

# A New Synthesis of a Functionalized Bicyclo[5.4.0]undecane Skeleton based on a Sequence involving [2 + 2] Photoaddition and Regioselective $\beta$ -Scission of Alkoxy Radicals generated from the resulting Cyclobutanols<sup>1</sup>

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A new general synthesis of a functionalized bicyclo[5.4.0]undecane skeleton based on a regioselective  $\beta$ -scission of the alkoxy radicals generated from 2-hydroxytricyclo[5.4.0.0<sup>2,6</sup>]undecan-8-ones (prepared by [2 + 2] photoaddition of cyclic enones with the trimethylsilyl enol ethers of cyclic ketones) is described.

Compounds having a bicyclo[5.4.0]undecane skeleton are an important class of bicyclic molecules to which several sesquiterpenes, such as  $\alpha$ - and  $\beta$ -himachalenes and widdrol, belong. De Mayo's approach to the synthesis of this skeleton involves a retroaldolization of a [2 + 2] photoadduct obtainable from a cyclohexene derivative and the enol acetate of a cyclopentane-1,3-dione.<sup>2,3</sup>

From our continuing work on organic transformations through [2 + 2] photocycloaddition- $\beta$ -scission sequence,<sup>1,4</sup> we report here on an alternative approach to functionalized [5.4.0]undecanes based on a sequence involving [2 + 2] photoaddition and subsequent  $\beta$ -scission of the ring-fusion bond of the alkoxy radicals generated from the resulting cyclobutanols.

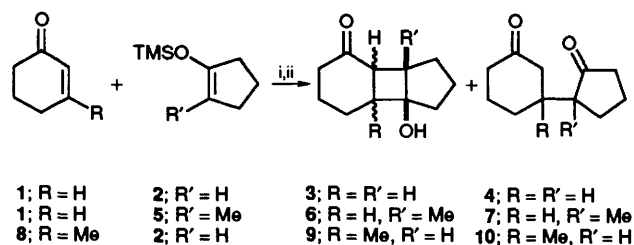
As a preliminary attempt, [2 + 2] photoaddition of cyclohexenone **1** with 1-trimethylsilyloxycyclopent-1-ene **2** in benzene, followed by an acid treatment gave a mixture of photoadducts from which a mixture of the stereoisomers of 2-hydroxytricyclo[5.4.0.0<sup>2,6</sup>]undecan-8-one **3** and 3-(2'-oxocyclopentyl)cyclohexan-1-one **4** were obtained in 42 and 40% yields.<sup>†</sup> Product **4** arose from a retroaldol reaction of the initially-formed [2 + 2] photoadduct (de Mayo reaction<sup>3</sup>).

Irradiation of the hypoiodite of cyclobutanol **3** in benzene containing red mercury(II) oxide-iodine (1 equiv.) with Pyrex-filtered light for 2 h gave bicyclo[5.4.0]undec-6-ene-2,8-dione **11**<sup>7</sup> and 6-iodobicyclo[5.4.0]undecane-2,8-dione **12** arising from a regioselective  $\beta$ -scission of the ring-fusion bond of the alkoxy radical in 36 and 3% yield<sup>†</sup> (Scheme 2). These results indicated that the new process is useful for the construction of a functionalized bicyclo[5.4.0]undecane skeleton. The [2 + 2] photoadditions of cyclohexenone **1** with 1-methyl-2-trimethylsilyloxycyclopent-1-ene **5** and 3-methylcyclohex-2-en-1-one **8** with 1-trimethylsilyloxycyclopent-1-ene **2** under similar conditions, followed by a treatment of the resulting products in each photoaddition with diluted hydrochloric acid, gave stereoisomeric mixtures of 2-hydroxy-6-methyltricyclo[5.4.0.0<sup>2,6</sup>]undecan-8-one **6** and 2-hydroxy-1-methyltricyclo[5.3.0.0<sup>2,6</sup>]undecan-8-one **9** in 33 and 30% yield, respectively.<sup>†</sup> Retroaldol products **7** (27%) and **10** (37%) formed by the de Mayo reaction were accompanying products in these reactions. An isomerization experiment and <sup>1</sup>H NMR spectroscopy indicated that the stereoisomeric mixture **6** was composed of *cis-cisoid-cis*, *cis-transoid-cis* and *trans-transoid-cis* isomers in a ratio of 1 : 1.5 : 2.5 (Scheme 1). The [2 + 2] photoadduct **9** was shown to be composed of *cis-cisoid-cis*, *cis-transoid-cis* and *trans-transoid-cis* isomers in

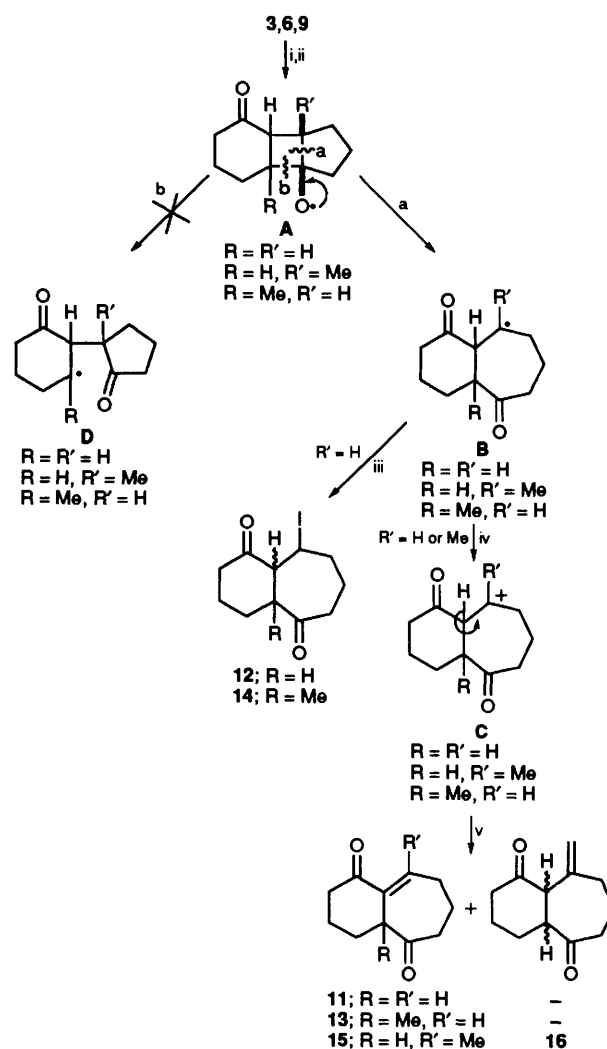
a ratio of 1:2.5:4.3 analogously. Thus, *trans-transoid-cis* isomers are predominant photoadducts in these photoadditions.<sup>5</sup>

Irradiation of the hypoiodite of cyclobutanols **9** in benzene for 2.5 h gave 1-methylbicyclo[5.4.0]undec-6-ene-2,8-dione **13** and 6-iodo-1-methylbicyclo[5.4.0]undecane-2,8-dione **14** in 16 and 36% yield<sup>††</sup> (Scheme 2).

Irradiation of the hypoiodite of cyclobutanols **6**, on the other hand, under the conditions mentioned above, gave an unstable 1:1 mixture of 6-methylbicyclo[5.4.0]undec-6-ene-2,8-dione **15** and 6-methylidenebicyclo[5.4.0]undecane-2,8-dione **16** in 31% yield. Olefins such as **11**, **13**, **15** and **16** are clearly formed by the removal of a proton from cationic intermediates **C** generated by a one-electron oxidation of the corresponding secondary carbon radicals **B** formed by a



Scheme 1 Reagents and conditions: i, hv-benzene; ii, HCl-H<sub>2</sub>O



Scheme 2 Reagents and conditions: i, HgO-I<sub>2</sub>, benzene; ii, hv; iii, HCl; iv, M<sup>2+</sup>, -e; v, -H<sup>+</sup>

cleavage of the ring-fusion bond of the alkoxy radicals **A** as outlined in Scheme 2. It is notable that as the scission of the ring-fusion bond is so strong, no product derived from a more likely stable tertiary radical **D** ( $R = \text{Me}$ ;  $R' = \text{H}$ ), arising from a cleavage of non ring-fusion bond of alkoxy radical **A** ( $R = \text{Me}$ ;  $R' = \text{H}$ ), is formed. The cleavage reaction here is thus kinetically controlled.

We have found that the present method can be similarly applied to the construction of 5/7, 5/8, 6/8 bicyclic systems. The transformation of the [2 + 2] photoadduct **6** into  $\alpha$ -himachalene and further applications of the present method to the construction of several bicyclic systems are in progress and the results will be reported in a future publication.

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### Footnotes

† Selected spectral data [IR,  $^1\text{H}$  NMR ( $\text{CDCl}_3$ , 270 MHz), EI-MS]: **3**;  $\nu_{\text{max}}/\text{cm}^{-1}$  (neat) 1690 (C=O) and 3400 (OH);  $m/z$  180 ( $\text{M}^+$ , 4.6%). **4**;  $\nu_{\text{max}}/\text{cm}^{-1}$  (neat) 1710 (C=O) and 1730 (C=O);  $m/z$  180 ( $\text{M}^+$ , 5.1%). **11**;  $\nu_{\text{max}}/\text{cm}^{-1}$  (neat) 1600 and 1690 (C=C-CO) and 1710 (CO);  $\delta$  7.13 (1 H, m, C=CH);  $m/z$  178 ( $\text{M}^+$ , 100%). **12**;  $\nu_{\text{max}}/\text{cm}^{-1}$  (neat) 1700 (2 C=O);  $\delta$  4.83 (1H, td,  $J$  9.3 and 3.9 Hz, CHI);  $m/z$  306 ( $\text{M}^+$ , 7.8) and 133 (100%). **6**;  $\nu_{\text{max}}/\text{cm}^{-1}$  (neat) 1703 (C=O) and 3412 (OH);  $\delta$  1.01 (0.6 H, s, Me), 1.03 (1.5 H, s, Me) and 1.28 (0.6 H, s, Me);  $m/z$  194 ( $\text{M}^+$ , 3.7%). **9**;  $\nu_{\text{max}}/\text{cm}^{-1}$  (neat) 1730 (C=O) and 3400 (OH);  $\delta$  1.06

(1.5 H, s, Me), 1.09 (2.6 H, s, Me) and 1.35 (0.6 H, s, Me);  $m/z$  194 ( $\text{M}^+$ , 1.7%). **13**;  $\nu_{\text{max}}/\text{cm}^{-1}$ : 1600 and 1670 (C=C-CO) and 1700 (C=O);  $\delta$  1.27 (3H, s, Me) and 6.92 (1 H, t,  $J$  7.8 Hz, C=CH);  $m/z$  193 [ $(\text{M} + 1)^+$ , 48.4%]. **14**;  $\nu_{\text{max}}/\text{cm}^{-1}$ : 1700 (2 C=O);  $\delta$  0.94 (3 H, s, Me) and 4.83 (1 H, td,  $J$  3.0 and 10.7 Hz, CHI);  $m/z$  320 ( $\text{M}^+$ , 17.2%).

‡ Satisfactory analytical results (high-resolution mass spectrometry) were obtained for all the single products.

§ Selected spectral data: **15** and **16**;  $\nu_{\text{max}}/\text{cm}^{-1}$  1709 (unstrained isolated C=O), 1596 and 1677 (C=C-CO);  $\delta$  1.57 (1.5 H, s, C=C-Me), 4.81 and 5.15 (each 0.5 H, each s, C=CH<sub>2</sub>).

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