Acylation of Aldo 1-Pyrroline 1-Oxides (4,5-Dihydro-3*H*-pyrrole 1-Oxides)† and the Oxidation of the Resulting 3-Acyloxy-1-pyrrolines (3-Acyloxy-4,5-dihydro-3*H*-pyrroles)

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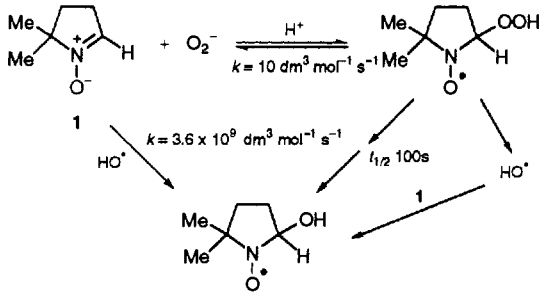
5,5-Dimethyl-1-pyrroline 1-oxide (DMPO), when treated with NaH (1 mol) followed by ethyl chloroformate, benzoyl chloride, pivaloyl chloride or 2-bromoisobutyryl bromide gave the corresponding 3-acyloxy-1-pyrrolines. With NaH (2–4 mol) followed by benzoyl chloride or 2-bromoisobutyryl bromide, DMPO gave the corresponding 2-(3′-acyloxy-1′-pyrrolin-3′-yl)-3-acyloxypyrrolidines. Acylation of the 3-phenyl and 3-methyl DMPOs also gave the corresponding 3-acyloxy-1-pyrrolines. Oxidation of the 3-acyloxy-1-pyrrolines with *m*-CPBA gave the corresponding oxaziridines in good yield. These oxaziridines were resistant to ring opening by acid hydrolysis, photolysis and thermolysis.

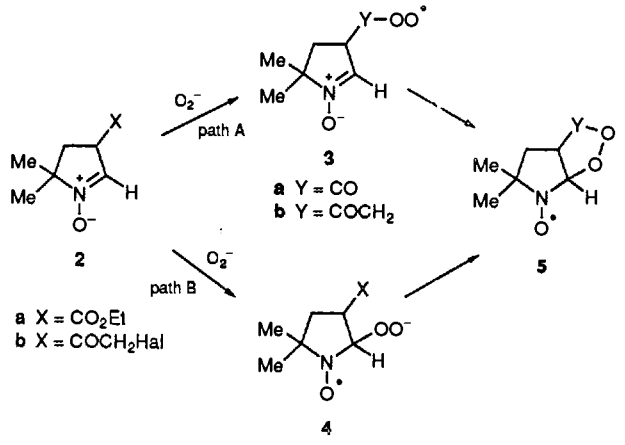
Spin-trapping of the superoxide radical anion ($O_2^{\cdot-}$) with the nitrone 5,5-dimethyl-1-pyrroline 1-oxide (DMPO) **1**† is an important biophysical technique (Scheme 1). By this method



Scheme 1

the generation of $O_2^{\cdot-}$ during the respiratory burst of neutrophils has been demonstrated.[1] However the limitations of DMPO as a spin trap for $O_2^{\cdot-}$ have been well documented.[2] DMPO is not an avid scavenger of $O_2^{\cdot-}$ and the DMPO–O_2H adduct is unstable, with a $t_{1/2}$ for its decay which is rarely greater than 100 s under physiological conditions. Furthermore, two of the decay pathways of the DMPO–O_2H adduct lead to formation of the hydroxyl radical adduct of DMPO (DMPO–OH, 3%) and free hydroxyl radicals (HO•) which then react rapidly with DMPO also to give DMPO–OH. One of the most important functions of spin trapping in biological milieu is to distinguish between the presence of $O_2^{\cdot-}$ and HO• radicals but the spin adduct of $O_2^{\cdot-}$ with DMPO is, in fact, a source of HO• radicals leading to difficulty and controversy in interpreting results. Clearly an improved spin trap for $O_2^{\cdot-}$ would be of great value in this important area. Since peroxy radicals, *e.g.* Bu^{t}OO•, form persistent adducts with DMPO,[3] the instability of the DMPO–O_2H adduct is probably due to the inherent instability of the secondary hydroperoxide functionality. If it were possible to convert DMPO–O_2H from an alkyl hydroperoxide into a dialkyl peroxide by 'capping' the free HOO group then the resultant spin adduct would be relatively long-lived.

Janzen[4] recently reported a novel spin trapping method whereby a short-lived radical first reacts with the spin trap at a site remote from the nitrone functionality to produce a secondary radical which is then trapped intramolecularly. HO• radicals selectively remove a hydrogen atom from one of the *ortho* methoxy groups of 2,4,6-trimethoxyphenyl-*tert*-butyl nitrone to produce an aryloxymethyl radical which is intramolecularly trapped to form a dihydrobenzofuranyl-aminoxyl which is detected. Since only HO• radicals abstract this hydrogen atom, the detection of the aminoxyl is specific to HO•. By analogy, 1-pyrroline 1-oxides of the type **2**, with an electrophilic functionality such as a halogenoacetonyl[5] or ester[6] function at position 3, could react with $O_2^{\cdot-}$ to give a peroxy radical intermediate **3** which would then undergo rapid intramolecular spin trapping to give a potentially persistent spin-adduct **5** (Scheme 2, path A). The conventional spin



Scheme 2

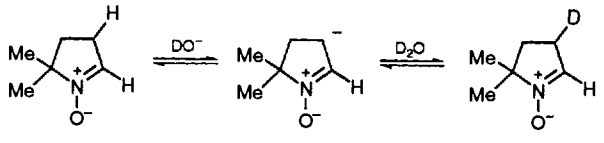
trapping of $O_2^{\cdot-}$ by the nitrone **2** would give the hydroperoxy nitroxide **4** which could undergo rapid ring closure to also give the bicyclic aminoxyl **5** (Scheme 2, path B). $O_2^{\cdot-}$ does not add rapidly to the nitrone functionality (k_m DMPO + $O_2^{\cdot-}$ = 10 mol^{-1} s^{-1} at pH 7.8) and it has been shown[7] that increasing the steric hindrance at the 3-position of DMPO reduces the rate of this reaction further (k_m 3,3-dimethyl-DMPO + $O_2^{\cdot-}$ = 1 dm^3 mol^{-1} s^{-1}, k_m 3,3-diethyl-DMPO + $O_2^{\cdot-}$ = 0 dm^3 mol^{-1} s^{-1}). The displacement of alkyl bromides by $O_2^{\cdot-}$ is reported[5a] to proceed with rate constants in the range 150–670 dm^3 mol^{-1} s^{-1}, while the rate of reaction between $O_2^{\cdot-}$ and phenyl acetate has been determined[6b] to be 140 dm^3 mol^{-1} s^{-1}. Consequently, it is expected that the spin trapping of $O_2^{\cdot-}$ by nitrones of the type **2** will proceed by path A. Two groups of researchers have used

† The term aldo refers to nitrones which are derived from the condensation of aldehydes with hydroxylamines. Although in the earlier sections of this paper the compounds are, for convenience, described as 1-pyrrolines, the IUPAC-approved names are given in the Experimental section.

similar methodologies to prepare cyclic peroxides. Dao and co-workers[8] treated 1,2-bis(bromomethyl) benzene with 2 equiv. of O_2^- to give a 1,2-dioxine while Corey and co-workers[9] prepared a 1,2-dioxacyclopentane from a 1,3-dimesylate.

The aldo 1-pyrroline 1-oxides **2a** and **2b** would be expected to be difficult to prepare by standard methods which require the Zn/NH_4OAc reduction of protected 4-nitro aldehydes. The reduction of the nitro group to the corresponding hydroxylamine in the presence of an ester would be expected to give the corresponding cyclic hydroxamic acid[10] while treatment of an acetonyl halide with zinc could lead to dehalogenation.[11]

Nitrones are isoelectronic with ketones and were originally named[12] as a contraction of 'nitrogen ketone'. The nitrone functionality increases the acidity of protons on carbons adjacent to the C=N bond and therefore nitrones readily undergo several base-catalysed aldol-type reactions. An apparently attractive method of preparing spin traps of the type **2** would be to functionalise DMPO by generating the 3-carbanion **6** and then allowing this to react with a suitable electrophile. A few nucleophilic reactions of 1-pyrroline 1-oxides of this type are known including deuterium exchange[13] (Scheme 3), the condensation of 1-pyrroline 1-oxides with 3,5-



1 **6**

Scheme 3

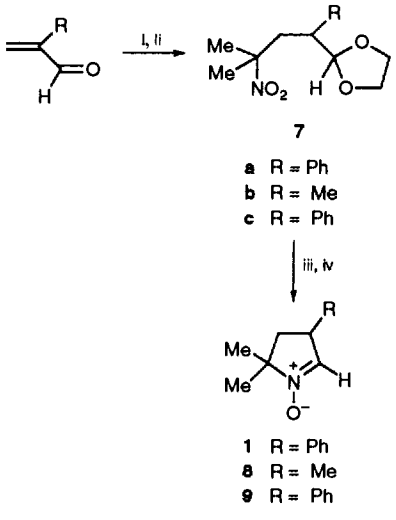
dimethoxycarbonylpyridinium tosylate[14] and the aldol-type dimerisations which can be effected by treating DMPO **1** with a strong anhydrous base such as trityl sodium or sodamide.[15] Accordingly three aldo 1-pyrroline 1-oxides were prepared and treated with strong base and electrophiles in order to effect substitution at position 3.

Results and Discussion

DMPO **1**, 3,5,5-trimethyl-1-pyrroline 1-oxide (Me_3PPO) **8** and 5,5-dimethyl-3-phenyl-1-pyrroline 1-oxide (DM_3PPO) **9** were prepared by the method shown in Scheme 4. Full details on the preparation of DM_3PPO **9** are presented in an accompanying paper.[16]

Spectral Characteristics of 1-Pyrroline 1-Oxides.—In this and in subsequent papers we have distinguished aldo 1-pyrroline 1-oxides from related pyrrolines, pyrrolidines and oxaziridines by their spectral characteristics. The stretching vibration of the $C{=}N^+(O^-)$ bond is highly characteristic, giving a strong, sharp absorption within the range 1575 ± 9 cm^{-1}. In the ^{13}C NMR spectra the nitronyl carbons (C-2) resonate within a very narrow frequency range (134.0 ± 3.5 ppm while in the ^1H NMR spectra the nitronyl protons show greater variation in frequency (6.70 ± 0.2 ppm), however the resonances appear in a relatively clear part of the spectrum and can be readily distinguished from aromatic and 1-pyrroline proton resonances (> 7.0 ppm).

Reaction of Aldo 1-Pyrroline 1-Oxides with Acylating Agents.—Acylation of DMPO **1**. Nitrones act as O nucleophiles with sulfonyl chlorides,[17] ketenes,[18] ketene imines,[19] acid halides[20] and acid anhydrides.[21] The reaction with acid halides and anhydrides to give *N*-acyloxy imines is usually followed by a hetero-Cope rearrangement to give β-acyloxy imines. However, according to a report by Black and Boscacci,[22] when DMPO is treated first with sodium hydride followed by ethyl chloroformate, 3-ethoxycarbonyl-5,5-dimethyl-1-pyrroline 1-oxide **2a**, a putative spin-trap for DMPO, is formed. Repetition of this work and extensive modification in our hands always resulted in a product which displayed the same spectral characteristics as were reported for **2a** but which was identified by us as the 1-pyrroline **10** (Scheme 5). The C=N bond stretch in **10** occurs at 1626 cm^{-1} which is inconsistent with an aldo 1-pyrroline 1-oxide but corresponds to the expected stretching frequency for a 1-pyrroline.[23] The ^{13}C NMR spectrum shows that 2-C resonates at 159.7 ppm which is in the correct range for a 1-pyrroline[23] but not for a 1-pyrroline 1-oxide, that 3-C resonates at 88.32 ppm which suggests that it is attached to oxygen and that the carbonyl carbon resonates at 154.4 ppm which is highly characteristic of the carbonate functionality.[23] The ^1H NMR spectrum shows a signal for 2-H at 7.43 ppm which is a low field position for a 1-pyrroline 1-oxide while the 3-H signal is at 5.55 ppm which is consistent with 3-C being bonded to oxygen. It appears that despite the earlier report[22] reaction of the nitrone **1** with ethyl chloroformate is exclusively at O, there being no evidence from IR or NMR for the co-formation of the 3-oxycarbonylnitrone



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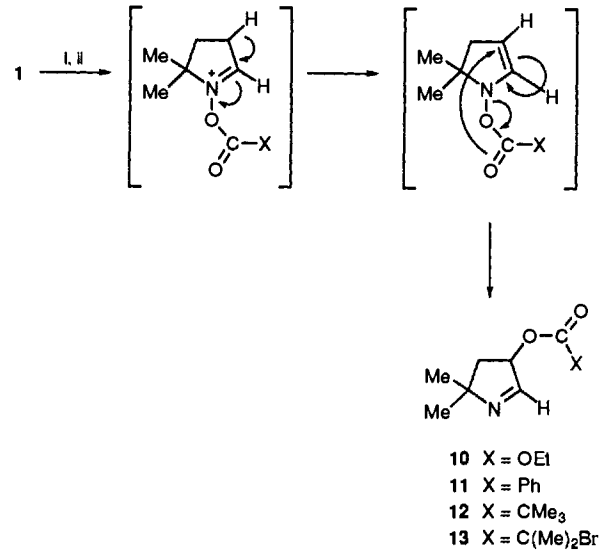
a R = Ph
b R = Me
c R = Ph

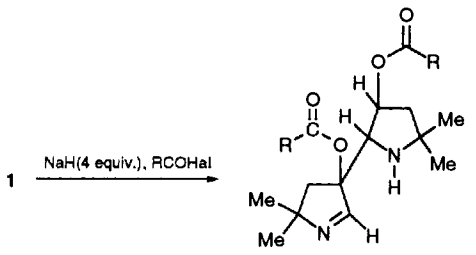
1 R = Ph
8 R = Me
9 R = Ph

Scheme 4 i, Me_2CHNO_2, base; ii, $HOCH_2CH_2OH$, *p*TSA, C_6H_6, reflux; iii, Zn, NH_4Cl; iv, HCl_{aq}



10 X = OEt
11 X = Ph
12 X = CMe_3
13 X = $C(Me)_2Br$

Scheme 5 i, NaH; ii, XCOHal



14 R = Ph
15 R = $C(Me)_2Br$

Table 1 ESR parameters for the aminoxyl spin adducts detected when the nitrones **1**, **8** and **9** were treated with di-*tert*-butyl peroxalate in benzene. Hyperfine splittings in gauss

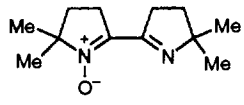
	Nitrone	a_N/G	$a_H\beta$/G	$a_H\gamma$/G
1	**1**[3]	13.11	7.93	1.97
2	**1**	13.12	7.88	2.00
3	**8** (Major)	13.38	15.13	
4	**8** (Minor)	13.12	4.88	1.25
5	**9**	13.35	16.10	

2a. The participation of NaH in this reaction appears to be confined to neutralising the HCl produced, permitting the isolation of the free 1-pyrroline **10**.

Replacement of the ethyl chloroformate with the more active electrophiles benzoyl chloride, trimethylacetyl chloride and 2-bromoisobutyryl bromide also gave the 3-acyloxy-1-pyrrolines **11**–**13** in moderate to low yields. All 1-pyrrolines showed a band of medium intensity in their FTIR spectrum at 1626–1638 cm^{-1} from the C=N stretch, a resonance in the range 159–161 ppm in the ^{13}C NMR spectrum from 2-C and a resonance in the range 7.50–7.60 in the ^1H NMR spectrum from 2-H. There was no evidence on examination of the crude reaction mixtures by FTIR or NMR for the co-formation of the desired 3-keto-1-pyrroline 1-oxides. However some indirect evidence for the possible formation of a 3-keto-1-pyrroline 1-oxide in low yields was obtained from ESR measurements (*vide infra*).

The ability of NaH to act as a proton abstracter under these reaction conditions was demonstrated by the formation of the dimeric products **14** and **15** when DMPO was pre-treated with NaH (2–4 mol) followed by benzoyl chloride or 2-bromoisobutyryl bromide (1 mol), respectively. In each case the rapid formation of the 3-acyloxy-1-pyrroline was followed by base-catalysed 3,2′ coupling. No further oligomerisation occurred, probably for steric reasons. The dimers **14** and **15** showed an absorption at 1638 cm^{-1} due to stretch of the C=N bond. The ^{13}C NMR spectra showed one resonance at 160 ppm from the 1-pyrroline carbon and two resonances from the carbonyl groups showing that each carbonyl was in a slightly different environment. Hydrolysis of each diester with aqueous base gave the corresponding dialcohol, the ^{13}C NMR spectrum of which showed 12 non-equivalent carbons as expected, including the 1-pyrroline signal at 164.9 ppm.

When DMPO was treated with LDA at −70 °C in order to generate the carbanion **6**, subsequent treatment with benzoyl chloride gave the 3-benzoyloxy-1-pyrroline **11** in good yield. When benzyl bromide was used as electrophile most of the DMPO was recovered and a small amount of the 2,2′ coupled bipyrroline mono-oxide **16** was isolated. Compound **16** can also be prepared in moderate yield by treating DMPO with sodamide[15b] and its formation has been explained by a benzoin-type mechanism following nucleophilic attack by sodamide at C-2.[24] It would appear therefore that the reaction



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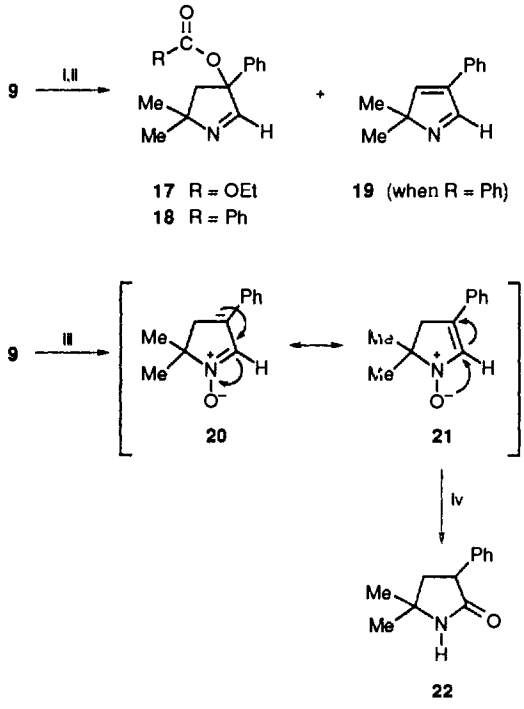
of benzyl bromide with the anion of DMPO at both O and C is so slow that the benzoin-type self-condensation is preferred.

Acylation of DM_3PPO **9**. When DM_3PPO **9** was treated with NaH, it was expected that the influence of the 3-phenyl group would be to stabilise the carbanion **20** thereby allowing easier reaction at position 3 by an alkyl or acyl halide. However this 1-pyrroline 1-oxide showed similar reactivity to that of DMPO **1**. Thus, treatment of DM_3PPO with NaH in benzene followed by ethyl chloroformate gave the carbonate **17** while reaction with benzoyl chloride gave the 3-benzoyloxy-1-pyrroline **18** and a



Scheme 6 i, NaH; ii, EtOCOCl or PhCOCl; iii, lithium diamide; iv, H_2O

small amount of the 2H-pyrrole **19**, formed by the elimination of benzoic acid from **18** (Scheme 6). When the nitrone **9** was treated with LDA at −70 °C, subsequent treatment with benzoyl chloride gave the 3-benzoyloxy 1-pyrroline **18** in good yield. In the case of prolonged exposure of DM_3PPO to LDA and benzyl bromide, initially at −70 °C and subsequently at room temperature, isomerisation to the γ-lactam **22** occurred and most of the benzyl bromide was recovered. The nitrone **9** also isomerises to the amide **22** when treated with trityl sodium.[16] In each case the isomerisation probably proceeds by base-catalysed removal of the C-3 proton to give the carbanion (**20** ⟷ **21**) which undergoes an oxygen migration from N-1 to C-2, possibly *via* an oxaziridine intermediate. The failure of 1-pyrroline 1-oxide **9** to dimerise in the presence of strong anhydrous base may be due to steric hindrance by the phenyl group.

Acylation of Me_3PPO **8**. When Me_3PPO **8** was treated with NaH and benzoyl chloride, the corresponding acyloxypyrroline was isolated in good yield. No nitrones were isolated amongst the minor products. (See Table 2 and legend.)

Detection of Nitrones in the Crude Reaction Mixtures by Spin Trapping.— The apparent non-detection, by FTIR and NMR,

Table 2 ESR parameters for the aminoxyl spin adducts detected when the crude reaction mixtures from the acylation of the nitrones **1**, **8** and **9** were treated with di-*tert*-butyl peroxalate in benzene. Hyperfine splittings in gauss, nd = no adduct detected

	Nitrone	Electrophile	a_N/G	$a_H\beta$/G	$a_H\gamma$/G	Intensity
1	**1**	EtOCOCl	13.10	7.90	2.00	vw
2	**1**	PhCOCl	14.10	18.81		w
3	**1**	Me_3CCOCl	nd			
4	**1**	$Me_2BrCCOBr$	13.13	7.94	2.01	vw
5	**9**	EtOCOCl	13.52	8.63		w
6	**9**	PhCOCl	17.85			w
7	**8**	PhCOCl	nd			

of 3-substituted 1-pyrroline 1-oxides when 1-pyrroline 1-oxides are treated with base followed by chloroformates and acid chlorides was examined more closely by ESR. If any of the crude products of the acylations contained nitrones, either unchanged starting material or small amounts of the desired 3-substituted 1-pyrroline 1-oxides, then characteristic signals should be detected by ESR when these nitrones spin trap a suitable radical. The limit of detection by ESR has been estimated[25] to be approximately 3×10^{-9} mol dm^{-3} which is many orders of magnitude more sensitive than ^1H NMR. A convenient method of generating *tert*-butoxy radicals at room temperature is by the dissolution of di-*tert*-butylperoxyoxalate[26] in a hydrophobic solvent such as benzene.

The three 1-pyrroline 1-oxides DMPO **1**, Me_3PPO **8** and DM_3PPO **9** bear increasingly large groups adjacent to the spin trapping centre at C-3. These groups correspondingly present an increasingly large barrier to the approach of the bulky Bu^{t}O$^\bullet$ radical to the spin trapping centre. The hyperfine coupling constants of the Bu^{t}O$^\bullet$ spin adducts of these nitrones are listed in Table 1. In the case of DMPO there is effectively no barrier to spin trapping and only one adduct is possible for which $a_N > a_H\beta > a_H\gamma$ [Fig. 1(*a*)] while in the case of DM_3PPO the steric hindrance to the formation of a *cis* adduct is large and only the *trans* adduct, for which $a_H > a_N$, is observed [Fig. 1(*b*)]. There appears to be no splitting due to $a_H\gamma$. Me_3PPO presents an intermediate case and two spin adducts are observed. The spectra may be due either to (i) the *cis* and *trans* isomers of the Bu^{t}O radical spin adduct or (ii) a mixture of the Bu^{t}O and the methyl radical spin adducts (the methyl radical arising from the decomposition of the Bu^{t}O radical). We prefer the former possibility since we have not detected methyl radical adducts with other spin traps under the same conditions. It would be expected that the presence of the 3-Me group would favour the formation of the *trans* adduct and indeed the major adduct shows similarity to (DM_3PPO–Bu^{t}O) with $a_H\beta > a_N$ and no $a_H\gamma$ splitting while the minor *cis* adduct is similar to DMPO–Bu^{t}O with $a_N > a_H\beta > a_H\gamma$.

Despite there being no trace of DMPO by NMR in the crude products following the acylation of DMPO with ethyl chloroformate or 2-bromoisobutyryl bromide, the DMPO–Bu^{t}O adduct was observed at low intensity when the crude products were treated with di-*tert*-butyl peroxyoxalate in benzene (Table 2). No other signals were detected. No signals were detected when the crude reaction mixture of DMPO with pivaloyl chloride was treated with di-*tert*-butyl peroxyoxalate. When the crude product of the reaction of DMPO with benzoyl chloride was treated with di-*tert*-butyl peroxyoxalate a new spin adduct was detected at low intensity. The spectrum of the new aminoxyl resembles that of DM_3PPO–Bu^{t}O in that $a_H\beta > a_N$ and there is no $_H\gamma$ coupling [Fig. 1(*c*)]. This is consistent with this aminoxyl arising from the *trans* addition of Bu^{t}O$^\bullet$ to a nitrone with a sterically bulky group at C-3 such as **23**. This possibility could not be verified since the putative nitrone was formed in too low a yield to be isolated.

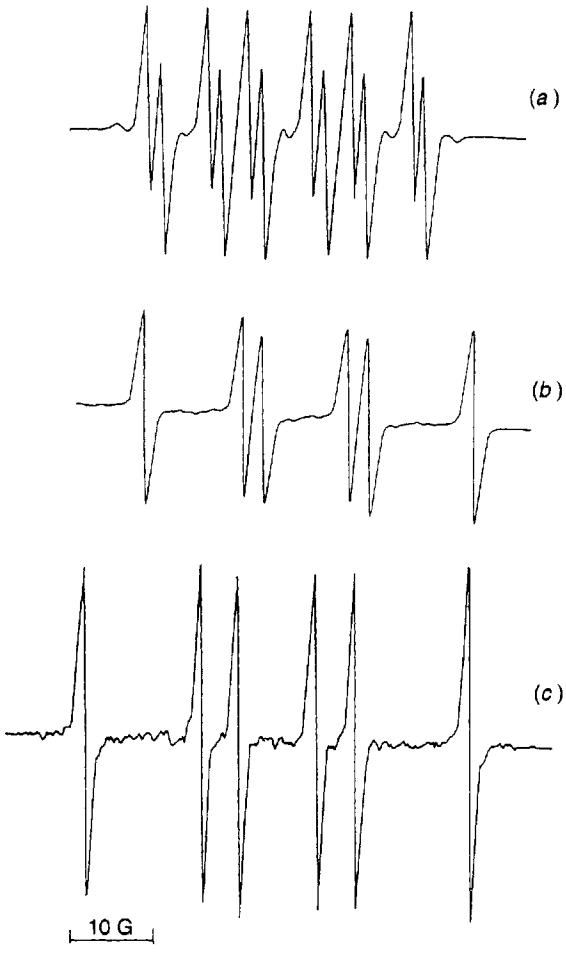
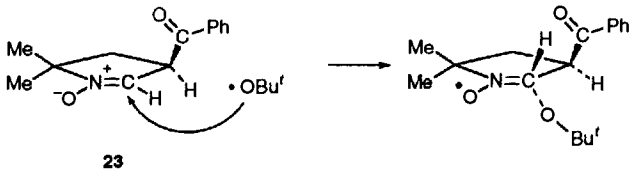
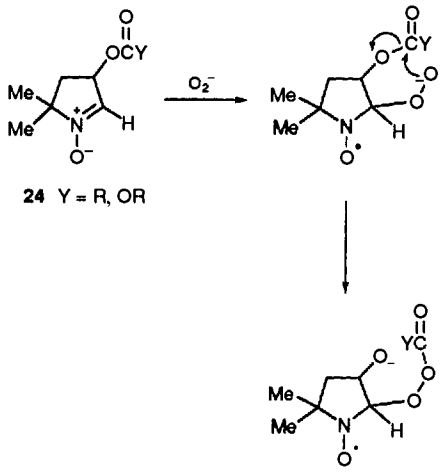


Fig. 1 (*a*) ESR spectrum of DMPO–Bu^{t}O (Table 1, entry 2), a_N = 13.12 G, $a_H\beta$ = 7.88 G, $a_H\gamma$ = 2.00 G. (*b*) ESR spectrum of DM_3PPO–Bu^{t}O (Table 1, entry 5), a_N = 13.35 G, $a_H\beta$ = 16.10 G. (*c*) ESR spectrum of adduct obtained when crude reaction mixture of DMPO and PhCOCl was treated with di-*tert*-butyl peroxalate (Table 2, entry 2), a_N = 14.10 G, $a_H\beta$ = 18.81 G.



Preparation of 3-Acyloxy-1-pyrroline 1-Oxides.—Failure to produce 3-substituted 1-pyrrolidine 1-oxides directly by acylation procedures led us to examine the possibility of converting the 3-acyloxy-1-pyrrolines formed to the corresponding 1-pyrroline 1-oxides *via* their oxaziridines. The 1-pyrroline 1-oxides of type **24** produced in this way should be possible

replacements for the target 3-acyl-1-pyrroline 1-oxides (Scheme 7).

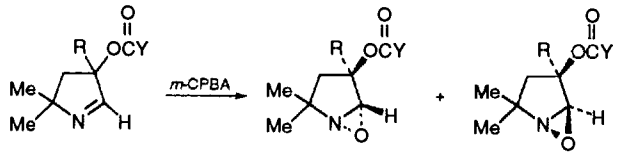


24 Y = R, OR

Scheme 7

The peracid oxidation of imines usually results in the formation of oxaziridines[27] although nitrones have also been reported as products, sometimes in good yields.[27a,28] The rearrangement of the strained oxaziradine ring system to give the corresponding nitrone has also been reported following photolysis,[27a,28,29] thermolysis[27a] or upon treatment with acid.[27a,c,d] However, the illumination and heating of oxaziridines usually results in non-nitrone products, often amides[30] although deoxygenation to the imine and more complex rearrangements have also been reported.[27a]

When the 3-acyloxy-1-pyrrolines **10**, **11**, **13**, **18** and **22** were treated with *m*-CPBA the corresponding oxaziridines were isolated in good yield, usually as stable solids (Scheme 8). Oxidation of the 1-pyrrolines mono-substituted at position 3 proceeded with high stereoselectivity; the ^{1}H NMR spectra of the resulting oxaziridines **25**–**27** show the presence of only one isomer, presumably that with the *trans* conformation of the oxaziridine oxygen and the acyloxy group, formed by attack of the peracid upon the less hindered face of the double bond. The absolute stereochemistry of these products was not determined. Disubstitution at the 3-position of the 1-pyrroline reduces the stereoselectivity of the reaction. Thus, the oxidation of the 3-benzoyloxy-3-methyl-1-pyrroline **22** gives a mixture of two



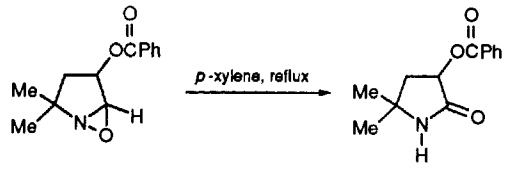
			trans	*cis*
10	Y = OEt	R = H	**25** 100	0
13	Y = C(Me)$_2$Br	R = H	**26** 100	0
11	Y = Ph	R = H	**27** 100	0
22	Y = Ph	R = Me	**28** 86	14
17	Y = Ph	R = Ph	**29** 50	50

Scheme 8

isomers in the ratio 86 : 14 while oxidation of the 3-benzoyloxy-3-phenyl-1-pyrroline **18** gives both isomers in the ratio 50 : 50. The stereoselectivity of the oxidation of the 3-benzoyloxy-1-pyrrolines **11**, **18** and **22**, therefore, decreases with the corresponding increase in size of the co-substituent at C-3 in the order H, Me, Ph.

The ^{1}H NMR spectra of the oxaziridines **25**–**27** are similar and show a doublet from 4-H adjacent to the acyloxy group in the range 5.35–5.75 ppm. This proton is not coupled to the 5-H proton and is coupled to only one of the 3-CH_2 protons. As a result, the 5-H proton gives rise to a singlet with a chemical shift in the range 4.50–4.60 ppm. The ^{13}NMR spectra of these oxaziridines all show six signals from the oxaziridine nucleus including two signals from methine carbons bonded to oxygen. The ^{1}H–^{13}C correlation spectrum of **27** reveals that the oxaziridine carbon C-5 (80.6 ppm) is at lower field than the acyloxy carbon C-4 (75.3 ppm).

When the oxaziridine **27** was heated in refluxing *p*-xylene for 48 h, the γ-lactam **30** was produced in low yield. The IR



27 **30**

spectrum of **30** shows absorptions at 1721 and 1705 cm^{-1} resulting from the ester and γ-lactam amide carbonyl stretches, respectively. The ^{13}C NMR spectrum shows two low field signals; that at 165.9 ppm is consistent with a benzoyl ester while that at 171.8 ppm is consistent with the presence of a γ-lactam. Similar thermal isomerisations of bicyclic oxaziridines to lactams have been reported.[27c,30b]

The oxaziridines **3a**–**e** were recovered after several days following treatment with ethanolic hydrogen chloride at room temperature according to the method of Black and Bapat.[27c] More forcing conditions were not used to avoid hydrolysis of the 3-acyloxy group. The stability of these oxaziridines under these conditions was unexpected.

Conclusion

The carbanion **6**, although potentially bidentate, has been shown (despite earlier reports) to react with electrophiles exclusively at O rather than 3-C except for the case of nitrone–nitrone coupling. The preference for reaction at O is understandable and it is the occurrence of 3,2′ coupling in the self condensation which is the anomaly.

Experimental

All m.p.s were determined on a Reichart hot-stage apparatus and are uncorrected. The IR spectra of liquids were measured as films on sodium chloride plates and those of solids were measured in pressed potassium bromide discs on a Philipps PU9800 FTIR spectrophotometer. All NMR spectra were measured on a Bruker AC-F250 instrument. The solvent was $CDCl_3$ unless stated otherwise. ^{1}H NMR spectra were measured at 250.133 MHz and ^{13}C NMR spectra were measured at 62.896 MHz. Coupling constants are reported in Hz. Mass spectra were determined by the SERC mass spectrometry service at Swansea. Low resolution mass spectra were measured on a VG 12-253 quadrupole instrument, high resolution mass spectra were measured on a VG ZAB-E instrument. Elemental analyses were carried out by Butterworth Laboratories Ltd.

2-(*Dioxolan-2-yl*)-4-*methyl*-4-*nitropentane* **7b**.—To 2,4-dimethyl-4-nitropentanal[31] (29.78 g, 0.19 mol) was added ethylene glycol (14.15 g, 0.228 mol) and *p*-TSA (toluene-*p*-sulfonic acid) (50 mg) according to the procedure of Todd and

co-workers[32] for preparing γ-nitrodioxalanes. The title dioxolane **7b** (32.08 g, 84%) was distilled to give an oil, b.p. 90–91 °C at 0.7 mmHg; ν_{max}/cm^{-1} 1537, 1472, 1400, 1375 and 1348; δ_H 0.90 (3 H, d, *J* 6.7, 2-CH_3), 1.56, 1.57 (both 3 H, s, 2 × CH_3), 1.76–2.15 (3 H, m, 2-H, 3-CH_2), 3.78–3.94 (4 H, m, OCH_2CH_2O) and 4.61 (1 H, *J* 3.6, 2′-H); δ_C 15.13q (CH_3-1), 25.23q, 27.24q (2 × CH_3), 33.04 (C-2), 41.46 (C-3), 64.92, 64.98 (OCH_2CH_2O), 87.52 (C-4) and 106.8 (C-2′); *m*/*z* (EI) = 95 (10%), 73 (100); *m*/*z* (NH_3 chemical ionisation) = 221 (M^+ + NH_4, 5%), 157 (75), 128 (45), 112 (35) and 95 (100).

5,5-*Dimethyl*-4,5-*dihydro*-3H-*pyrrole* 1-*Oxide* **1**.—DMPO was prepared from acrolein according to the method of Janzen and co-workers;[33] δ_C 23.17t (C-3), 24.14q (2 × CH_3), 32.86t (C-4), 72.20 (C-5) and 130.7 (C-2).

3,5,5-*Trimethyl*-4,5-*dihydro*-3H-*pyrrole* 1-*Oxide* **8**.—The nitro-dioxolane **7b** (12.27 g, 0.064 mol) was reduced with zinc and deprotected with mineral acid according to the procedure described by Todd and co-workers[32] for the preparation of 1-pyrroline 1-oxides. The title nitrone (5.97 g, 78%), was purified by distillation to give an oil, b.p. 78–80 °C at 1.5 mmHg; ν_{max}/cm^{-1} 1570, 1455, 1379, 1364, 1310, 1265 and 1240; δ_H 1.00 (3 H, d, *J* 7.4, 3-CH_3), 1.21, 1.27 (both 3 H, s, 2 × CH_3), 1.47 (1 H, dd, *J* 12.8 and 8.5, 4-H), 2.20 (1 H, dd, *J* 12.8 and 8.5, 4′-H), 2.79 (1 H, m, *J* 7.4, 7.2, 8.5 and 2.4, 3-H) and 6.51 (1 H, d, *J* 2.4, 2-H); δ_C 18.52q (3-CH_3), 24.95q, 26.26q (2 × CH_3), 31.34d (C-3), 42.60t (C-4), 73.73s (C-5) and 136.2d (C-2); *m*/*z* (EI) = 127 (M^+, 30%), 112 (10), 71 (45), and 41 (100); *m*/*z* (NH_3 chemical ionisation) 128 (M^+ + 1, 100%).

Ethyl 5,5-*Dimethyl*-4,5-*dihydro*-3H-*pyrrol*-3-*yl Carbonate* **10**.—DMPO **1** was treated with sodium hydride and ethyl chloroformate according to the method of Black and Boscacci.[22] (This compound was reported by these authors to be 3-ethoxycarbonyl-5,5-dimethyl-4,5-dihydro-3*H*-pyrrole 1-oxide **2a**). The distilled product had b.p. 72–74 °C at 0.30 mmHg (lit.,[22] 60–63 °C at 0.15 mmHg); ν_{max}/cm^{-1} 1748, 1626 and 1258; δ_H 1.20, 1.30 (both 3 H, s, 2 × CH_3), 1.27 (3 H, t, *J* 7.1, CH_2CH_3), 1.65 (1 H, dd, *J* 13.9 and 5.2, 4-H), 2.13 (1 H, dd, *J* 13.9 and 8.3, 4′-H), 4.17 (2 H, q, *J* 7.1, CH_2CH_3), 5.55 (1 H, dd, *J* 5.2 and 8.3, 3-H) and 7.43 (1 H, s, 2-H); δ_C 14.06q (CH_2CH_3), 28.84q, 29.72q (2 × CH_3), 41.76t (C-4), 64.25t (CH_2CH_3), 73.33s (C-5), 83.22 (C-3), 154.4s (CO) and 159.7d (C-2); *m*/*z* (EI) 185 (M^+, 30%), 112 (30), 99 (22), 96 (50), 84 (78), 71 (99) and 69 (100).

3-*Benzoyloxy*-5,5-*dimethyl*-4,5-*dihydro*-3H-*pyrrole* **11**.—A solution of DMPO **1** (2.533 g, 22.4 mmol) in benzene (20 cm^3) was dried by the azeotropic removal of water for 1 h. The cooled solution was added to sodium hydride (60% dispersion in oil; 0.896 g, 22.4 mmol) in dry benzene (30 cm^3) over 30 min with vigorous stirring. Stirring was continued for a further 15 min whereupon freshly distilled benzoyl chloride (3.149 g, 22.4 mmol) in dry benzene (20 cm^3) was added dropwise to the mixture over 1.5 h. Stirring was continued for 16 h after which the mixture was diluted cautiously with water (30 cm^3) and the two phases were separated. The aqueous phase was extracted with DCM (dichloromethane; 50 cm^3) and the combined organic phases were washed with saturated aqueous potassium hydrogen carbonate (2 × 40 cm^3), dried ($MgSO_4$) and evaporated to give an orange oil which was distilled to afford the title 1-pyrroline (1.075 g, 22%) as a yellow oil, b.p. 82–88 °C at 0.02 mmHg (Found: M^+, 217.1103. $C_{13}H_{15}NO_2$ requires *M*, 217.1103); ν_{max}/cm^{-1} 1723, 1626, 1453, 1314, 1267, 1111 and 712; δ_H 1.32, 1.42 (both 3 H, s, 2 × CH_3), 1.82 (1 H, dd, *J* 13.9 and 5.0, 4-H), 2.27 (1 H, dd, *J* 13.9 and 8.2, 4′-H), 5.95 (1 H, ddd, *J* 5.0, 8.2 and 2.5, 3-H), 7.27–7.56 (3 H, m, *p*,*m* ArH), 7.59 (1 H, d, *J* 2.5, 2-H) and 8.01–8.12 (2 H, m, *o* ArH); δ_C 29.04, 30.07, (2 × CH_3), 42.42 (C-4), 73.51 (C-5), 80.77 (C-3), 128.0, 129.7, 132.3, 133.3 (ArH), 160.5 (C-2) and 165.9 (CO); *m*/*z* (EI) 218 (M^+ + 1, 4%), 217 (M^+, 6%), 105 (100) and 77 (46); *m*/*z* (NH_3 chemical ionisation) 218 (M^+ + 1, 100%).

3-tert-*Butyryloxy*-5,5-*dimethyl*-4,5-*dihydro*-3H-*pyrrole* **12**.—DMPO **1** (1.763, 15.58 mmol) was treated with sodium hydride (1 equiv.) and *tert*-butyryl chloride (1.879 g, 15.58 mmol) as previously described for the 1-pyrroline **11**. The title 1-pyrroline (1.33 g, 43%) was purified by distillation, b.p. 52–65 °C at 0.005 mmHg (Found: M^+ + 1, 198.1494. $C_{11}H_{20}NO_2$ requires *M*, 198.1494); ν_{max}/cm^{-1} 1730, 1630, 1482 and 1460; δ_H 1.20 (9 H, s, Bu^t), 1.27, 1.35 (both 3 H, s, 2 × CH_3), 1.59 (1 H, dd, *J* 13.9 and 4.9, 4-H), 2.14 (1 H, dd, *J* 13.8 and 8.1, 4′-H), 5.67 (1 H, ddd, *J* 4.9, 8.1 and 0.5, 3-H) and 7.51 (1 H, d, *J* 0.5, 2-H); δ_C 27.05q (Bu^t), 28.73q, 29.71q (2 × CH_3), 38.46s [$C(CH_3)_3$], 42.26t (C-4), 73.17s (C-5), 79.68d (C-3), 161.2d (C-2) and 183.9s (CO); *m*/*z* (EI) 198 (M^+ + 1, 5%), 112 (18) and 57 (100); *m*/*z* (NH_3 chemical ionisation) 198 (M^+ + 1, 100%).

3-(2-*Bromoisobutyryloxy*)-5,5-*dimethyl*-4,5-*dihydro*-3H-*pyrrole* **13**.—DMPO **1** (2.221 g, 19.62 mmol) was treated with sodium hydride (1 equiv.) and 2-bromoisobutyryl bromide (4.511 g, 19.62 mmol) as previously described for the 1-pyrroline **11**. The title 1-pyrroline (1.492 g, 29%) was isolated by distillation as an orange oil, b.p. 80–85 °C at 0.005 mmHg (Found: M^+, 261.036. $C_{10}H_{16}{}^{79}BrNO_2$ requires *M*, 261.0365); ν_{max}/cm^{-1} 1763, 1626, 1464, 1389, 1372, 1366 and 1271; δ_H 1.30, 1.37 (both 3 H, s, 2 × CH_3), 1.70 (1 H, dd, *J* 14.0 and 4.6, 4-H), 1.92 [6 H, s, $BrC(CH_3)_2$], 2.16 (1 H, dd, *J* 14.0 and 8.1, 4′-H), 5.72 (1 H, ddd, *J* 4.6, 8.1 and 0.6, 2-H) and 7.52 (1 H, d, *J* 0.6, 2-H); δ_C 28.84q, 29.73q (2 × CH_3), 30.49q [$BrC(CH_3)_2$], 41.73t (C-4), 55.07s (C-Br), 73.49s (C-5), 81.35d (C-3), 159.8d (C-2) and 171.0s (CO); *m*/*z* (EI) 263 (M^+ + 2, 2%), 262 (3), 261 (M^+, 2%), and 182 (M^+ − Br, 5%); *m*/*z* (NH_3 chemical ionisation) 264 (M^+ + 3, 95%) and 262 (M^+ + 1, 100%).

3-(3′-*Benzoyloxy*-5′,5′-*dimethylpyrrolidin*-2′-*yl*)-3-*benzoyloxy*-5,5-*dimethyl*-4,5-*dihydro*-3H-*pyrrole* **14**.—DMPO **1** (1.12 g, 9.9 mmol) was dried with benzene as previously described for the preparation of compound **11**. Sodium hydride (60% dispersion in oil; 1.58 g, 4 equiv.) was stirred vigorously in dry benzene (30 cm^3) and the cooled DMPO solution was added dropwise to it over 15 min. This was followed after a further 15 min by benzoyl chloride (1.35 g, 9.9 mmol) in dry benzene (10 cm^3), added over 30 min. Stirring was continued for 16 h after which water (30 cm^3) was added cautiously to the mixture. The phases were separated and the aqueous phase was extracted with DCM (30 cm^3). The combined organic phases were washed with sat. aqueous $NaHCO_3$ (2 × 20 cm^3), dried ($MgSO_4$) and evaporated to afford an oil which was shaken with hexane (5 cm^3) and the solution cooled to −20 °C. After several days the title 1-pyrroline (0.56 g, 26%) was collected and recrystallised from hexane; it had m.p. 168–169 °C (Found: M^+ + 1, 435.2284. $C_{26}H_{31}N_2O_4$ requires M^+ + 1, 435.2284); ν_{max}/cm^{-1} 3254, 1721, 1638, 1601 and 712; δ_H 1.18, 1.27, 1.30, 1.33 (each 3 H, s, 4 × CH_3), 1.48 (1 H, br s, NH), 1.73 (1 H, dd, *J* 13.7 and 3.2, 4′-Ha), 2.05 (1 H, dd, *J* 13.7 and 10.8, 4′-Hb), 2.08 (1 H, d, *J* 13.1, 4-Ha), 2.19 (1 H, d, *J* 13.1, 4-Hb), 4.38 (1 H, d, *J* 4.8, 2′-H), 5.42 (1 H, ddd, *J* 4.8, 3.2 and 10.3, 3′-H) and 7.07–7.77 (11 H, m, 2 × ArH plus 2-H); δ_C 29.02, 29.19, 29.70, 30.38 (4 × CH_3), 42.27 (C-4′), 46.39 (C-4), 58.27 (C-5′), 63.40 (C-2′), 73.41 (C-5), 76.68 (C-3′), 97.13 (C-3), 128.1, 129.3, 129.4, 129.6, 129.8, 132.8, 132.9 (2 × ArH), 161.0 (C-2) and 165.3 and 165.6 (2 × CO); *m*/*z* (EI) 217 (5%), 191 (20), 105 (100) and 77 (38); *m*/*z* (NH_3 chemical ionisation) 435 (M^+ + 1, 1%), 313 (30), 218 (100) and 98 (90).

3-[3′-(2″-*Bromoisobutyryloxy*)-5′,5′-*dimethylpyrrolidin*-2′-*yl*]-3-(2-*bromoisobutyryloxy*)-5,5-*dimethyl*-4,5-*dihydro*-3H-*pyrrole* **15**.—DMPO **1** (1.32 g, 11.7 mmol) was treated with sodium hydride and 2-bromoisobutyryl bromide as previously described for compound **14**. The title 1-pyrroline (2.25 g, 56%) was isolated as prisms and recrystallised from ether, m.p. 152.5–153.0 °C (Found: C, 46.2; H, 6.3; Br, 29.8; N, 5.6. $C_{20}H_{32}Br_2N_2O_4$ requires C, 45.8; H, 6.2; Br, 30.5; N, 5.3%) (Found: $M^+ + 3$, 525.0787. $C_{20}H_{33}{}^{79}Br^{81}BrN_2O_4$ requires $M + 3$, 525.0787); ν_{max}/cm^{-1} 3266, 1736, 1638, 1285 and 1169; δ_H 1.16, 1.23 (both 3 H, s, 2 × CH_3), 1.29 (6 H, s, 2 × CH_3), 1.68–2.06 [17 H, m, NH, 4-CH_2, 4′-CH_2, 2 × $BrC(CH_3)_2$], 4.10 (1 H, d, *J* 2.9, 2′-H), 5.15 (1 H, m, 3′-H) and 7.51 (1 H, s, 2-H); δ_C 29.09, 29.80, 30.23, 30.82 (4 × CH_3), 42.91 (C-4′), 46.43 (4-C), 55.53, 56.23 (2 × C-Br), 59.21 (C-5′), 65.77 (C-2′), 73.95 (C-5), 78.28 (C-3′), 97.68 (C-3), 159.7 (C-2) and 170.2 and 170.5 (2 × CO); *m*/*z* (EI) 263 (22%), 262 (24), 261 (23), 191 (85), 112 (90), 96 (53) and 41 (100); *m*/*z* (NH_3 chemical ionisation) 525 ($M^+ + 3$, 25%), 523 ($M^+ + 1$, 15%), 264 (95) and 262 (100).

3-(3′-*Hydroxy*-5′,5′-*dimethylpyrrolidin*-2′-*yl*)-3-*hydroxy*-5,5-*dimethyl*-4,5-*dihydro*-3H-*pyrrol*.—A solution of the diester **15** (0.285 g, 0.54 mmol) and potassium hydroxide (0.18 g, 3.2 mmol) in water (15 cm^3) and ethanol (10 cm^3) was stirred at room temperature for 24 h and then extracted with chloroform (3 × 20 cm^3). The combined extracts were dried and concentrated under reduced pressure to give the crude product which was recrystallised from ether to afford the title dialcohol (0.078 g, 64%) as prisms, m.p. 125–126 °C (Found: C, 63.9; H, 9.7; N, 12.4. $C_{12}H_{22}N_2O_2$ requires C, 63.7; H, 9.8; N, 12.4%); ν_{max}/cm^{-1} 3306, 3252, 1632, 1153 and 893; δ_H 1.19, 1.30 (both 3 H, s, 2 × CH_3), 1.34 (6 H, s, 2 × CH_3), 1.70 (1 H, dd, *J* 13.0 and 5.5, 4′-Ha), 1.72 (1 H, d, *J* 13.0, 4-Ha), 1.83 (1 H, d, *J* 13.0, 4-Hb), 1.95 (1 H, dd, *J* 13.0, 7.6, 4′-Hb), 3.27 (1 H, d, *J* 5.6, 2′-H), 4.40 (1 H, ddd, *J* 5.6, 5.5 and 7.6, 3-H) and 7.39 (1 H, s, 2-H); δ_C 29.66, 30.31, 30.67, 31.23 (4 × CH_3), 48.74, 48.78 (C-4, C-4′), 57.41 (C-5′), 71.74 (C-2′), 72.61 (C-3′), 73.45 (C-5), 86.97 (C-3) and 164.9 (C-2).

Ethyl 5,5-*Dimethyl*-3-*phenyl*-4,5-*dihydro*-3H-*pyrrol*-3-*yl Carbonate* **17**.—DMP_3PO **9**[16] (0.565 g, 3.00 mmol), in dry benzene (20 cm^3) was added to sodium hydride (60% dispersion in oil; 120 mg, 3.00 mmol) suspended in dry benzene (10 cm^3) with vigorous stirring for 10 min. After a further 15 min, ethyl chloroformate (0.326 g, 3.00 mmol) in dry benzene (10 cm^3) was added dropwise to the mixture over 30 min. After the mixture had been stirred for 10 h, water (20 cm^3) was added cautiously to it and the phases were separated. The aqueous phase was extracted with DCM (20 cm^3) and the combined organic phases were washed with saturated potassium hydrogen carbonate (10 cm^3), dried ($MgSO_4$) and evaporated to afford a yellow oil. A sample of this was purified by preparative HPLC (5% ethanol in hexane) or by chromatotron (10% ether in hexane) to give the title 1-pyrroline as an oil which was purified further by Kugehlrohr distillation (160 °C, 0.01 mmHg) (Found: M^+, 261.136. $C_{15}H_{19}NO_3$ requires *M*, 261.1365); ν_{max}/cm^{-1} 1752, 1649, 1624, 1603, 1157, 760 and 700; δ_H 1.18 (3 H, t, *J* 7.1, CH_2CH_3), 1.23, 1.34 (both 3 H, s, 2 × CH_3), 2.01 (1 H, d, *J* 14.4, 4-H), 2.38 (1 H, d, *J* 14.4, 4′-H), 4.03 (2 H, q, *J* 7.1, CH_2CH_3), 7.19–7.53 (5 H, m, ArH) and 7.91 (1 H, s, 2-H); δ_C 14.10q (CH_2CH_3), 29.12q, 29.37q (2 × CH_3), 50.94t (C-4), 64.13t (CH_2CH_3), 73.49s (C-5), 91.12s (C-3), 124.5d, 126.8d, 127.8d, 140.5s (ArH), 153.1s (CO) and 161.1d (C-2); *m*/*z* (EI) 261 (M^+, 2%), 170 (94), 162 (55), 147 (95), 129 (84), 105 (100), 91 (26) and 77 (66).

3-*Benzoyloxy*-5,5-*dimethyl*-3-*phenyl*-4,5-*dihydro*-3H-*pyrrole* **18** *and* 5,5-*Dimethyl*-3-*phenyl*-2H-*pyrrole* **19**.—DM_3PPO **9** (0.468 g, 2.47 mmol) was treated with sodium hydride (1 equiv.) and benzoyl chloride (1 equiv.) as described for the 1-pyrroline **17**. The crude product was purified by chromatotron (5% ethanol in hexane) to give the 1-pyrroline **18** (0.565 g, 78%) and the 2*H*-pyrrole **19** (0.038 g, 9%).

The 1-pyrroline **18** gave crystals when mixed with ether (5 cm^3) and cooled to −20 °C for several weeks, m.p. 103–104 °C (Found: C, 77.6; H, 6.5; N, 4.7. $C_{19}H_{19}NO_2$ requires C, 77.8; H, 6.5; N, 4.8%); ν_{max}/cm^{-1} 1725, 1618, 1601, 1451, 1277, 714 and 698; δ_H 1.28, 1.34 (both 3 H, s, 2 × CH_3), 2.07 (1 H, d, *J* 14.4, 4-H), 2.53 (1 H, d, *J* 14.4, 4′-H), 7.15–7.6 (10 H, m, 2 × ArH) and 8.05 (1 H, s, 2-H); δ_C 29.22q, 29.32q (2 × CH_3), 51.35t (C-4), 73.27s (C-5), 94.96s (C-3), 124.3d, 127.1d, 128.4d, 128.7d, 129.6d, 129.9s, 133.2d, 140.6s (2 × ArH), 161.5d (C-2) and 164.7s (CO).

The 2*H*-pyrrole **19** crystallised when cooled to −20 °C for several weeks, m.p. 5–7 °C (lit.,[33] 16.5–17.5 °C); ν_{max}/cm^{-1} 1624, 1601, 1532, 1489, 1462, 1449, 760 and 694; δ_H 1.34 (6 H, s, 2 × CH_3) and 7.19–7.50 (7 H, m, ArH, 2-H, 4-H); δ_C 23.23 (2 × CH_3), 77.11 (C-5), 126.3, 128.1, 128.8, 132.4, 153.6 (ArH, C-3, C-4) and 161.3 (C-2).

3-*Benzoyloxy*-3,5,5-*trimethyl*-4,5-*dihydro*-3H-*pyrrole*.—Me_3PPO **8** (2.35 g, 18.5 mmol) was treated with sodium hydride (1 equiv.) and benzoyl chloride (2.60 g, 18.5 mmol) in dry benzene as described for the 1-pyrroline **15**. The crude product was obtained as an oil which was distilled to give the title 1-pyrroline (3.25 g, 76%) as an oil, b.p. 75–80 °C at 0.02 mmHg (Found: $M^+ + 1$, 232.134. $C_{14}H_{18}NO_2$ requires $M + 1$, 232.134); ν_{max}/cm^{-1} 1717, 1632, 1601, 1453 and 714; δ_H 1.33, 1.35, 1.74 (each 3 H, s, 3 × CH_3), 1.95 (1 H, d, *J* 14.1, 4-H), 2.33 (1 H, d, *J* 14.1, 4′-H), 7.27–7.59 (3 H, m, *m*,*p* ArH), 7.70 (1 H, s, 2-H) and 7.97–8.01 (2 H, m, *o* ArH); δ_C 23.20q, 29.43q, 29.72q (3 × CH_3), 49.15t (C-4), 73.13 (C-5), 92.48 (C-3), 128.3d, 129.5d, 130.4d, 133.0s (ArH), 163.4d (C-2) and 165.2s (CO); *m*/*z* (EI) 232 ($M^+ + 1$, 6%), 231 (M^+, 2%) and 105 (100); *m*/*z* (NH_3 chemical ionisation) 232 ($M^+ + 1$, 100%).

Di-tert-*butyl Peroxalate*.—The title peroxide was prepared by the method of Bartlett and co-workers.[26] The peroxide gave fine needles from hexane, m.p. (decomp.) 46–47 °C (lit.,[25] 50.5–51.5 °C).

Ethyl 2,2-*Dimethyl*-6-*oxa*-1-*azabicyclo*[3.1.0]*hexan*-4-*yl Carbonate* **25**.—The carbonate **10** (1.002 g, 5.51 mmol) was oxidised with *m*-chloroperbenzoic acid (*m*CPBA) according to a variation of the method of Black and Strauch.[27e] A solution of *m*CPBA (50% peracid; 1.902g, 5.51 mmol) in DCM (20 cm^3) was added dropwise in 1 h to a stirred solution of the 1-pyrroline **10** in DCM (10cm^3). After 16 h the solution was filtered, concentrated to 10 cm^3 and after 1 h filtered again. It was then washed with saturated aqueous sodium hydrogen carbonate (2 × 10 cm^3), dried ($MgSO_4$) and reduced to an oil which was mixed with ether (5 cm^3) and hexane (3 cm^3) and cooled to −20 °C. The title oxaziridine (0.578 g, 53%) was collected as microcrystals after several days, m.p. 82–83 °C (Found: $M^+ + 1$, 202.108, $C_9H_{16}NO_4$ requires $M + 1$ 202.108); ν_{max}/cm^{-1} 1750, 1574, 1543, 1470, 1264 and 1015; δ_H 1.22, 1.27, (both 3 H, s, 2 × CH_3), 1.27 (3 H, t, *J* 7.1, CH_2CH_3), 1.63 (1 H, d, *J* 14.6, 3-H), 1.76 (1 H, dd, *J* 14.6 and 6.1, 3′-H), 4.17 (2 H, q, *J* 7.1, CH_2CH_3), 4.56 (1 H, s, 5-H) and 5.38 (1 H, d, *J* 6.1, 4-H); δ_C 14.10 (CH_2CH_3), 25.03, 25.61 (2 × CH_3), 39.25 (C-3), 64.48 (CH_2CH_3), 66.61 (C-2), 78.15 (C-4), 80.27 (C-5) and 154.2 (C=O); *m*/*z* (EI) 86 (22%), 84 (32) and 49 (100); *m*/*z* (NH_3 chemical ionisation) 202 ($M^+ + H$, 3%), 150 (15), 140 (28), 136 (16), 126 (25), 108 (30), 94 (35), 74 (38) and 58 (100).

4-(2′-*Bromoisobutyryloxy*)-2,2-*dimethyl*-6-*oxa*-1-*azabicyclo*[3.1.0]*hexane* **26**.—5,5-Dimethyl-3-(2′-bromoisobutyryl-

oxy)-1-pyrroline (0.898 g, 3.43 mmol) was oxidised as previously described for oxaziridine **25**. The title oxaziridine (0.591 g, 62%) was obtained as a powder, m.p. 42–43 °C (Found: $M^+ + 1$, 278.039. $C_{10}H_{17}{}^{79}BrNO_3$ requires $M + 1$, 278.039); ν_{max}/cm^{-1} 1738, 1512, 1466, 1163, 1134 and 1105; δ_H 1.25, 1.29 (both 3 H, s, 2 × CH_3), 1.59 (1 H, d, J 14.7, 3-H), 1.77 (1 H, dd, J 14.7 and 6.1, 3'-H), 1.87 and 1.88 [both 3 H, s, $BrC(CH_3)_2$], 4.52 (1 H, s, 5-H) and 5.54 (1 H, d, J 6.1, 4-H); δ_C 25.07, 25.68 (2 × CH_3), 30.47, 30.49 [$BrC(CH_3)_2$], 39.04 (C-3), 54.96 (Br-C), 66.66 (C-2), 76.35 (C-4), 80.14 (C-5) and 170.7 (C=O); m/z (NH_3 chemical ionisation) 280 ($M^+ + 3$, 40%), 278 ($M^+ + 1$, 40%), 264 (11) and 112 (100).

4-*Benzoyloxy*-2,2-*dimethyl*-6-*oxa*-1-*azabicyclo*[3.1.0]*hexane* **27**.—3-Benzoyloxy-5,5-dimethyl-1-pyrroline was oxidised as previously described for oxaziridine **25** to give an oil which was mixed with hexane–ether (1 : 1; 3 cm^3). This afforded crystals of the title oxaziridine (1.541 g, 72%) after several days at −20 °C; m.p. 84.5–86.0 °C (Found: $M^+ + 1$, 234.113. $C_{13}H_{16}NO_3$ requires $M + 1$, 234.113); ν_{max}/cm^{-1} 1719, 1601, 1464, 1455, 1269 and 712; δ_H 1.29, 1.30 (both 3 H, s, 2 × CH_3), 1.67 (1 H, d, J 14.6, 3-H), 1.83 (1 H, dd, J 14.6 and 6.1, 3'-H), 4.60 (1 H, s, 5-H), 5.71 (1 H, d, J 6.1, 4-H) and 7.12–8.00 (5 H, m, ArH); δ_C 25.18, 25.66 (2 × CH_3), 39.41 (C-3), 66.59 (C-2), 75.30 (C-4), 80.56 (C-5), 128.5, 129.3, 129.6, 133.4 (ArH) and 165.4 (C=O); m/z (EI) 234 ($M^+ + 1$, 2%), 218 (2) and 105 (100); m/z (NH_3 chemical ionisation) 234 ($M^+ + 1$, 56%) and 105 (100).

cis *and* trans-4-*Benzoyloxy*-2,2,4-*trimethyl*-6-*oxa*-1-*azabicyclo*[3.1.0]*hexane* **28a**, **b**.—3-Benzoyloxy-3,5,5-trimethyl-1-pyrroline was oxidised with *m*CPBA as previously described for the oxaziridine **25**. The title oxaziridine was obtained as microcrystals, m.p. 88–90 °C (Found: C, 67.2; H, 7.0; N, 5.7. $C_{14}H_{17}NO_3$ requires C, 68.0; H, 6.9; N, 5.7%) (Found: $M^+ + 1$, 248.129. $C_{14}H_{18}NO_3$ requires $M + 1$, 248.129); ν_{max}/cm^{-1} 1717, 1453, 1377, 1318, 1283 and 712; δ_H (major isomer, 86%) 1.27, 1.36 (both 3 H, s, 2 × CH_3), 1.68 (1 H, d, J 14.5, 3-H), 1.87 (3 H, s, 4-CH_3), 2.32 (1 H, d, J 14.5, 3'-H), 4.95 (1 H, s, 5-H) and 7.43–8.04 (5 H, m, ArH); δ_H (minor isomer, 14%), 1.30, 1.43 (both 3 H, s, 2 × CH_3), 1.82 (3 H, s, 4-CH_3), 2.25 (1 H, d, J 14.6, 3-H), 2.62 (1 H, d, J 14.6, 3'-H), 4.95 (1 H, s, 5-H) and 7.43–8.04 (5 H, m, ArH); δ_C (major isomer) 19.74q (4-CH_3), 25.02q, 26.16q (2 × CH_3), 44.62t (C-3), 67.04s (C-2), 83.16d (C-5), 88.25s (C-4), 128.5d, 129.5d, 130.4d, 133.2s (ArH) and 165.1s (C=O); m/z (EI) 247 (M^+, 1%), 232 (9), 105 (100) and 77 (41); m/z (NH_3 chemical ionisation) 248 ($M^+ + 1$, 100%) and 232 (100).

cis *and* trans-4-*Benzoyloxy*-2,2-*dimethyl*-4-*phenyl*-6-*oxa*-1-*azabicyclo*[3.1.0]*hexane*, **29a**, **b**.—The 1-pyrroline **17** (0.078 g, 0.26 mmol) was oxidised as previously described for the oxaziridine **25** to give the title oxaziridine (0.061 g, 74%), as a gum (Found: $M^+ + 1$, 310.144. $C_{19}H_{20}NO_3$ requires $M + 1$, 310.144); ν_{max}/cm^{-1} 1725, 1601, 1466, 1275 and 714; δ_H (both isomers), 0.98, 1.33, 1.34, 1.36 (each 3 H, s, 4 × CH_3), 1.96–2.45 (4 H, 8 signals, 2 × CH_2), 5.31, 5.54 (each 1 H, s, 2 × 5-H) and 7.19–7.98 (20 H, m, 2 × ArH); δ_C (both isomers), 25.00, 25.03, 26.32, 26.85 (4 × CH_3), 45.14, 45.74 (2 × C-3), 65.11, 67.06 (2 × C-2), 82.18 (C-4), 87.35, 90.35 (2 × C-5), 125.2, 125.9, 126.3, 128.2, 128.3, 128.4, 128.5, 128.6, 129.6, 129.7, 129.8, 129.9, 130.0, 133.1, 133.2, 133.3, 138.3, 139.0, 140.3 (4 × ArH) and 164.6 and 165.1 (2 × C=O); m/z (EI) 309 (M^+, 1%), 294 (3), 188 (15), 105 (100) and 77 (53); m/z (NH_3 chemical ionisation) 310 ($M^+ + 1$, 35%), 294 (45), 188 (71) and 105 (100).

3-*Benzoyloxy*-5,5-*dimethylpyrrolidin*-2-*one* **30**.—A solution of the oxaziridine **11** (0.121 g, 0.56 mmol) in *p*-xylene (10 cm^3) was heated at reflux for 48 h and then cooled to −20 °C for several days to give the title lactam (0.016 g, 12%) as crystals, m.p. 174–175 °C; ν_{max}/cm^{-1} 3194, 3090, 1721, 1705, 1603, 1279, 1262, 1123 and 720; δ_H 1.39, 1.43 (both 3 H, s, 2 × CH_3), 2.04 (1 H, dd, J 13.2 and 7.8, 4-H), 2.61 (1 H, dd, J 13.2 and 8.3, 4'-H), 5.67 (1 H, t, J 7.8 and 8.3, 3-H), 6.50 (1 H, br s, NH) and 7.28–8.12 (5 H, m, ArH); δ_C 29.65q, 30.24q (2 × CH_3), 42.51t (C-4), 54.17s (C-5), 71.52d (C-3), 128.4d, 129.4d, 129.9d, 133.4s (ArH), 165.9s (ester) and 171.8s (amide); m/z (EI) 218 (11%) and 105 (100); m/z (NH_3 chemical ionisation) 234 ($M^+ + 1$, 100%).

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