−N(1)−C(8) dihedral angle in **D** is about 123°, indicating a severe distortion of the amide moiety from planarity.

Thus, the calculation results indicate that only 8-endo cyclization occurs while 7-exo cyclization of **4a** is highly unlikely, which is in excellent agreement with our experimental observations. In addition, the results suggest that both s-cis and s-trans eight-membered lactams should be formed. Then how to account for the experimental fact that only the s-cis lactam was observed? It should be noted that iodolactam **5a**, once formed, was quite stable under the experimental conditions. Deliberate treatment of **5a** with $BF_3{\cdot}OEt_2$ at room temperature did not give any decomposition product, indicating that

SCHEME 3



lactone **9** could not result from the decomposition of **5a** in an s-cis conformation.

We propose that the s-trans lactam (**11**) was indeed formed in the experiment. However, it underwent an intramolecular S_N2 reaction to give an tetrahydrofuran iminium salt **12**, as shown in Scheme 3.[15] Compound **12**, which exists as a precipitate, is converted into soluble salt **9** when treated with water.[15]

We then performed the calculations of lactams **5a** and **11** at the B3LYP/6-31G* level. The calculated structures are presented in Figure 2. The calculation results show that the s-cis lactam **5a** and its s-trans isomer **11** have only about 0.9 kcal/mol difference in energy. The calculated structure of **5a** (**P-5a**) is almost identical to its X-ray structure shown in Scheme 2. An examination of the structure of **P-11** reveals that the carbonyl oxygen lies at the backside of the C(5)−I bond and is quite close to the C-5 carbon (3.68 Å). Thus, intramolecular nucleophilic attack of the carbonyl oxygen at the C-5 carbon readily occurs.

We also performed the similar calculations on the cyclization of *N*-(2,2-dimethyl-4-pentenyl)iodoacetamides **4c**. The results showed that the s-trans and the s-cis conformational transition structures for 8-endo cyclization of **4c** were very close in free energy with the s-cis structure more stable by 0.1 kcal/mol, while the transition structures for 7-exo cyclization of **4c** were at least 3.5 kcal/mol higher in energy than those for 8-endo cyclization (see Supporting Information for details). These results coincided well with those of **4a** as shown above.

The calculations on **4a** and **4c** are also in good qualitative agreement with the experimental data. As the s-cis transition structure **B** is less stable than the s-trans

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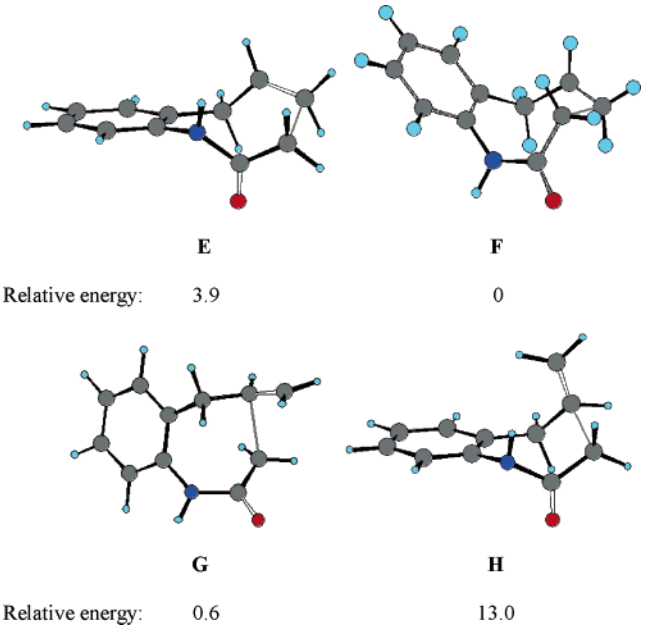

FIGURE 3. Calculated structures of the transition structures for the cyclization of **6a** with relative free energies in kcal/mol.

transition structure **A**, the yield of the cyclized product **5a** is lower than 50%. On the other hand, the s-cis transition structure is more stable than the s-trans transition structure for 8-endo cyclization of **4c**. As a result, the yield of **5c** is higher (59%).

The above discussion illustrates that the 8-endo cyclization of *N*-alkenyl-substituted α-carbamoyl radicals is a highly regioselective and efficient process. Although the decomposition of the cyclization product via the s-trans conformational transition structure appears unsatisfactory in a synthetic point of view, it can be envisioned that, with the development of an appropriate radical precursor or initiation system, the s-trans lactams formed might rotate to the more stable s-cis lactams rather than decomposition to lactones, thus of more synthetic value. A similar process is the 8-endo cyclization of α-ester radicals in which the s-cis conformational eight-membered lactones were achieved in high yield via the s-trans conformational transition structures.[8a,16]

The calculated transition structures for the cyclization of **6a** are presented in Figure 3. The two optimized transition structures for 8-endo cyclization are **E** and **F**. The s-trans conformational transition structure **E** is about 3.9 kcal/mol less stable than conformation **F**, which is in an s-cis boat-chair-like conformation. This result indicates that only **F** is the possible transition structure for the 8-endo cyclization of **6a**. The two optimized transition structures for 7-exo cyclization are **G** and **H**. The s-trans conformer **H** is much higher in energy than the s-cis conformer **G**, strongly suggesting that the 7-exo cyclization of **6a** proceeds via the s-cis conformational transition structure **G**. Moreover, the calculated energy of **G** is only about 0.6 kcal/mol higher than that of **F**, indicating that both 7-exo and 8-endo cyclization can occur. The measured product ratio is consistent with this small computed energy difference between **F** and **G**.

The different behaviors between **4a** and **6a** can be readily understood based on the above calculated structures. With the phenyl substitution, the N(2)−C(2)−C(3)−C(4) dihedral angle has to be 0°. This causes tremendous ring strain in s-trans structures **E** and **H**. For example, the C(4)−N(8)−C(9)−O(10) dihedral angle is about 175° in both the s-cis structures **F** and **G**, while the corresponding dihedral angle is about −29° in **E** and is much larger (−55°) in **H**.

The calculations on the cyclization of **6a** may also provide a reasonable explanation to Ikeda's results shown in Scheme 1.[5] As the relative energy between the transition structures **F** (8-endo) and **G** (7-exo) is small, it can be envisioned that different α-substitutents (Y) in **1** may alter the relative energies in different directions, thus resulting in different regioselectivities.

Conclusion

The chemistry detailed above has demonstrated that 8-endo cyclization of *N*-alkenyl α-carbamoyl radicals is an intrinsically favored process, which can be efficiently promoted by Lewis acid $BF_3{\cdot}OEt_2$. Theoretical investigation reveals that the cyclization of *N*-alkenyl α-carbamoyl radicals proceeds with excellent regioselectivity in favor of the 8-endo mode via both the s-cis and the s-trans conformational transition structures. These understanding should be of important implication in the further development of α-carbamoyl radical-based synthetic methodology.

Experimental Section

Typical Procedure for the Cyclization Reactions of *N*-(4-Pentenyl)iodoacetamides. Bis(tributyltin) (29 μL, 0.06 mmol) was added to the mixture of *N*-(4-pentenyl)iodoacetamide **4a** (151 mg, 0.6 mmol) and $BF_3{\cdot}OEt_2$ (0.14 mL, 1.2 mmol) in CH_2Cl_2 (20 mL) and the solution was photostimulated with stirring at room temperature for 30 min with the aid of a 300 W sunlamp. The resulting mixture was filtered and the precipitate was collected for further reaction. The filtrate was washed with saturated Na_2CO_3 (10 mL) and then dried over anhydrous $MgSO_4$. After removal of the solvent under reduced pressure, the crude product was purified by column chromatography on silica gel with ethyl acetate as the eluent to give pure **5a** as a yellow solid. Yield: 65 mg (43%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.63−1.86 (2H, m), 1.94−2.18 (2H, m), 2.22−2.30 (1H, m), 2.43−2.49 (2H, m), 2.61−2.70 (1H, m), 3.21−3.31 (1H, m), 3.41−3.54 (1H, m), 4.52−4.59 (1H, m), 6.15 (1H, br); ^{13}C NMR ($CDCl_3$) δ 31.2, 32.3, 32.7, 34.8, 40.5, 41.0, 176.4; IR (film) ν (cm^{-1}) 3195, 1678; EIMS *m/z* (rel intensity) 253 (M^+, 2), 126 (100), 97 (16), 81 (10), 69 (18), 55 (29), 41 (25); HRMS calcd for $C_7H_{12}INO$ 252.9964, found 252.9982. The structure was further confirmed by its X-ray diffraction analysis.

The precipitate collected above was dissolved in water (5 mL) and THF (10 mL). The mixture was cooled to 0 °C and K_2CO_3 powder was added until the pH was close to 9. Benzyl chloroformate (102 mg, 0.6 mmol) was added and the mixture was stirred at 0 °C for 2 h and then at room temperature for 4 h. The resulting mixture was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic phase was washed with brine (10 mL) and then dried over anhydrous $MgSO_4$. After removal of the solvent under reduced pressure, the crude product was purified by column chromatography on silica gel with ethyl acetate/hexane (1:1, v:v) as the eluent to give pure **10** as a colorless liquid. Yield: 43 mg (26% based on **4a**). ^{1}H NMR (300

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MHz, $CDCl_3$) δ 1.64−1.86 (5H, m), 2.27−2.33 (1H, m), 2.52 (2H, dd, J = 9.0, 7.2 Hz), 3.19−3.30 (2H, m), 4.44−4.52 (1H, m), 4.90 (1H, br), 5.10 (2H, s), 7.28−7.37 (5H, m); ^{13}C NMR ($CDCl_3$) δ 26.0, 27.9, 28.7, 32.6, 40.4, 66.6, 80.4, 128.0, 128.1, 128.4, 136.5, 156.4, 177.0; IR (film) ν (cm^{-1}) 3341, 1769, 1702, 1529; EIMS *m/z* (rel intensity) 277 (M^+, 1), 170 (9), 126 (20), 108 (62), 91 (100), 85 (10), 65 (12), 41 (5). Anal. Calcd for $C_{15}H_{19}NO_4$: C, 64.97; H, 6.91; N, 5.05. Found: C, 64.88; H, 6.73; N, 5.01.

Acknowledgment. This project was supported by the National Natural Science Foundation of China (nos. 20472109 and 20325207) and by the Shanghai Municipal Scientific Committee (no. 04QMH1418).

Note Added after ASAP Publication. Bu_3SnH was incorrectly listed as $(Bu_3Sn)_2$ in the text description of Scheme 1 in the version published ASAP January 26, 2005. The corrected version was published ASAP January 28, 2005.

Supporting Information Available: Characterization of **4**−**10**; computational results on the structures **A**−**H**, **P-5a**, **P-11** and on the transition structures for the cyclization of **4c**; and X-ray crystal structures of **5a** and **8a** in CIF format. This material is available free of charge via the Internet at http://pubs.acs.org.

JO0481349