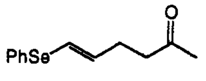
(SiMe$_3$) groups is based on 2D-NOESY. The relative configuration at C$_2$ and C$_6$ could not be determined from the NMR spectra.

The reaction of **1** and **2a** with SnCl$_4$ in CH$_2$Cl$_2$ (−78 °C, 3 h), followed by quenching with water instead of triethylamine gave **3a** (51%) and the Michael adduct (*E*)-6-(phenylseleno)-5-hexen-2-one (**6**) (8%). The NMR spectra of the cycloadducts **3b–d** are also in complete agreement with the cyclopropane structures.



6

The structure of **3a** was confirmed by a three-step conversion to the three-membered natural product, (±)-rothrockene (**4**)[9] (Scheme II). Methylenation of the carbonyl group of **3a** by Zn–CH$_2$Br$_2$–TiCl$_4$[12] gave **7** in 90% yield. Olefin **7** was oxidized with NaIO$_4$ in THF–H$_2$O solution at room temperature to give the sila-Pummerer products **8** and **9**.[13] Aldehyde **8** was obtained in 39% yield as a major product along with the ring-opened byproduct **9** (12.9% yield, *E*/*Z* = 8/1). Wittig reaction of **8** with isopropylidene–triphenylphosphorane in THF gave (±)-rothrockene (**4**) in 67% yield. The spectral data of **4** are in accord with the reported data.[9]

The observed preference for cyclopropanation instead of four-membered ring formation is rationalized as follows. In the first step, the nucleophilic vinyl selenide **1** attacks the electrophilic olefins **2a–d** activated by a Lewis acid to give carbonium ion X in Scheme I. The regioselectivity of this reaction with respect to selenium is the same as it is in the reaction of **1** or 1-(phenylseleno)-1-(trimethylsilyl)ethene (**10**) and unsaturated acid chlorides in the presence of Lewis acids.[14,10] Furthermore, the zwitterionic intermediate X is stabilized by interaction with the adjacent carbon-silicon bond ("β-silicon effect") to give a silicon-bridged carbocation Y. Nucleophilic attack of C$_6$ at the kinetically favored C$_\beta$ position rather than at C$_\alpha$ generates the cyclopropane ring as a result of a 1,2-shift of the trimethylsilyl group (Scheme I).

To our knowledge, this is the first example of a 1,2-silicon migration giving rise to a cyclopropane ring. The synthetic utility of the unsymmetrically substituted cyclopropane products is demonstrated by the synthesis of (±)-rothrockene (**4**). Further studies are under way in our laboratory so as to determine why the Se–Si combination leads to a strained three-membered ring and to carry out further applications of this novel cyclopropanation.

Acknowledgment. We are grateful to Prof. I. Murata and Dr. K. Yamamoto (Osaka University) for measurement of NMR (400 and 500 MHz), mass spectra, and elemental analyses. We also thank Dr. K. Yamamoto and Dr. David Barrett for helpful discussions.

Supplementary Material Available: Experimental details and spectral data for **3a–d**, **4**, and **6–9**, ^{1}H, ^{13}C, ^{13}C/^{1}H COSY, long-range ^{13}C/^{1}H COSY, and 2D-NOESY actual spectra of **3a**, and ^{1}H and ^{13}C NMR actual spectra of **4** (19 pages). Ordering information is given on any current masthead page.

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Carbonyl-Protected β-Lithio Aldehydes and Ketones via Reductive Lithiation. A General Preparative Method for Remarkably Versatile Homoenolate Equivalents

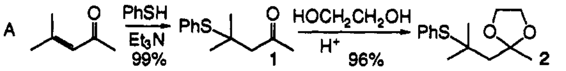
John P. Cherkauskas and Theodore Cohen*

Department of Chemistry, University of Pittsburgh, Pittsburgh, Pennsylvania 15260

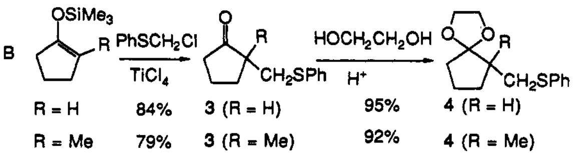
Received November 5, 1991

Summary: A general procedure for producing homoenolate equivalents consists of reductive lithiation, induced by 4,4′-di-*tert*-butylbiphenylide, of carbonyl-protected β-(phenylthio) carbonyl compounds prepared in turn by thiophenol addition to enones or the alkylation of silyl enol ethers by α-chlorothioethers.

Although homoenolate anions and their synthetic equivalents have been long recognized as potentially powerful synthons,[1] there are as yet no general methods available for their preparation. We now present the most general and versatile preparative method for homoenolate equivalents. It is based on the reductive lithiation[2] of carbonyl-protected β-(phenylthio) aldehydes and ketones. The key is the ease with which the substituted β-(phenylthio) carbonyl compounds are prepared. One method (A) involves the nearly quantitative 1,4 addition of thiophenol to α,β-unsaturated aldehydes and ketones[3] as shown for mesityl oxide in eq 1. Another involves alkylation[4] of the enol silyl ethers[5] of ketones with β-chloro



(1)



(2)

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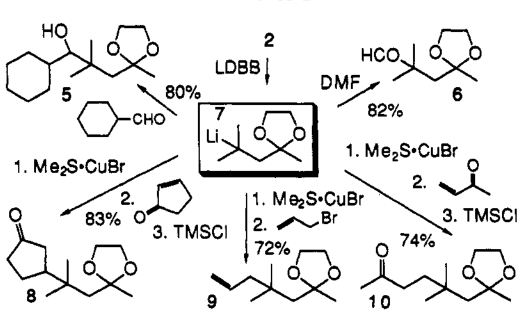
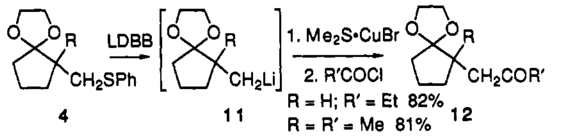
Scheme I



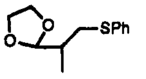
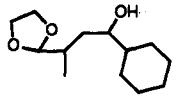
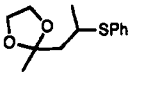
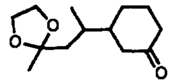
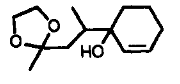
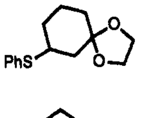
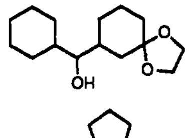
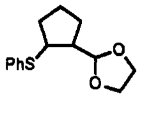
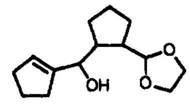
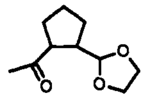
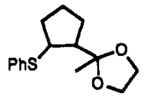
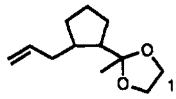
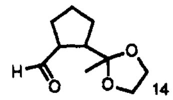
phenyl thioethers (e.g., eq 2). Both have the attractive feature of starting with a ketone to produce a closely related homoenolate. Protection of the carbonyl group as an acetal[6] is simple to execute and generally proceeds in high yield (eqs 1 and 2).

Reductive lithiation of the carbonyl-protected thioethers with lithium 4,4′-di-*tert*-butylbiphenylide (LDBB)[7] affords the homoenolate equivalents. A most attractive feature of this method of organolithium generation, aside from the ease of preparation of the substrates, is that the least stable anions are often produced with the greatest facility.[2a] This allows for the formation of tertiary homoenolate equivalents that are otherwise inaccessible.[8] The primary, secondary, and tertiary organolithiums thus prepared are capable of 1,2-addition to aldehydes and ketones (homoaldol reaction[1b]), including conjugated enals and enones, and reaction with dimethylformamide to produce the β-formyl carbonyl-protected aldehyde or ketone (Scheme I). Treatment with $CuBr{\cdot}SMe_2$ yields cuprates capable of allylation, conjugate addition to enones to provide monoprotected 1,6-diketones, and acylation by acyl halides to monoprotected 1,4-diketones (Scheme I and eq 3).[9] Some additional characteristic examples are displayed in Table I.



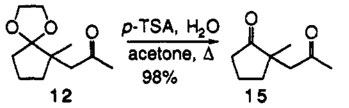
(3)

Table I. Additional Examples of Preparation and Reductive Lithiation of 3-(Phenylthio) Acetals

substrate[a]	yield[b] (%)	product	yield[c] (%)
	80		85
	83		82[d]
			91
	86		88
	74		86
			75[d]
	72	 13	81[d]
		 14	83

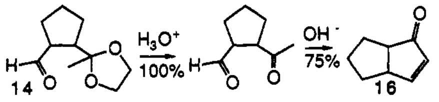
[a] Prepared by method A. [b] Combined yield, addition, and protection. [c] Mixture of diastereomers. [d] Via cuprate.

The reaction products of the homoenolate equivalents with these electrophiles are nearly quantitatively hydrolyzed to the substituted carbonyl compounds in acid.[11] 12 (R = R′ = Me) yields a 1,4-diketone 15 which is an intermediate in the synthesis of (±)-gymnomitrol[12] (eq 4). Such deprotection of 6 should produce the Magnus–Nobbs[13] ketoaldehyde by a method that avoids the use of palladium.

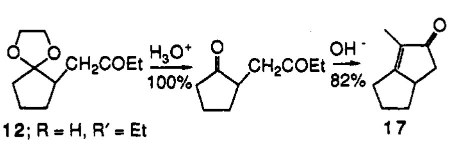


(4)

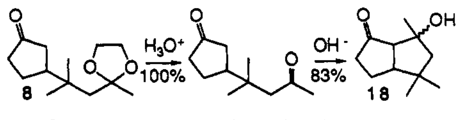
This technology is a component of a facile annulation to diquinanes when certain of the acylation or β-addition products are deprotected and the resulting 1,4- or 1,6-dicarbonyl compounds are allowed to undergo aldol reactions. Thus, hydrolysis of 14 yields a ketoaldehyde that undergoes base-induced condensation to the well-known[14] bicyclic enone 16 (eq 5). Similar treatment of 12 (R = H, R′ = Et) produces enone 17 (eq 6) which was prepared



(5)



(6)



(7)

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(9) Tertiary cuprates such as that from 7 have heretofore been rare[10] but are now readily available by reductive lithiation.

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previously in a more tedious manner.[15] Base-induced cyclization of the 1,6-diketone resulting from hydrolysis of 8 yields a pair of diastereomeric aldols (18, eq 7) that would be expected[16] to be capable of dehydration to an enone which is an intermediate in Paquette's synthesis of (±)-silphinene.[16]

Thiophenol can be added to enones generated in this way leading to iterative cyclizations. This aspect is being explored as well as methods of controlling stereochemistry in some of the reactions of homoenolate equivalents with electrophiles.

Acknowledgment. We thank the National Institutes of Health for financial support.

Supplementary Material Available: Characteristic procedures, spectral data, and ^{1}H NMR spectra of new compounds (43 pages). This material is contained in many 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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Cobalt-Catalyzed Intramolecular Homo Diels–Alder Reactions

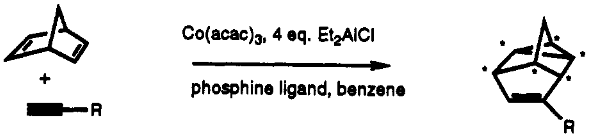
Mark Lautens,*[,1a] William Tam,[1b] and Louise G. Edwards[1c]

Department of Chemistry, University of Toronto, Toronto, Ontario, Canada M5S 1A1

Received November 6, 1991

Summary: Norbornadienes bearing a tether at C-2 which contains an acetylene have been found to undergo a cobalt-catalyzed intramolecular homo-Diels–Alder reaction creating pentacyclic cycloadducts.

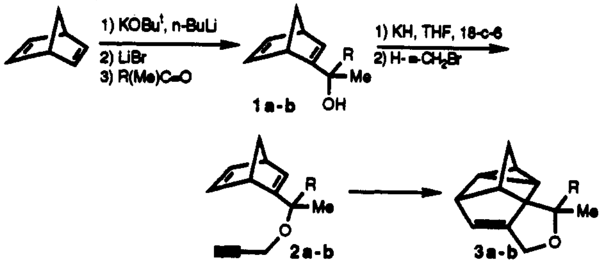
There is considerable interest in metal-catalyzed cycloaddition processes, in particular those between dienes and unactivated olefins, dienes, or acetylenes.[2,3] We have recently reported the cobalt-catalyzed [2 + 2 + 2] homo-Diels–Alder cycloaddition (HDA) between norbornadiene and a variety of unactivated acetylenes.[3a] An asymmetric version has also been developed.[3b] This reaction is very efficient for the construction of complex polycycles, eq 1.



(1)

We were interested in examining the facility of the intramolecular variant of this reaction. The decrease in entropy associated with tethering the two reactive components suggests that the reaction will be significantly more facile than the intermolecular reaction.[4] However, this likely rate enhancement is compromised by the dramatic decrease in rate associated with intermolecular cycloadditions with substituted norbornadienes.[5] In fact, prior to this study, there were no reported examples of successful intramolecular HDA reactions.[6] In this report, we detail the first examples of a transition metal catalyzed intramolecular homo-Diels–Alder reaction.

Efficient routes to the cycloaddition precursors were developed starting with norbornadiene. Deprotonation of norbornadiene with *n*-BuLi/KOBu^t occurred smoothly at −78 °C in THF.[7] Treatment of this anion with lithium bromide followed by acetaldehyde or acetone gave alcohols **1a** (R = H, 1.5:1 mixture of diastereomers) and **1b** (R = Me). Treatment with KH, THF, −50 to 0 °C and reaction of the alkoxide (in the presence of 18-crown-6) with propargyl bromide gave **2a** (R = H) and **2b** (R = Me) in 96% and 39% yield, eq 2.



(2)

Thermal cycloaddition of **2a** was attempted. No reaction was observed after heating **2a** for 24 h in toluene at 110 °C; however, in mesitylene at 170 °C for 24 h, a 3% yield of **3a** (6:1 diastereomeric mixture of cycloadducts) was isolated.[8]

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[1] (a) Fellow of the Alfred P. Sloan Foundation, 1991–1993. NSERC (Canada) University Research Fellow 1987–1992. Bio-Mega Young Investigator 1990–93. (b) Simcoe Scholar 1990–93. (c) NSERC (Canada) Postgraduate Scholar 1987–1991.

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[5] Substituents reduce the rate of the cycloaddition, see: Lautens, M.; Edwards, L. G. *J. Org. Chem.* **1991**, *56*, 3761.

[6] In one instance a competing ene reaction occurred, see: Kelly, T. R. *Tetrahedron Lett.* **1973**, *14*, 437.

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[8] *A priori* there are two possible modes of cyclization to consider: A or B. The structure of the cycloadduct was determined by examination of the ^{13}C APT spectrum. In all cases we have examined, the cycloadducts observed are of general structure A.

A

B