Pyrrolizidine Alkaloid Analogues. Synthesis of 10-Membered Macrocyclic Diesters of (±)-Synthanecine A. *X*-Ray Molecular Structure of (±)-6,7-*O*,*O*-(Succinyl)synthanecine A

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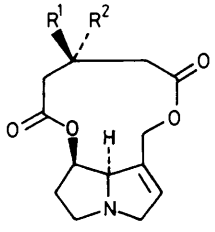
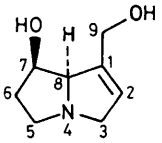
The first 10-membered macrocyclic diesters of (±)-synthanecine A (**4**) have been synthesized. Treatment of (±)-synthanecine A with succinic anhydride yielded the 6-monoester of (±)-synthanecine A, which was lactonized *via* its pyridine-2-thiol ester to give (±)-6,7-*O*,*O*-(succinyl)synthanecine A (**5**). The macrocyclic nature of this new pyrrolizidine alkaloid analogue was established by spectroscopic data and by carrying out an *X*-ray crystal-structure analysis on the analogue (**5**). The ester carbonyl groups within the macrocyclic compound (**5**) are antiparallel. Further examples of 10-membered [(**7**)—(**9**)] macrocyclic diesters of (±)-synthanecine A were prepared similarly using *trans*-2,3-dimethylsuccinic anhydride, cyclohexane-*trans*-1,2-dicarboxylic anhydride, and phthalic anhydride, respectively.

There is much interest in pyrrolizidine alkaloids because of their toxicity and their wide distribution in a number of unrelated plant families.[1] The most toxic of these pyrrolizidine alkaloids contain an allylic ester as part of a macrocyclic diester system as in dicrotaline (**1**). Pyrrolizidine alkaloids with ring sizes of 11, 12, 13, and 14 have been isolated. Dehydrogenation of the 1,2-unsaturated alkaloids by hepatic oxidase enzymes gives the corresponding pyrrole derivatives which are bifunctional alkylating agents.[2] Pyrrolizidine alkaloids and structurally related analogues are therefore important synthetic targets for toxicity studies. The synthesis of dicrotaline (**1**),[3] and a series of 11-membered[4] and 10-membered[5] analogues containing a (+)-retronecine core (**3**), have been reported by us. One of the 11-membered pyrrolizidine alkaloid analogues (**2**), prepared from (+)-retronecine and 3,3-dimethylglutaric anhydride, produced hepatotoxic effects similar to those caused by macrocyclic pyrrolizidine alkaloids.[6]

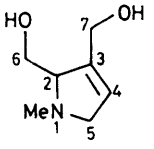


(**1**) R^1 = OH, R^2 = Me
(**2**) R^1 = R^2 = Me



(**3**)

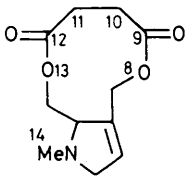
The amounts of macrocyclic pyrrolizidine alkaloid analogues available for testing purposes are seriously limited by the need to obtain (+)-retronecine (**3**) by extraction from plant sources or by synthesis.[7] Mattocks provided a possible solution to this problem when he showed that simple diester derivatives of a monocyclic analogue of retronecine caused damage to the livers of animals.[8] The monocyclic analogue he used was (±)-2,3-bis(hydroxymethyl)-1-methyl-2,5-dihydropyrrole (**4**) [(±)-synthanecine A]. Our research programme began with the preparation[9] of a range of 11-membered macrocyclic diesters of (±)-synthanecine A for an investigation of their hepatotoxicity. In order to increase our understanding of structure–biological activity relationships in this area, we then sought to prepare a series of 10-membered macrocyclic diesters of (±)-synthanecine A.



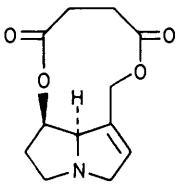
(**4**)

Results and Discussion

(±)-Synthanecine A (**4**) was prepared from diethyl maleate and methylamine as starting materials in six steps in *ca.* 20% overall yield.[10] Treatment of (±)-synthanecine A with succinic anhydride in dry 1,2-dimethoxyethane (DME) gave a quantitative yield of a precipitate of the 6-succinate monoester of (±)-synthanecine A. Regioselective esterification was indicated by a downfield shift in the ^{1}H n.m.r. spectrum of *ca.* 0.4 p.p.m. for the protons at C-6 of the monoester, whereas the chemical shift of the C-7 protons of the monoester remained unchanged, when compared with the corresponding signals in the n.m.r. spectrum of (±)-synthanecine A. The C-6 monoester was converted into the corresponding pyridine-2-thiol ester using 2,2′-dithiodipyridine and triphenylphosphine.[11] Lactonization was then effected under high-dilution conditions. Purification of the reaction mixture was achieved by column chromatography on basic alumina. The 10-membered macrocyclic diester (**5**) was obtained crystalline in *ca.* 30% yield. The high-resolution mass spectrum of the base indicated a molecular ion of $C_{11}H_{15}NO_4$. In addition, the fragmentation pattern was typical for a dilactone of (±)-synthanecine A.[9] The i.r. spectrum of the analogue (**5**) displayed ester carbonyl absorption at 1 736 cm^{-1}. In the ^{1}H n.m.r. spectrum of the macrocyclic diester (**5**), the protons assigned to C-6 and C-7 had both shifted downfield relative to the corresponding signals in the n.m.r. spectrum of (±)-synthanecine A. The chemical-shift difference between the protons at C-6 was 0.42 p.p.m., while for C-7 it was 0.68 p.p.m. These values are considerably larger than those observed for the 11-membered analogue, (±)-6,7-*O*,*O*-(glutaryl)synthanecine A, of 0.07 and 0.0 p.p.m., respectively.[9] The different values may be a result of different conformations adopted by the macrocyclic rings in these two pyrrolizidine alkaloid analogues.



(5)



(6)

An *X*-ray structure analysis of a crystal of the analogue (**5**) grown from benzene was carried out in order to confirm the presence of the macrocyclic system, and to establish the conformation of the molecule. The crystal structure was determined by direct methods and the atomic parameters were refined by full-matrix least-squares calculations.

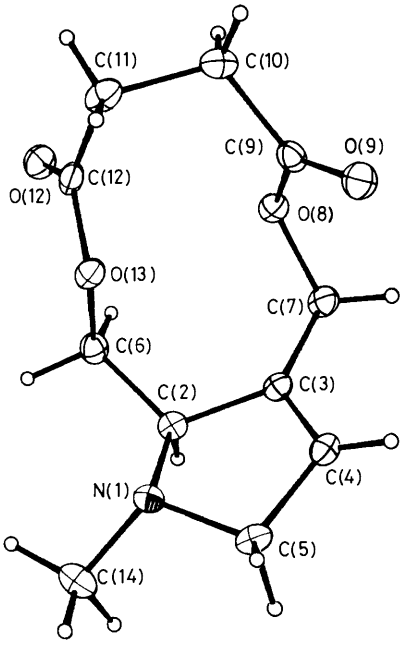


Figure. An ORTEP diagram of compound (**5**) showing the numbering scheme and vibrational ellipsoids (50% probability level)

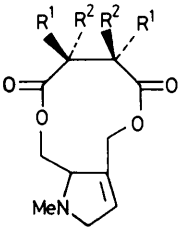
The ester carbonyl groups of the synthanecine A dilactone (**5**) are antiparallel with the oxygen of the saturated ester carbonyl on the same side of the macrocyclic ring as the bridgehead hydrogen (2-H) (Figure). Similar conformations have been established for the corresponding 10-membered analogue (**6**) containing a (+)-retronecine core,[12] and for all 12-membered macrocyclic pyrrolizidine alkaloids whose *X*-ray crystal structures have been established.[1] The dihedral angle between the ester groups of the analogue (**5**) defined by the planes C(7), O(8), C(9), O(9), and O(12), C(12), O(13), C(6), is 159(3)°, which is the same as that found for the analogue (**6**), and close to the average value of 163° found for macrocyclic pyrrolizidine alkaloids that contain a (+)-retronecine core.[1] Torsion angles defining the conformations of the two succinate cyclic diesters (**5**) and (**6**) are given in Table 1. The largest torsional deviations between the two 10-membered analogues occur at the ring junctions. The transannular distances O(8)···C(12) of 2.782(3) Å and O(8)···O(13) of 2.779(3) Å are comparable with equivalent distances found in other pyrrolizidine alkaloids.

It has been suggested that steric hindrance, which is created in many pyrrolizidine alkaloids by the presence of substituents at the α-positions of the diacid moiety, enhances the toxicity of the

Table 1. Macrocycle torsion angles (°) for (±)-6,7-*O*,*O*-(succinyl)-synthanecine A (**5**) and (+)-7,9-*O*,*O*-(succinyl)retronecine (**6**) with e.s.d.s in parentheses [numbering refers to structure (**5**) and the Figure]

	Analogue (**5**)	Analogue (**6**)
C(9)–O(8)–C(7)–C(3)	73.3(2)	73.7(3)
C(7)–O(8)–C(9)–C(10)	−170.4(2)	−168.8(3)
C(12)–O(13)–C(6)–C(2)	143.3(2)	133.7(3)
C(6)–O(13)–C(12)–C(11)	−160.2(2)	−168.5(3)
C(3)–C(2)–C(6)–O(13)	−50.4(2)	−24.4(2)
C(6)–C(2)–C(3)–C(7)	−42.8(2)	−64.5(3)
C(2)–C(3)–C(7)–O(8)	67.2(2)	70.0(3)
O(8)–C(9)–C(10)–C(11)	77.0(2)	81.9(3)
C(9)–C(10)–C(11)–C(12)	−54.7(2)	−55.7(3)
C(10)–C(11)–C(12)–O(13)	91.2(2)	90.5(3)

alkaloid.[2] This effect is believed to occur because steric hindrance in the diacid portion reduces the extent to which the alkaloid is detoxified by hydrolysis. In order to see if this effect could be observed in analogues, we decided to prepare 10-membered analogues containing α-substituents on the diacid portion. Separate treatment of (±)-synthanecine A (**4**) with (±)-*trans*-2,3-dimethylsuccinic anhydride and (±)-*trans*-cyclohexane-1,2-dicarboxylic anhydride afforded the corresponding 6-monoesters which were lactonized by the Corey–Nicolaou method[11] in yields of 32 and 23%, respectively. In each case, a mixture of two diastereoisomeric racemates, (**7**) and (**8**) respectively, was formed. Neither mixture could be resolved by t.l.c. Characterization data were therefore obtained for each mixture. The high-resolution mass spectra displayed molecular ions of $C_{13}H_{19}NO_4$ for mixture (**7**) and $C_{15}H_{21}NO_4$ for mixture (**8**). The fragmentation patterns were again consistent for macrocyclic dilactones derived from (±)-synthanecine A.[9] The i.r. spectra of mixtures (**7**) and (**8**) showed ester carbonyl absorption at 1 735 cm^{-1}. Examination of the ^1H and ^{13}C n.m.r. spectra of the two mixtures allowed estimates to be made that

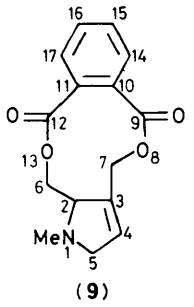


(**7**) R^1 = Me, R^2 = H and
R^1 = H, R^2 = Me

(**8**) R^1R^1 = $[CH_2]_4$, R^2 = H and
R^1 = H, R^2R^2 = $[CH_2]_4$

the diastereoisomeric racemates were present in a ratio of *ca.* 1:1.6 in both mixtures. In the ^1H n.m.r. spectra of the mixtures (**7**) and (**8**), large chemical-shift differences of *ca.* 0.6 and 0.9 p.p.m. were observed for the C-6 and C-7 protons, respectively, for each racemate in each mixture.

As a further test of the scope of this cyclization procedure to make 10-membered pyrrolizidine alkaloid analogues, it was repeated using phthalic anhydride. Lactonization of this aromatic anhydride with (±)-synthanecine A (**4**) produced a low yield of a crystalline product. An accurate mass measurement corresponding to $C_{15}H_{15}NO_4$ was obtained for this base (**9**) together with a fragmentation pattern typical for a synthanecine dilactone.[9] In the i.r. spectrum of the phthalate diester (**9**), the



(9)

ester carbonyl absorption was present at 1 720 cm^{-1}, indicative of the additional aromatic conjugation. In the ^1H n.m.r. spectrum of the aromatic dilactone (**9**), the signals corresponding to the protons on C-6 and C-7 were shifted downfield by *ca.* 0.45 p.p.m. relative to those for (±)-synthanecine A (**4**). The chemical-shift differences between these protons were 0.36 p.p.m. for C-6 and 0.48 p.p.m. for C-7. These data are convincing evidence for the formation of the aromatic dilactone (**9**).

When 4,5-dichlorophthalic anhydride was treated with (±)-synthanecine A (**4**) under Corey–Nicolaou conditions,[11] no macrocyclic dilactone formation could be detected, although thiol ester formation appeared to occur (t.l.c. evidence). Treatment of (±)-synthanecine A with maleic anhydride under similar conditions also failed to yield any cyclized product.

The toxicity of pyrrolizidine alkaloids and analogues is estimated by the production of the toxic pyrrolic metabolites.[2] Low levels of these metabolites were formed from the succinate (**5**) and phthalate (**9**) diesters; both these compounds were also very susceptible to hydrolysis *in vivo*. By contrast, much higher levels of toxic pyrrolic metabolites were formed from the 2,3-dimethylsuccinate mixture (**7**); this mixture was also much more resistant to enzymic hydrolysis.[13] It does therefore appear that steric hindrance at the α-positions of the diacid moieties of pyrrolizidine alkaloid analogues increases the toxicity of these compounds.

Experimental

M.p.s were measured with a Kofler hot-stage apparatus and are uncorrected. Organic extracts were dried with anhydrous $MgSO_4$, and solvents were then evaporated off under reduced pressure below 40 °C. N.m.r. spectra were recorded with a Bruker WP-200SY spectrometer operating at 200 MHz for ^1H. Spectra were recorded for solutions in deuteriochloroform with tetramethylsilane as internal standard, and they were subjected to first-order analysis in order to obtain *J*-values. Mass spectra were obtained with A.E.I. MS 12 or 902 spectrometers. T.l.c. of the bases was carried out on Kieselgel G plates of 0.25 mm thickness developed with chloroform–methanol–conc. ammonia (85:14:1), and the unsaturated bases were located by oxidation with *o*-chloranil, followed by treatment with Ehrlich's reagent.[14] DME was dried by distillation from potassium hydroxide and then from sodium–benzophenone under argon immediately prior to use.

(±)-6,7-O,O-(*Succinyl*)*synthanecine A* (**5**).—Succinic anhydride (1 mmol) was added to a solution of (±)-synthanecine A (**4**)[10] (1 mmol) in dry DME (20 ml) under argon. The mixture was stirred until the 6-monoester had completely precipitated (18 h; t.l.c. R_F 0.0). 2,2′-Dithiodipyridine (1.2 mmol) and triphenylphosphine (1.2 mmol) were added, and the mixture was stirred vigorously for 18 h to complete the formation of the thiol ester (R_F 0.3). The clear yellow solution was diluted with DME (20 ml), and the mixture was heated at reflux under argon until lactonization was complete (6 h). The cooled solution was concentrated to yield an oil, which was extracted with 1M-aqueous citric acid (3 × 4 ml). The combined aqueous extracts were washed with chloroform (6 × 12 ml), basified with conc. ammonia (pH > 10), and extracted with chloroform (4 × 15 ml). The extracts were dried, filtered, and concentrated to afford a yellow oil. Purification by column chromatography on basic alumina, and elution with increasing proportions of chloroform in dichloromethane, gave (±)-6,7-O,O-(*succinyl*)*synthanecine A* (**5**) as white needles (30%), m.p. 106—108 °C [from benzene–light petroleum (b.p. 60—80 °C)]; R_F 0.67; $\nu_{max.}$($CHCl_3$) 2 950, 2 795, 1 735, 1 600, 1 575, 1 560, 1 419, 1 165, and 1 040 cm^{-1}; δ_H (200 MHz) 2.50 (3 H, s, NMe), 2.41—2.72 (4 H, m, 10- and 11-H_2), 3.22 (1 H, m, 5-H), 3.59 (1 H, m, 2-H), 3.85 (1 H, m, 5-H), 3.98 (1 H, dd, J_{gem} 12, J_{vic} 5 Hz, 6-H), 4.40 (1 H, dd, J_{gem} 12, J_{vic} 2 Hz, 6-H), 4.40 (1 H, d, J_{gem} 13 Hz, 7-H), 5.08 (1 H, d, J_{gem} 13 Hz, 7-H), and 5.94 (1 H, br s, 4-H); δ_C (25 MHz) 33.2 (C-10 and -11), 41.4 (NMe), 60.9 and 61.9 (C-5 and -6), 65.7 (C-7), 71.1 (C-2), 131.0 (C-4), 136.1 (C-3), and 171.9 and 172.8 p.p.m. (C-9 and -12); *m/z* 225 (M^+), 123, 111, 108, 107, 94, 82, and 80 (Found: M^+, 225.1005; C, 58.8; H, 6.9; N, 5.9%. $C_{11}H_{15}NO_4$ requires *M*, 225.1001; C, 58.65; H, 6.71; N, 6.22%).

6,7-O,O-(trans-2,3-*Dimethylsuccinyl*)*synthanecine A* (**7**).—Treatment of (±)-*trans*-2,3-dimethylsuccinic anhydride as described in the above procedure gave the *title compound* (**7**) (32%) as a mixture of the two diastereoisomeric racemates, R_F 0.67; $\nu_{max.}$($CHCl_3$) 2 980, 2 945, 2 790, 1 735, 1 452, 1 335, 1 185, and 1 096 cm^{-1}; δ_H (360 MHz) 1.15—1.22 (6 H, m, 10- and 11-Me), 2.34—2.53 (2 H, m, 10- and 11-H), 2.48 and 2.50 (3 H, s, NMe), 3.22 (1 H, m, 5-H), 3.62 (1 H, m, 2-H), 3.88 (1 H, m, 5-H), 3.89—3.99 (1 H, m, 6-H), 4.16—4.30 (1 H, m, 7-H), 4.52—4.57 (1 H, m, 6-H), 5.11 and 5.21 (1 H, d, *J ca.* 13 Hz, 7-H), and 5.86 and 5.93 (1 H, br s, 4-H); *m/z* 253 (M^+), 111, 108, 107, 94, 82, 69, and 55 (Found: M^+, 253.1313. $C_{13}H_{19}NO_4$ requires *M*, 253.1313).

6,7-O,O-(trans-*Cyclohexane*-1,2-*dicarbonyl*)*synthanecine A* (**8**).—The *title compound* (**8**) was prepared, as a mixture of two diastereoisomeric racemates, when synthanecine A was treated with (±)-*trans*-cyclohexane-1,2-dicarboxylic anhydride in a similar fashion (23%), R_F 0.75; $\nu_{max.}$($CHCl_3$) 2 945, 2 865, 2 790, 1 733, 1 578, 1 450, 1 420, 1 328, 1 255, 1 183, and 1 120 cm^{-1}; δ_H (200 MHz) 1.07—1.86 (8 H, m, $[CH_2]_4$), 2.23—2.50 (2 H, m, 10- and 11-H), 2.47 and 2.49 (3 H, s, NMe), 3.21 (1 H, m, 5-H), 3.58 (1 H, m, 2-H), 3.60—3.91 (1 H, m, 6-H), 3.87 (1 H, m, 5-H), 4.08—4.78 (2 H, m, 6- and 7-H), 5.20—5.52 (1 H, m, 7-H), and 5.85 and 5.92 (1 H, br s, 4-H); *m/z* 279 (M^+), 123, 111, 108, 107, 94, 82, and 67 (Found: M^+, 279.1465. $C_{15}H_{21}NO_4$ requires *M*, 279.1471).

(±)-6,7-O,O-(*Phthaloyl*)*synthanecine A* (**9**).—When synthanecine A (**4**) was treated with phthalic anhydride by the above method, the *title compound* (**9**) was afforded (16%) as white prisms, m.p. 153—155 °C [from benzene–light petroleum (b.p. 60—80 °C)]; R_F 0.72; $\nu_{max.}$($CHCl_3$) 2 950, 2 785, 1 720, 1 602, 1 450, 1 283, 1 130, and 1 035 cm^{-1}; δ_H (200 MHz) 2.55 (3 H, s, NMe), 3.26 (1 H, m, 5-H), 3.80 (1 H, m, 2-H), 3.92 (1 H, m, 5-H), 4.30 (1 H, dd, J_{gem} 12, J_{vic} 7 Hz, 6-H), 4.66 (1 H, dd, J_{gem} 12, J_{vic} 4 Hz, 6-H), 4.80 (1 H, d, J_{gem} 12 Hz, 7-H), 5.28 (1 H, d, J_{gem} 12 Hz, 7-H), 6.00 (1 H, br s, 4-H), and 7.50—7.85 (4 H, m, ArH); δ_C 41.6 (NMe), 60.5 and 61.9 (C-5 and -6), 65.4 (C-7), 71.3 (C-2), 129.3, 129.5, 131.7, and 131.8 (C-14, -15, -16, and -17), 130.6 (C-4), 132.1 and 132.4 (C-10 and -11), 136.8 (C-3), and 168.1 and 168.6 p.p.m. (C-9 and -12); *m/z* 273 (M^+), 197, 124, 110, 94, 82, and 42 (Found: M^+, 273.1004; C, 66.1; H, 5.7; N, 5.1%. $C_{15}H_{15}NO_4$ requires *M*, 273.1001; C, 65.92; H, 5.52; N, 5.13%).

Crystal Structure Analysis of the Pyrrolizidine Alkaloid Analogue (**5**).—*Crystal data.* Crystals were grown from a

Table 2. Fractional atomic co-ordinates for compound (**5**) with e.s.d.s in parentheses

	x	*y*	*z*
O(8)	1.4037(2)	0.1308(0)	0.5244(1)
O(9)	1.1154(4)	0.0887(1)	0.6426(1)
O(12)	1.2511(3)	0.2495(1)	0.3948(1)
O(13)	0.9643(2)	0.1806(0)	0.3237(1)
N(1)	0.8051(3)	0.0916(1)	0.1113(1)
C(2)	1.0930(3)	0.1102(1)	0.1805(2)
C(3)	1.1799(3)	0.0749(1)	0.3145(2)
C(4)	1.0108(4)	0.0340(1)	0.2966(2)
C(5)	0.7916(4)	0.0370(1)	0.1552(2)
C(6)	1.1093(4)	0.1684(1)	0.2083(2)
C(7)	1.4339(4)	0.0842(1)	0.4388(2)
C(9)	1.2247(4)	0.1283(1)	0.6150(2)
C(10)	1.1819(5)	0.1814(1)	0.6737(2)
C(11)	0.9793(4)	0.2153(1)	0.5582(2)
C(12)	1.0789(4)	0.2186(1)	0.4185(2)
C(14)	0.7154(6)	0.1002(1)	−0.0484(2)

Table 3. Bond lengths (Å) and bond angles (°) for compound (**5**) with e.s.d.s in parentheses

(a) Bond lengths

O(8)–C(7)	1.459(3)	O(8)–C(9)	1.344(2)
O(9)–C(9)	1.197(3)	O(12)–C(12)	1.207(3)
O(13)–C(6)	1.446(3)	O(13)–C(12)	1.337(2)
N(1)–C(2)	1.467(3)	N(1)–C(5)	1.461(3)
N(1)–C(14)	1.456(3)	C(2)–C(3)	1.511(3)
C(2)–C(6)	1.510(3)	C(3)–C(4)	1.314(3)
C(3)–C(7)	1.490(3)	C(4)–C(5)	1.479(3)
C(9)–C(10)	1.497(3)	C(10)–C(11)	1.536(3)
C(11)–C(12)	1.488(3)		

(b) Bond angles

C(7)–O(8)–C(9)	117.6(2)	C(6)–O(13)–C(12)	116.4(2)
C(2)–N(1)–C(5)	106.7(2)	C(2)–N(1)–C(14)	114.7(2)
C(5)–N(1)–C(14)	113.9(2)	N(1)–C(2)–C(3)	102.5(2)
N(1)–C(2)–C(6)	113.5(2)	C(3)–C(2)–C(6)	117.1(2)
C(2)–C(3)–C(4)	109.2(2)	C(2)–C(3)–C(7)	123.9(2)
C(4)–C(3)–C(7)	126.7(2)	C(3)–C(4)–C(5)	111.3(2)
N(1)–C(5)–C(4)	103.1(2)	O(13)–C(6)–C(2)	109.0(2)
O(8)–C(7)–C(3)	112.3(2)	O(8)–C(9)–O(9)	123.9(2)
O(8)–C(9)–C(10)	110.4(2)	O(9)–C(9)–C(10)	125.7(2)
C(9)–C(10)–C(11)	112.3(2)	C(10)–C(11)–C(12)	110.7(2)
O(12)–C(12)–O(13)	123.6(2)	O(12)–C(12)–C(11)	125.2(2)
O(13)–C(12)–C(11)	111.1(2)		

benzene solution, $C_{11}H_{15}NO_4$, M = 225.2, monoclinic, a = 4.840(1), b = 25.580(2), c = 9.268(1) Å, β = 103.77(1)°, V = 1 114.4 Å^3, D_c = 1.34 g cm^{-3}, Z = 4, F(000) = 480, μ(Mo-K_α) = 0.92 cm^{-1}, systematic absences $h0l$: $h + l = 2n + 1$; $0k0$: $k = 2n + 1$; $h00$: $h = 2n + 1$; $00l$: $l = 2n + 1$, space group $P2_1/n$ (C^5_{2h}, No. 14).

Crystallographic measurements. Cell dimensions were derived by least-squares treatment of the setting angles of 25 reflections measured on an Enraf-Nonius CAD4 diffractometer with Mo-K_α radiation. 2 438 Observed intensities were collected in the range $\theta \leqslant 26°$ with Mo-K_α radiation and of these 1 574 satisfied the criterion $I \geqslant 3.0\sigma(I)$.

Structure analysis. The crystal structure was solved using the direct phasing procedure MITHRIL.[15] After preliminary least-squares adjustment of the co-ordinates of the C, N, and O atoms a subsequent difference Fourier synthesis enabled the location of all the H atoms to be determined. Refinement with anisotropic thermal parameters for the C, N, O atoms, with H atoms isotropic, converged at R 0.033, R_w 0.048 with weights $w \propto 1/\sigma^2(F)$. Fourier, least-squares, geometry, and ORTEP calculations were performed with the GX system of programs.[16]

Atomic co-ordinates are listed in Table 2, and bond lengths and angles in Table 3.*

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* *Supplementary data* [see section 5.6.3 of Instructions for Authors (1987), in the January issue]. Lists of thermal parameters, H-atom co-ordinates, and C-H bond lengths and H–C–H bond angles have been deposited at the Cambridge Crystallographic Data Centre.

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