to prepare analogues and derivatives of these compounds by altering the C_3 substituent and/or by using suitably substituted dipolarophiles. Further studies using (trimethylsilyl)methyl-substituted indoles and pyrroles in natural product synthesis are in progress and will be discussed in subsequent papers.

Acknowledgment. We gratefully acknowledge support of this work by the National Institutes of Health.

Supplementary Material Available: ^{1}H NMR and X-ray data for compounds **8–16** (7 pages). Ordering information is given on any current mastheat page.

Tandem Radical Cyclization Approach to Angular Triquinanes. A Short Synthesis of (±)-Silphiperfol-6-ene and (±)-9-Episilphiperfol-6-ene

Dennis P. Curran*[1] and Shen-Chun Kuo

Department of Chemistry, University of Pittsburgh Pittsburgh, Pennsylvania 15260

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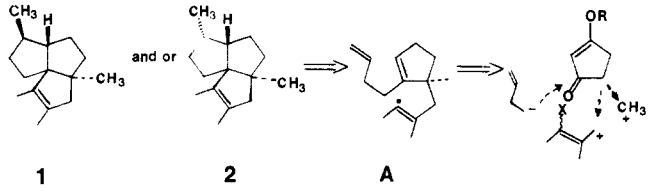
Largely through the effects of Bohlmann and co-workers, a variety of angular triquinanes have been isolated from natural sources over the past decade or so.[2] Synthetic strategies toward these compounds have most commonly employed sequential annulations to construct the interesting tricyclic ring system.[2] In principle, multiple cyclizations can present a more convergent approach to these compounds. We now outline a facile tandem radical cyclization approach to the representative angular triquinane silphiperfol-6-ene (**1**) and its C-9 epimer (**2**).

Silphiperfol-6-ene was isolated by Bohlmann and Jakupovic in 1980 from the roots of *Silphium perfoliatum*.[3] A recently reported synthesis by Paquette, et al. in 15 steps from (*R*)-(+)-pulegone served to determine the absolute stereochemistry of **1** and also confirm the initial spectroscopic structural assignment.[4]

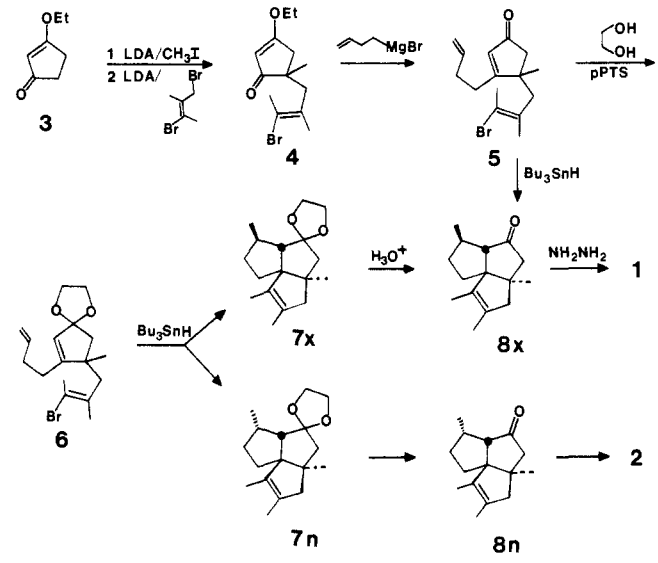
We have recently demonstrated that a tandem radical cyclization strategy can provide a unified approach to the linear class of triquinane natural products.[5,6] In this approach, exemplified by the syntheses of hirsutene and $\Delta^{9(12)}$-capnellene, the two outer rings of the tricyclic system were simultaneously closed about a preformed central ring. Equation 1 depicts the adoption of a



1 **2** **A** (1)

related strategy for the synthesis of silphiperfolene. Note in particular that the cyclization precursor A should be readily available from an alkoxy cyclopentenone by routine transformations. Finally, note that the plan requires generation and cyclization of a vinyl radical.[7,8]

Scheme I



The synthesis is outlined in Scheme I. Cyclization precursor **5** is readily available in ~45% overall yield by sequential alkylation of 3-ethoxy-2-cyclopenten-1-one (**3**) with methyl iodide and (*E*)-2-methyl-1,3-dibromo-2-butene[8] to produce **4**, followed by standard Grignard addition of butenyl magnesium bromide and hydrolysis.[9] Direct tin hydride promoted tandem cyclization[5] of **5** gave a 66% isolated yield of a mixture of 2-oxosilphiperfol-6-ene (**8x**) and 9-epi-2-oxosilphiperfolene (**8n**). By no means unexpectedly,[10] the major product was the undesired epimer **8n** (ratio **8x**/**8n**:1/3). In addition, chromatographic separation of the **8x**/**8n** mixture was not readily accomplished. Standard Wolff–Kishner reduction[4] of the mixture provided a 1/3 mixture of silphiperfolene (**1**) and its C-9 epimer (**2**). While the stereochemical control (in the desired sense) at C9 is poor, it must be noted that the synthesis is exceptionally short and each of the five steps proceeds in good to excellent yield.[11]

In order to disfavor formation of the 9-endo isomer **8n**, a substituent was introduced on the "endo" face of the forming tricyclic system by the simple process of ketalization of **5** with ethylene glycol. Ketal **6** was isolated in nearly quantitative yield in a good state of purity. Due to its hydrolytic sensitivity, crude **6** was directly subjected to tandem cyclization to produce a mixture of **7x**/**7n** in 65% yield. In the absence of the carbonyl group to activate the initial cyclization, the use of a vinyl (rather than alkyl)

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radical is crucial for the success of this reaction.[7c,d,12] Direct dioxolane cleavage gave the previously prepared ketones **8x/8n**, however, in a reversed ratio of 2.5/1. As an added bonus, ketals **7x/7n** were readily separable by chromatography. Hydrolysis of the individual epimers produced pure **8x** and **8n**. Each of these ketones was then separately reduced to produce silphiperfol-6-ene (**1**) and 9-episilphiperfolene (**2**) in 66-80% yields. Synthetic **1** exhibited spectroscopic properties identical with those reported by Bohlmann.[3] Copies of spectra (^{1}H NMR, IR, MS) of synthetic silphiperfolene kindly provided by Processor Paquette were also identical.

In conclusion, the tandem radical cyclization approach to condensed cyclopentanoid natural products has now been extended to encompass angular triquinanes such as silphiperfolene.[13] With appropriate modifications, a variety of related angular triquinanes should also be readily accessible.[12]

Acknowledgment. We thank the National Institutes of Health (GM 33372) for funding of this work. We also thank American Cyanamid and Stuart Pharmaceuticals for unrestricted financial support.

Supplementary Material Available: Spectra of compounds **2**, **4**, **5**, and **8x,n** (1 page). Ordering information is given on any current masthead page.

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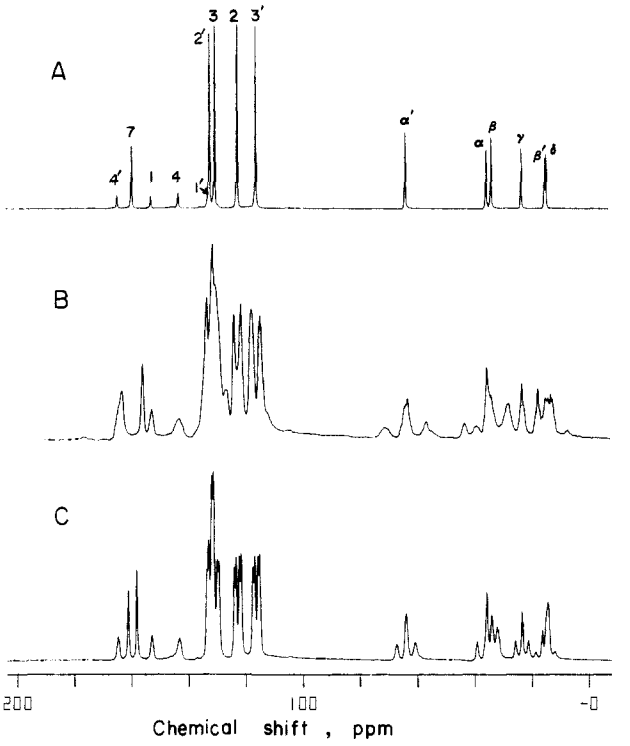


Figure 1. Carbon-13 spectra of EBBA at 75.4 MHz and 54 °C. The sample was spun at an angle of 52.8° with respect to B_0 at a rate of 1 kHz; $\gamma H_2/2\pi$ = 20 kHz; 50% duty cycle: (A) with broad-band proton decoupling; (B) without decoupling; (C) with BLEW-48 decoupling. The accumulation time was 15 min for A and 1 h each for B and C. The scaling factor f for C is 0.420.[13]

Carbon-13 NMR of Liquid Crystals. Spinning near the Magic Angle with Proton-Proton Dipolar Decoupling

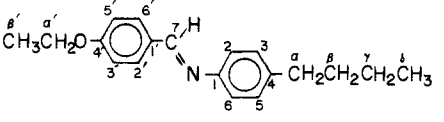
B. M. Fung* and Jalees Afzal

Department of Chemistry, University of Oklahoma Norman, Oklahoma 73019

Received July 29, 1985

Liquid crystals have orientational ordering and nonzero dipolar couplings. NMR spectra of small solute molecules often show well-resolved peaks which can be analyzed to determine order parameters and molecular structures.[1] On the other hand, molecules of the liquid crystal itself have extensive proton-proton couplings and show broad, overlapping proton NMR peaks. Fortunately, the carbon-13 spectra of liquid crystals are better resolved and proton-carbon dipolar couplings can be determined[2] by a 2-D method called separated local field spectroscopy.[3] We have found that the quality of the carbon-13 spectra can be greatly improved by using a combination of sample spinning near the magic-angle and proton-proton dipolar decoupling.

When a nematic sample is spun rapidly ($\gtrsim$1 kHz at 7 T) at or near the magic angle, the long axes of the molecules can align along the spinning axis[4-6] and sharp carbon-13 peaks can be observed with only moderate proton decoupling power.[5,6] If the angle θ between the spinning axis and the magnetic field B_0 is equal to the magic angle (54.7°), the chemical shifts are essentially the same as those in the isotropic phase. They change with θ because of chemical shift anisotropies. The decoupled carbon-13 spectrum of *N*-(*p*-ethoxybenzylidene)*p*-*n*-butylaniline (EBBA) spun at θ



= 52.8° is shown in Figure 1A. Assignment of the peaks is given in the literature[7] and was checked by selective decoupling in an isotropic solution. At this angle, the signals of the 1'- and 2'-carbons overlap. For θ < 50°, the signal of the 1'-carbon is resolved and appears at a lower field than that of the 2'-carbon, but the two methyl signals may overlap with each other. With rapid sample spinning at an angle θ, dipolar couplings are reduced by a factor of (3 cos^2 θ - 1)/2 and can be observed if proton decoupling is not used (Figure 1B). However, the carbon-13 spectrum is affected by both proton-proton and proton-carbon couplings. The peaks are rather broad and spectral analysis is not straightforward. This problem can be overcome by applying a pulse sequence which removes proton-proton dipolar couplings.[8-12] The spectrum is simplified and the resolution is en-

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