separated. The aqueous layer was extracted with an additional 10 mL of benzene and the combined extracts were dried (Na_2SO_4). *n*-Octanoic acid (114 mg, 0.79 mmol) was obtained (yield, 99%). The NMR, IR, and mass spectral data of *n*-octanoic acid obtained were identified with those of an authentic sample.

Registry No. IV, 31645-22-4; V, 97625-48-4; VII, 99232-63-0; KO_2, 12030-88-5; $Bu_4N^+ \cdot Cl^-$, 1112-67-0; $CH_3(CH_2)_6CO_2Me$, 111-11-5; $CH_3(CH_2)_6CO_2H$, 124-07-2; O_2, 7782-44-7; superoxide ion, 11062-77-4.

Methods for the Synthesis of Chiral Hindered Amines

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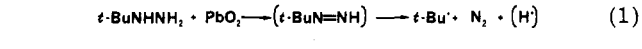
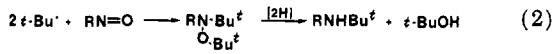
Hindered chiral amines are of interest in connection with the development of new methodology for catalytic enantioselective transformations, for example, a reaction such as cyclohexene oxide → 2-cyclohexen-1-ol. This paper describes an effective method for the synthesis of such amines which is based on a free-radical approach. We recently reported[1] that *tert*-butyl radicals can be generated on a preparative scale by reaction of commercially available *tert*-butylhydrazine with lead dioxide and that efficient trapping occurs with *tert*-alkylnitroso compounds to afford substituted N,N,O-trisubstituted hydroxylamines which can be reduced directly to di-*tert*-alkylamines as shown by the sequence in eq 1 and 2.

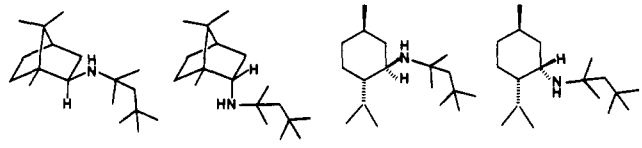


(1)

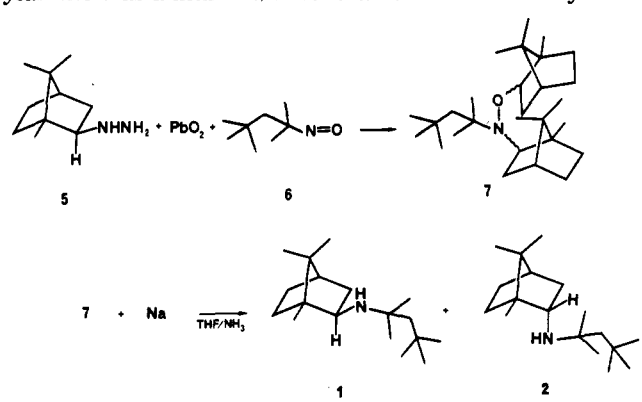


(2)

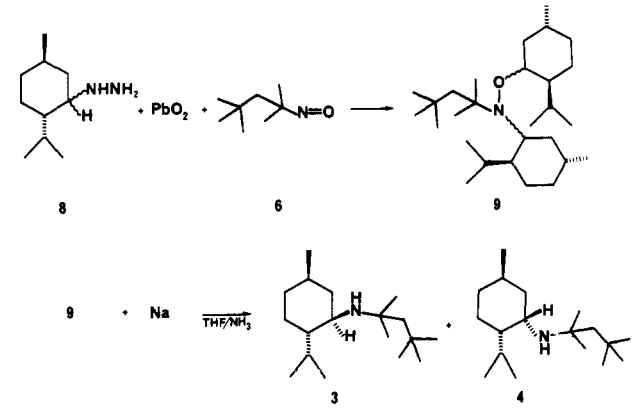
The synthesis of the chiral amines (1–4) was carried out using this new methodology starting from (+)-camphor and (−)-menthone. The key step in these syntheses was the



generation of the secondary alkyl radicals from camphor and menthone. As for the reaction of *tert*-butylhydrazine, reaction of bornylhydrazine **5** with PbO_2 in the presence of nitroso-*tert*-octane (**6**) gave the trisubstituted hydroxylamine **7** as a mixture of several isomers. The hydroxylamine **7** was unstable to acid and heat (80 °C) and therefore was reduced directly without purification. Reduction of **7** with either sodium in tetrahydrofuran (THF)–ammonia or sodium naphthalenide in THF afforded the chiral *exo*- and *endo*-bornyl-*tert*-octylamines **1** and **2** in a 1:1 ratio. The amines were easily separated by chromatography on silica gel (ethyl acetate–hexane) with the less polar amine (R_f 0.7) being assigned as the exo compound **1** and the more polar amine (R_f 0.2) as the Endo compound **2** by analogy with the observed polarities of bornyl and isobornylamines.

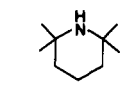
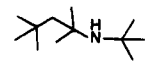
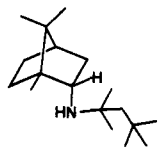
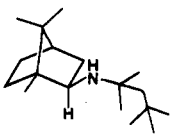
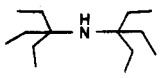
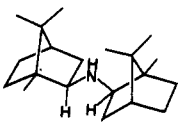


Similarly, reaction of menthylhydrazine **8** with PbO_2 in the presence of nitroso-*tert*-octane gave the hydroxylamine **9** as a mixture of isomers which upon reduction with sodium in THF–ammonia gave the equatorial amine **3** and the epimer **4** in a ratio of 20:1, respectively. Again the amines **3** and **4** were readily separable by chromatography, and their respective configurations were assigned on the basis of their polarities. The high selectivity for the equatorial amine indicates a strong steric influence in the addition of the menthone radical to the nitroso compound.



Bornylhydrazine (**5**) and menthylhydrazine (**8**) were readily prepared by condensation of (+)-camphor and (−)-menthone with ethyl carbazate[2] to yield the carbo-

Table I

	pK_a
	10.1
	9.6
	8.6
	7.9
	7.1
	4.7

(1) Corey, E. J.; Gross, A. W. *Tetrahedron Lett.* **1984**, *25*, 491.

(2) (a) Ghali, N.; Venton, D.; Hung, S.; Le Baron, G. *J. Org. Chem.* **1981**, *46*, 5413. (b) Chaco, M. C.; Stapp, P. R.; Ross, J. A.; Rabjohn, N. *J. Org. Chem.* **1962**, *27*, 3371. (c) Geigy, J. R. A. G. Swiss 307 629, **1955**; *Chem. Abstr.* **1957**, *51*, 5113.

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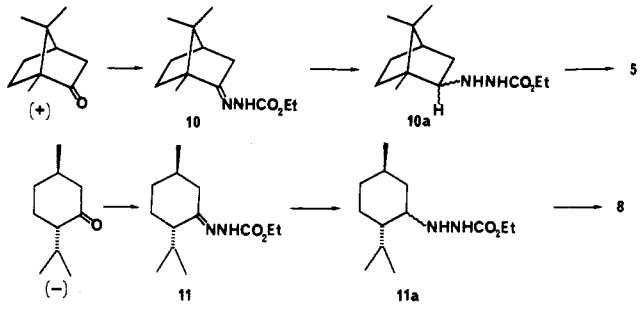
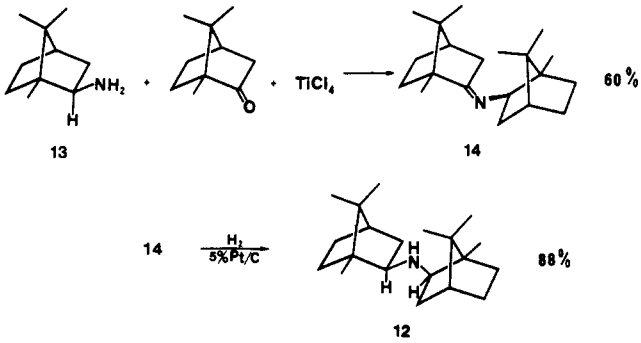
ethoxyhydrazones **10** and **11**. Hydrogenation followed by basic hydrolysis of the resultant carboethoxyhydrazines afforded **5** and **8**.[3]



In addition to the amines (**1**–**4**) the C_{2v} symmetric diisobornylamine[4] (**12**) was of interest. Since secondary alkyl nitroso compounds are tautomeric with their oximes, diisobornylamine was prepared via a different route. Conversion of (+)-camphor to its oxime followed by catalytic reduction over Raney nickel gave isobornylamine (**13**).[5]



Condensation of isobornyl amine with (+)-camphor in the presence of titanium tetrachloride afforded imine **14**.[6] Catalytic hydrogenation of the imine gave diisobornylamine (**12**), mp 60 °C.[4]

Table I tabulates the pK_a's of several hindered amines in 90% ethanol–water. It is apparent that increased steric hindrance leads to a decrease in pK_a. The low pK_a value for diisobornylamine is of special interest. The extreme steric hindrance of diisobornylamine as compared to *tert*-octyl-*tert*-butylamine is further illustrated by their differing reactivities with methyllithium. The reaction of excess *tert*-octyl-*tert*-butylamine with methyllithium in ether at 23 °C for 1 h led to complete consumption of methyllithium with concomitant formation of the lithium amide. Diisobornylamine was not metalated under these conditions. Indeed, diisobornylamine was not metalated under a variety of more strenuous conditions including methyllithium–HMPA and *n*-BuLi–TMEDA at 60 °C. No reaction was observed between diisobornylamine and acetic anhydride at reflux or between diisobornylamine and methyl iodide in dimethoxyethane at reflux.

Experimental Section

General. ^{1}H NMR spectra were taken on either a Varian HFT-80 or a Jeol FX-270 nuclear magnetic resonance spectrometer. All chemical shifts are reported in parts per million downfield from internal tetramethylsilane. Infrared spectra were recorded on a Perkin-Elmer Model 683 spectrophotometer and optical rotations were determined on a Perkin-Elmer Model 241 polarimeter. Mass spectra were taken on either an AEI MS-9 or Kratos MS-50 spectrometer. Melting points were determined with a Fischer-Johns melting point apparatus and are uncorrected.

2-Bornanone *N*-Carboethoxyhydrazone (10). Into a 250-mL flask with reflux condenser were placed (+)-camphor (10.0 g, 69.67 mmol), ethyl carbazate (10.0 g, 96.0 mmol, 1.46 equiv), 150 mL of ethanol, and 100 mg of acetic acid. After being heated for 54 h at reflux the reaction mixture was cooled, diluted with water, and extracted with 1:1 ether–hexane. The extracts were washed with water and then with brine. Drying over sodium sulfate and concentration in vacuo gave a white solid, which was triturated with pentane to yield pure **10** (14.75 g, 61.96 mmol, 94%): mp 143–144 °C; $[\alpha]^{22}_D$ −35.0° (*c* 1.0, chloroform); ^{1}H NMR ($CDCl_3$) δ 7.22 (s, 1 H), 4.24 (q, 2 H), 2.40 (m, 1 H), 2.23 (m, 1 H), 2.0–1.1 (m, 5 H), 1.30 (t, 3 H), 1.07 (s, 3 H), 0.92 (s, 3 H), 0.75 (s, 3 H); IR 3380, 1745, 1715 cm^{-1}; MS, *m/e* 238 (M^+).

Menthone *N*-Carboethoxyhydrazone (11). (−)-Menthone (10.0 g, 64.8 mmol), ethyl carbazate (9.0 g, 96.4 mmol, 1.33 equiv), 60 mL of ethanol, and 100 mg of acetic acid were placed in a 100-mL flask. After being stirred at 23 °C for 24 h the reaction mixture was diluted with water and extracted with 1:1 ether–hexane. The extracts were washed with water and then brine and dried over sodium sulfate. Removal of solvent in vacuo afforded **11** as a viscous oil (14.79 g, 61.55 mmol, 95%); $[\alpha]^{22}_D$ −9.6° (*c* 1.0, chloroform); ^{1}H NMR ($CDCl_3$) δ 7.63 (s, 1 H), 4.32 (q, 2 H), 2.5–0.80 (m, 18 H), 1.29 (t, 3 H); IR 3260, 1730 cm^{-1}; MS, *m/e* 240 (M^+).

2-Bornyl-*N*-carboethoxyhydrazine (10a). 2-Bornanone *N*-carboethoxyhydrazone (**10**) (10.0 g, 41.96 mmol), 40 mL of ethanol, 18 mL of acetic acid, and 200 mg of platinum oxide were placed in a Parr pressure bottle, and the bottle was charged with hydrogen (40 psi). After 36 h the catalyst was recovered by filtration, and the filtrate was neutralized with saturated sodium bicarbonate. Extraction into 1:1 ether–hexane, drying over sodium sulfate, and evaporation of solvent gave **10a** as a viscous oil (9.68 g, 40.3 mmol, 96%), exo/endo 98:2. Exo compound: $[\alpha]^{22}_D$ −58.0° (*c* 1.0, chloroform); ^{1}H NMR ($CDCl_3$) δ 6.13 (s, 1 H), 4.15 (q, 2 H), 3.76 (s, 1 H), 2.89 (t, 1 H), 1.60 (m, 7 H), 1.25 (t, 3 H), 1.01 (s, 3 H), 0.93 (s, 3 H), 0.70 (s, 3 H); IR 3330, 1718 cm^{-1}; MS, *m/e* 240 (M^+).

***p*-Menth-3-yl-*N*-carboethoxyhydrazine (11a).** Hydrogenation of **11** (13.5 g, 56.18 mmol) as described for **10** afforded **11a** (12.90 g, 53.37 mmol, 95%) as a 10:1 mixture of diastereomers. Major diastereomer: $[\alpha]^{22}_D$ −47.0° (*c* 1.0, chloroform); ^{1}H NMR ($CDCl_3$) δ 5.97 (s, 1 H), 4.15 (q, 2 H), 3.91 (s, 1 H), 3.34 (s, 1 H), 1.80–1.30 (m, 9 H), 1.25 (t, 3 H), 1.10, 1.02, 0.95, 0.87, 0.80 (total 9 H); IR 3330, 1715 cm^{-1}; MS, *m/e* 242 (M^+).

2-Bornylhydrazine (5). 2-Bornyl-*N*-carboethoxyhydrazine (**10a**) (10.0 g, 41.6 mmol), 40 mL of ethanol, and 25 mL of 3 N sodium hydroxide were placed in a 100-mL flask. The reaction mixture was heated at reflux for 4 h and then cooled to room temperature. The solution was diluted with water and extracted with 1:1 ether–hexane. Treatment with dry, gaseous HCl afforded **5** as its hydrochloride salt (8.52 g, 41.6 mmol, 100%): ^{1}H NMR ($CDCl_3$) δ 8.60 (s, 3 H), 3.79 (m, 1 H), 2.48 (m, 1 H), 2.15–1.15 (m, 8 H), 1.29 (s, 3 H), 1.16 (s, 3 H), 0.86 (s, 3 H).

***p*-Menth-3-ylhydrazine (8).** Basic hydrolysis of **11a** (15.0 g, 61.9 mmol) as described for **10a** afforded **8** which was isolated as its hydrochloride salt (11.9 g, 57.55 mmol, 93%): ^{1}H NMR ($CDCl_3$) δ 9.0 (br s, 3 H), 3.54 (m, 1 H), 2.5–1.0 (m, 10 H), 1.07, 0.99, 0.94, 0.92, 0.87 (total 9 H).

Hydroxylamine 7. Nitroso-*tert*-octane[1] (1.0 g, 6.93 mmol) and 40 mL of hexane were placed in a 100-mL flask fitted with mechanical stirrer, addition funnel, and gas inlet. The solution was stirred for 1 h to establish monomer–dimer equilibrium, and lead dioxide (7.46 g, 31.18 mmol, 4.5 equiv) was added. 2-Bornylhydrazine (**5**) (3.54 g, 20.79 mmol, 3 equiv) was added dropwise to the stirred solution so as to give brisk but controlled nitrogen evolution. When the addition was complete the characteristic blue nitroso monomer color had been discharged. Lead oxides were removed by filtration through Celite, the filtrate was dried over sodium sulfate, and solvent was removed in vacuo to give

(3) The alkylhydrazines were readily air oxidized and therefore were handled in solution or as their hydrochloride salts.

(4) Diisobornylamine had been previously prepared as a byproduct in the Leuckart reaction for the preparation of bornylamine and isobornylamine. Huckel, W.; Rieckmann, P. *Ann.* **1957**, *625*, 1.

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(8) This work was assisted financially by a grant from the National Science Foundation.

7 as a viscous oil (2.85 g, 6.90 mmol, 99.5% mass recovery). The product was thermally labile (80 °C) and acid sensitive and was reduced directly.

Hydroxylamine 9. The reaction of *p*-menth-3-ylhydrazine (8) (12.5 g, 73.2 mmol, 3 equiv), lead dioxide (35.0 g, 146 mmol, 6 equiv), and nitroso-*tert*-octane (3.5 g, 24.4 mmol) as described for the preparation of 7 afforded 9 (10.3 g, 24.4 mmol). The product was reduced directly.

***exo*- and *endo*-2-Bornyl-*tert*-octylamines (1 and 2).** Ammonia (50 mL) was condensed into a 250-mL flask at −78 °C and hydroxylamine 7 was added in 50 mL of THF. The solution was allowed to warm to −30 °C, and sodium pieces (1.0 g, 43.4 mmol, 8.6 equiv) were added in four portions over 6 h. The reaction was carefully quenched with 30% isopropanol–hexanes, and ammonia was removed under a nitrogen stream. The product was extracted into 1 N HCl, and the extracts were neutralized with saturated sodium bicarbonate. Extraction into ether, drying over sodium sulfate, and evaporation gave a 1:1 mixture of the amines 1 and 2 (1.06 g, 3.99 mmol, 79.4%). Chromatography on silica gel (hexane → 90% ethyl acetate–hexane) afforded the pure amines. *exo*-2-Bornyl-*tert*-octylamine (1): $[\alpha]^{22}_D$ −71.0° (*c* 2.5, chloroform); ^{1}H NMR ($CDCl_3$) δ 2.50 (m, 1 H), 2.0–1.0 (m, 7 H), 1.35 (s, 2 H), 1.04 (s, 6 H), 1.00 (s, 9 H), 0.94 (s, 3 H), 0.86 (s, 3 H), 0.78 (s, 3 H); MS, *m/e* 265 (M^+). *endo*-2-Bornyl-*tert*-octylamine (2): $[\alpha]^{22}_D$ +31.0° (*c* 3.7, chloroform); ^{1}H NMR 2.70 (m, 1 H), 2.4–1.0 (m, 7 H), 1.40 (s, 2 H), 1.08 (s, 6 H), 1.02 (s, 9 H), 0.87 (s, 3 H), 0.86 (s, 3 H), 0.78 (s, 3 H).

***p*-Menth-3-yl-*tert*-octylamines (3 and 4).** The reduction of hydroxylamine 9 (36.7 g, 87 mmol) as described for hydroxylamine 7 afforded 3 and 4 (16.5 g, 61.7 mmol, 71%) in a ratio of 20:1, respectively. 3: $[\alpha]^{22}_D$ −46.0° (*c* 2.5, chloroform); ^{1}H NMR ($CDCl_3$) δ 2.88 (m, 1 H), 2.0–1.0 (m, 9 H), 1.40 (s, 2 H), 1.11 (d, 6 H), 1.00 (s, 9 H), 0.90, 0.88, 0.82 (total 9 H); MS, *m/e* 267 (M^+). 4: $[\alpha]^{22}_D$ −35.0° (*c* 2.5, chloroform); ^{1}H NMR 3.03 (m, 1 H), 2.0–1.0 (m, 9 H), 1.39 (s, 2 H), 1.12 (d, 6 H), 1.02 (s, 9 H), 0.93, 0.85, 0.81 (total 9 H). MS, *m/e* 267 (M^+).

***N*-Isobornylcamphor Imine (14).** Isobornylamine (25.0 g, 163 mmol), (+)-camphor (6.6 g, 43.3 mmol), and 200 mL of toluene were placed in a 250-mL flask. Titanium tetrachloride (4.13 g, 21.7 mmol) was added, and the reddish-brown solution was heated to reflux for 14 h. The reaction mixture was cooled to room temperature and filtered to remove isobornylamine hydrochloride. Removal of solvent and chromatography on silica gel (5% ether–hexane) gave 14 (7.7 g, 26.27 mmol, 60.6%): $[\alpha]^{22}_D$ −41.0° (*c* 0.8, chloroform); ^{1}H NMR ($CDCl_3$) δ 3.1 (dd, 1 H), 2.55 (m, 2 H), 2.0–1.0 (m, 12 H), 1.14 (s, 3 H), 0.90 (s, 3 H), 0.88 (s, 3 H), 0.82 (s, 3 H), 0.74 (s, 3 H), 0.70 (s, 3 H); MS, *m/e* 287 (M^+).

Diisobornylamine (12). The imine 14 (7.7 g, 26.27 mmol), 30 mL of ethanol, and 500 mg of 5% platinum on carbon were placed in a Parr pressure bottle. The bottle was charged with hydrogen (45 psi), and the reaction mixture was shaken for 18 h. The catalyst was recovered by filtration and the filtrate concentrated. Chromatography on silica gel (5% ether–hexane, R_f 0.75) gave 12 as a white solid (6.7 g, 23.1 mmol, 87.9%). Recrystallization from methanol gave an analytical sample: mp 60 °C (lit. mp 60 °C[4]); $[\alpha]^{22}_D$ −140.0° (*c* 1.0, chloroform); ^{1}H NMR ($CDCl_3$) δ 2.46 (dd, 2 H), 1.5 and 1.05 (m, 15 H), 0.95 (s, 6 H), 0.79 (s, 6 H), 0.78 (s, 6 H); MS, *m/e* 289 (M^+).

A Practical and Efficient Synthesis of α,β-Unsaturated Acylsilanes

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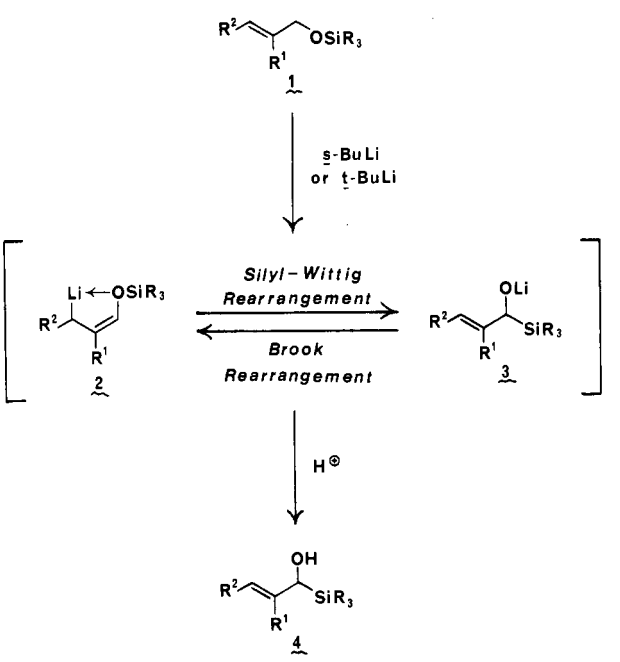
Received June 28, 1985

In recent years, α,β-unsaturated acylsilanes have emerged as valuable building blocks for the synthesis of complex organic compounds. Functioning as α,β-unsaturated carbonyl derivatives, they readily participate in a variety of carbon–carbon bond forming processes, including organocuprate conjugate additions,[2] $TiCl_4$-mediated conjugate allylations,[3] Diels–Alder reactions,[2] 1,3-dipolar cycloadditions,[4] and the [3 + 2] annulation reaction recently developed in our laboratory.[4,5] The synthetic utility of these reactions is enhanced by the fact that the product acylsilanes are subject to a variety of useful further transformations,[6] including, for example, Brook reactions,[2,7] oxidation to carboxylic acids,[8] and fluoride-promoted conversion to ketones and aldehydes.[8b,9]

Scheme I



Although several general synthetic approaches to α,β-unsaturated acylsilanes have previously been reported,[2-4,8b,10] these methods have proved less than satisfactory when applied to the synthesis of compounds lacking β-substituents such as the acryloyl and methacryloyl derivatives **7a** and **7b**. Not surprisingly, these simple but highly

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