Articles

Tributyltin Hydride-Mediated Free-Radical Cyclization of Allene-Tethered Oxime Ethers and Hydrazones

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In this work, we have shown that the tributyltin hydride-mediated cycloisomerization of allene-tethered oxime ethers or hydrazones is a convenient method for the preparation of (vinylstannyl)-cyclopentylamine derivatives in terms of simplicity and chemical yields. As a result, the first and detailed analysis of the tributyltin hydride-mediated free-radical cyclization of alkyl-substituted allene-tethered oxime ethers and hydrazones is reported. The site-directed intermolecular attack of the tributyltin radical at the allene moiety and the final size of the ring after cyclization depends on the type of substitution in the substrate. Some general trends can be observed: (1) In crowded substrates having full substitution at Cβ or at the terminal-trigonal carbon, the steric hindrance favors attack at the digonal carbon. (2) When different positions in the allene are free for attack, the kinetically more favored irreversible mode of cyclizations (5-exo > 6-exo > 6-endo) determines the ratio of isomers or the final size of the ring. Finally, after acid hydrolysis of the vinyltin products, the resulting *O*-methyl- or *O*-benzyl(hydroxylamino)cycloalkanes have been obtained in good yield.

Introduction

Free-radical inter- and intramolecular carbon−carbon bond-forming reactions are of paramount importance in organic synthesis.[1] In recent years, densely functionalized carbocycles have been efficiently prepared from conveniently functionalized precursors using free-radical-based methodologies.[1c] There has also been an increasing number of papers dealing with radical additions to N-containing multiple bonds.[2] Carbocyclization of radicals onto C=N bonds has been most studied in oxime ethers[3] and hydrazones.[4] Our teams in Marseille[5] and Madrid[6] have been particularly active in this topic, and in recent years, we have described extensively the tributyltin hydride-mediated synthesis of highly functionalized, chiral complex aminocyclitols or cyclopentyl/cyclohexylamine derivatives using halogeno-tethered-oxime ethers,[6a−g] carbonyl-tethered-oxime ethers,[6j] and allenic-tethered-oxime ethers.[5a,b] These studies have largely contributed to establish the synthetic usefulness of this strategy and enlarge the basic knowledge of these free-radical cyclizations.

The pioneer studies described by some of us in the carbocyclization of allenic-tethered oxime ethers deserve particular mention.[5] In 1992, nothing was known about this reaction and its synthetic potential. In this paper, we now describe in full the first results obtained in the free-radical cycloisomerization of allene-tethered oxime ethers and complementary studies in analogous racemic or enantiomerically pure allene-tethered hydrazones.

Results and Discussion

The particular structure and functionality of these allene-containing molecules raises several interesting problems. First, we have to consider that in the reversible intermolecular addition of the tributyltin species to the allene three positions are available for attack (C-1,

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(1) (a) Giese, B. *Radicals in Organic Synthesis: Formation of Carbon−Carbon Bonds*; Pergamon Press: New York, 1986. (b) Curran, D. P. *Synthesis* **1988**, 417−439, 489−513. (c) Jasperse, C. P.; Curran, D. P.; Fevig, T. L. *Chem. Rev.* **1991**, *91*, 1237−1286. (d) Motherwell, W. B.; Crich, D. *Free Radical Chain Reactions in Organic Synthesis*; Academic Press: London, 1991.

(2) Bowman, W. R.; Stephenson, P. T.; Terrett, N. K.; Young, A. R. *Tetrahedron* **1995**, *51*, 7959−7980 and references cited therein.

(3) Booth, S. E.; Jenkins, P. R.; Swain, C. J.; Sweeney, J. B. *J. Chem. Soc., Perkin Trans. 1* **1994**, 3499 and references cited therein.

(4) Sturino, C. F.; Fallis, A. G. *J. Org. Chem.* **1994**, *59*, 6514−6516.

(5) (a) Hatem, J.; Henriet-Bernard, C.; Grimaldi, J.; Maurin, R. *Tetrahedron Lett.* **1992**, *33*, 1057−1058. (b) Henriet-Bernard, C.; Grimaldi, J.; Hatem, J. *Tetrahedron Lett.* **1994**, *35*, 3699−3702. (c) El Gueddari, F.; Grimaldi, J.; Hatem, J. *Tetrahedron Lett.* **1995**, *36*, 6685−6688.

(6) (a) Marco-Contelles, J.; Martínez, L.; Martínez-Grau, A.; Pozuelo, C.; Jimeno, M. L. *Tetrahedron Lett.* **1991**, *32*, 6437−6440. (b) Marco-Contelles, J.; Pozuelo, C.; Jimeno, M. L.; Martínez, L.; Martínez-Grau, A. *J. Org. Chem.* **1992**, *57*, 2625−2631. (c) Marco-Contelles, J.; Sánchez, B.; Pozuelo, C. *Nat. Prod. Lett.* **1992**, *1*, 167−170. (d) Marco-Contelles, J.; Sánchez, B. *J. Org. Chem.* **1993**, *58*, 4293−4297. (e) Marco-Contelles, J.; Bernabé, M.; Ayala, D.; Sánchez, B. *J. Org. Chem.* **1994**, *59*, 1234−1235. (f) Marco-Contelles, J.; Sánchez, B.; Pozuelo, C. *Tetrahedron: Asymmetry* **1992**, *3*, 689−692. (g) Marco-Contelles, J.; Martínez, L.; Martínez-Grau, A. *Tetrahedron: Asymmetry* **1991**, *2*, 961−964. (h) Marco-Contelles, J.; Destabel, C.; Chiara, J. L.; Bernabé, M. *Tetrahedron: Asymmetry* **1995**, *6*, 1547−1550. (i) Marco-Contelles, J.; Destabel, C.; Gallego, P. *J. Carbohydr. Chem.* **1995**, *14*, 1343−1352. (j) Chiara, J. L.; Marco-Contelles, J.; Khiar, N.; Gallego, P.; Destabel, C.; Bernabé, M. *J. Org. Chem.* **1995**, *60*, 6010−6011. (k) Marco-Contelles, J.; Destabel, C.; Gallego, P.; Bernabé, M. *J. Org. Chem.* **1996**, *61*, 1354−1362.

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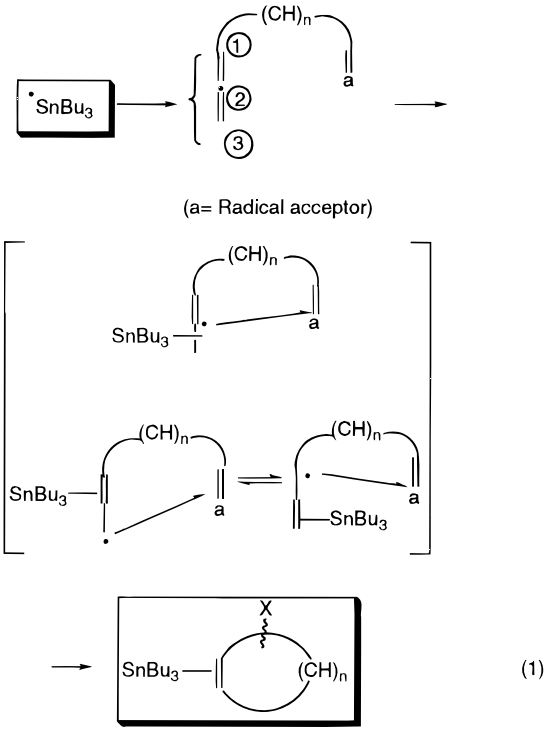
C-2, C-3) (eq 1); second, we also have to consider the different reactivity of the resulting vinylic versus allylic radicals and the allyl isomerization in each of these species; and third, these radicals species have several options possible for the intramolecular cyclization (5-exo/6-exo/6-endo). Fortunately, in oxime ethers and hydrazones the endo-intramolecular additions are disfavored, and this simplifies matters with regard to possible products.[2]

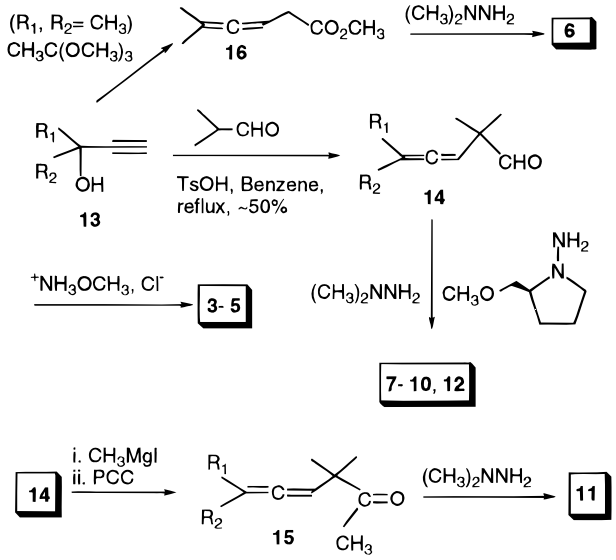


(1)

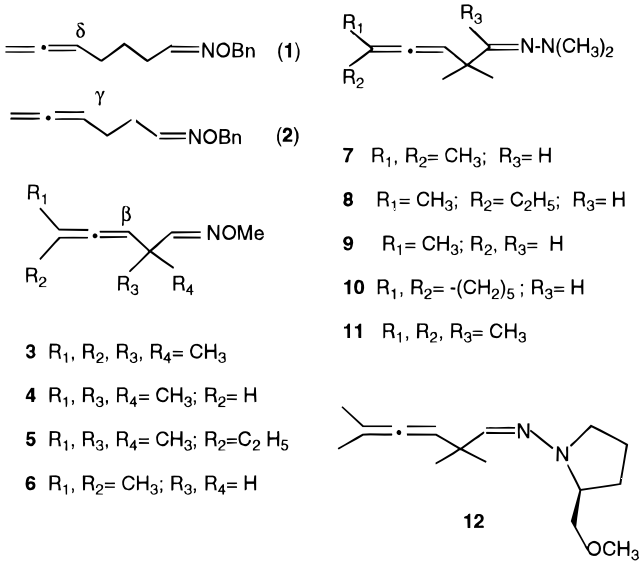
A careful survey of the literature has shown that reports on the intermolecular free-radical addition of heteroatom-centered radicals to allenes are scarce, but documented: i.e., photochemical addition of disulfides and diselenides[7] and palladium-catalyzed hydrostannation.[8] From these studies, it was soon clear that the simple tributyltin hydride + AIBN addition to allenes was, surprisingly, almost unexplored, and in addition, the reaction of the tin species, catalyzed by palladium complexes, to allenes was poorly regioselective. In summary, a systematic structure−reactivity analysis would be necessary to determine the factors and parameters governing this process.

Synthesis of the Radical Precursors. Then, with this in mind we have designed and prepared the radical precursors **1**−**12**. Compounds **1** and **2** are *δ*- and *γ*-allenic *O*-benzyloxime ethers, respectively. Compounds **3**−**6** are *β*-allenic *O*-methyloxime ethers, derived from aldehydes, having different alkyl substitution at the α-carbon or at the terminal allenyl carbon. Compounds **7**−**11** are *β*-allenic *N*,*N*-dimethylhydrazones, derived from ketones or aldehydes, having different alkyl substitution at the terminal allenyl carbon. Compound **12** is a chiral hydrazone with a similar substitution pattern,

Scheme 1. Synthetic Routes to Radical Precursors 3−12



having a proline motive as the chiral inductor. In summary, with this large array of radical precursors, we wanted to analyze the effect of the number of carbons connecting the tether and the allene, the effect of the alkyl substitution at the different positions, and the type of C=N multiple bond used as radical acceptor during the tributyltin radical attack and subsequent cyclization.



3 $R_1, R_2, R_3, R_4 = CH_3$

4 $R_1, R_3, R_4 = CH_3$; $R_2 = H$

5 $R_1, R_3, R_4 = CH_3$; $R_2 = C_2H_5$

6 $R_1, R_2 = CH_3$; $R_3, R_4 = H$

7 $R_1, R_2 = CH_3$; $R_3 = H$

8 $R_1 = CH_3$; $R_2 = C_2H_5$; $R_3 = H$

9 $R_1 = CH_3$; $R_2, R_3 = H$

10 $R_1, R_2 = -(CH_2)_5-$; $R_3 = H$

11 $R_1, R_2, R_3 = CH_3$

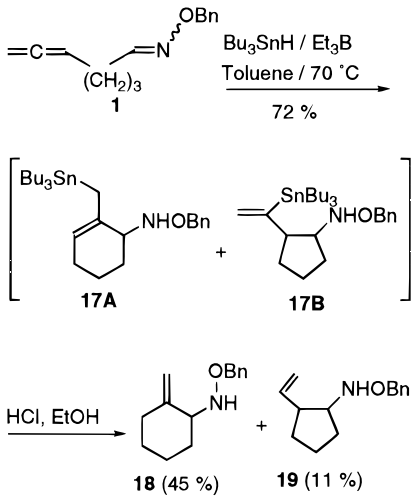
Compounds **1** and **2**[9a] were prepared by routine manipulation (Supporting Information). Compounds **3**−**12** were prepared as shown in Scheme 1 by standard or known synthetic methodologies (see the Supporting Information). Oxime ethers **3**−**5** and hydrazones **7**−**10** and **12** have been isolated only as pure *E* isomers, as we could determine by ^{1}H NMR analysis, measuring the chemical shift for the proton in the C=N multiple bond (around 7.2 ppm in oxime ethers and 6.5 ppm in hydrazones). On the contrary, precursor **6** was isolated as a

(7) Ogawa, A.; Yokoyama, K.; Yokoyama, H.; Sekiguchi, M.; Kambe, N.; Sonoda, N. *Tetrahedron Lett.* **1990**, *31*, 5931−5934.

(8) (a) Mitchell, T. N.; Schneider, U. *J. Organomet. Chem.* **1991**, *405*, 195−199. (b) Mitchell, T. N.; Schneider, U. *J. Organomet. Chem.* **1991**, *407*, 319−327. (c) Koerber, K.; Goré, J.; Vatéle, M. *Tetrahedron Lett.* **1991**, *32*, 1187−1190. The stannylcupration of allenes has also been described: (d) Barbero, A.; Cuadrado, P.; Fleming, I.; González, A. M.; Pulido, F. J. *J. Chem. Soc., Perkin Trans. 1* **1992**, 327−331.

(9) (a) J.M.-C. thanks Dr. Manuel Bernabé for ^{1}H NMR spectroscopic analyses of compounds **1** and **2**. (b) J.M.-H. thanks Dr. M. Pierrot and Dr. H. Alilou (Centre de Cristallographie, Faculté de St. Jérôme, Marseille) for the X-ray structure determination of compound **25d**.

Scheme 2. Free-Radical Cyclization of Precursor 1



mixture (1:1) of *E* and *Z* isomers (see the Supporting Information).

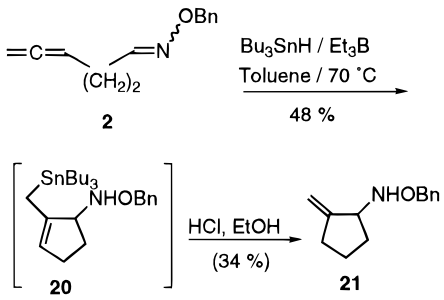
Free-Radical Cyclization of the Radical Precursors. (A) Allene-Tethered Oxime Ethers. (A1) δ-Isomers. When compound **1** (obtained as an inseparable mixture of *E*/*Z* isomers in 7.2:1 ratio)[9a] was treated with tributyltin hydride in the presence of triethylborane,[10] in toluene at 70 °C, a mixture of tin-derived adducts **17** was isolated in 72% yield and without further analysis was submitted to acid hydrolysis with HCl/EtOH.[11] Under these conditions, we were able to separate and isolate compounds **18** (45%) and **19** (11%) in reasonable yield (Scheme 2). *O*-Benzylhydroxylamine **19** appears as a single product (^{1}H NMR analysis) whose stereochemistry could not be established.

(A2) γ-Isomers. Compound **2** (obtained as an inseparable mixture of *E*/*Z* isomers in 3:1 ratio),[9a] when submitted to the same experimental conditions, afforded the allyltin intermediate **20** that after acid hydrolysis gave the cyclopentylamine derivative **21** as the only detected and isolated compound (Scheme 3).

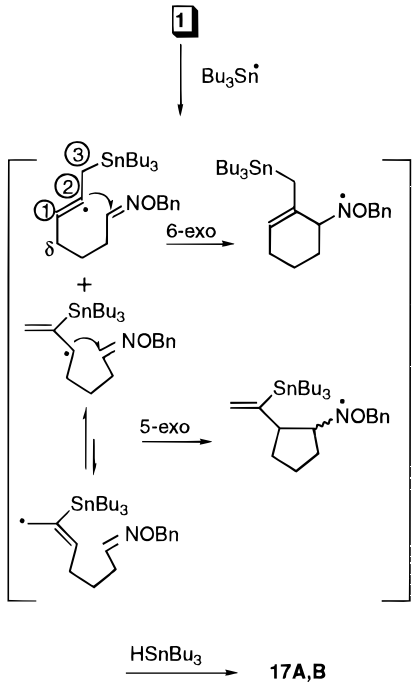
Compounds **18** (Scheme 2) and **21** (Scheme 3) obviously arise from the simultaneous allylic isomerization of the corresponding allyltin intermediates **17A** and **20**, respectively, to give the most stable exo methylene product. This type of isomerization under these experimental conditions is very well known.[12] We can assume that the ratio of isomers **18**/**19** represents very exactly the true ratio of the tributyltin intermediates, since compound **19** (Scheme 2) comes from simple acid hydrolysis of the vinyltin adduct **17B**.

In Scheme 4 we present a hypothetical mechanism for the observed results in the cyclization of radical precursors **1**. As there is no substitution in the δ position, the attack at the carbon (C-1) is possible, but this is less sterically favored than the attack at C-2 (digonal) or at C-3 (trigonal). From the experimental results it is clear that the formation of major compound **18** requires preferential attack of the tributyltin radical at C-3 over C-2 in a ratio 4:1. This can be explained as follows: the tributyltin radical reaction with the allene is likely

Scheme 3. Free-Radical Cyclization of Precursor 2



Scheme 4. Mechanism for the Free-Radical Cyclization of Radical Precursor 1



reversible; in addition, the tributyltin radical attacks the sp^2 carbon instead of the sp carbon, where the electronic interaction is more repulsive. Each of the radical species cyclizes in a 5-exo or 6-exo mode to the corresponding radical, which on reaction with tributyltin hydride traps hydrogen to give the mixture **17**, reinitiating the free-radical chain reaction. These results are also in good agreement with the reported results for intermolecular reactions with unsubstituted allenes.[8]

In the carbocyclization of compound **2** only attack at the terminal (C-3) or at the C-1 carbons is observed. This leads to a vinyl radical species that after 5-*exo*-*trig* free-radical cyclization gives an allyltin derivative that after acid hydrolysis yields the observed compound **21**. Interestingly, the attack at the digonal carbon C-2, which would have given allylic positioned radicals, is not detected; one of these allylic species would have cyclized in an unusual 4-exo[13] mode and the other in a favorable 6-exo process, but much less favored than the 5-exo mode that leads finally to compound **21** (Scheme 5).

In summary, attack at sp^2 carbons is always electronically exclusive or favored; in these cases attack at the sp carbon proceeds if the resulting reactive allylic radical

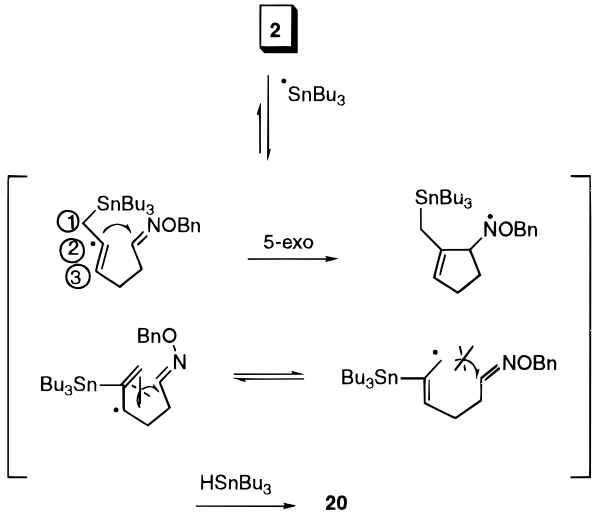
(10) Nozaki, K.; Oshima, K.; Utimoto, K. *J. Am. Chem. Soc.* **1987**, *109*, 2547.

(11) Ardisson, J.; Férézou, J. P.; Julia, M.; Pancrazi, A. *Tetrahedron Lett.* **1987**, *28*, 2001.

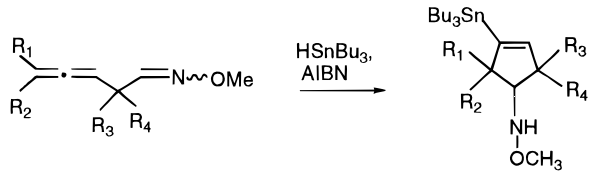
(12) Pereyre, M.; Quintard, J. P.; Rahm, A. *Tin in Organic Synthesis*; Butterworths: London, 1986.

(13) (a) Park, S. U.; Varick, T. R.; Newcomb, M. *Tetrahedron Lett.* **1990**, *31*, 2975−2978. (b) Jung, M. E.; Trifunovich, I. D.; Lensen, N. *Tetrahedron Lett.* **1992**, *33*, 6719−6722.

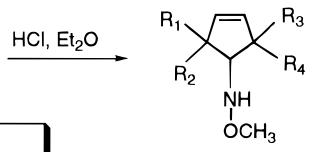
Scheme 5. Mechanism for the Free-Radical Cyclization of Precursor 2



Scheme 6. Free-Radical Cyclization of Radical Precursors 3−6



3	$R_1, R_2, R_3, R_4 = CH_3$	**22a** (77%)
4	$R_1, R_3, R_4 = CH_3$; $R_2 = H$	**22b** (74%)
5	$R_1, R_3, R_4 = CH_3$; $R_2 = C_2H_5$	**22c** (91%)
6	$R_1, R_2 = CH_3$; $R_3, R_4 = H$	**22d** (37%)



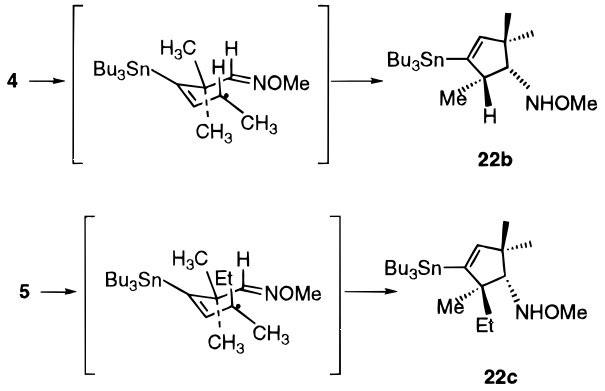
a	$R_1, R_2, R_3, R_4 = CH_3$	**23a** (82%)
b	$R_1, R_3, R_4 = CH_3$; $R_2 = H$	**23b** (77%)
c	$R_1, R_3, R_4 = CH_3$; $R_2 = C_2H_5$	**23c** (83%)
d	$R_1, R_2 = CH_3$; $R_3, R_4 = H$	**23d** (53%)

can undergo a very kinetically 5-exo-favored mode of cyclization.

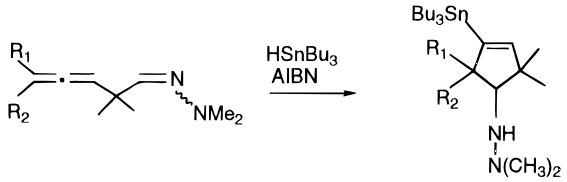
(A3) *β*-Isomers. The following radical precursors tested were the allene-tethered oxime ethers **3**−**6**. In these substrates, the terminal position C-3 and the *β* carbon are dialkyl substituted (except for the oxime ether **6**). Obviously, with this substitution pattern the tributylstannyl radical attack at C-1 and C-3 was precluded by strong steric interactions; as a consequence, only the attack at C-2 was possible. The experimental results largely confirmed this assumption (Scheme 6).

With the experimental conditions ($HSnBu_3$, AIBN), compounds **3**−**6** gave the vinyltin derivatives **22a**−**d** in moderate to good yield; carbocycles **22b** and **22c** have been isolated as inseparable mixtures of isomers in 66/34 and 88/12 ratios, respectively. These values have been obtained by ^1H NMR spectrum integration. The assignment of the relative stereochemistry at the newly formed stereocenters in these compounds has been established by detailed ^1H and ^{13}C NMR analysis. In both cases, the major isomer always has the methyl group and the amino function in cis relative orientation. Final acid hydrolysis in strong conditions (HCl/Et_2O; note that other standard conditions for protodestannylations were unsuccessful: AcOH, SiO_2, BuLi)[11] gave the destannylated compounds **23a**−**d** in good yield (Scheme 6).

Scheme 7. Mechanism for the Free-Radical Cyclization of Radical Precursors 4 and 5



Scheme 8. Free-Radical Cyclization of Radical Precursors 7−9



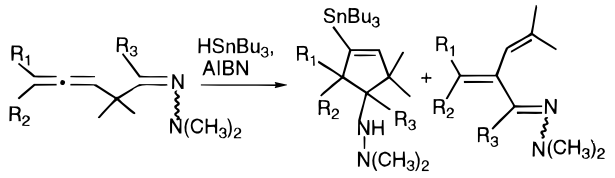
7	$R_1, R_2 = CH_3$	**24a** (89%)
8	$R_1 = CH_3$; $R_2 = C_2H_5$	**24b** (77%)
9	$R_1 = CH_3$; $R_2 = H$	**24c** (90%)

a	$R_1, R_2 = CH_3$
b	$R_1 = CH_3$; $R_2 = C_2H_5$
c	$R_1 = CH_3$; $R_2 = H$

(B) Allene-Tethered *N*,*N*-Dimethylhydrazones 7−11. Radical precursors **7**−**9**, when submitted to the same experimental conditions, gave the corresponding vinyltin hydrazines **24a**−**c** in good yield (Scheme 8). The cyclization of **8** (→ **24b**: 81/19) and **9** (→ **24c**: 60/40) is diastereoselective; the major product is, in both cases, the one that has the methyl group and the amino function

(14) Beckwith, A. L. J.; Schiesser, C. H. *Tetrahedron* **1985**, *41*, 3925.

Scheme 9. Free-Radical Cyclization of Radical Precursors 10 and 11



10 R_1, R_2= -$(CH_2)_5$, R_3= H	**24d** (58%)	**25d** (25%)
11 R_1, R_2, R_3= CH_3	**24e** (16%)	**25e** (58%)

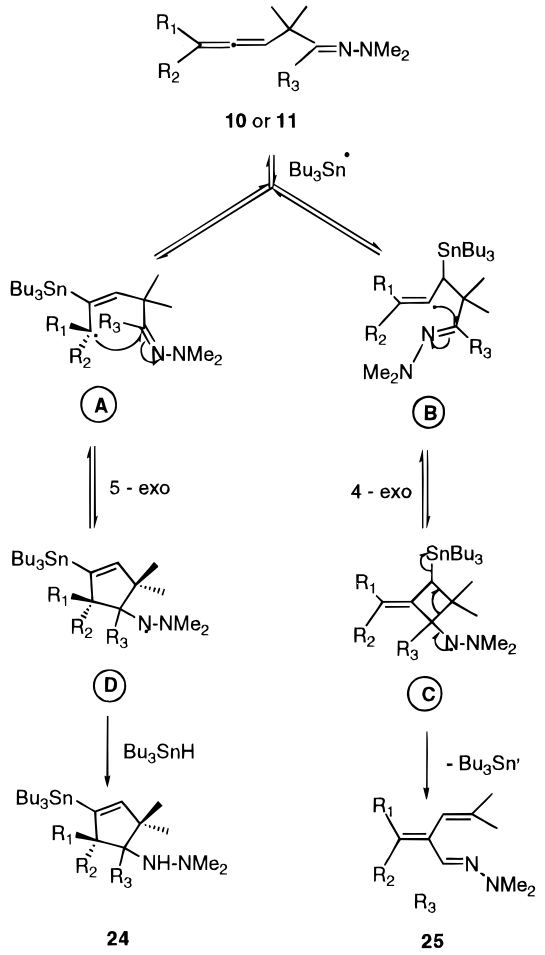
d R_1, R_2= -$(CH_2)_5$, R_3= H

e R_1, R_2, R_3= CH_3

in the cis orientation.[15] This is also in agreement with the results obtained for the cyclization of the similar oxime ethers previously described (see above) and can be explained according to the same stereoelectronic arguments as shown in Scheme 7. However, under the same experimental conditions, radical precursors **10** and **11** gave different results, and the new product (**25d** or **25e**) was detected (Scheme 9). Hydrazone **25e** has been isolated as a mixture of *E* and *Z* isomers, in a 7/3 ratio, respectively, that we were unable to separate. The structure of product **25d** (only the *E* product has been detected) has been conclusively determined by X-ray analysis.[9b]

The formation of compounds of type **25** was unexpected, and in Scheme 10 we show a tentative mechanism. The cyclopentene derivatives **24** originate from the initial attack of the tin radical on the digonal carbon of the allene. The alkyl radical **A** binds to the carbon atom of the hydrazone function via a 5-exo ring-closure process. When $R_3 = CH_3$ and to a lesser extent when R_1, $R_2 = -(CH_2)_5-$, the 5-exo mode of cyclization and the formation of linear compounds **25** become competitive. It is well known that the presence of an alkyl substituent on C-5 slows down the 5-exo ring closure of 5-hexenyl radicals and thus allows the 6-endo process to become predominant.[16] However, in the case of **24e** this 6-endo carbocyclization implies the attack of the nucleophile radical **A** on the sp^2 nitrogen atom of the hydrazone moiety, which is far less favorable than the attack on the carbon.[17] In the case of **24d**, the 5-exo cyclization of the corresponding cyclohexyl radical **A** is less favorable than for species **A** formed from radical precursors **24a**−**c**, probably for steric reasons. The formation of products **25d,e** may be explained by the attack of the tin radical on the less substituted trigonal carbon of the allenic function. The very reactive vinyl radical[18] **B** adds to the carbon atom of the hydrazone in an unusual 4-*exo*-*trig* addition.[13,19] This cyclization is facilitated by the presence of the *gem*-dimethyl group on the α-carbon atom of the hydrazone function, in agreement with recent similar reports.[19] The cyclobutyl aminyl radical **C** fragments immediately into products **25d,e** with subsequent elimination of the tributyltin group.[20]

Scheme 10. Possible Mechanism for the Tin-Mediated Radical Reaction of Precursors 10 and 11



(C) Chiral Allene-Tethered SAMP Hydrazone (12). The interesting results obtained in the cyclization of allene-tethered *N*,*N*-dimethylhydrazones **7**−**11** prompted us to prepare and cyclize the chiral hydrazone **12**. In fact, asymmetric intramolecular carbocyclizations mediated by chiral auxiliaries have not been extensively studied,[21] and our substrates are ideal to test the asymmetric induction in these processes. Our first choice was the commercially available SAMP hydrazine. The radical precursor was obtained by standard methodology from 2,2,5-trimethylhexa-3,4-dienal. In our experimental conditions, compound **12** gave exclusively the cyclopentylhydrazine derivative **26** (eq 2) in 78% yield and as an inseparable mixture of diastereoisomers. The diastereomeric excess estimated by ^1H NMR spectrometry was about 50%. The ^1H NMR spectrum of the mixture of the two diastereomers obtained is so complex that we did not succeeded in analyzing it completely; fortunately, the vinylic proton signals were completely separated to allow us a correct diastereomeric excess estimation. We have

(15) It should be noted that the stereoselectivities given in ref 5b are incorrect.

(16) Beckwith, A. L. J. *Tetrahedron* **1981**, *37*, 3073−3100.

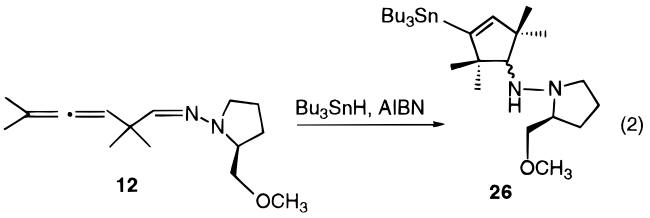
(17) Tomaszewski, M. J.; Warkentin, J. *Tetrahedron Lett.* **1992**, *33*, 2123−2126.

(18) Stork, G.; Baine, N. H. *J. Am. Chem. Soc.* **1982**, *104*, 2321−2323 and references cited therein.

(19) (a) Araki, Y.; Endo, T.; Arai, Y.; Tanji, M.; Ishido, Y. *Tetrahedron Lett.* **1989**, *30*, 2829−2832. (b) Pattenden, G.; Reynolds, S. J. *Tetrahedron Lett.* **1991**, *32*, 259−262. (c) Fremont, S. L.; Belletire, J. L.; Ho, D. M.; Kodama, K.; Sato, T.; Ikeda, M. *Synlett* **1993**, 649−650. (d) Ogura, K.; Sumitani, N.; Kayano, A.; Igushi, H.; Fugita, M. *Chem. Lett.* **1992**, 1487−1488.

(20) (a) Maeda, Y.; Inglod, K. U. *J. Am. Chem. Soc.* **1980**, *102*, 328−331. (b) Newcomb, M.; Park, S.-U. Kaplan, J.; Marquardt, D. J. *Tetrahedron Lett.* **1985**, *26*, 5651−5654. (c) Bowman, W. R.; Clark, D. N.; Marnon, R. J. *Tetrahedron* **1994**, *50*, 1275−1294.

(21) For a review, see: Porter, N. A.; Giese, B.; Curran, D. P. *Acc. Chem. Res.* **1991**, *24*, 296−304.



(2)

been unable to determine the absolute configuration at the new stereocenter in the major isomer.

In summary, in this work we have shown that the tributyltin hydride-mediated cycloisomerization of allene-tethered oxime ethers or hydrazones is a convenient method for the preparation of (vinylstannyl)cyclopentylamine derivatives. The site-directed intermolecular attack of the tributyltin radical at the allene moiety and the final size of the ring after cycloisomerization depends on the type of substitution in the substrate. Some general trends can be observed: (1) In crowded substrates having full substitution at Cβ or at the terminal-trigonal carbon, the steric hindrance favors attack at the digonal carbon. (2) When different positions in the allene are free for attack, the kinetically more favored irreversible mode of cyclizations (5-exo > 6-exo > 6-endo) determines the ratio of isomers or the final size of the ring. Finally, the acid-promoted destannylation of the resulting vinyltin intermediates has afforded unsaturated cyclopentylamine derivatives in good chemical yield.

Experimental Section

Reactions were monitored by TLC using precoated silica gel aluminum plates containing a fluorescent indicator (Merck, 5539). Detection was done by UV (254 nm) followed by charring with sulfuric−acetic acid spray, 1% aqueous potassium permanganate solution, or 0.5% phosphomolybdic acid in 95% EtOH. Anhydrous Na_2SO_4 was used to dry organic solutions during workup, and the removal of solvents was carried out under vacuum with a rotary evaporator. Flash column chromatography was performed using Kieselgel 60 (230−400 mesh, Merck) and hexane−ethyl acetate mixtures as eluent. ^{1}H and ^{13}C NMR spectra were recorded with a Varian VXR-300S spectrometer, using tetramethylsilane as internal standard.

1-[(Benzyloxy)amino]-2-methylenecyclohexane (18) and **1-[(Benzyloxy)amino]-2-ethylenecyclopentane (19).** Triethylborane (1 M in hexanes, 0.15 mL, 0.15 mmol) was added to a degassed solution of allenic oxime ether **1** (0.065 g, 0.30 mmol) and tributyltin hydride (0.10 mL, 0.74 mmol) in dry toluene (15 mL) under Ar. The reaction mixture was stirred at 70 °C for 3 h, triethylborane (1 M in hexanes, 0.15 mL, 0.15 mmol) and tributyltin hydride (0.10 mL, 0.74 mmol) were added, and the reaction mixture was stirred at 70 °C overnight and concentrated under reduced pressure. The crude product (0.53 g) was purified by flash column chromatography. Elution with ethyl acetate/hexane (0/100 and 2/98) gave the cyclized product **17** (0.110 g, 72%) as an oil. The mixture of product **17** (0.104 g, 0.20 mmol) was stirred in a solution of HCl/EtOH (4 mL) at rt for 2 h 45 min and the solvent removed under reduced pressure. The residue was partitioned between water (10 mL) and hexane (10 mL) and extracted with hexane (3 × 5 mL). The combined organic extract was concentrated under reduced pressure. The crude product (0.10 g) was purified by flash column chromatography. Elution with ethyl acetate/hexane (0/100 and 2/98) gave **1-(benzyloxy)amino]-2-methylenecyclohexane (18)** (0.020 g, 45%) as an oil [R_f = 0.43 (6% ethyl acetate/hexane); IR (film) ν 2920, 2860, 1460, 900, 740, 700 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.55 (4 H, m), 1.83 (2 H, m), 2.07 (1 H, m), 2.33 (1 H, m), 3.54 (1 H, dd, J = 4, 7 Hz), 4.74 (2 H, s), 4.80 (2 H, s), 5.57 (1 H, s), 7.40 (5 H, m); ^{13}C NMR ($CDCl_3$) δ 23.0, 28.1, 31.6, 33.7, 62.8, 76.6, 107.6, 127.7, 128.3, 128.4, 148.7. Anal. Calcd for $C_{14}H_{19}NO$: C, 77.38; H, 8.81; N, 6.44. Found: C, 77.10; H, 9.12; N, 6.31] and **1-[(benzyloxy)amino]-2-ethylenecyclopentane (19)** (0.005 g, 11%) as an oil: R_f = 0.31 (6% ethyl acetate/hexane); IR (film) ν 2960, 2860, 1640, 1455, 1360, 990, 910, 740, 695 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.40−1.97 (6 H, m), 2.35 (1 H, quintet, J = 8 Hz), 3.19 (1 H, q, J = 8 Hz), 4.73 (2 H, s), 4.97 (1 H, br d, J = 10 Hz), 5.05 (1 H, br d, J = 17 Hz), 5.62 (1 H, br s), 5.78 (1 H, ddd, J = 8, 10, 17 Hz), 7.40 (5 H, br s); ^{13}C NMR ($CDCl_3$) δ 22.9, 30.2, 31.4, 47.5, 67.2, 76.2, 112.3, 114.4, 128.2, 128.3, 128.5, 141.4. Anal. Calcd for $C_{14}H_{19}NO$: C, 77.38; H, 8.81; N, 6.44. Found: C, 77.20; H, 9.02; N, 6.41.

1-[(Benzyloxy)amino]-2-methylenecyclopentane (21). Triethylborane (1 M in hexanes, 0.30 mL, 0.30 mmol) was added to a degassed solution of allenic oxime ether **2** (0.115 g, 0.57 mmol) and tributyltin hydride (0.20 mL, 1.48 mmol) in dry toluene (30 mL) under Ar. The reaction mixture was stirred at 70 °C for 1 h 30 min, triethylborane (1 M in hexanes, 0.30 mL, 0.30 mmol) and tributyltin hydride (0.20 mL, 1.48 mmol) were added, the reaction mixture was stirred at 70 °C overnight, more triethylborane (1 M in hexanes, 0.30 mL, 0.30 mmol) and tributyltin hydride (0.20 mL, 1.48 mmol) were added, and the reaction mixture was stirred at 70 °C for 1 h and then concentrated under reduced pressure. The crude product (1.15 g) was purified by flash column chromatography. Elution with dichloromethane/hexane (20/80 and 40/60) gave the cyclized products (**20**) (0.135 g, 48%) as an oil. The product (**20**) (0.135 g, 0.27 mmol) was stirred in a solution of HCl/EtOH (5 mL) at rt overnight and the solvent removed under reduced pressure. The residue was partitioned between saturated sodium bicarbonate solution (5 mL) and dichloromethane (10 mL) and extracted with dichloromethane (3 × 10 mL). The combined organic extract was dried over sodium sulfate and concentrated under reduced pressure. The crude product (0.12 g) was purified by flash column chromatography. Elution with ethyl acetate/hexane (3/97) gave **1-[(benzyloxy)amino]-2-methylenecyclopentane (21)** (0.033 g, 59%) as an oil: R_f = 0.38 (5% ethyl acetate/hexane); IR (film) ν 2960, 2860, 1610, 1500, 1455, 1025, 915, 740, 700 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.48−1.86 (4 H, m), 2.26 (2 H, m), 3.78 (1 H, m), 4.66 (2 H, s), 4.98 (2 H, m), 5.33 (1 H, br s), 7.30 (5 H, m); ^{13}C NMR ($CDCl_3$) δ 23.1, 30.8, 32.0, 64.1, 76.5, 109.7, 127.8, 128.2, 128.4, 137.8, 151.4; MS (70 eV) m/z 203 (M, 0.13), 92 (7), 91 (100), 77 (7). Anal. Calcd for $C_{13}H_{17}NO$: C, 76.81; H, 8.43; N, 6.89. Found: C, 76.53; H, 8.72; N, 7.18. **1-[(Benzyloxy)amino]-2-methylenecyclopentane (21)** was obtained in 34% overall from allenic oxime ether (**6**) using the crude cyclization mixture for the destannylation.

General Procedure for the Cyclization of the β-Allenic Oxime Ethers. Bu_3SnH (1.2 equiv) and AIBN (0.2 equiv) were added to a benzene solution (0.02 M) of the *O*-methyl oxime **3**−**6**. After this solution was degassed with a stream of argon, the mixture was refluxed and monitored by TLC until the starting material had disappeared. The reaction was monitored by TLC. After evaporation of the solvent, the crude product was purified by flash chromatography over silica gel.

1-(Tri-*n*-butylstannyl)-3,3,5,5-tetramethyl-4-(methoxyamino)cyclopentene (22a). Reaction of **3** (1 g, 5.98 mmol) with Bu_3SnH (2.09 g, 7.18 mmol) and AIBN (0.196 g, 1.19 mmol) in benzene (300 mL) during 24 h produced **22a** (2.1 g, 77%) as a colorless oil after purification by column chromatography (pentane/diethyl ether 96/4): IR (film) ν 2960, 2850, 1575, 1460 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.87 (15 H, t, J = 7.3 Hz), 0.90 (3 H, s), 0.94 (3 H, s), 1.13 (3 H, s), 1.14 (3 H, s), 1.29 (6 H, sext, J = 7 Hz), 1.45 (6 H, m), 3.01 (1 H, s), 3.49 (3 H, s), 5.42 (1H, s); ^{13}C NMR ($CDCl_3$) δ 9.9, 13.7, 23.0, 23.8, 27.4, 29.2, 30.2, 31.1, 48.6, 52.7, 60.7, 76.1, 149.2, 151.0.

1-(Tri-*n*-butylstannyl)-3,3,5-trimethyl-4-(methoxyamino)cyclopentene (22b). Reaction of **4** (1 g, 6.53 mmol) with Bu_3SnH (2.28 g, 7.84 mmol) and AIBN (0.214 g, 1.3 mmol) in benzene (325 mL) during 26 h provided **22b** (2.07 g, 74%) after purification by column chromatography (pentane/diethyl ether 92/8): IR (film) ν 3400, 2900, 2850, 1580, 1470 cm^{-1}. Anal. Calcd for $C_{21}H_{43}NOSn$: C, 56.77; H, 9.75; N, 3.15. Found: C, 56.61; H, 9.9; N, 3.2. The ^{1}H and ^{13}C NMR were recorded on a mixture of two isomers (cis 2/3−trans 1/3): ^{1}H

NMR ($CDCl_3$) (major isomer) δ 0.86 (18 H, t, J = 7.5 Hz, including 3 H, s), 0.93 (3 H, s), 1.13 (3 H, d, J = 7 Hz); 1.28 (6 H, sext, J = 7.5 Hz), 1.45 (6 H, m) 2.91 (1 H, quin d, J = 8 Hz, J = 1 Hz), 3.35 (1 H, d, J = 8 Hz), 3.52 (3 H, s), 5.53 (1 H, d, J = 1.2 Hz); ^{13}C NMR ($CDCl_3$) δ 9.5, 13.7, 16.0, 24.0, 27.3, 29.2, 29.6 47.5, 47.7, 61.0, 69.7, 145.5 150.8; ^{1}H NMR ($CDCl_3$) (minor isomer) δ 0.86 (15 H, t, J = 7.5 Hz), 0.88 (3 H, s), 0.95 (3 H, s), 1.13 (3 H, d, J = 7 Hz), 1.28 (6 H, sext, J = 7.5 Hz), 1.45 (6 H, m) 2.43 (1 H, quin d, J = 8, 2.3 Hz), 2.89 (1 H, d, J = 8 Hz), 3.50 (3 H, s), 5.49 (1 H, d, J = 2.3 Hz); ^{13}C NMR ($CDCl_3$) δ 9.6, 13.7, 20.8, 21.5, 27.3, 29.0, 29.2, 47.7, 48.9, 61.2, 77.3, 144.6, 151.4.

1-(Tri-*n*-butylstannyl)-5-ethyl-3,3,5-trimethyl-4-(methoxyamino)cyclopentene (22c). Reaction of **5** (1.2 g, 6.63 mmol) with Bu_3SnH (1.93 g, 7.95 mmol) and AIBN (0.217 g, 1.32 mmol) in benzene (330 mL) during 49 h provided **22c** (2.9 g, 91%) after purification by column chromatography (pentane/diethyl ether 98/2): IR (film) 2900, 2800, 1575, 1455 cm^{-1}. Anal. Calcd for $C_{23}H_{47}NOSn$: C, 58.48; H, 10.03; N, 2.96. Found: C, 58.44; H, 10.01; N, 2.96. The ^{1}H and ^{13}C NMR were recorded on a mixture of two isomers (88% cis−12% trans); ^{1}H NMR ($CDCl_3$) (major isomer) δ 0.80−0.91 (24 H, compl m), 0.98 (3 H, s), 1.13 (3 H, s), 1.29 (6 H, sext, J = 7.4 Hz), 1.44 (6 H, m), 3.17 (1 H, s), 3.47 (3 H, s), 5.43 (1 H, s); ^{13}C NMR ($CDCl_3$) δ 9.9, 10.2, 13.6, 13.7, 22.9, 23.4, 27.4, 29.2, 34.5, 49.1, 56.2, 60.7, 70.7, 149.5, 150.30; ^{1}H NMR ($CDCl_3$) (minor isomer) δ 0.80 to 0.91 (24 H, compl m), 0.96 (3 H, s), 1.12 (3 H, s), 1.32 (6 H, sext, J = 7.2 Hz), 1.61 (6 H, m), 3.03 (1 H, s), 3.47 (3 H, s), 5.45 (1 H, s); ^{13}C NMR ($CDCl_3$) δ 9.6, 9.96, 13.7, 17.5, 22.9, 23.4, 27.4, 29.2, 30.1, 49.1, 56.2, 60.7, 70.7, 149.5, 150.3.

1-(Tri-*n*-butylstannyl)-5,5-dimethyl-4-(methoxyamino)-cyclopentene (22d). Exposure of **6** (1 g, 7.19 mmol) to Bu_3SnH (2.51 g, 8.63 mmol) and AIBN (0.236 g, 1.44 mmol) in benzene (350 mL) during 48 h provided **22d** (1.13 g, 37%) after purification by column chromatography (pentane/diethyl ether 98/2): IR (liquid film) ν 3300, 2900, 2800, 1570, 1460 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.86 (9 H, t, J = 7.3 Hz), 0.87 (6 H, t, J = 8.3 Hz), 0.90 (3 H, s), 1.12 (3 H, s), 1.30 (6 H, sext, J = 7.3 Hz), 1.44 (6 H, m), 2.20 (1 H, ddd, J = 16.2 Hz, J = 7.6, 2.0 Hz), 2.57 (1 H, ddd, J = 16.2, 7.6, 2.5 Hz), 3.36 (1 H, t, J = 7.6 Hz), 3.51 (3 H, s), 5.63 (1H, dd, J = 2.5, 2.0 Hz); ^{13}C NMR ($CDCl_3$) δ 9.9, 13.7, 21.5, 27.4, 29.2, 38.2, 51.5, 61.3, 69.3, 136.5, 156.2.

General Procedure for the Destannylation Reaction of Compounds 22a−d. The stannyl derivatives **22** were treated with a saturated solution of HCl in diethyl ether at room temperature. The reaction was monitored by TLC. After evaporation of the solvent, the residue was taken up in ether and washed twice with an aqueous solution of $NaHCO_3$ and once with water. The organic layer was dried ($MgSO_4$) and evaporated in vacuo. The crude cyclopentene **23a−d** was purified by column chromatography over silica gel followed by bulb-to-bulb distillation.

3,3,5,5-Tetramethyl-4-(methoxyamino)cyclopentene (23a). Treatment of **22a** (0.75 g, 1.63 mmol) with a saturated solution of HCl in ether (30 mL) produced **23a** (0.228 g, 82%): IR (film) ν 3040, 2980, 1470 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.94 (6 H, s), 1.14 (6 H, s), 3.04 (1 H, s), 3.49 (3 H, s), 5.31 (2 H, s); ^{13}C NMR ($CDCl_3$) δ 23.1, 30.0, 47.2, 60.7, 75.5, 137.7. Anal. Calcd for $C_{10}H_{19}NO$: C, 70.96; H, 11.31; N, 8.27. Found: C, 70.98; H, 11.19; N, 8.18.

3,3,5-Trimethyl-4-(methoxyamino)cyclopentene (23b). Treatment of **22b** (1.36 g, 2.92 mmol) with a saturated solution of HCl in ether (40 mL) produced **23b** (0.348 g, 77%) in a cis/trans ratio of 62/38: IR (film) ν 3250, 3025, 2850, 1615, 1470 cm^{-1}. Anal. Calcd for $C_9H_{17}NO$: C, 69.63; H, 11.03; N, 9.02. Found: C, 69.52; H, 11.13; N, 9.15. NMR data: ^{1}H NMR ($CDCl_3$) (major isomer) δ 0.95 (3 H, s), 0.96 (1 H, d, J = 8 Hz), 1.13 (3 H, s), 2.83 (1 H, quin dd, J = 7.6, 2.6, 1.3 Hz), 3.37 (1 H, d, J = 8 Hz), 3.51 (3 H, s), 5.43 (1 H, dd, J = 5.9, 1.3 Hz), 5.55 (1 H, dd, J = 5.9, 2.7 Hz); ^{13}C NMR ($CDCl_3$) δ 15.3, 24.0, 29.2, 41.7, 46.1, 60.9, 69.0, 132.5, 139.8; ^{1}H NMR ($CDCl_3$) (minor isomer) δ 0.94 (3 H, s), 1.12 (3 H, d, J = 7 Hz), 1.14 (3 H, s), 2.40 (1 H, quin br t, J = 7.7, 2.0 Hz), 2.91 (1 H, d, J = 8 Hz), 3.50 (3 H, s), 5.33 (1 H, dd, J = 5.9, 1.7 Hz), 5.39 (1 H, dd, J = 5.9, 2.2 Hz); ^{13}C NMR ($CDCl_3$) δ 19.5, 21.5, 29.1, 43.0, 47.2, 61.2, 76.8, 131.6, 140.3.

5-Ethyl-3,3,5-trimethyl-4-(methoxyamino)cyclopentene (23c). Treatment of **22c** (0.9 g, 1.9 mmol) with a saturated solution of HCl in ether (40 mL) produced **23c** (0.29 g, 83%) in a cis/trans ratio of 80/20: IR (film) ν 2290, 1470 cm^{-1}. Anal. Calcd for $C_{11}H_{21}NO$: C, 58.48; H, 10.03; N, 2.96. Found: C, 58.44; H, 10.01; N, 2.96. NMR data: ^{1}H NMR ($CDCl_3$) (major isomer) δ 0.84 (3 H, t, J = 7.5 Hz), 0.90 (3 H, s), 0.98 (3 H, s), 1.14 (3 H, s), 1.45 (2 H, q, J = 7.5 Hz); 3.10 (1 H, s), 3.48 (3 H, s), 5.31 (1 H, d, J = 6 Hz), 5.35 (1 H, d, J = 6 Hz); ^{13}C NMR ($CDCl_3$) δ 9.3, 21.3, 23.4 30.1, 34.4, 47.2, 50.7, 60.8, 72.49, 135.3, 138.5; ^{1}H NMR ($CDCl_3$) (minor isomer) δ 0.77 (3 H, t, J = 7.5 Hz), 0.90 (3 H, s), 0.95 (3 H, s), 0.95 (3 H, s), 1.12 (3 H, s), 1.47 (2 H, q, J = 7.5 Hz), 3.07 (1 H, s), 3.49 (3 H, s), 5.37 (1 H, d, J = 6 Hz), 5.44 (1 H, d, J = 6 Hz); ^{13}C NMR ($CDCl_3$) δ 8.9, 23.4, 26.1, 29.1, 30.3, 47.0, 50.4, 60.8, 77.1, 135.5, 138.7.

3,3-Dimethyl-4-(methoxyamino)cyclopentene (23d). Treatment of **22d** (0.68 g, 1.58 mmol) with a saturated solution of HCl in ether (30 mL) produced **23d** (0.109 g, 53.5%): IR (film) ν 3250, 3040, 2950, 1610, 1465 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.94 (3 H, s), 1.12 (3 H, s), 2.09 (1 H, ddt, J = 16.4, 7.5, 2.1 Hz), 2.52 (1 H, dddd, J = 16.4, 7.5, 2.5, 1.5 Hz), 3.39 (1 H, t, J = 7.5 Hz), 3.50 (3 H, s), 5.44 (1 H, dbr t, J = 6, 1.8 Hz), 5.48 (1 H, dbr, t, J = 6, 2.1 Hz); ^{13}C NMR ($CDCl_3$) δ 20.9, 28.4, 36.2, 46.3, 61.4, 68.6, 125.3, 141.7.

General Procedure for the Cyclization of the *β*-Allenic *N,N*-Dimethylhydrazones. In a typical experiment, a benzene solution of Bu_3SnH (2 equiv) and AIBN (0.2 equiv) was slowly added to a refluxing benzene solution (0.02 M) of hydrazone **7**−**11**. The mixture was refluxed until the starting material disappeared (TLC analysis). After evaporation of the solvent the crude product was purified by flash chromatography.

1-(Tri-*n*-butylstannyl)-3,3,5,5-tetramethyl-4-(*N,N*-dimethylhydrazino)cyclopentene (24a). Exposure of **7** (1.26 g, 7 mmol) to Bu_3SnH (4.08 g, 14 mmol) and AIBN (0.23 g, 1.4 mmol) in benzene (170 mL) during 32 h produced **24a** (2.9 g, 89%) as a colorless oil after purification by column chromatography (pentane/diethyl ether 98/2): IR (film) ν 2954, 2805, 2765, 1582, 1463, 1361 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.94 (9 H, t, J = 7.3 Hz), 1.03 (6 H, t, J = 8.2 Hz), 1.14 (3 H, s), 1.17 (3 H, s), 1.23 (3 H, s), 1.30 (3 H, s), 1.39 (6 H, sext, J = 7.3 Hz), 1.62 (6 H, m), 1.74 (1 H, br m), 2.26 (6 H, s), 2.90 (1 H, s), 5.65 (1 H, s); ^{13}C NMR ($CDCl_3$) δ 10.2, 13.9, 23.8, 24.7, 27.7, 29.6, 30.1, 31.1, 47.1, 49.6, 53.7, 73.7, 150.0, 151.3. Anal. Calcd for $C_{23}H_{48}N_2Sn$: C, 58.61; H, 10.26; N, 5.94. Found: C, 58.58; H, 10.32; N, 5.98.

1-(Tri-*n*-butylstannyl)-5-ethyl-3,3,5-trimethyl-4-(*N,N*-dimethylhydrazino)cyclopentene (24b). Exposure of **8** (1.35 g, 7 mmol) to Bu_3SnH (4.08 g, 14 mmol) and AIBN (0.23 g, 1.4 mmol) in benzene (170 mL) during 24 h produced **24b** (2.61 g, 77%) as a colorless oil after purification by column chromatography (pentane/diethyl ether 98/2): IR (film) ν 2905, 2800, 1430 cm^{-1}. Anal. Calcd for $C_{24}H_{50}N_2Sn$: C, 59.39; H, 10.38; N, 5.77. Found: C, 59.35; H, 10.40; N, 5.78. The ^{1}H and ^{13}C NMR were recorded on a mixture of the both isomers (cis 81%−trans 19%). Major isomer: ^{1}H NMR (C_6D_6) δ 0.94 (12 H, t, J = 7.3 Hz), 1.03 (6 H, m), 1.13 (3 H, s), 1.21 (3 H, s), 1.29 (3 H, s), 1.39 (6 H, sext, J = 7.5 Hz), 1.48 (2 H, q, J = 7.3 Hz), 1.62 (6 H, m), 1.76 (1 H, br m), 2.25 (6 H, s), 3.05 (1 H, s), 5.67 (1 H, s); ^{13}C NMR (C_6D_6) δ 10.1, 10.2, 13.9, 23.9, 24.2, 27.8, 29.6, 30.1, 34.8, 47.2, 50.2, 57.1, 67.4, 149.6, 151.2. Minor isomer: ^{1}H NMR (C_6D_6) δ 0.94 (12 H, t, J = 7.3 Hz), 1.03 (6 H, m), 1.07 (3 H, s), 1.15 (3 H, s), 1.24 (3 H, s), 1.39 (6 H, sext, J = 7.5 Hz), 1.48 (2 H, q, J = 7.3 Hz), 1.62 (6 H, m), 1.76 (1 H, br m), 2.24 (6 H, s), 2.95 (1 H, s), 5.68 (1 H, s); ^{13}C NMR (C_6D_6) δ 10.5, 11.4, 13.9, 23.4, 27.8, 29.6, 29.9, 30.4, 31.2, 47.1, 49.7, 57.3, 74.5, 149.7, 151.0.

1-(Tri-*n*-butylstannyl)-3,3,5-trimethyl-4-(*N,N*-dimethylhydrazino)cyclopentene (24c). Exposure of **9** (0.5 g, 3 mmol) to Bu_3SnH (1.74 g, 6 mmol) and AIBN (0.1 g, 0.6 mmol) in benzene (85 mL) during 24 h produced **24c** (1.24 g, 77%) as a colorless oil after purification by column chromatography (pentane/diethyl ether 94/6). In this way, the cis (60%) and

trans (40%) stereoisomers were separated. Cis isomer: IR (film) ν 2955, 2925, 2871, 2766, 1456, 1376, 1361 cm^{-1}; ^1H NMR (C_6D_6) δ 0.93 (9 H, t, J = 7.3 Hz), 1.00 (6 H, t, J = 8.0 Hz), 1.11 (3 H, s), 1.17 (3 H, s), 1.19 (3 H, d, J = 7.2 Hz), 1.37 (6 H, sext, J = 7.4 Hz), 1.60 (6 H, m), 1.77 (1 H, br m), 2.28 (6 H, s), 3.03 (1 H, dqd, J = 7.7, 7.2, 1.1 Hz), 3.23 (1 H, d, J = 7.7 Hz), 5.74 (1 H, d, J = 1.1 Hz); ^{13}C NMR (C_6D_6) δ 9.4, 13.6, 16.6, 24.5, 27.4, 28.9, 29.3, 47.3, 48.0, 49.6, 66.8, 146.0, 151.2. Anal. Calcd for $C_{22}H_{46}N_2Sn$: C, 57.78; H, 10.14; N, 6.12. Found: C, 57.77; H, 10.23; N, 6.10. Trans isomer: IR (film) ν 2954, 2855, 2765, 1456, 1463, 1376 cm^{-1}; ^1H NMR (C_6D_6) δ 0.93 (9 H, t, J = 7.4 Hz), 0.98 (6 H, t, J = 8.0 Hz), 1.15 (3 H, s), 1.17 (3 H, d, J = 7.0 Hz), 1.31 (3 H, s), 1.37 (6 H, sext, J = 7.4 Hz), 1.59 (6 H, m), 1.79 (1 H, br m), 2.27 (6 H, s), 2.61 (1 H, dqd, J = 8.0, 7.0, 2.2 Hz), 2.78 (1 H, d, J = 8.0 Hz), 5.74 (1 H, d, J = 2.2 Hz); ^{13}C NMR (C_6D_6) δ 9.8, 13.9, 20.6, 22.3, 27.6, 29.0, 29.6, 47.4, 49.9, 54.3, 74.3, 144.2, 152.7. Anal. Calcd for $C_{22}H_{46}N_2Sn$: C, 57.78; H, 10.14; N, 6.12. Found: C, 57.77; H, 10.23; N, 6.10.

Cyclization of 5-Cyclohexylidene-2,2-dimethylpenta-3,4-dienal *N*,*N*-Dimethylhydrazone (10). Exposure of **10** (0.88 g, 4 mmol) to Bu_3SnH (4.66 g, 14 mmol) and AIBN (0.23 g, 1.4 mmol) in benzene (170 mL) during 58 h produced **24d** (1.18 g, 58%) as a colorless oil and **25d** (0.22 g, 25%) as a white solid (mp 35−40 °C), after purification by column chromatography (gradient pentane/diethyl ether 96/4, 90/10, 85/15). **1-(Tri-*n*-butylstannyl)-3,3-dimethyl-4-(*N*,*N*-dimethylhydrazino)spiro[4,5]decene (24d):** IR (film) ν 2900, 2820, 1464, 1376 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.82 (15 H, 2t, J = 7.5 Hz), 0.96 (3 H, s), 1.06 (3 H, s), 1.24 (6 H, sext, J = 7.5 Hz), 1.40 (6 H, m), 1.50 (9 H, m), 1.66 (1 H, m), 2.13 (1 H, br m), 2.54 (6 H, s), 2.77 (1 H, s), 5.37 (1 H, s); ^{13}C NMR ($CDCl_3$) δ 10.4, 13.7, 23.6, 23.7, 24.1, 25.7, 27.4, 29.2, 30.6, 33.2, 40.9, 47.4, 50.6, 56.1, 74.7, 150.8, 150.8. Anal. Calcd for $C_{26}H_{52}N_2Sn$: C, 61.06; H, 10.24; N, 5.48. Found: C, 61.09; H, 10.19; N, 5.46. **2-Cyclohexylidene-4-methylpent-3-enal *N*,*N*-dimethylhydrazone (25d):** IR (KBr) ν 2900, 2800, 1464, 1558, 1471, 1437 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.49 (3 H, s), 1.58 (6 H, m), 1.80 (3 H, s), 2.18 (2 H, m), 2.80 (6 H, s), 5.76 (1 H, s), 7.43 (1 H, s); ^{13}C NMR ($CDCl_3$) δ 19.9, 25.3, 26.9, 27.7, 28.1, 30.0, 32.7, 43.1, 122.3, 127.0, 133.7, 135.5, 141.5; MS *m*/*e* (70 eV) 220 (M^+, 34), 205 (42.7), 176 (92.4). Anal. Calcd for $C_{14}H_{24}N_2$: C, 76.31; H, 10.97; N, 12.71. Found: C, 76.78; H, 10.56; N, 12.37.

Cyclization of 3,3,6-Trimethylhepta-4,5-dien-2-one *N*,*N*-Dimethylhydrazone (11). Exposure of **11** (1.19 g, 6.13 mmol) to Bu_3SnH (2.14 g, 7.36 mmol) and AIBN (0.20 g, 1.22 mmol) in benzene (300 mL) during 11 h produced **24e** (0.47 g, 16.2%) and **25e** (0.78 g, 57.2%) as colorless oils after purification by column chromatography (gradient pentane/diethyl ether 96/4, pentane/ethyl acetate 80/20). **1-(Tri-*n*-butylstannyl)-3,3,4,5,5-pentamethyl-4-(*N*,*N*-dimethylhydrazino)-cyclopentene (24e):** IR (film) ν 2950, 2800, 1420, 1350 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.86 (6 H, t, J = 8.2 Hz), 0.87 (9 H, t, J = 7.3 Hz), 0.96 (3 H, s), 0.97 (3 H, s), 1.01 (3 H, s), 1.05 (3 H, s), 1.06 (3 H, s), 1.30 (6 H, sext, J = 7.3 Hz), 1.46 (6 H, m), 2.11 (1 H, br s), 2.42 (6 H, s), 5.37 (1 H, s); ^{13}C NMR ($CDCl_3$) δ 9.9, 13.8, 21.1, 25.4, 26.5, 26.9, 27.4, 27.5, 29.2, 51.5, 51.6, 55.9, 69.4, 149.3, 150.0. Anal. Calcd for $C_{24}H_{50}N_2Sn$: C, 59.39; H, 10.38; N, 5.77. Found: C, 59.35; H, 10.42; N, 5.80. **3-Isopropylidene-5-methylhex-4-en-2-one *N*,*N*-dimethylhydrazone (25e).** The ^1H and ^{13}C NMR of this compound were recorded on a mixture of two stereoisomers, which are the *E* (70%) and *Z* (30%) isomers of the hydrazone. ***E* stereoisomer:** ^1H NMR ($CDCl_3$) δ 1.44 (3 H, d, J = 1.1 Hz), 1.50 (3 H, br s), 1.59 (3 H, d, J = 1.3 Hz), 1.61 (3 H, d, J = 1.3 Hz), 1.78 (3 H, s), 2.34 (6 H, s), 5.50 (1 H, m); ^{13}C NMR ($CDCl_3$) δ 17.2, 19.2, 20.8, 21.1, 25.7, 46.8, 122.2, 131.9, 132.8, 135.8, 167.6. ***Z* stereoisomer:** ^1H NMR ($CDCl_3$) δ 1.45 (3 H, d, J = 1.1 Hz), 1.47 (3 H, br s), 1.48 (3 H, d, J = 1.3 Hz), 1.61 (3 H, d, J = 1.3 Hz), 1.78 (3 H, s), 2.28 (6 H, s), 5.50 (1 H, m); ^{13}C NMR ($CDCl_3$) δ 19.5, 20.3, 21.7, 23.4, 25.7, 47.0, 121.1, 128.0, 132.3, 135.0, 165.1.

Cyclization of 2,2,5-Trimethylhexa-3,4-dienal SAMP-hydrazone (12). Exposure of **12** (0.5 g, 2 mmol) to Bu_3SnH (0.7 g, 2.4 mmol) and AIBN (0.065 g, 0.4 mmol) in benzene (100 mL) during 20 h produced the cyclized product **1-(tri-*n*-butylstannyl)-3,3,5,5-tetramethyl-4-(SAMP-hydrazino)-cyclopentene (26)** (0.84 g, 78%) as a slightly yellow oil after purification by column chromatography (pentane/diethyl ether 91/9): $[\alpha]^{25}_{5461A}$ −74.4° (*c* 0.58, cyclohexane); IR (film) ν 2900−2800, 1600, 1464, 1376, 1362 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.82 (15 H, t, J = 7 Hz), 0.84 (3 H, s), 0.87 (3 H, s), 0.90 (3 H, s), 0.92 (3 H, s), 1.03 (3 H, s), 1.06 (3 H, s), 1.07 (3 H, s), 1.23 (6 H, sext, J = 7.2 Hz), 1.40 (6 H, m), 1.46 (2 H, m), 1.62 (2 H, m), 1.83 (2 H, m), 2.76 (1 H, s), 3.26 (3 H, s), 3.24−3.32 (1 H, m), 3.36−3.41 (1 H, m), 3.62 (1 H, br dd, J = 8.9, 4.3 Hz), 5.36 (major) and 5.38 (minor) (1H, 2s); ^{13}C NMR ($CDCl_3$) (major diastereomer) δ 9.8, 13.7, 20.8, 23.4, 24.1, 26.5, 27.3, 29.2, 29.6, 31.0, 48.3, 53.6, 56.9, 58.9, 66.2, 74.8, 75.8, 148.7, 151.7; (minor diastereomer) δ 9.8, 13.7, 20.8, 23.3, 24.1, 26.5, 27.3, 29.2, 30.0, 31.6, 49.4, 52.5, 56.5, 58.9, 66.0, 74.5, 75.9, 150.1, 150.3. Anal. Calcd for $C_{27}H_{54}N_2OSn$: C, 59.89; H, 10.05; N, 5.17. Found: C, 59.65; H, 10.00; N, 5.09.

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Supporting Information Available: Experimental procedures and ^1H and ^{13}C NMR spectra for compounds **1**, **2**, and **3**−**12** (3 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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