Photooxygenation of Pregnanes

by **María A. Ponce** and **Rosa Erra-Balsells***

CIHIDECAR-CONICET, Departamento de Química Orgánica, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Pabellón II, 3°, Ciudad Universitaria, 1428-Buenos Aires, Argentina (tel/fax: 54-11-45763346; e-mail: erra@qo.fcen.uba.ar)

and **Andrea C. Bruttomesso** and **Eduardo G. Gros**[1])

UMYMFOR-CONICET, Departamento de Química Orgánica, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Pabellón II, 3°, Ciudad Universitaria, 1428-Buenos Aires, Argentina

The course of the singlet-oxygen reaction with pregn-17(20)-enes and pregn-5,17(20)-dienes was studied to compare the reactivity of the two alkene moieties present in some steroid families. Thus, from commercially available (3β,5α)-hydroxy-androstan-17-one and (3β)-3-hydroxyandrost-5-en-17-one, the following 3-{[(*tert*-butyl)dimethylsilyl]oxy}-substituted, 17(20)-unsaturated pregnanes were prepared (see *Fig. 1*): (3β,5α)-21-norpregn-17(20)-ene **1**; (3β,5α,17*Z*)-pregn-17(20)-ene **2**, (3β,5α,16α,17*E*)-pregn-17(20)-en-16-ol **3**, (16β,5α,17*E*)-pregn-17(20)-en-16-ol **4**, (3β,5α,16β,17*E*)-pregn-17(20)-en-16-ol acetate **5**, (3β,16α)-21-norpregna-5,17(20)-dien-16-ol **6**, (3β,16α,17*E*)-pregna-5,17(20)-dien-16-ol **7**, (3β,17*Z*)-pregna-5,17(20)-diene **8**, (3β,17*E*)-pregna-5,17(20)-dien-21-ol **9** and (3β,17*E*)-5,17(20)-dien-21-ol acetate **10**. The oxygenated products (see *Fig. 2*) obtained from **1**–**10** and $^1O_2$, generated by irradiation of Rose Bengal in $^3O_2$-saturated pyridine solution, were characterized by ^{1}H-, ^{13}C-NMR, and MS (EI, FAB, HR-EI, ESI- and UV-MALDI-TOF) data. Major products were those formed by the ene reaction involving as intermediates the corresponding hydroperoxides and the cyclic tautomers of the allylic hydroperoxides, *i.e.*, the corresponding oxiranium oxide-like intermediate (*Scheme 5*).

Introduction. – The phototransformations of steroids owing to the direct absorption of light or to the interaction with electronically excited species have been calling continuously the attention of researchers. It is known that sterols, as important lipidic components of human skin cells, may contribute to phototoxicity by means of photochemical reactions in the UVB region through oxygen-dependent reactions in the UVA region [1]. Sterols with a 5,7,9-triene substructure are the only naturally occurring $^1O_2$ sensitizers described in UVA region, but they are also easily oxidized by this species. On the other hand, cholesterol and other sterols with their isolated non-conjugated C=C bonds do not absorb UVA or UVB light but quench $^1O_2$. To prevent photodamage owing to photooxidation of steroids, the $^1O_2$ quenching process needs to be understood.

In an early work (1958), *Schenck* and co-workers showed that cholesterol reacts with $^1O_2$ yielding (3β,5α)-5-hydroperoxycholest-6-en-3-ol, which rearranges, in non-polar solvent, to (3β,7α)-7-hydroperoxycholest-5-en-3-ol [2]. In 1961, *Nickon* and co-workers found that hydroperoxidation of steroids with a C=C bond is stereospecific, and the new C–O bond is in the *cis* position to the C–H bond that is broken [3a,b].

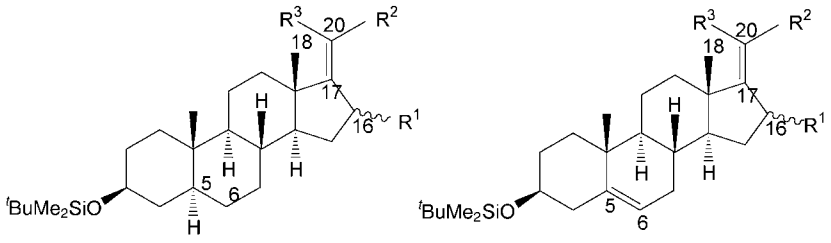
[1]) In memory of Dr. *Eduardo G. Gros*

© 2004 Verlag Helvetica Chimica Acta AG, Zürich

Since these early works, a dozen or more examples of these phenomena in which an allyl hydroperoxide rearranges to its allylic isomer, have been identified, half of which refer to cholestene derivatives. Several years later, *Beckwith et al.* [4] showed that the tertiary 5α-yl hydroperoxide originally formed from cholesterol rearranges by a nondissociative mechanism (sigmatropic 1,3-rearrangement; *Schenck* suprafacial rearrangement) yielding the 7α-yl hydroperoxide.

In a previous project, we examined the reaction of stigmasterol, a 5,22-diunsaturated sterol, and of some 3β-substituted 5,22-diunsaturated stigmastanes with $^1O_2$, *i.e.*, of 3β-F-, 3β-Cl-, 3β-Br-, 3β-I-, 3β-AcO-, 3β-MsO-, and 3α-Br-substituted derivatives; depending on the substituent present at C(3), the initially formed 5α-yl hydroperoxides rearranged to the 7α- or the 3α-isomeric structures [5]. In an attempt to understand further some of the structural factors that affect the reactivity of steroids with $^1O_2$, we then compared the reactivity of ergosterol and $^1O_2$ by using different combinations of photosensitizers and solvents [6].

In the present report, we describe the photooxygenation of C=C bonds present in some steroids of the pregnane family. Thus, a series of new unsaturated (3β)-3-{[(*tert*-butyl)dimethylsilyl]oxy}pregnanes were prepared and fully characterized to study their reaction with $^1O_2$. In these new unsaturated pregnanes **1**–**10**, a C(17)=C(20) bond with H-atoms in allylic positions and in some cases, also a C(5)=C(6) bond is present (*Fig. 1*). The latter C=C bond was shown to be quite reactive in the stigmastane family [5]. Commercially available (3β,5α)-3-hydroxyandrostan-17-one and (3β)-3-hydroxyandrost-5-en-17-one were used as starting materials. All new compounds **1**–**10** were fully characterized by ^{1}H- and ^{13}C-NMR and MS (EI, FAB, HR-EI, ESI- and UV-MALDI-TOF) data.



	R^1	R^2	R^3
1	H	H	H
2	H	H	Me
3	α-OH	H	Me
4	β-OH	H	Me
5	β-OAc	H	Me

	R^1	R^2	R^3
6	α-OH	H	H
7	α-OH	H	Me
8	H	H	Me
9	H	CH_2OH	H
10	H	CH_2OAc	H

Fig. 1. *Pregnanes studied*

Results. – A solution of pregnene **1** and Rose Bengal in pyridine was stirred under O_2 and irradiated with a tungsten lamp for 24 h. After isolation and purification of the products, the ^{1}H- and ^{13}C-NMR spectra showed that the (5α)-21-norpregn-16-en-20-al

1a was obtained in 22% yield besides the starting material (*Fig. 2*). All spectroscopic data of **1a** supported the structure of an α,β-unsaturated aldehyde (see *Exper. Part*).

When **2**, carrying an ethylidene group at C(17), was oxygenated according to the general conditions, (20*S*)-pregn-16-en-20-yl hydroperoxide **2a** was isolated in 64% yield, besides trace amounts (< 0.5%) of pregn-16-en-20-one **2b** and starting material (*Fig. 2*). Comparison of the ^{1}H- and ^{13}C-NMR spectra of **2** and **2a** clearly established the presence of a shifted C=C bond as well as a MeCH(OOH) moiety at C(20) of **2a** (see *Exper. Part*). The MS data supported the formula $C_{27}H_{48}O_3Si$ and the hydroperoxide structure of **2a**. Compound **2b** of formula $C_{27}H_{46}O_2Si$ (MS data) showed the typical ^{1}H-NMR signals of the C(16)=C(17) bond and of the acetyl group in vinylic position at C(17) (see *Exper. Part*).

Photooxygenation of **3** and **4** under the usual conditions gave the following results: Pregnenol **3** was recovered quantitatively after 24 h. In contrast, pregnenol **4** gave 17α- and 17β-isomers in 26% yield besides starting material (*Fig. 2*). Comparison of the ^{1}H- and ^{13}C-NMR spectra of **4** and **4a** established the presence of a C(16)=O and an OH–C(20) group in **4a** (see *Exper. Part*).

When the acetyl derivative **5** of pregnenol **4** was submitted to the general oxygenation conditions, a product with similar R_f value than that of compound **4a** and a new product, *i.e.*, **5a** and **5b**, were isolated in 38 and 40% yield, respectively, besides starting material. The spectral data of **5a** established its identity with **4a** (17α/17β mixture), and those of **5b** were compatible with the proposed structure (see *Fig. 2* and *Exper. Part*).

To compare the reactivity of the H-atoms in allylic position of the C(17)=C(20) and C(5)=C(6) bonds located in the pregnane skeleton, five new pregna-5,17(20)-dienes were subjected to the usual oxygenation conditions. Pregnadienol **6** afforded one oxidized product, **6a** (*Fig. 2*), which was obtained in 36% yield, besides starting material. The structure of **6a** was established by spectroscopic means and was also in agreement with the *Schenck* mechanism described in the literature for the reaction of $^1O_2$ with the C(5)=C(6) bond of cholesterol [1–4] and stigmastanes [5].

Pregnadienol **7** gave on oxygenation the expected (7α,16α,17*E*)-7-hydroperoxypregna-5,17(20)-dien-16-ol **7a** in 26% yield besides starting material (*Fig. 2*). The NMR and MS data of **7a** were in agreement with the proposed structure (see *Exper. Part*).

It is interesting to note that in **6a** and **7a**, the C(17)=C(20) bond was unchanged as compared to the starting materials. Furthermore, it is well-known that the attack of $^1O_2$ at the C(5)=C(6) bond in cholesterol-like structures yields only the 5-en-7-yl hydroperoxide with (7α) configuration by a concerted rearrangement of the primarily formed 6-en-5-yl hydroperoxide with (5α) configuration [1–5].

However, when pregnadiene **8**, which is devoid of OH–C(16), was oxygenated, the obtained products **8a** and **8b** (36 and 9% yield, resp.) showed an unchanged C(5)=C(6) bond region (*Fig. 2*), *i.e.*, the reaction with $^1O_2$ had taken place at C(17)=C(20). Comparison of the ^{1}H- and ^{13}C-NMR spectra of compounds **8**, **8a**, and **8b** clearly established the positions of the two C=C bonds in the products. The ^{1}H- and ^{13}C-NMR spectra of **8a** and **8b** were quite similar, except for major differences in the ^{1}H-NMR signals of H–C(20) and Me(21) (see *Exper. Part*). Detailed analysis of the MS data of **8a** and **8b** supported the hydroperoxy structure of **8a** and the hydroxy structure of **8b** (see *Exper. Part*).

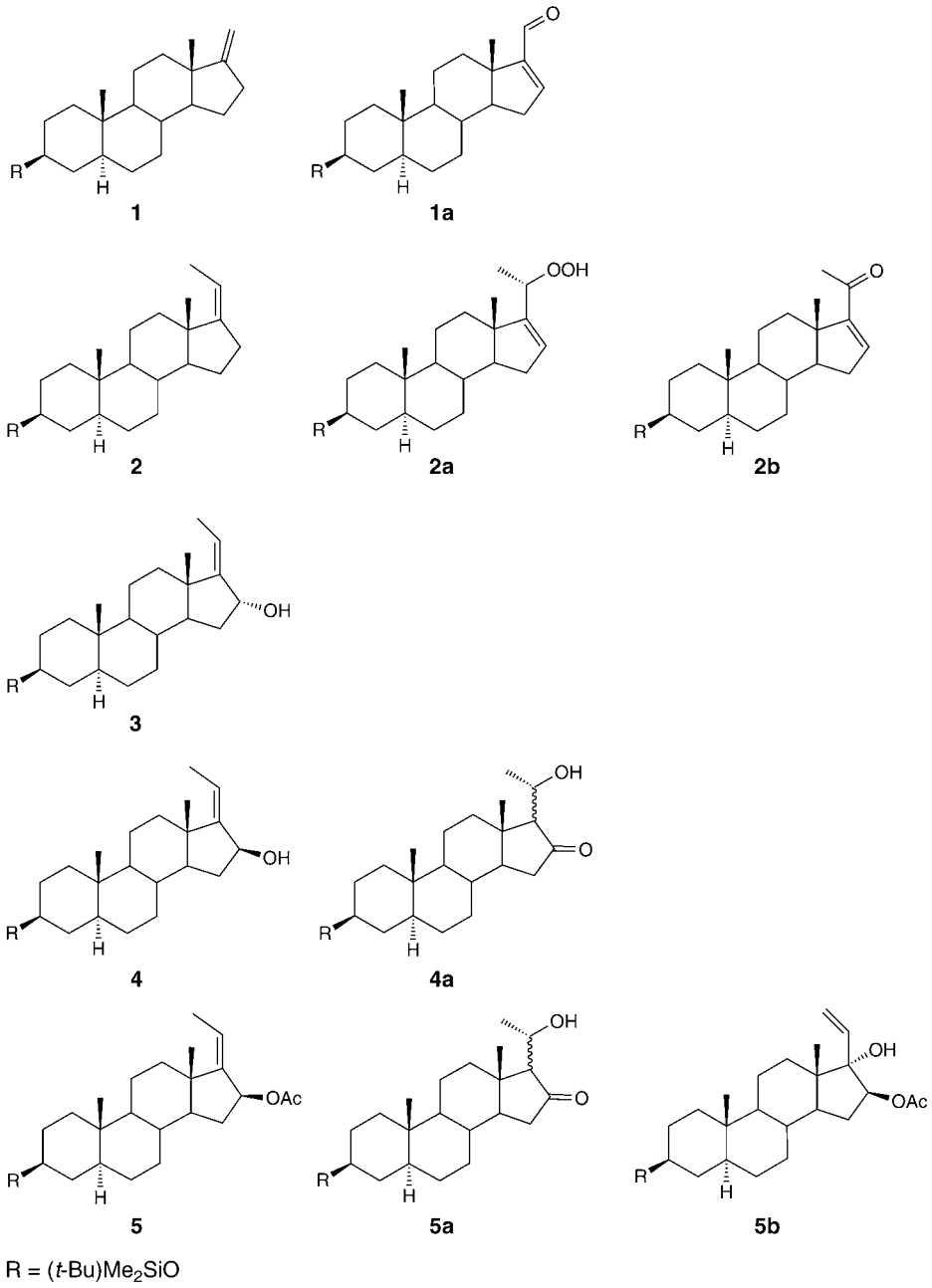


Fig. 2. *Pregnanes studied and products obtained by photooxygenation*

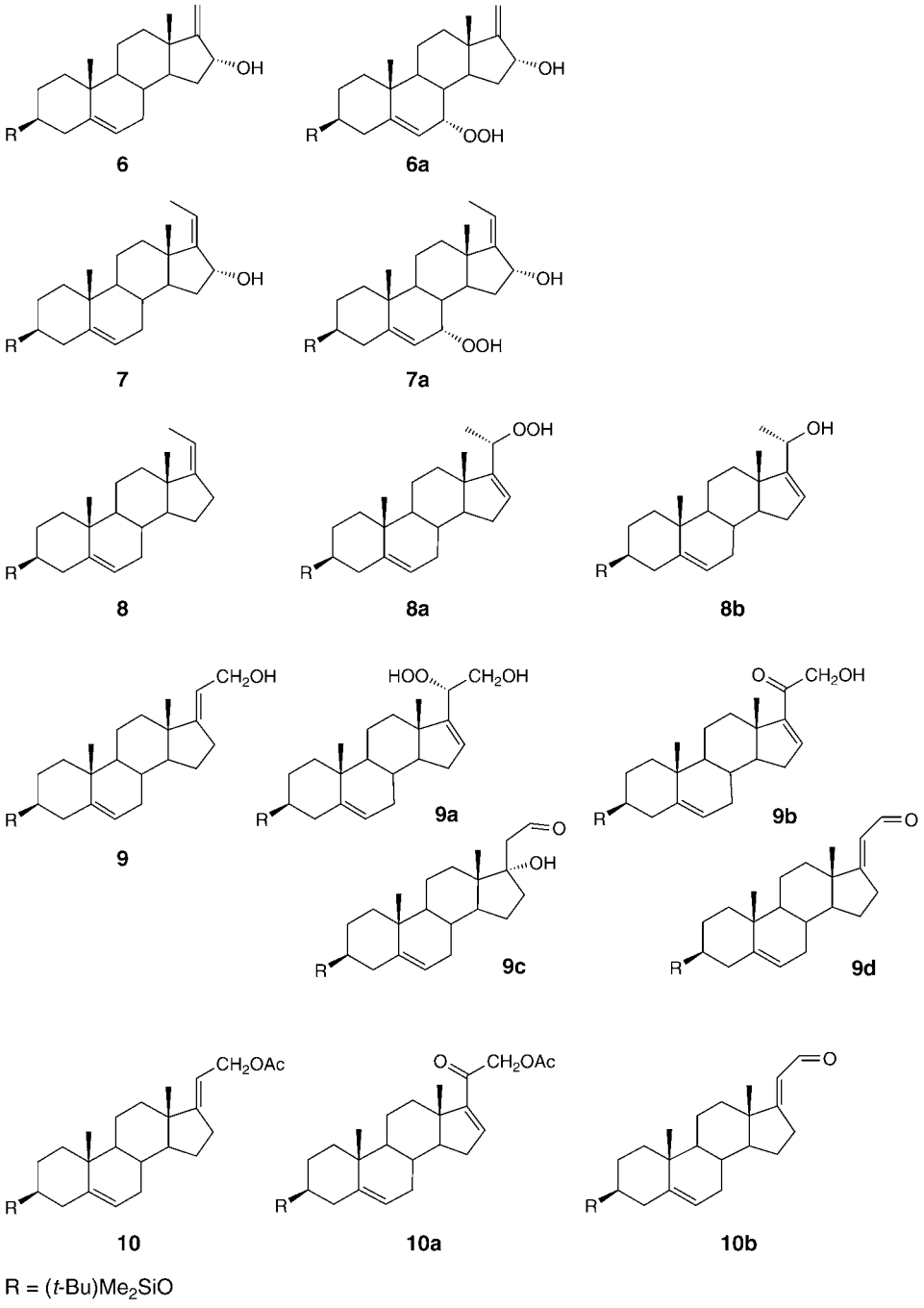

OH
R
6
OH
OOH
R
6a
OH
R
7
OH
OOH
R
7a
R
8
OOH
R
8a
OH
R
8b
CH2OH
R
9
HOO
CH2OH
R
9a
O
CH2OH
R
9b
O
OH
R
9c
O
R
9d
CH2OAc
R
10
O
CH2OAc
R
10a
O
R
10b
R = (t-Bu)Me2SiO

Fig. 2 (cont.)

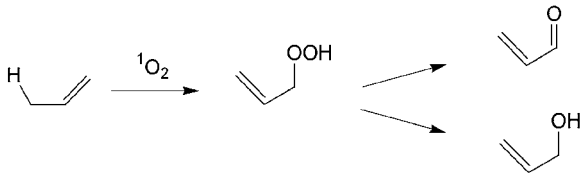
Pregnadienol **9** yielded, after photooxidation under the usual conditions, isolation, and purification, the four new photoproducts, **9a** (6%), **9b** (27%), **9c** (10%), and **9d** (17%), besides starting material. Comparison of the ^{1}H- and ^{13}C-NMR spectra of compounds **9**, **9a**, and **9b** showed that the C(17)=C(20) bond of **9** was shifted to C(16)=C(17) in **9a** and **9b**, that the CH_2(21)OH group was retained, and that the C(5)=C(6) was unaffected by the oxygenation. In addition, **9a** carried an OOH group at C(20), while **9b** showed a conjugated oxo group at C(20). The presence of these functional groups were confirmed by MS and UV data (*Exper. Part*). The ^{1}H- and ^{13}C-NMR data of **9c** and **9d** clearly indicated that only the C(5)=C(6) bond was present, besides an aldehyde functionality at C(21) and an α-OH group at C(17) in the case of **9c**, and a corresponding α,β-unsaturated aldehyde structure in the case of **9d** (see data in *Exper. Part*) MS and UV data were in agreement with the proposed structures.

Finally, when the acetyl derivative **10** of pregnadienol **9** was oxygenated in the usual manner, two products **10a** and **10b** were isolated, besides starting material. The R_f value of **10b** corresponded to that of authentic **9d**, and its spectral data established the identity of the two compounds (see *Exper. Part*). The ^{1}H- and ^{13}C-NMR spectra of **10a** showed the presence of the unmodified C(5)=C(6) bond and of a C(16)=C(17) bond with an oxo function at C(20). Additional data supported the α,β-unsaturated keto structure of **10a** (see *Exper. Part*).

It is interesting to note that both the ^{1}H- and ^{13}C-NMR and the MS data (EI-, HR-, and ESI-TOF-MS) revealed the presence of the unmodified 3-{[(*tert*-butyl)dimethylsilyl]oxy}substituent in all the products obtained by reaction of $^1O_2$ with the unsaturated pregnanes **1**–**10**; this stability was also observed in the pregn-5-ene series **6**–**10**, even when the ene reaction took place at the C(5)=C(6) bond.

Discussion. – *Preamble.* The reaction of $^1O_2$ with unsaturated olefins provides a valuable and convenient route to introduce O-functionality in the reactants [7a]. The major reaction pathway for alkenes with H-atoms in allylic position is the ene reaction [7a,b], which is a powerful method for the synthesis of allyl hydroperoxides. The hydroperoxides may then be transformed into allyl alcohols, allylic carbonyl compounds (ketones, aldehydes), or may be used as O-transfer agents in epoxidation reactions (*Scheme 1*) [7c].

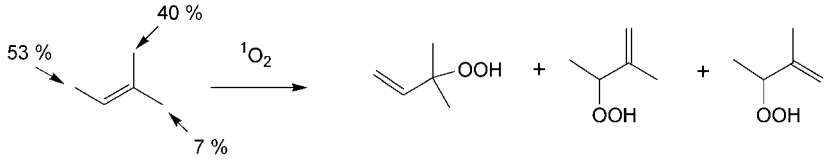
Scheme 1. *Singlet-Oxygen Ene Reaction and Photooxygenated Products*



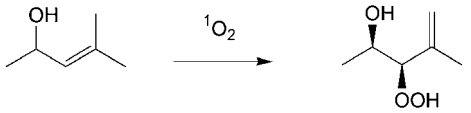
The reaction shows low regioselectivity when simple trisubstituted alkenes are used [7d] but shows a noticeable side selectivity called '*cis* effect' [7e], (the higher substituted side of the trisubstituted alkene is more reactive) for the same compounds (*Scheme 2*). Additional regio- and stereoselectivity phenomena observed in the ene

reaction suggest a perepoxide intermediate or a perepoxide-like transition-state geometry [7a,f–g], making this reaction useful in stereoselective synthesis. Furthermore, for chiral allyl alcohols and analogous substrates, the 'hydrogen-directing effect' described by *Adam et al.* [7g,h] helps the reaction to proceed with high regioselectivity and high *syn* diastereoselectivity (*Scheme 3*). Thus, depending on the nature of the functional groups at the allylic position around a C=C bond and on the experimental conditions (*i.e.*, solvent polarity), photooxygenation of ene compounds can be a valuable tool in stereoselective synthesis [7g,i].

Scheme 2. *The* cis *Effect in the Singlet Ene Reaction with 2-Methylbut-2-ene.* The percentages of H-abstraction are indicated.



Scheme 3. *The Hydroxy-Directing Effect in the Ene Reaction of the Allyl Alcohol 4-Methylpent-3-en-2-ol*



Behavior of Pregn-17(20)-enes **1**–**5** *and Pregna-5,17(20)-dienes* **6**–**10**. The low regioselectivity observed when noncyclic trisubstituted alkenes are studied changes, as a rule, when cyclic trisubstituted alkenes are attacked by $^1O_2$. The photosensitized oxidation in pyridine solution of pregnene **1** with the exocyclic C(17)=C(20) bond yielded as the sole product the 16-en-20-al derivative **1a**. This is the stable carbonyl derivative formed from the expected primary C(20) hydroperoxide (not observed) after elimination of H_2O.

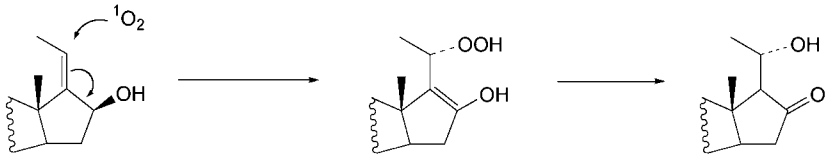
As the 17-keto derivative formed by a [2+2]-cycloaddition of $^1O_2$ and the C=C bond was not detected in any of the unsaturated pregnanes studied, the ene reaction is the preferential reaction pathway when the exocyclic C(17)=C(20) bond reacts with $^1O_2$.

Pregnene **2**, the (*Z*)-17-ethylidene analogue of **1**, gave on photooxygenation the now secondary allyl hydroperoxide **2a** as a stable product together with its dehydrated product **2b**. Dehydration of allyl hydroperoxides in pyridine solution has been previously reported [7g]. Although the C(17)=C(2=) bond in pregnene **2** represents a trisubstituted alkene, with two potentially active allylic H-atoms at C(16) and C(21) and with the higher substituted side involving Me(21), only **2a** and **2b** were isolated. Neither the 20-en-17-yl hydroperoxide nor any product formed from this hydroperoxide intermediate was observed in the reaction mixture. Thus, the so-called '*cis* effect' [7e] is not operating in the photooxygenation of C(17)=C(20) in pregnene **2**.

To evaluate the so-called 'hydrogen-directing effect' [7g,h] in the photooxygenation of the C(17)=C(20) bond, the behavior of the unsaturated hydroxypregnanols **3**, **4**, **6, 7**, and **9** and of two of their corresponding *O*-acetyl derivatives, **5** and **10**, was compared

(*Fig. 2*). The formation of hydroxy ketone **4a** can be rationalized by an ene reaction involving the allylic H-atom located at C(16) of 17(20)-en-16-ol **4**, yielding the 20-hydroperoxy-16-en-16-ol intermediate, which leads to the more stable 20-hydroxy-16-one **4a** (*Scheme 4*). As mentioned above, the absence of the corresponding 17-hydroperoxy-20-en derivative and of products formed from this intermediate in the product mixture obtained from **4** suggests again that the so-called '*cis* effect' [7e] is not operating in the photooxygenation of the C(17)=C(20) bond. The 16-*O*-acetyl derivative **5** of **4**, also yielded **4a** (≡**5a**) *i.e.*, deacetylation had occurred under the photooxygenation conditions. In the second product **5b**, the C(17)=C(20) bond of **5** was shifted to C(20)=C(21) and the AcO still located at C(16); this can be rationalized by the interaction of $^1O_2$ with the allylic H–C(21) of **5** leading to the 20-en-17α-yl hydroperoxide intermediate (not detected) which yields the stable 16-(acetyloxy)-20-en-17α-ol **5b**.

Scheme 4. *Singlet-Oxygen Attack at the Pregn-17(20)-ene Double Bond. Formation of 20-Hydroxypregnan-16-one*



The results obtained with **4** and **5** and the fact that no photooxygenated product was isolated from pregnen-16-ol **3**, the 16α-isomer of **4**, suggests that a concrete effect is operating due to the presence of the α-OH group at C(16). As it is known, stereoselective transformation with asymmetric induction by an allylic stereogenic center is rationalized in terms of allylic $A^{1,3}$ and $A^{1,2}$ strain (*Fig. 3*) [7j,k]. This concept presupposes the eclipsed alignment of an allylic C–H bond and the adjacent C=C bond. These stereoelectronic factors determine, in flexible structures, the preferential conformers which interact with $^1O_2$. On the basis of the allylic-strain model, it may be assumed that in all substrates, a nearly perpendicular alignment of the allylic OH group is adopted. From the allylic functional group, two major effects may be anticipated: electronic influence on the reactivity of the adjacent C=C, and noncovalent interactions with the incoming electrophilic $^1O_2$ molecule. The second effect has been described as activating or de-activating [7j]. In the case of unsaturated pregnanes, due to the reduced flexibility of the cyclopentane ring, we propose that both the allylic $A^{1,3}$ and $A^{1,2}$ strains are not operating, and the ene reaction of compounds **2** and **4** with $^1O_2$ proceeds with high regioselectivity, yielding the 20-yl hydroperoxide. Furthermore, the inertness of pregnen-16α-ol **3** shows that a *cis*-effect is not operating in this case, and, as a consequence, the major effect of the hydroxyallyl moiety is deactivating the α-attack of $^1O_2$ at C(17)=C(20). As the β-attack does not occur due to the fixed axial Me–C(18), the hydroxyallyl moiety of **3** is not attacked by $^1O_2$. When the substituent at C(16) is located on the β-side as in the pregnen-16β-ol **4**, this deactivating effect is not operating, and the $^1O_2$ α-attack at the hydroxyallyl system occurs yielding the corresponding 20-yl hydroperoxide and, hence, the 20-hydroxy-16-one **4a**.

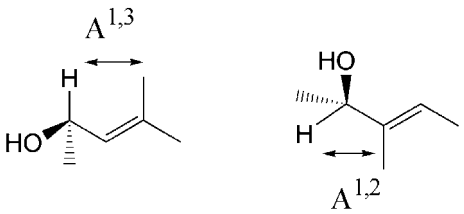


Fig. 3. *Lowest-energy conformers due to allylic $A^{1,3}$ and $A^{1,2}$ strain*

The apparent deactivation or protective effect of the 16α-OH substituent was also observed in the photooxidation of pregnadienols **6** and **7** on comparison with the behavior of pregnadiene **8**. Moreover, the results obtained with **6**–**8** allowed also a comparison with the recently described sensitized photooxygenation of several 3-substituted derivatives of cholesterol [5]; this family of steroids represent trisubtituted cyclic alkenes whose C(5)=C(6) bond can be regarded as exocyclic with respect to ring A as well as endocyclic with respect to ring B. Thus, the photooxygenation of pregna-5,17(20)-dien-16α-ols **6** and **7** occurred at the allylic H–C(7) leading to the expected 7α-yl hydroperoxides **6a** and **7a**, respectively. However, the pregna-5,17(20)-diene **8**, which carries no OH group at C(16), reacted with $^1O_2$ in a regioselective way at the C(17)=C(20) bond, yielding the 16-en-20-yl hydroperoxide **8a** and the 16-en-20-ol **8b**.

In a similar way, the C(5)=C(6) bond was kept intact on photooxygenation of the pregna-5,17(20)-dienes **9** and **10**, although the $^1O_2$ attack at C(17)=C(20) was not regioselective. Not only the 16-en-20-yl hydroperoxide **9a** and its dehydrated 16-en-20-one derivative **9b** but also 17-hydroxy-21-al **9c** and 17(20)-en-21-al **9d** were isolated. The former ene reaction involved H–C(16) and the latter H–C(21). Similar results were obtained by photooxygenation of the acetyl derivative **10** of **9**.

Concerning the diastereoselectivity of the photooxygenation of pregnanes **1**–**10**, the $^1O_2$ attack showed α-facial stereoselectivity for compounds **2**, **4**, **5**, and **8**. As a consequence, the products **2a**, **4a**, **5a**, and **8a** were obtained as the corresponding hydroperoxy and hydroxy compounds with (20*S*)-configuration.

Finally, the photooxygenation of pregnadienol **9** showed low regioselectivity but both ene reactions proceeded with very high diastereoselectivity. Steric factors explain the preferential α-π-facial attack when **9c** was formed *via* the 17-hydroperoxy intermediate, while a hydroxy-directing effect would account for the diastereoselectivity of the formation of 21-hydroperoxy derivative **9a**.

Stereoselectivity and Regioselectivity at C(17)=C(20). The α-π-facial stereoselectivity of the reaction of $^1O_2$ with C(17)=C(20) of the unsaturated pregnanes **1**–**10** to form the oxiranium-oxide-like intermediate (*Scheme 5*) can be rationalized by the fact that Me–C(18) is on the β-side (axial) (*Fig. 4*). Thus, as expected, the photosensitized oxidation of pregnen-16α-ol **3** did not afford any product because of the stereoelectronically deactivating effect of the α-OH substituent at C(16). Similarly, pregnadien-16α-ols **6** and **7** yielded only the expected 7α-yl hydroperoxides *via* the normal ene reaction at C(5)=C(6) keeping the C(17)=C(20) bond intact.

From the oxiranium-oxide-like intermediate, the reaction can follow two different pathways: *i*) involvement of the allylic H–C(16) on the α-face (compounds **1**, **2**, **4**, **5**, and **8**–**10**) and/or *ii*) involvement of one H–C(21) (compounds **2**, **4**, **5**, and **8**–**10**). In

Scheme 5. *Singlet-Oxygen Attack and the* para-*Epoxy-like Intermediate*

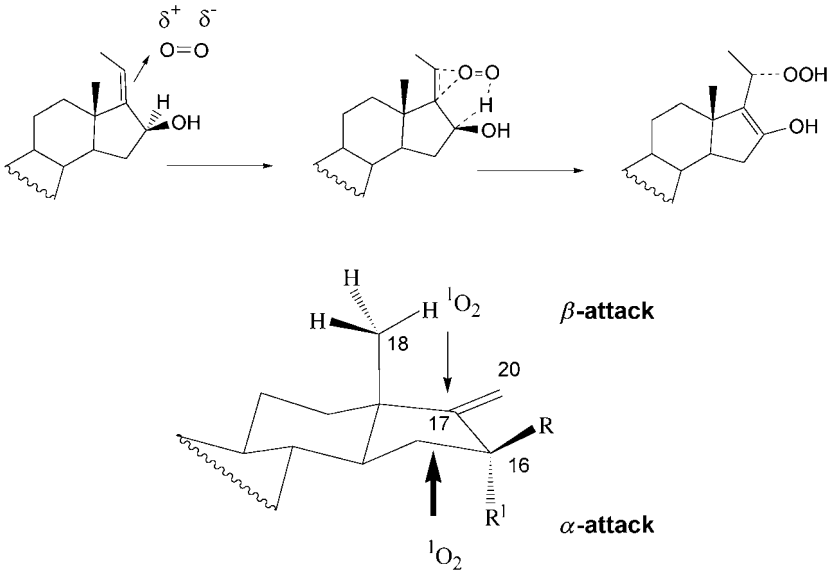


Fig. 4. *Singlet-oxygen attack at the pregn-17(20)-ene double bond.* R, R′=H, OH.

the case of **2**, **4**, **5**, and **8**, the products obtained showed that the former was the only mechanism operating. For **9** and **10**, both mechanisms were operating, the former leading to **9a** and **9b** and the latter to **9c** and **9d** in the case of **9**.

Regioselectivity of the Reaction of **8** *and* **9**. The clear regioselectivity of the $^1O_2$ ene reaction at C(17)=C(20) of **8** and **9** was a bit surprising. Analysis of the geometry-optimized structures (semi-empirical (AM1 and PM3); *ab initio* (HF/3-21G and B3LYP/3-21G) level) showed that $^1O_2$ attack at the C(5)=C(6) bond would be feasible from the steric point of view. However, the HOMOs of **8** and **9** were calculated (ZINDO/S//AM1, ZINDO/S//PM3, ZINDO/S/HF/3-21G, and ZINDO/S//B3LYP/3-21G level), and the shapes of the calculated orbitals were almost the same in all cases, the largest coefficients being found at C(17)=C(20), and no important (or any) contribution of the C(5)=C(6) π-system to the HOMO was observed. As the $^1O_2$ ene reaction with alkenes can be considered an electrophilic attack forming an exciplex in the rate-determining step (*Scheme 5*), the analysis of the HOMO properties of the pregnadienes **8** and **9** agrees with the regioselectivity observed. In the same way, when $^1O_2$ attacks the C(17)=C(20) bond region with partial structures C(16)=C(17)=C(20)−C(21) or β-HO−C(16)−C(17)=C(20)−C(21), only the 16-en-20-hydroperoxy and/or its dehydrated and/or reduced products were obtained.

Conclusions. – Photooxygenation of C=C bonds of unsaturated pregnane structures depends on *i*) their location in the skeleton, *ii*) the location and nature of the allylic functional groups, and *iii*) steric factors. The C(17)=C(20) bond proved to be more reactive than the C(5)=C(6) bond [8]. This behavior was very different when an

OH substituent was present at C(16) on the α-side. For the ene reaction involving the C(17)=C(20) bond, high regioselectivity was found when the allylic OH group was located at C(16) on the β-side, whereas no regioselectivity was observed when the allylic OH group was located at C(21). The stereoselectivity of these reactions was dependent not only on steric factors (*i.e.*, axial Me–C(18)) but also on the activating or deactivating effect of the allylic OH groups at C(16) and C(21), respectively.

We wish to acknowledge the Universidad de Buenos Aires (022), *CONICET* (PIP/904), and *ANPCyT* (PICT 12312) for partial financial support, and *UMYMFOR* (UBA-*CONICET*) for technical support. *R. E.-B.* is a research member of *CONICET*. ESI-TOF-MS Experiments were performed as part of the academic agreement between *R. E.-B.* (FCEyN, Universidad de Buenos Aires, Argentina) and *Hiroshi Nonami* (CA, Ehime University No, Japan) with the facilities of the high-resolution liquid-chromatography-integrated mass spectrometer system of the United Graduated School of Agricultural Sciences (Ehime University, Japan).

Experimental Part

General. Toluene, hexane, CH_2Cl_2, $CHCl_3$, Et_2O, and AcOEt of anal. grade were used after purification. MeCN, EtOH, MeOH, ^{t}BuOMe and pyridine were obtained from *JT Baker*. Rose Bengal (sodium salt 95%), (3β,5α)-3-hydroxyandrostan-17-one and (3β)-3-hydroxyandrost-5-en-17-one were purchased from *Aldrich*. Column chromatography (CC): *Merck* silica gel *60* (0.040–0.063 mm). TLC: *Merck* silica gel *60* F_{254} on aluminium sheets (0.2 mm thickness). M.p.: *Fisher–Jones* apparatus; not corrected. UV Spectra: *Shimadzu UV-1203* spectrophotometer; λ_{max} in nm. IR Spectra: *Nicolet Magna-550-FT/IR* spectrophotometer; in cm^{-1}. ^{1}H- and ^{13}C-NMR Spectra: *Bruker AC-200* and *Bruker 500* spectrometer; chemical shifts δ in ppm rel. to internal $SiMe_4$, *J* in Hz; standard pulse sequences. EI-MS: *VG TRIO-2* mass spectrometer; in *m*/*z* (rel. int. in %). HR- and FAB-MS: *VG ZAB BEQ* instrument. ESI-TOF-MS: *Mariner Applied-Biosystems*, ESI-TOF spectrometer, in positive-ion mode (no signals in the negative-ion mode); *m*/*z* range 10–1000 Da; infusion of 0.5–50 µl of the steroid soln. in THF into the ion source by a *Harvard PHD-2000* syringe infusion pump at a flow-rate of 5 µl/min, with MeOH/H_2O 9:1 as solvent stream; spray-tip potential +2796.68 V, nozzle potential +245.12 V, skimmer voltage +11.01 V, nozzle temp. 140°; N_2 flow rate 0.40 l/min, analyzer temp. 29.0°, pressure 0.55 MPa; mass calibration with 1 µM standard in MeOH/H_2O 9:1 (standards: caffeine, tetrabutylammonium bromide, β-estradiol 3-sulfate 17-glucuronide dipotassium salt, γ-cyclodextrin, and angiotensin I ($z=1$, 1296.685 Da; $z=2$, 648.342 Da).

*(3β,5α)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-21-norpregn-17(20)-ene* (**1**). A mixture of methyltriphenylphosphonium bromide (4.2 g, 11.8 mmol) and KO^{t}Bu (1.27 g, 11.4 mmol) in dry THF (30 ml) was vigorously stirred for 5 min. To this suspension, (3β,5α)-3-{[(*tert*-butyl)dimethylsilyl]oxy}androstan-17-one (prepared from commercial (3β,5α)-3-hydroxyandrostan-17-one according to [8][9]; 1 g, 2.5 mmol) in THF (5 ml) was added. The mixture was heated at 55° for 15 h and partitioned between hexane (30 ml) and 50% aq. MeOH (50 ml). The H_2O/MeOH layer was extracted with hexane (3 × 10 ml), the combined org. phase evaporated, and the residue purified by filtration through a short column (silica gel, hexane): **1** (0.92 g, 93%). M.p. 203–205° (hexane/EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.77 (*s*, Me(18)); 0.82 (*s*, Me(19)); 0.88 (*s*, ^{t}Bu); 3.55 (*m*, H–C(3)); 4.61 (br. *s*, 2 H–C(20)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.5 (Me_2Si); 12.4 (C(19)); 18.5 (C(18)); 18.2 (Me_3C); 25.9 (Me_3C); 72.2 (C(3)); 100.6 (C(20)); 162.1 (C(17)). EI-MS (70 eV): 402 (0.6, $M^{+\cdot}$), 387 (1, $[M-Me]^+$), 345 (62, $[M-{}^t\mathrm{Bu}]^+$), 269 (7), 75 (100, Me_2SiOH^+). HR-MS: 345.2606 ($[M-{}^t\mathrm{Bu}]^+$, $C_{22}H_{37}OSi^+$, calc. 345.2604). ESI-TOF-MS (pos.): 425.320 ($[M+Na]^+$, $C_{26}H_{46}NaOSi^+$; calc. 425.3204), 403.3384 ($[M+H]^+$, $C_{26}H_{47}OSi^+$; calc. 403.3384).

The corresponding (3β,5α)-21-norpregn-17(20)-en-3-ol was described elsewhere [10].

*(3β,5α,17Z)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregn-17(20)-ene* (**2**) was prepared from (3β,5α)-3-{[(*tert*-butyl)dimethylsilyl]oxy}androstan-17-one (see above) according to [8][9]. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.86 (*s*, Me(18)); 0.81 (*s*, Me(19)); 0.88 (*s*, ^{t}Bu); 3.55 (*m*, H–C(3)); 5.11 (*tq*, *J*(20,16) = 2, *J*(20,21) = 7, H–C(20)); 1.64 (*dt*, *J*(21,16) = 2, *J*(20,21) = 7, Me(21)). ^{13}C-NMR ($CDCl_3$, 200 MHz): −4.5 (Me_2Si); 12.4 (C(19)); 13.1 (C(18)); 16.9 (C(21)); 18.2 (Me_3C); 25.9 (Me_3C); 72.2 (C(3)); 113.2 (C(20)); 150.4 (C(17)). ESI-TOF-MS (pos.): 439.336 ($[M+Na]^+$, $C_{27}H_{48}NaOSi^+$; calc. 439.3360), 417.354 ($[M+H]^+$, $C_{27}H_{49}OSi^+$; calc. 417.3540).

*(3β,5α,16α-17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregn-17(20)-en-16-ol* (**3**) was prepared from **2** according to [8][9]. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.87 (*s*, Me(18)); 0.82 (*s*, Me(19)); 0.90 (*s*, ^{t}Bu); 3.57 (*m*, H–C(3)); 5.58 (*dq*, *J*(20,16) = 1, *J*(20,21) = 7, H–C(20)); 1.74 (*dd*, *J*(21,16) = 2, *J*(20,21) = 7, Me(21)); 4.41 (br. *d*, H–C(16)). ^{13}C-NMR ($CDCl_3$, 200 MHz): −4.6 (Me_2Si); 12.3 (C(19)); 13.1 (C(18)); 17.5 (C(21)); 18.2 (Me_3C); 25.9 (Me_3C); 72.1 (C(3)); 119.2 (C(20)); 155.5 (C(17)); 74.31 (C(16)). ESI-TOF-MS (pos.); 455.330 ($[M+Na]^+$, $C_{27}H_{48}NaO_2Si^+$; calc. 455.3309), 433.348 ($[M+H]^+$, $C_{27}H_{49}O_2Si^+$; calc. 433.3489).

*(3β,5α,16β,17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregn-17(20)-en-16-ol* (**4**). A mixture of (3β,5α,17*E*)-3-{[(*tert*-butyl)dimethylsilyl]oxy}pregn-17(20)-en-16-one (prepared from **3** according to [8][9]; 526.9 mg, 1.22 mmol) and $NaBH_4$ (200 mg, 5.26 mmol) in MeOH/^{i}PrOH 3:1 (20 ml) was stirred at r.t. for 3 h. The reaction was quenched by addition of H_2O/AcOH 100:5 (105 ml) and extracted with CH_2Cl_2. The org. layer was washed with H_2O, dried (Na_2SO_4), and evaporated. The solid obtained was recrystallized: **4** (524 mg, 100%). M.p. 215–218° (dec.; hexane/EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.82 (*s*, Me(19)); 0.89 (*s*, ^{t}Bu); 1.02 (*s*, Me(18)); 1.72 (*dd*, *J*(16,21) = 1.7, *J*(20,21) = 7.2, Me(21)); 3.55 (*m*, H–C(3)); 4.34 (br. *t*, H–C(16)); 5.49 (*dq*, *J*(20,16) = 1.7, *J*(20,21) = 7.2, H–C(20)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.5 (Me_2Si); 12.3 (C(19)); 13.2 (C(18)); 18.2 (Me_3C); 25.9 (Me_3C); 72.1 (C(3)); 75.4 (C(16)); 118.5 (C(20)); 155.1 (C(17)). EI-MS (70 eV): 432 (1.4, $M^{+\bullet}$), 417 (1.7, $[M-Me]^+$), 375 (22, $[M-{}^t\!Bu]^+$), 281 (7), 75 (100, Me_2SiOH^+). HR-MS: 375.2711 ($[M-{}^t\!Bu]^+$, $C_{23}H_{39}O_2Si^+$; calc. 375.2709). ESI-TOF-MS (pos.): 455.330 ($[M+Na]^+$, $C_{27}H_{48}NaO_2Si^+$; calc. 455.3309), 403.3384 ($[M+H]^+$, $C_{27}H_{49}O_2Si^+$; calc. 433.3489).

The (3β,5α,16β)-pregn-17(20)-ene-3,16-diol diacetate analogue has been described as a compound with unkown double-bond geometry [11].

*(3β,5α,16β,17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregn-17(20)-en-16-ol Acetate* (**5**). A soln. of **4** (300 mg, 0.69 mmol) in Ac_2O (1 ml, 10 mmol) and pyridine (2 ml) was stirred at r.t. for 15 h. The mixture was diluted with cold H_2O, and dil. HCl soln. was added to neutrality. The mixture was extracted with CH_2Cl_2, the combined org. phase washed with H_2O, dried (Na_2SO_4), and evaporated, and the solid obtained recrystallized: **5** (297.5 mg, 91%). M.p. 195–197° (hexane/EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.82 (*s*, Me(19)); 0.89 (*s*, ^{t}Bu); 1.01 (*s*, Me(18)); 1.71 (br. *d*, *J* = 7, Me(21)); 2.05 (*s*, MeCO)); 3.55 (*m*, H–C(3)); 5.42 (*m*, H–C(20), H–C(16)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.5 (Me_2Si); 12.3 (C(19)); 13.5 (C(18)); 17.5 (C(21)); 18.3 (^{t}Bu); 21.5 (*Me*CO); 26.0 (Me_3C); 72.1 (C(3)); 77.0 (C(16)); 120.4 (C(20)); 149.4 (C(17)); 171.3 (Me*C*O). EI-MS (70 eV): 474 (5, $M^{+\bullet}$), 459 (2, $[M-Me]^+$), 431 (10, $[M-Me-CO]^+$), 399 (32, $[M-{}^t\!Bu]^+$), 281 (7), 75 (100, Me_2SiOH^+). HR-MS: 417.2816 ($[M-{}^t\!Bu]^+$, $C_{25}H_{41}O_3Si^+$; calc. 417.2814). ESI-TOF-MS (pos.): 497.000 ($[M+Na]^+$, $C_{29}H_{50}NaO_3Si^+$; calc. 497.0001), 475.000 ($[M+H]^+$; $C_{29}H_{51}O_3Si^+$; calc. 475.0000).

For a description of this compound in the literature, see **4**.

*(3β)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}androst-5-en-17-one* was prepared by a procedure different from that previously described [12]. To a soln. of commercial (3β)-3-hydroxyandrost-5-en-17-one (1 g, 3.5 mmol) in CH_2Cl_2 (25 ml) was added ^{t}BuMe$_2$SiCl (1.5 g, 9.7 mmol), Et_3N (1.1 ml, 7.9 mmol), and *N*,*N*-dimethylpyridin-4-amine (914 mg, 7.5 mmol). The mixture was stirred at r.t. for 15 h poured into H_2O (300 ml), and extracted with CH_2Cl_2. The org. layer was washed with 10% aq. NH_4Cl soln. and brine, dried (Na_2SO_4), and evaporated, and the residue purified by CC (silica gel, 5% AcOEt/hexane): pure product (1.4 g, 100%). M.p. 151–152° (MeOH) ([12]: 146–147°). FT-IR (KBr): 1748 (C=O), 1092 (Si–O–C), 837, 774 (Me_2Si). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.88 (*s*, Me(18)); 1.03 (*s*, Me(19)); 0.89 (*s*, ^{t}Bu); 3.49 (*m*, H–C(3)); 5.34 (br. *d*, *J* = 5, H–C(6)). ^{13}C-NMR ($CDCl_3$), 500 MHz): −4.6 (Me_2Si); 13.5 (C(18)); 18.2 (Me_3C); 19.4 (C(19)); 25.9 (Me_3C); 72.4 (C(3)); 120.3 (C(6)); 141.8 (C(5)); 220.8 (C(17)). EI-MS (70 eV): 402 (0, $M^{+\bullet}$), 387 (3, $[M-Me]^+$), 345 (99, $[M-{}^t\!Bu]^+$), 269 (10), 75 (100, Me_2SiOH^+). HR-MS: 402.2956 ($M^{+\bullet}$, $C_{25}H_{42}O_2Si^+$; calc. 402.2954). Anal. calc. for $C_{25}H_{42}O_2Si$: C 74.6, H 10.5; found: C 74.4, H 10.6.

*(3β,16α)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-21-norpregna-5,17(20)-dien-16-ol* (**6**). As described for **1**, with methyltriphenylphosphonium bromide (4.2 g, 11.8 mmol), KO^{t}Bu (1.27 g, 11.4 mmol), dry THF (30 ml), (3β)-3-{[(*tert*-butyl)dimethylsilyl]oxy}androst-5-en-17-one (1 g, 2.5 mmol), and THF (5 ml): (3β)-3-{[(*tert*-butyl)dimethylsilyl]oxy}-21-norpregna-5,17(20)-diene (0.93 g, 93%), which was not isolated and characterized.

To a suspension of selenium dioxide (40 mg, 0.36 mmol) in CH_2Cl_2 (10 ml) at 0° was added dropwise 70% *tert*-butyl hydroperoxide soln. 0.07 ml, 0.7 mmol). After stirring for 1 h at r.t., a homogeneous soln. was obtained. A soln. of (3β)-3-{[(*tert*-butyl)dimethylsilyl]oxy}-21-norpregna-5,17(20)-diene (300 mg, 0.75 mmol) in CH_2Cl_2 (10 ml) was added dropwise, and the mixture was stirred for 30 min at r.t. Toluene was added (40 ml), and the resulting mixture was washed, with 10% aq. NaOH soln. (3 × 10 ml) and brine (3 × 10 ml), the org. phase dried (Na_2SO_4) and evaporated, and the crude solid thus obtained purified by CC (silica gel, 3% AcOEt/hexane): **6** (218 mg, 70%). M.p. 199–200° (hexane/EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.80 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.02 (*s*, Me(19)); 3.49 (*m*, H–C(3)); 4.67 (*dd*, H–C(16)); 4.90 (*d*, *J* = 2, 1 H–C(20));

5.10 (*d*, *J* = 2, 1 H–C(20)); 5.32 (br. *d*, *J* = 5, H–C(6)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 18.0 (C(18)); 18.2 (Me_3C); 19.4 (C(19)); 25.9 (Me_3C); 72.5 (C(3)); 72.7 (C(16)); 103.8 (C(20)); 141.6 (C(5)); 120.8 (C(6)); 165.9 (C(17)). EI-MS (70 eV): 416 (1, $M^{+\bullet}$), 399 (2, $[M-OH]^+$), 359 (20, $[M-{}^t\mathrm{Bu}]^+$), 281 (7), 75 (100, Me_2SiOH^+). HR-MS: 359.2399 ($[M-{}^t\mathrm{Bu}]^+$, $C_{22}H_{35}O_2Si^+$; calc. 359.2397). ESI-TOF-MS (pos.): 439.299 ($[M+Na]^+$, $C_{26}H_{44}NaO_2Si^+$; calc. 439.2997), 417.317 ($[M+H]^+$, $C_{26}H_{45}O_2Si^+$, calc. 417.3177).

*(3β,16β,17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregna-5,17(20)-dien-16-ol* (**7**). As described for **6** (second part), with selenium dioxide (40 mg, 0.36 mmol), CH_2Cl_2 (10 ml), 70% *tert*-butyl hydroperoxide soln. (0.07 ml, 0.7 mmol), **8** (350.6 mg, 0.85 mmol), and CH_2Cl_2 (10 ml): **7** (297.3 mg, 82%). M.p. 149–150° (MeOH/H_2O). FT-IR (KBr): 3278 (OH), 1098 (Si–O–C), 837; 774 (Me_2Si). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.88 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.02 (*s*, Me(19)); 1.74 (*dd*, *J*(21,16) = 1, *J*(20,21) = 7, Me(21)); 3.49 (*m*, H–C(3)); 4.43 (*dd*, H–C(16)); 5.32 (br. *d*, *J* = 5, H–C(6)); 5.59 (*dq*, *J*(20,16) = 1, *J*(20,21) = 7, H–C(20)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 13.2 (C(18)); 17.3 (C(21)); 18.2 (Me_3C); 19.4 (C(19)); 25.9 (Me_3C); 72.5 (C(3)); 74.4 (C(16)); 119.6 (C(20)); 120.9 (C(6)); 141.5 (C(5)); 155.4 (C(17)). EI-MS (70 eV): 430 (0, M^+), 373 (38, $[M-{}^t\mathrm{Bu}]^+$), 355 (7, $[M-57-18]^+$), 75 (100, Me_2SiOH^+). HR-MS: 373.2555 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}O_2Si^+$; calc. 373.2553). ESI-TOF-MS (pos.): 453.315 ($[M+Na]^+$, $C_{27}H_{46}NaO_2Si^+$; calc. 453.3153), 431.333 ($[M+H]^+$, $C_{27}H_{47}O_2Si^+$; calc. 431.3333).

The corresponding, 3*β*,16*α*,17*E*)-pregna-5,17(20)-diene-3,16-diol has been described [13].

*(3β,17*Z*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregna-5,17(20)-diene* (**8**). As described for **1**, with ethyltriphenylphosphonium bromide (4 g, 10.7 mmol), KO^{t}Bu (1.15 g, 10.3 mmol), dry THF (30 ml), (3*β*)-3-{[(*tert*-butyl)dimethylsilyl]oxy}androst-5-en-17-one (1 g, 2.5 mmol), and THF (5 ml): **8** (0.98 g, 95%). M.p. 129–130° (CH_2Cl_2/MeOH). FT-IR: (KBr): 3030 (C=C), 1086, 890 (Si–O–C), 850, 773 (Me_2Si). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.88 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.01 (*s*, Me(19)); 1.66 (*dd*, *J*(21,16) = 2, *J*(20,21) = 7, Me(21)); 3.49 (*m*, H–C(3)); 5.13 (*dq*, *J*(20,16) = 2, *J*(20,21) = 7, H–C(20)); 5.32 (br. *d*, *J* = 5, H–C(6)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 13.1 (C(18)); 16.6 (C(21)); 18.2 (Me_3C); 19.4 (C(19)); 26.0 (Me_3C); 72.6 (C(3)); 113.5 (C(20)); 121.0 (C(6)); 141.6 (C(5)); 150.2 (C(17)). EI-MS (70 eV): 414 (0, $M^{+\bullet}$), 399 (0.5, $[M-Me]^+$), 357 (30, $[M-{}^t\mathrm{Bu}]^+$), 281 (6), 75 (100, Me_2SiOH^+). HR-MS: 357.2606 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}OSi^+$; calc. 357.2604). ESI-TOF-MS (pos.): 437.325 ($[M+Na]^+$, $C_{27}H_{46}NaOSi^+$; calc. 437.3258), 415.338 ($[M+H]^+$, $C_{27}H_{47}OSi^+$; calc. 415.3384).

The corresponding (3*β*,17*Z*)-pregna-5,17(20)-diene-3-ol has been fully described [14].

*(3β,17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregna-5,17(20)-dien-21-ol* (**9**). A mixture of diethoxyphosphinylacetate (3 ml, 15.1 mmol) and NaOEt (344 mg of Na/5 ml of abs. EtOH, 15.0 mmol of NaOEt in abs. EtOH (20 ml) was vigorously stirred for 5 min. To this soln. was added (3*β*)-3-{[(*tert*-butyl)dimethylsilyl]oxy}androst-5-en-17-one (600 mg, 1.5 mmol) in EtOH (5 ml). The mixture was heated under reflux for 15 h and then poured into H_2O (100 ml) and extracted with CH_2Cl_2 (3 × 25 ml). The combined org. phase was dried (Na_2SO_4) and evaporated and the residue purified by CC (silica gel, 1% AcOEt/hexane to give the corresponding 5,17(20)-dien-21-oic acid ethyl ester (650 mg, 92%). M.p. 187–189° (CH_2Cl_2/MeOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.84 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.02 (*s*, Me(19)); 1.28 (*t*, *J* = 7, $MeCH_2$); 3.48 (*m*, H–C(3)); 4.15 (*q*, *J* = 7, $MeCH_2$); 5.32 (br. *d*, *J* = 5, H–C(6)); 5.54 (*t*, *J*(20,16) = 2, H–C(20)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 12.4 (C(18)); 19.4 (C(19)); 18.2 (Me_3C); 26.8 (Me_3C); 72.6 (C(3)); 108.4 (C(20)); 121.0 (C(6)); 141.6 (C(5)); 167.5 (C(17)); 176.5 (C(21)). EI-MS (70 eV): 472 (0.2, $M^{+\bullet}$), 457 (2.4, $[M-Me]^+$), 415 (100, $[M-{}^t\mathrm{Bu}]^+$), 75 (93, Me_2SiOH^+). HR-MS: 415.2214 ($[M-{}^t\mathrm{Bu}]^+$, $C_{29}H_{48}O_3Si^+$; calc. 415.2212.

A mixture of $LiAlH_4$ (95 mg, 2.5 mmol) and 5,17(20)-dien-21-oic ethyl ester (232 mg, 0.5 mmol) in dry THF (10 ml) was vigorously stirred for 30 min. To this suspension was added H_2O (50 ml). The aq. phase was extracted with AcOEt (3 × 10 ml), the combined org. phase evaporated, and the residue purified by CC (silica gel, 5% AcOEt/hexane: **9** (200 mg, 95%). M.p. 210–212° (MeOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.78 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.02 (*s*, Me(19)); 3.49 (*m*, H–C(3)); 4.13 (*m*, 2 H–C(21)); 5.25 (*m*, H–C(20)); 5.32 (br. *d*, *J* = 5, H–C(6)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 18.5 (C(18)); 19.4 (C(19)); 18.2 (Me_3C); 25.9 (Me_3C); 60.4 (C(21)); 72.6 (C(3)); 115.6 (C(20)); 120.9 (C(6)); 141.7 (C(5)); 155.8 (C(17)). EI-MS (70 eV): 430 (0.3, $M^{+\bullet}$), 415 (2.8, $[M-Me]^+$), 355 (9), 373 (100, $[M-{}^t\mathrm{Bu}]^+$), 281 (10), 75 (65.5, Me_2SiOH^+). HR-MS: 373.2555 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}O_2Si^+$; calc. 373.2553). ESI-TOF-MS (pos.): 453.315 ($[M+Na]^+$, $C_{27}H_{46}NaO_2Si^+$; calc. 453.3153), 431.333 ($[M+H]^+$, $C_{27}H_{47}O_2Si^+$; calc. 431.3333).

The (3*β*,17*E*)-pregna-5,17(20)-diene-3,21-diol 3-acetate has been described [15].

*(3β,17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-5,17(20)-dien-21-ol Acetate* (**10**). As described for **5**, with **9** (300 mg, 0.70 mmol), Ac_2O (1 ml, 10 mmol), and pyridine (2 ml): **10** (300 mg, 90%). M.p. 173–175° (hexane/EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.79 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.02 (*s*, Me(19)); 2.05 (*s*, $MeCO$); 3.49 (*m*, H–C(3)); 4.54 (*m*, 2 H–C(21)); 5.18 (*m*, H–C(20)); 5.32 (br. *d*, *J* = 5, H–C(6)).

^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 18.2 (Me_3C); 18.4 (C(18)); 19.4 (C(19)); 21.1 (*Me*CO); 25.9 (*Me*$_3$C); 62.4 (C(21)); 72.5 (C(3)); 110.7 (C(20)); 120.9 (C(6)); 141.7 (C(5)); 158.1 (C(17)); 171.1 (Me*C*O). EI-MS (70 eV): 472 (1, $M^{+\bullet}$), 457 (2.8, $[M-Me]^+$), 429 (7, $[M-Me-CO]^+$), 415 (31, $[M-{}^t\!Bu]^+$), 413 (23, $[M-Me-COO]^+$), 399 (22, $[M-MeCOOCH_2]^+$), 75 (100, Me_2SiOH^+). HR-MS: 415.2658 ($[M-{}^t\!Bu]^+$, $C_{25}H_{39}O_3Si$; calc. 415.2658). ESI-TOF-MS (pos.): 495.325 ($[M+Na]^+$, $C_{29}H_{48}NaO_3Si^+$; calc. 495.3258), 473.343 ($[M+H]^+$, ($[C_{29}H_{49}O_3Si^+$; calc. 473.3438).

Irradiation Conditions, Isolation, and Characterization of the Products: General Procedure (*G.P.*). A soln. of the steroid (190 mg) and Rose Bengal (1 mg) in pyridine (5 ml), contained in a *Pyrex* tube kept in a water-cooled bath, was saturated with oxygen. The soln., vigorously stirred by the gas bubbling, was irradiated with light from a *220-V-400-Im-CE-4-300* W lamp placed at a distance of 15 cm. The oxygen bubbling was stopped after 24 h. The irradiated soln. was analyzed by TLC (precoated silica gel *60* F_{254} plates, hexane/AcOEt and AcOEt/EtOH mixtures): The irradiated soln. was then evaporated, the solid residue dried and dissolved in a minimum volume of CH_2Cl_2, and this soln. adsorbed on silica gel, which was added to the top of a prep. column. After flash CC (silica gel, 2% MeOH/CH_2Cl_2), the isolated products were characterized by m.p., ^{1}H- and ^{13}C-NMR, EI-MS, HR-MS, and ESI-TOF-MS.

Irradiation of **1**: *(3β,5α)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-21-norpregn-16-en-20-al* (**1a**). The *G.P.* yielded **1a** (22%). M.p. 162–164° (hexane/EtOH). UV (EtOH): 248. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.77 (*s*, Me(18)); 0.82 (*s*, Me(19)); 0.88 (*s*, ^{t}Bu); 3.56 (*m*, H–C(3)); 5.73 (br. *s*, H–C(16)); 9.70 (*s*, H–C(20)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.5 (Me_2Si); 12.3 (C(19)); 18.5 (C(18)); 18.2 (Me_3C); 25.9 (*Me*$_3$C); 72.1 (C(3)); 152.9 (C(16)); 157.2 (C(17)); 190.0 (C(20)). EI-MS (70 eV): 416 (1.2, $M^{+\bullet}$), 387 (3, $[M-HCO]^+$), 361 (50, $[M-{}^t\!Bu]^+$), 75 (100, Me_2SiOH^+). HR-MS: 359.2399 ($[M-{}^t\!Bu]^+$, ($C_{22}H_{35}O_2Si^+$; calc. 359.2397). ESI-TOF-MS (pos.): 439.299 ($[M+Na]^+$, $C_{26}H_{44}NaO_2Si^+$; calc. 439.2997), 417.317 ($[M+H]^+$, $C_{26}H_{45}O_2Si^+$; calc. 417.3177).

Irradiation of **2**: *(3β,5α,20S)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregn-16-en-20-yl Hydroperoxide* (**2a**) *and (3β,5α)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregn-16-en-20-one* (**2b**). The *G.P.* yielded **2a** (64%) and **2b** (<0.5%).

Data of **2a**: M.p. 182–183° (dec.; EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.85 (*s*, Me(18)); 0.88 (*s*, Me(19)); 0.88 (*s*, ^{t}Bu); 1.35 (*d*, *J* = 6.5, Me(21)); 3.54 (*m*, H–C(3)); 4.59 (*q*, *J* = 6.5, H–C(20)); 5.73 (br. *s*, H–C(16)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.5 (Me_2Si); 12.4 (C(19)); 16.8 (C(18)); 18.2 (Me_3C); 25.9 (*Me*$_3$C); 18.9 (C(21)); 72.2 (C(3)); 79.1 (C(20)); 126.4 (C(16)); 154.9 (C(17)). EI-MS (70 eV): 448 (0, $M^{+\bullet}$), 433 (0.6, $[M-Me]^+$), 431 (5, $[M-OH]^+$), 391 (42, $[M-{}^t\!Bu]^+$), 75 (100, Me_2SiOH^+). FAB-MS (propylene glycol): 449 ($[M+H]^+$), 432. HR-MS: 391.2659 ($[M-{}^t\!Bu]^+$, $C_{23}H_{39}O_3Si^+$; calc. 391.2658). ESI-TOF-MS (pos.): 471.325 ($[M+Na]^+$, $C_{27}H_{48}NaO_3Si^+$; calc. 471.3258), 449.343 ($[M+H]^+$, $C_{27}H_{49}O_3Si^+$; calc. 449.3438).

Data of **2b**: ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.78 (*s*, Me(18)); 0.82 (*s*, Me(19)); 0.88 (*s*, ^{t}Bu); 2.22 (*s*, Me(21)); 2.30 (*m*, 2 H–C(15)); 3.54 (*m*, H–C(3)); 5.93 (br. *s*, H–C(16)). EI-MS (70 eV): 430 (2, $M^{+\bullet}$), 415 (6, $[M-Me]^+$), 387 (0.5, $[M-MeCO]^+$), 373 (23, $[M-{}^t\!Bu]^+$), 75 (100, Me_2SiOH^+). HR-MS: 373.2555 ($[M-{}^t\!Bu]^+$, $C_{23}H_{37}O_2Si^+$; calc. 373.2553). ESI-TOF-MS (pos.): 453.315 ($[M+Na]^+$, $C_{27}H_{46}NaO_2Si^+$; calc. 453.3153), 431.333 ($[M+H]^+$; $C_{27}H_{47}O_2Si^+$; calc. 431.3333).

Data of **2b**: The compound has been previously described [16].

Irradiation of **3**. The *G.P.* yielded only nonconverted **3**.

Irradiation of **4**: *(3β,5α,17α,20S)- and (3β,5α,17β,20S)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-20-hydroxypregnan-16-one* (**4a**). The *G.P.* yielded **4a** (26%). M.p. 203–205° (MeOH). ^{1}H-NMR ($CDCl_3$, 500 MHz): 0.05 (*s*, Me_2Si); 0.84 (*s*, Me(19)); 0.89 (*s*, ^{t}Bu); 1.04 (*s*, Me(18)); 1.39 (*d*, *J* = 2.3, Me(21)); 2.31 (*d*, *J* = 2.7), 2.34 (*d*, *J* = 2.6) (H–C(17)); 2.50 (*m*, 2 H–C(15)); 3.45 (*q*, *J* = 2.3, H–C(20)); 3.56 (*m*, H–C(3)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.5 (Me_2Si); 12.3 (C(19)); 14.3 (C(18)); 15.1 (C(21)); 18.2 (Me_3C); 25.9 (*Me*$_3$C); 69.6 (C(20)); 71.9 (C(3)); 215.4 (C(16)). EI-MS (70 eV): 448 (4, $M^{+\bullet}$), 433 (1.5, $[M-Me]^+$), 431 (3, $[M-OH]^+$), 420 (2, $[M-CO]^+$), 391 (53, $[M-{}^t\!Bu]^+$), 75 (100, Me_2SiOH^+). HR-MS: 391.2659 ($[M-{}^t\!Bu]^+$, $C_{23}H_{39}O_3Si^+$; calc. 391.2658). ESI-TOF-MS (pos.): 471.326 ($[M+Na]^+$, $C_{27}H_{48}NaO_3Si^+$; calc. 471.3258), 449.344 ($[M+H]^+$, $C_{27}H_{49}O_3Si^+$; calc. 449.3438).

The (3*β*,5*α*,17*β*,20*S*)-3-(acetyloxy)-20-hydroxypregnan-16-one analogue has been described [17].

Irradiation of **5**: **5a** (≡**4a**) *and (3β,5α,16β,17α)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregn-20-ene-16,17-diol 16-Acetate* (**5b**). The *G.P.* gave **5a** (38%) and **5b** (40%).

Data of **5a** (≡**4a**): identical to those of **4a** (see above).

Data of **5b**: M.p. 193–195° (dec.; hexane/EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.05 (*s*, Me_2Si); 0.88 (*s*, Me(19)); 0.89 (*s*, ^{t}Bu); 0.91 (*s*, Me(18)); 2.07 (*s*, MeCO)); 3.53 (*m*, H–C(3)); 5.13 (*d*, *J* = 8, 1 H–C(21)); 5.53 (*d*, *J* = 19, 1 H–C(21)); 6.04 (*t*, *J* = 7.8, H–C(16)); 5.52 (*dd*, *J* = 8 and 19, H–C(20)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.5 (Me_2Si); 12.3 (C(19)); 14.2 (C(18)); 18.3 (Me_3C); 21.2 (*Me*CO); 26.0 (*Me*$_3$C); 72.1 (C(3)); 76.7 (C(17)); 95.2 (C(16)); 115.8 (C(21)); 133.2 (C(20)); 169.8 (Me*C*O). EI-MS (70 eV): 490 (7, $M^{+\bullet}$), 475 (2,

$[M-Me]^+$), 447 (2, $[M-MeCO]^+$), 432 (37, $[M-{}^t\mathrm{Bu}]^+$), 75 (100, Me_2SiOH^+). HR-MS: 433.2765 ($[M-{}^t\mathrm{Bu}]^+$, $C_{25}H_{41}O_4Si^+$; calc. 433.2763). ESI-TOF-MS (pos.): 513.346 ($[M+Na]^+$, $C_{29}H_{50}NaO_4Si^+$; calc. 513.3465), 491.354 ($[M+H]^+$, $C_{29}H_{51}O_4Si^+$; calc. 491.3543).

Irradiation of **6**: *(3β,7α,16α)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-7-hydroperoxy-21-norpregna-5,17(20)-dien-16-ol* (**6a**): The *G.P.* yielded **6a** (36%). M.p. 170–172° (dec.; EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.79 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.00 (*s*, Me(19)); 3.57 (*m*, H–C(3)); 4.20 (br. *t*, *J* = 4.8, H–C(7)); 4.68 (*dd*, H–C(16)); 4.89 (*d*, *J* = 1.5, 1 H–C(20)); 5.08 (*d*, *J* = 1.5, 1 H–C(20)); 5.67 (*d*, *J* = 4.8, H–C(6)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 19.4 (C(19)); 18.2 (C(18)); 18.2 (Me_3C); 25.9 (Me_3C); 72.5 (C(3)); 72.7 (C(16)); 77.9 (C(7)); 103.8 (C(20)); 120.3 (C(6)); 147.6 (C(5)); 165.9 (C(17)). EI-MS (70 eV): 448 (0, $M^{+\bullet}$), 431 (2, $[M-OH]^+$), 430 (10, $[M-H_2O]^+$), 391 (25, $[M-{}^t\mathrm{Bu}]^+$), 75 (100, Me_2SiOH^+). HR-MS: 391.2297 ($[M-{}^t\mathrm{Bu}]^+$, $C_{22}H_{35}O_4Si^+$; calc. 391.2295). ESI-TOF-MS (pos.): 471.289 ($[M+Na]^+$, $C_{26}H_{44}NaO_4Si^+$; calc. 471.2895), 449.308 ($[M+H]^+$, $C_{26}H_{45}O_4Si^+$; calc. 449.3075).

Irradiation of **7**: *(3β,7α,16α,17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-7-hydroperoxypregna-5,17(20)-dien-16-ol* (**7a**). The *G.P.* yielded **7a** (26%). M.p. 168–171° (dec.; MeOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.87 (*s*, Me(18)); 0.90 (*s*, Me(19)); 0.89 (*s*, ^{t}Bu); 1.75 (*d*, *J* = 5.9, Me(21)); 3.50 (*m*, H–C(3)); 4.15 (br. *t*, H–C(7)); 4.45 (br. *d*, H–C(16)); 5.58 (br. *d*, *J* = 8, H–C(6)); 5.76 (*q*, *J* = 5.9, H–C(20)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 13.2 (C(18)); 17.3 (C(21)); 18.2 (Me_3C); 19.4 (C(19)); 25.9 (Me_3C); 72.5 (C(3)); 74.4 (C(16)); 78.0 (C(7)); 119.6 (C(20)); 120.9 (C(6)); 141.5 (C(5)); 155.4 (C(17)). EI-MS (70 eV): 462 (0, $M^{+\bullet}$), 445 (8, $[M-OH]^+$), 405 (28, $[M-{}^t\mathrm{Bu}]^+$), 387 (7, $[M-57-18]^+$), 75 (100, Me_2SiOH^+). HR-MS: 405.2453 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}O_4Si^+$; calc. 405.2451). ESI-TOF-MS (pos.): 485.305 ($[M+Na]^+$, $C_{27}H_{46}NaO_4Si^+$; calc. 485.3051), 463.323 ($[M+H]^+$, $C_{27}H_{47}O_4Si^+$; calc. 463.3231).

Irradiation of **8**: *(3β,20*S*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregna-5,16-dien-20-yl Hydroperoxide* (**8a**) *and (3β,20*S*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregna-5,16-dien-20-ol* (**8b**). The *G.P.* yielded **8a** (36%) and **8b** (9%).

Data of **8a**: M.p. 192–194° (dec.; EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): =0.06 (*s*, Me_2Si); 0.89 (*s*, ^{t}Bu); 1.03 (*s*, Me(18)); 1.04 (*s*, Me(19)); 1.35 (*d*, *J* = 6.6, Me(21)); 3.50 (*m*, H–C(3)); 4.50 (*q*, *J* = 6.6, H–C(20)); 5.31 (br. *d*, H–C(6)); 5.75 (br. *d*, *J* = 1.5, H–C(16)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 13.1 (C(18)); 18.2 (Me_3C); 19.4 (C(19)); 19.8 (C(21)); 26.0 (Me_3C); 72.6 (C(3)); 83.5 (C(20)); 121.0 (C(6)); 128.9 (C(16)); 141.6 (C(5)); 148.2 (C(17)). EI-MS (70 eV): 446 (0, $M^{+\bullet}$), 429 (5, $[M-OH]^+$), 414 (0.5, $[M-Me-HO]^+$), 389 (30, $[M-{}^t\mathrm{Bu}]^+$), 75 (100, MeO_2SiOH^+). HR-MS: 389.2504 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}O_3Si^+$; calc. 389.2502). ESI-TOF-MS (pos.): 469.310 ($[M+Na]^+$, $C_{27}H_{46}NaO_3Si^+$; calc. 469.3102), 447.328 ($[M+H]^+$, $C_{27}H_{47}O_3Si^+$; calc. 447.3282).

Data of **8b**: ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.89 (*s*, ^{t}Bu); 0.90 (*s*, Me(18)); 1.05 (*s*, Me(19)); 1.47 (*d*, *J* = 8.4, Me(21)); 3.50 (*m*, H–C(3)); 4.60 (*q*, *J* = 8.4, H–C(20)); 5.34 (br. *d*, *J* = 5.0, H–C(6)); 5.75 (br. *d*, *J* = 1.5, H–C(16)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 13.1 (C(18)); 18.2 (Me_3C); 19.4 (C(19)); 23.0 (C(21)); 26.0 (Me_3C); 72.6 (C(3)); 73.5 (C(20)); 120.0 (C(6)); 127.5 (C(16)); 143.6 (C(5)); 150.2 (C(17)). EI-MS (70 eV): 430 (1.1, $M^{+\bullet}$), 413 (8, $[M-OH]^+$), 398 (0.9, $[M-Me-HO]^+$), 373 (25, $[M-{}^t\mathrm{Bu}]^+$), 75 (100, Me_2SiOH^+). HR-MS: 373.2555 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}O_2Si^+$; calc. 373.2553). ESI-TOF-MS (pos.): 453.315 ($[M+Na]^+$, $C_{27}H_{46}NaO_2Si^+$; calc. 453.3153), 431.333 ($[M+H]^+$, $C_{27}H_{47}O_2Si^+$; calc. 431.3333)).

The (3β,20*R*/*S*)-pregna-5,16-diene-3,20-diol has been described [18].

Irradiation of **9**: *(3β,20*R*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-20-hydroperoxypregna-5,16-dien-21-ol* (**9a**), *(3β)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-21-hydroxypregna-5,16-dien-20-one* (**9b**), *(3β,17α)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-17-hydroxypregn-5-en-21-al* (**9c**), *and (3β,17*E*)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}pregna-5,17(20)-dien-21-al* (**9d**). The *G.P.* yielded **9a** (6%), **9b** (27%), **9c** (10%), and **9d** (17%).

Data of **9a**: M.p. 179–180° (dec.; EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.86 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.04 (*s*, Me(19)); 3.48 (*m*, H–C(3)); 3.68 (*m*, 2 H–C(21)); 5.33 (br. *d*, *J* = 5.1, H–C(6)); 5.72 (*t*, H–C(20)); 6.74 (br. *d*, *J* = 1.8, H–C(16)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 16.6 (C(18)); 19.4 (C(19)); 18.2 (Me_3C); 25.9 (Me_3C); 66.1 (C(21)); 69.84 (C(20)); 72.6 (C(3)); 120.8 (C(6)); 126.4 (C(16)); 141.9 (C(5)); 154.4 (C(17)). EI-MS (70 eV): 462 (0, $M^{+\bullet}$), 445 (1, $[M-OH]^+$), 431 (0.9, $[M-MeO]^+$), 415 (0.9, $[M-MeO-O]^+$), 405 (33, $[M-{}^t\mathrm{Bu}]^+$), 387 (10, $[M-MeO-O-CO]^+$), 75 (100, Me_2SiOH^+). HR-MS: 405.2453 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}O_4Si^+$; calc. 405.2451). ESI-TOF-MS (pos.): 485.305 ($[M+Na]^+$, $C_{27}H_{46}NaO_4Si^+$; calc. 485.3051), 463.323 ($[M+H]^+$, $C_{27}H_{47}O_4Si^+$; calc. 463.3231).

Data of **9b**: M.p. 158–161° (dec.; EtOH). UV (EtOH): 246. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.96 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.04 (*s*, Me(19)); 3.29 (*t*, *J* = 4.7, disappeared after adding D_2O, OH); 3.50 (*m*, H–C(3)); 4.39 (*dd*, *J* = 4.7, 17.8, → *d*(*J* = 17) after adding D_2O, 1 H–C(21)); 4.51 (*dd*, *J* = 4.7, 17.8, → *d*, *J* = 17 after adding D_2O, 1 H–C(21)); 5.33 (br. *d*, *J* = 5.1, H–C(6)); 6.74 (br. *d*, *J* = 1.8, H–C(16)).

^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 15.9 (C(18)); 19.4 (C(19)); 18.2 (Me_3C); 25.9 (Me_3C); 65.1 (C(21)); 72.6 (C(3)); 120.4 (C(6)); 142.2 (C(5)); 144.6 (C(16)); 151.6 (C(17)); 196.6 (C(20)). EI-MS (70 eV): 444 (0, $M^{+\cdot}$), 427 (1, $[M-OH]^+$), 413 (0.9, $[M-MeO]^+$), 387 (26, $[M-{}^t\mathrm{Bu}]^+$), 385 (20, $[M-MeO-CO]^+$), 75 (100, Me_2SiOH^+). HR-MS: for 387.2348 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{35}O_3Si^+$; calc. 387.2346). ESI-TOF-MS (pos.): 467.294 ($[M+Na]^+$, $C_{27}H_{44}NaO_3Si^+$; calc. 467.2946), 445.312 ($[M+H]^+$ $C_{27}H_{45}O_3Si^+$; calc. 445.3126).

The (3β)-3,21-bis(acetyloxy)pregna-5,16-dien-20-one analogue has been described [19].

Data of **9c**: M.p. 189–192° (dec.; EtOH). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.83 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.00 (*s*, Me(19)); 3.22 (*d*, *J* = 5.9, 2 H–C(20)); 3.50 (*m*, H–C(3)); 5.32 (br. *d*, *J* = 5.4, H–C(6)); 9.23 (br. *d*, *J* = 5.9, H–C(21)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 15.9 (C(18)); 19.5 (C(19)); 18.2 (Me_3C); 25.9 (Me_3C); 72.5 (C(3)); 75.8 (C(17)); 120.4 (C(6)); 141.7 (C(5)); 199.7 (C(21)). EI-MS (70 eV): 446 (0.8, $M^{+\cdot}$), 426 (3, $[M-H_2O]^+$), 417 (9, $[M-HCO]^+$), 398 (32, $[M-{}^t\mathrm{Bu}]^+$), 75 (100, Me_2SiOH^+). HR-MS: 398.2504 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{37}O_3Si^+$; calc. 398.2502. ESI-TOF-MS (pos.): 469.310 ($[M+Na]^+$, $C_{27}H_{46}NaO_3Si^+$; calc. 469.3102), 447.320 ($[M+H]^+$, $C_{27}H_{47}O_3Si^+$; calc. 447.3204).

Data of **9d**: M.p. 162–164° (hexane/EtOH). UV (EtOH): 248. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.94 (*s*, Me(18)); 0.89 (*s*, ^{t}Bu); 1.06 (*s*, Me(19)); 3.48 (*m*, H–C(3)); 5.32 (br. *d*, *J* = 5.4, H–C(6)); 6.78 (*m*, H–C(20)); 9.71 (*s*, H–C(21)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 15.8 (C(18)); 19.4 (C(19)); 18.2 (Me_{3C}); 25.9 (Me_3C); 72.6 (C(3)); 120.4 (C(6)); 142.2 (C(5)); 152.9 (C(20)); 157.1 (C(17)); 189.9 (C(21)). EI-MS (70 eV): 428 (1, $M^{+\cdot}$), 399 (2, $[M-HCO]^+$), 374 (5, $[M-HCOCCH]^+$), 371 (29, $[M-{}^t\mathrm{Bu}]^+$), 75 (100, Me_2SiOH^+). HR-MS: 371.3101 ($[M-{}^t\mathrm{Bu}]^+$, $C_{23}H_{35}O_2Si^+$; calc. 371.3099). ESI-TOF-MS (pos.): 451.299 ($[M+Na]^+$, $C_{27}H_{44}NaO_2Si^+$; calc. 451.2997), 429.317 ($[M+H]^+$, $C_{27}H_{45}O_2Si^+$; calc. 429.3177).

The analogue of **9d**, (3β,17*E*)-3-(acetyloxy)pregna-5,17(20)-dien-21-al, has been described [20].

Irradiation of **10**: *(3β)-3-{[(*tert*-Butyl)dimethylsilyl]oxy}-21-hydroxypregna-5,16-dien-20-one Acetate* (**10a**) *and* **10b** (≡**9d**). The G.P. yielded **10a** (8%) and **10b** (7%).

Data of **10a**: M.p. 203–205° (hexane/EtOH). UV (EtOH): 246. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.06 (*s*, Me_2Si); 0.89 (*s*, ^{t}Bu); 0.94 (*s*, Me(18)); 1.03 (*s*, Me(19)); 2.17 (*s*, MeCO); 3.48 (*m*, H–C(3)); 4.88 (*d*, *J* = 16, 1 H–C(21)); 5.01 (*d*, *J* = 16, 1 H–C(21)); 5.32 (*d*, *J* = 5.2, H–C(6)); 6.74 (br. *d*, *J* = 1.4, H–C(16)). ^{13}C-NMR ($CDCl_3$, 500 MHz): −4.6 (Me_2Si); 15.8 (C(18)); 18.0 (C(19)); 18.2 (Me_3C); 19.4 (*Me*CO); 25.9 (Me_3C); 65.7 (C(21)); 72.6 (C(3)); 120.4 (C(6)); 142.2 (C(5)); 143.9 (C(16)); 152.1 (C(17)); 170.4 (Me*C*O); 190.5 (C(20)). EI-MS (70 eV): 486 (2, $M^{+\cdot}$), 471 (1, $[M-Me]^+$), 443 (5, $[M-MeCO]^+$), 429 (33, $[M-{}^t\mathrm{Bu}]^+$), 427 (5, $[M-MeCOO]^+$), 414 (15, $[M-MeCOOCH]^+$), 75 (100, Me_2SiOH^+). HR-MS: 429.2427 ($[M-{}^t\mathrm{Bu}]^+$, $C_{25}H_{37}O_4Si^+$; calc. 429.2425). ESI-TOF-MS (pos.): 509.305 ($[M+Na]^+$, $C_{29}H_{46}NaO_4Si^+$; calc. 509.3051), 487.323 ($[M+H]^+$, $C_{29}H_{47}O_4Si^+$; calc. 487.3231).

The (3β)-3,21-bis(acetyloxy)pregna-5,16-dien-20-one analogue has been described [19].

Data of **10b** (≡**9d**): identical with those of **9d** (see above).

Computational Details. Geometries were fully optimized without imposing any symmetry constraints by *ab initio* and semiempirical methods. For *ab initio* DFT calculations, we used the hybrid gradient-corrected exchange functional combined with the gradient-corrected correlation functional, commonly known as B3LYP, which has been shown to be quite reliable for geometries. For geometry optimization, the standardized 3-21G basis set was used. We denote our B3LYP calculations by B3LYP/3-21G. For single-point and frequency calculations, the standarized 3-21G basis set was used at the B3LYP and HF (*Hartree–Fock*) theory level. The 6-311 + G(d,p) basis set was used at the B3LYP level for single-point calculations. All the *ab initio* calculations were carried out with the Gaussian 98W program.

The ground-state geometry and heat of formation of steroids were also calculated by using the semiempirical parametrized AM1 and PM3 methods as implemented in the version of the HyperChem Suite (professional) 7.05 program. PM3 has been proven effective in studies on molecules containing heteroatoms, compared with other methods such as MINDO/3 or MNDO.

The molecular orbitals were calculated by the ZINDO/S (Cl, 6:6) method transferring the optimized geometries obtained by *ab initio* calculations and by semiempirical methods. Similarly, HOMO and LUMO descriptions were obtained from geometries optimized at the AM1, PM3, HF/3-21G, and B3LYP/3-21G levels.

We also calculated ΔH_f at the HF/3-21G and B3LYP/21G levels, including the effect of the solvent. These calculations were performed by using, as self-consistent reaction field method (SCRF), the isodensity *Tomasi*'s polarized continuum model (IPCM) (IPCM/HF/3-21G//B3LYP/21G and IPCM/B3LYP/3-21G//B3LYP/3-21G). For solvent correction, pyridine with relative permittivity ($\varepsilon = 12.3$) was used.

REFERENCES

[1] W. Albro, P. Bilski, J. T. Corbett, J. L. Schroeder, C. F. Chignell, *Photochem. Photobiol*. **1997**, *66*, 316.
[2] G. O. Schenck, O. A. Neumuller, W. Eisfeld, *Justus Liebigs Ann. Chem*. **1958**, *618*, 202.
[3] a) A. Nickon, J. F. Bagli, *J. Am. Chem. Soc.* **1961**, *83*, 1498; b) A. Nickon, W. L. Mendelson, *J. Am. Chem. Soc*. **1963**, *85*. 1849.
[4] A. L. J. Beckwith, A. G. Davies, I. G. E. Davison, A. Maccoll, M. H. Mruzek, *J. Chem. Soc., Perkin Trans. 2* **1989**, 815.
[5] M. A. Ponce, J. A. Ramirez, L. R. Galagovsky, E. G. Gros, R. Erra-Balsells, *J. Chem. Soc., Perkin Trans. 2* **2000**, 2351.
[6] M. A. Ponce, J. A. Ramirez, L. R. Galagovsky, E. G. Gros, R. Erra-Balsells, *Photochem. Photobiol. Sci*. **2002**, *1*, 745.
[7] a) C. S. Foote, E. L. Clennan, in 'Active Oxygen in Chemistry', Eds. C. S. Foote, J. S. Valentine, A. Greenberg, and J. F. Liebman, Blackie Academic, New York,1995, p. 105; b) G. O. Schenck, H. Eggert, W. Denk, *Liebigs Ann. Chem.* **1953**, *584*, 177; c) A. G. Griesbeck, T. T. EL-Idreesy, W. Adam, O. Krebs, 'Ene-Reaction with Singlet Oxygen', in 'CRC Handbook of Photochemistry and Photobiology', Eds. W. M. Horspool and P.-S. Sing, CRC, Boca Raton, Florida, 2004, Chap. 8, p. 8; d) M. Stratakis, M. Orfanopoulos, *Tetrahedron* **2000**, *56*, 1595; e) M. Orfanopoulos, M. B. Grdina, L. M. Stephenson, *J. Am. Chem. Soc*. **1979**, *101*, 275; f) A. G. Leach, K. N. Houk, *Chem. Commun.* **2002**, 1243; g) W. Adam, M. Prein, *Angew. Chem., Int. Ed.* **1996**, *35*, 477; h) W. Adam, B. Nestler, *J. Am. Chem. Soc.* **1993**, *115*, 5041; i) W. Adam, H.-G. Brünker, A. S. Kumar, E.-M. Peters, K. Peters, U. Schneider, H. G. von Schnering, *J. Am. Chem. Soc*. **1996**, *118*, 1899; j) A. G. Griesbeck, W. Adam, A. Bastoschek, T. El-Idreesy, *Photochem. Photobiol. Sci*. **2003**, *2*, 877; k) R. W. Hoffman, *Chem. Rev.* **1989**, *89*, 1841.
[8] A. Bruttomesso, D. Doller, E. G. Gros, *Synth. Commun*. **1998**, *28*, 4043.
[9] A. Bruttomesso, D. Doller, E. G. Gros, *Bioorg. Med. Chem*. **1999**, *7*, 943; A. Bruttomesso, E. G. Gros, *Molecules* **2000**, *5*, 564.
[10] K. Al-Fouti, J. R. Hanson, *J. Chem. Res. Sympo*. **2003**, *4*, 232.
[11] E. Mincione, C. Iavarone, *Gazz. Chim. Ital*. **1971**, *101*, 956.
[12] H. Hosoda, D. K. Fukushima, J. Fishman, *J. Org. Chem.* **1973**, *38*, 4209.
[13] S. V. Kessar, A. L. Rampal, *Tetrahedron* **1968**, *24*, 887.
[14] L. D. Timberlake, H. Morrison, *J. Am. Chem. Soc*. **1999**, *121*, 3618.
[15] G. Ortar, E. Morera, A. Romeo, *J. Org. Chem*. **1978**, *43*, 2927.
[16] H. Duddeck, D. Rosenbaum, M. Hani, A. Elgamal, M. B. E. Fayez, *Magn. Reson. Chem*. **1986**, *24*, 999; R. Mata, I. Rivero-Cruz, B. Rivero Cruz, R. Bye, B. N. Timmeermann, *J. Nat. Prod*. **2002**, *65*, 1030.
[17] S. Noguchi, M. Imanishi, K. Morita, *Chem. Pharm. Bull*. **1964**, *12*, 1184.
[18] A. G. Bajaj, S. Dev, *Tetrahedron* **1982**, *19*, 2949.
[19] D. H. R. Barton, W. B. Motherwell, S. Z. A. Zard, *J. Chem. Soc., Chem. Commun.* **1982**, 551.
[20] G. Ferrara, A. Ius, C. Parini, G. Sportoletti, G. Vecchio, *Tetrahedron* **1972**, *28*, 2461.

Received July 12, 2004