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# $Bu_3SnH$ Mediated Oxidative Radical Cyclisation onto Imidazoles and Pyrroles

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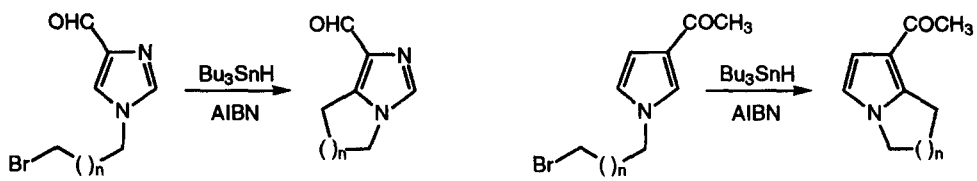
**Abstract:** A new protocol using radical cyclisation has been developed for the synthesis of [1,2-*c*]-fused imidazoles and [1,2-*a*]-fused pyrroles. The intermediate nucleophilic *N*-alkyl radicals, generated using $Bu_3SnH$ from *N*-(ω-bromoalkyl) or *N*-[ω-(phenylselanyl)alkyl] imidazoles and pyrroles, undergo regioselective radical cyclisation onto the azole rings followed by oxidative re-aromatisation. © 1999 Elsevier Science Ltd. All rights reserved.

Protocols for the synthesis of nitrogen heterocycles involving radical intermediates have become an important tool in the development of modern heterocyclic chemistry.[1] Radical methodology with nitrogen heteroarenes as synthetic targets has been less studied. Our aim was to develop protocols for the synthesis of [1,2-*a*]- and [1,2-*c*]-fused imidazoles in a programme orientated to new anticancer bicyclic imidazoles. In this paper we report the full details of our studies of the synthesis of [1,2-*a*]-fused imidazoles and pyrroles using tributyltin hydride ($Bu_3SnH$) by a protocol which involves oxidative radical cyclisation, *e.g.* Scheme 1. Part of the study has been published in preliminary form.[2]




**Scheme 1.** $Bu_3SnH$ mediated oxidative radical cyclisation

Although oxidation during $Bu_3SnH$ mediated radical reactions is unusual, this oxidative methodology has been used to facilitate the synthesis of a range of nitrogen heterocycles in recent years. One route involves cyclisation of *N*-(ω-alkyl or aryl)-radicals onto heteroarene moieties, *e.g.* indoles[3-5] pyrroles,[3,6,7] pyridinium salts,[8,9] purines,[10] and pyridines.[11] A second route involves the cyclisation of aryl radicals[7,11-17] or vinyl radicals[18,19] onto arene moieties to yield products in which the new rings formed by cyclisation are heterocyclic. Several cyclisations related to this study have been reported in the literature: cyclisation of *N*-(ω-alkyl) radicals onto the *C*-2 position of indole[3-5] and pyrrole[3] with electron withdrawing groups at *C*-3 and cyclisation of aryl radicals onto the *C*-2 and *C*-3 positions of pyrrole with an electron withdrawing groups at *C*-2 and *C*-3 respectively followed by a neophyl rearrangement.[6,7]

A number of other general routes can be defined for the synthesis of fused bicyclic heterocycles using radical cyclisation with heteroarenes. These include cyclisation of heteroaryl radicals, generated from heteroaryl (imidazole,[20] indole[21] and pyridine[22]) bromides or iodides using $Bu_3SnH$, onto *N*-(ω-alkenyl) side chains, *e.g.* cyclisation of *N*-(3-butenyl)imidazol-5-yl radicals to yield the [1,2-*c*] fused imidazole.[20] A second route involves radical cyclisations which are intramolecular *ipso*-homolytic aromatic substitutions,[23,24] *e.g.* synthesis of [1,2-*a*]-fused-benzimidazoles and -imidazoles from *N*-[(ω-phenylselanyl)alkyl]-benzimidazoles and -imidazoles with $SO_2Ar$ and SPh as radical leaving groups respectively on the *C*-2 positions.[24]

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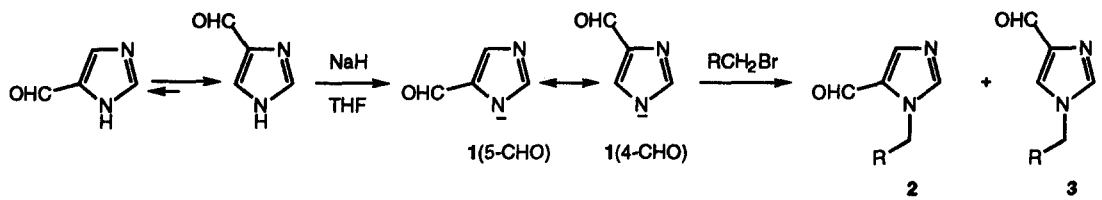
**Synthesis of imidazole radical precursors**

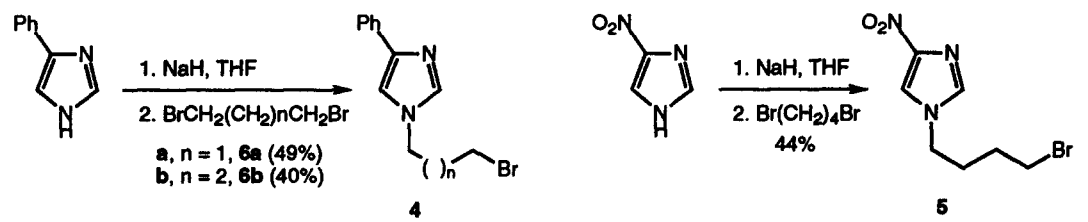
Precursors for the radical cyclisations were synthesised by standard alkylation of the anions of the imidazoles and pyrroles. 4(5)-Substituted imidazoles exist as a mixture of tautomers with the 4-substituted tautomers being predominant, *e.g.* for 4(5)-nitroimidazole the ratio of 4-nitro:5-nitro tautomers is 400:1.[25,26] The alkylation of 4(5)-nitroimidazoles has been extensively studied because of the importance of 5-nitroimidazoles as antibiotics for treatment of protozoal and anaerobic bacterial infections.[25] Alkylation selectively yields the 4-nitro product when the anion is used and the 5-nitro product is predominant under neutral conditions. 4(5)-Imidazolecarbaldehyde behaved similarly and alkylation reactions using the anion gave largely the required 4-isomer (Scheme 2). The anion is ambident and can undergo nucleophilic attack *via* either nitrogen-centred anion as represented by canonical forms **1**(5-CHO) and **1**(4-CHO). The nucleophilicity of the nitrogen anion in **1**(4-CHO) is less affected by the aldehyde group than in **1**(5-CHO) and therefore alkylation takes place predominantly *via* the nitrogen anion as represented by **1**(4-CHO). Steric hindrance will also favour alkylation *via* **1**(4-CHO).

Other 4-imidazolecarbaldehyde precursors were also regioselectively synthesised; 1-(3-bromopropyl)-2-methyl-1*H*-4-imidazolecarbaldehyde and 1-(3-bromopropyl)-5-methyl-1*H*-4-imidazolecarbaldehyde were prepared from 2- and 5-methyl-4(5)-imidazolecarbaldehydes respectively. The imidazole **3a** was converted to 1-(3-phenylselanyl)-1*H*-4-imidazolecarbaldehyde by treatment with $PhSe^-$.

Alkylation of 4(5)-phenylimidazole and 4(5)-nitroimidazole also gave selective alkylation to the 4-phenyl- and 4-nitro-imidazoles respectively as shown in Scheme 2. The regioselective alkylation of 4(5)-phenylimidazole is likely to be influenced by both electronic and steric factors.

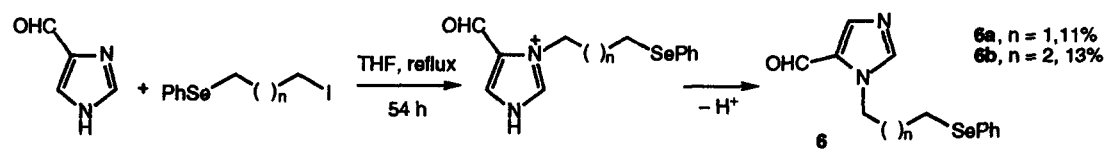



**a**, R = $(CH_2)_2Br$; **2a** (0%), **3a** (40%)
**b**, R = $(CH_2)_3Br$; **2b** (6%), **3b** (56%)
**c**, R = $(CH_2)_4Br$; **2c** (0%), **3c** (63%)
**d**, R = $(CH_2)_5Br$; **2d** (0%), **3d** (60%)
**e**, R = $(CH_2)_{11}Br$; **2e** (0%), **3e** (77%)
**f**, R = 2-bromophenyl; **2f** (0%), **3f** (45%)



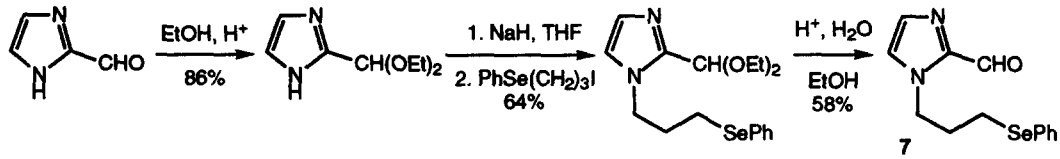

**Scheme 2.** Alkylation of 4(5)-substituted imidazoles

Alkylations of imidazole-4(5)-carbaldehyde under neutral conditions were very sluggish and even long reaction times gave only low yields of the 5-aldehydes (Scheme 3).




**Scheme 3.** Synthesis of 1-[ω-(phenylselanyl)]-1*H*-imidazole-5-carbaldehydes

The imidazole-2-carbaldehyde radical precursor **7** was synthesised with difficulty (Scheme 4) using imidazole-2-carbaldehyde which was synthesised using a modified literature procedure.[27] Commercial imidazole-2-carbaldehyde is expensive and was found to be impure. Direct alkylation of imidazole-2-carbaldehyde with 1-iodo-3-(phenylselanyl)propane failed due to the instability of the 2-aldehyde in base.[28] Reaction between the *C*-2 anion of 1-[3-(phenylselanyl)propyl]imidazole with DMF to form **7** also failed. Alkylation of the diethyl acetal of imidazole-2-carbaldehyde[29] proved successful.

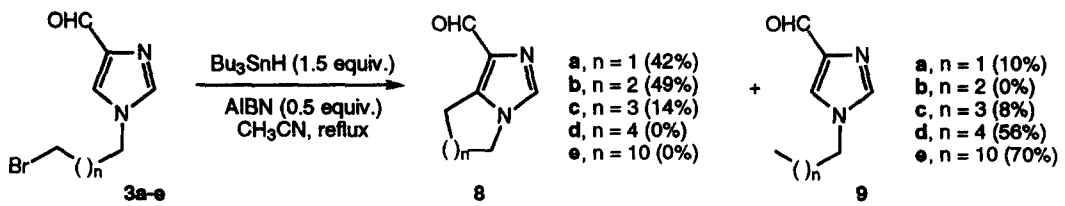



**Scheme 4.** Synthesis of 1-[3-(phenylselanyl)]-1*H*-imidazole-2-carbaldehyde

The alkylations of pyrrole-2-carbaldehyde and 3-acetylpyrrole were achieved using the same general procedure that was used for the alkylation of imidazoles. A large excess of the required dibromoalkane was used to avoid dialkylation of the dibromoalkane.

**Cyclisation reactions of imidazole precursors**

The imidazole-4-carbaldehydes **3a-e** were reacted under standard radical conditions with $Bu_3SnH$ using syringe pump addition. Reasonable yields of cyclised products **8a-c** were obtained for 5-, 6- and 7-membered ring cyclisation with small amounts of uncyclised reduced material for 5- and 7-membered ring cyclisation (Scheme 5). Yields were not optimised. No other products were detected indicating regio-selectivity to the 5-position of the imidazole ring, *i.e.* the weakly nucleophilic radical favours regioselective attack at the electrophilic *C*-5 centre in a Michael type addition. The regioselectivity shows the importance of the directing effect of the 4-aldehyde. Experimentally, acetonitrile was used as the solvent because of solubility problems with toluene. These results indicate that 6-*exo* cyclisation is more favoured than 5-*exo* cyclisation which is possibly due to ring strain in the 5,5-ring system of **8a** as compared to the 5,6 ring system of **8b**. The fact that 7-*exo* cyclisation to **8c** was also successful suggested that cyclisations in these reactions was particularly favourable. However, 8-membered ring cyclisation with imidazole precursor **3d** failed and only uncyclised reduced material was obtained. The constraints of 8-ring cyclisations are well known so a larger 14-ring cyclisation with **3e** was also attempted. The unfavourable entropic effect is obviously dominant which indicates that the effect of the α,β-unsaturated aldehyde moiety is not especially strong as observed for some macrocyclisations onto α,β-unsaturated carbonyl compounds.[30]




**Scheme 5.** Radical cyclisations of imidazole-4-carbaldehydes

Cyclisation of 1-(2-bromobenzyl)-1*H*-4-imidazolecarbaldehyde **3g** *via* an aryl radical failed. The reason for this failure is not obvious especially as a related cyclisation onto a pyrrole ring has proved successful.[3] Initial studies using **3a** to determine the best radical leaving group were carried out. Cyclisation studies using 1-(3-iodopropyl)-1*H*-4-imidazolecarbaldehyde and 1-[3-(phenylselanyl)propyl]-1*H*-4-imidazolecarbaldehyde

both gave low yields of the cyclised product **8a** (3% and 27% respectively) and uncyclised reduced material, 1-propyl-1*H*-4-imidazolecarbaldehyde **9a** (7% and 11% respectively). The lack of stability of the iodo precursor was problematic. Although further study with selenides was likely to be satisfactory the bromo precursors were easier to synthesise and were therefore used in these studies.

The regioselectivity of cyclisation onto the 5-position of **3a-c** to yield **8a-c**, [1,2-*c*]-fused, rather than the 2-position, [1,2-*a*]-fused, could not be verified using spectroscopy. Therefore, the regioselectivity of cyclisation onto *C*-5 was confirmed by determination of the structure of the cyclised imidazole **8a** by X-ray crystallography (Figure 1). The structure of 6,7-dihydro-5*H*-pyrrolo[1,2-*c*]imidazole-1-carbaldehyde **8a** is unusually flat indicating the strain in the alicyclic ring. The regioselectivity was further proven by blocking the 2- and 5-positions of the imidazole with methyl groups (Scheme 6). The 2-methylimidazole-4-carbaldehyde **10** gave the corresponding cyclised aldehyde which was derivatised without purification as the α,β-unsaturated ketone **11** by an aldol condensation with acetone. Attempted cyclisation of the 5-methylimidazole-4-carbaldehyde precursor **12** gave the corresponding uncyclised reduced product **14** as the only product indicating that attack at the *C*-2 position is not favoured when the aldehyde group is in the 4-position.

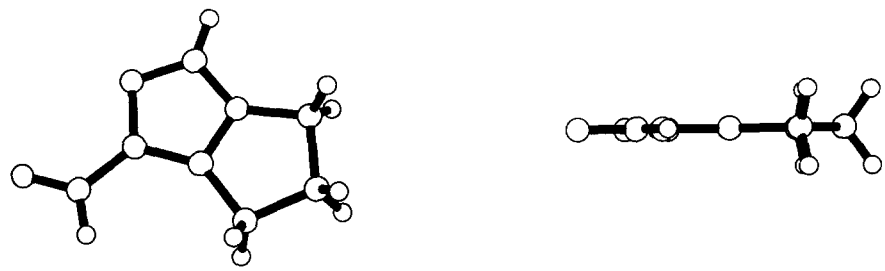
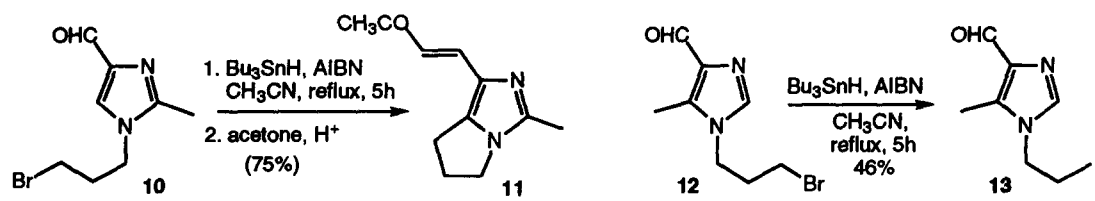
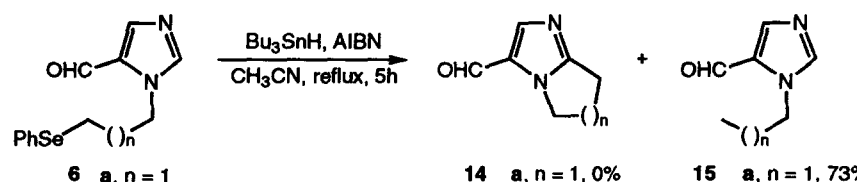


**Figure 1.** The molecular structure of 6,7-dihydro-5*H*-pyrrolo[1,2-*c*]imidazole-1-carbaldehyde **8a** in the crystal




**Scheme 6.** Radical cyclisations of 2- and 5-methylimidazole-4-carbaldehydes

The effect on cyclisation of a carbaldehyde group in the α-positions of imidazole, *e.g.* **6** and **7**, was also investigated. The radical reactions of the 5-carbaldehydes showed a marked difference between 5- and 6-*exo* cyclisation (Scheme 7). Imidazole **6a** yielded no 5-membered ring cyclisation to **14a** and gave only reduction



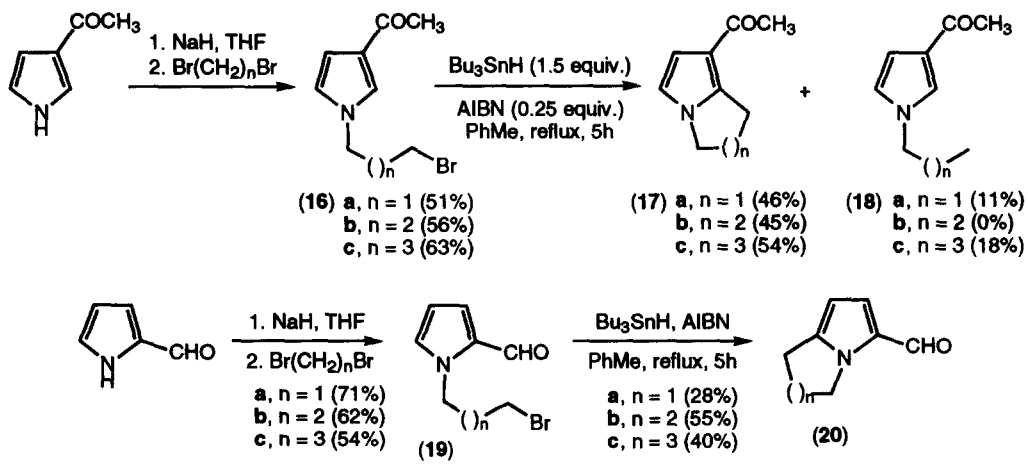

**Scheme 7.** Cyclisation of imidazole-2- and 5-carbaldehydes

to 1-propylimidazole-5-carbaldehyde **15a** (73%), whereas **6b** gave the cyclised imidazole **14a** selectively (53%) with no uncyclised product **15b**. This difference in reactivity provides further evidence that 6-*exo* cyclisation is more favourable and that 5-*exo* cyclisation is disfavoured due to ring strain. In contrast to the 4-aldehyde, the directing effect of the 5-aldehyde facilitates cyclisation at the electrophilic 2-position. However, the effect is less favourable than the directing effect of the 4-aldehyde to cyclisation at *C*-5.

Attempted cyclisation of the 2-aldehyde **7** gave 1-[3-(phenylselanyl)propyl]imidazole by loss of the 2-aldehyde rather than abstraction of phenylselanyl group. The reaction was not further investigated. Attempted radical cyclisation of 1-(4-bromobutyl)-4-nitro-1*H*-imidazole **5** gave a mixture of a large number of coloured products. Tributyltin radicals are known to react rapidly by attack on the oxygen of nitro groups to yield intermediate nitroxyl radicals which fragment to a variety of products.[31]

**Radical cyclisations of 1-(ω-bromoalkyl) pyrroles**

The syntheses of the 1-(ω-bromoalkyl)-1*H*-2-pyrrolecarbaldehyde and 1-(ω-bromoalkyl)-1*H*-3-pyrrolyl-1-ethanone radical precursors were carried out by alkylation of the respective pyrroles using the same procedures as for the 1*H*-imidazole-4-carbaldehydes as shown in Scheme 8. 1*H*-3-Pyrrolyl-1-ethanone was chosen in place of and 1*H*-3-pyrrolylcarbaldehyde because of a more facile synthesis. The results of the radical cyclisations are also shown in Scheme 8. Some difficulty was encountered in the purification of products because of tributyltin impurities. The crude reaction mixtures were analysed by GCMS, TLC and $^1$H NMR spectroscopy in order to determine which products were formed.




**Scheme 8.** Synthesis and radical cyclisation of 1-(ω-bromoalkyl)-1*H*-pyrroles

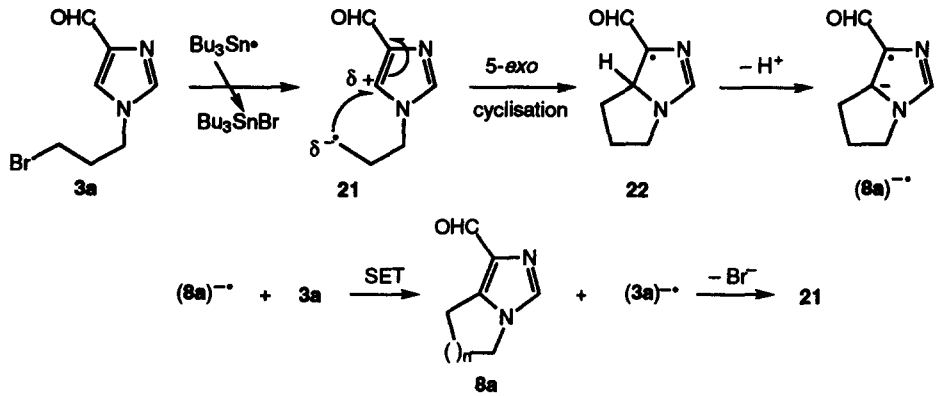
The regioselectivity of radical cyclisation exhibited by the 1*H*-3-pyrrolyl-1-ethanone precursors was similar to that of the corresponding 4-imidazolecarbaldehydes, *i.e.* the nucleophilic alkyl radical intermediates cyclise onto the electrophilic positions β to the electron withdrawing group as observed in Michael additions. Again, the 6-membered ring cyclisation of **16b** gave only cyclised product **17b** whereas the 5- and 7-membered ring cyclisation reactions also gave small amounts of reduced uncyclised products, **18a** and **18c** respectively as well as the respective cyclised products **17a** and **17c**. This is another example indicating that 6-membered ring cyclisation is more favoured than 5-membered ring cyclisation because of ring strain.

The 1*H*-2-pyrrolecarbaldehyde precursors **19a-c** gave selective cyclisation at the 5-position which can be regarded as the electrophilic δ-position of a α,β,γ,δ-unsaturated aldehyde. No uncyclised reduced products were detected indicating a particularly favourable cyclisation as compared to the corresponding 5-imidazole carbaldehydes (see Scheme 6). The lowish yields of **20a-c** were due to the common problem of separating

tributyltin residues from the products. The observed regioselectivities of both sets of cyclisations are similar to reported radical cyclisations onto related pyrrole derivatives.[3]

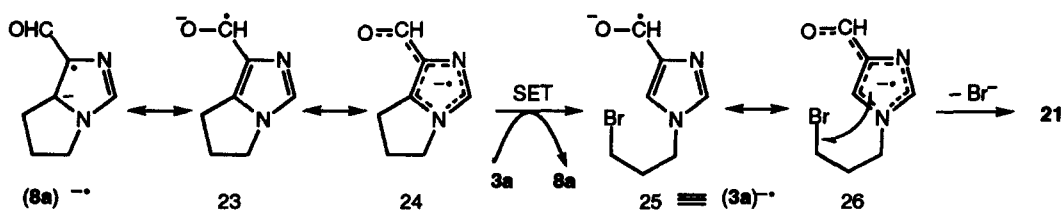
**Mechanism of the oxidative cyclisation**

$Bu_3SnH$ mediated reactions give reduced products and these radical chain mechanisms are well understood. In this now increasing group of oxidative reactions with $Bu_3SnH$ reported in the literature there is also a driving force towards re-aromatisation or in the case of thioamides[14] a driving force for loss of a proton. When we first encountered these unusual $Bu_3SnH$ reactions we proposed a mechanism[14,32] based on the aromatic $S_{RN}1$ mechanism.[33] We had studied $S_{RN}1$ reactions with similar substrates and recognised similar mechanistic steps.[32] On the basis of this comparison we defined the mechanism as 'pseudo $S_{RN}1$'. We propose that the 'pseudo $S_{RN}1$' is a probable mechanism for the cyclisations reported in this paper and is shown in Scheme 9 as exemplified for the cyclisation of the bromo precursor **3a** to 6,7-dihydro-5*H*-pyrrolo[1,2-*c*]-imidazole-1-carbaldehyde **8a**.




**Scheme 9.** Mechanism of oxidative cyclisation *via* proton loss followed by SET exemplified for the synthesis of bicyclic imidazole **8a** from precursor **3a**

In this 'pseudo $S_{RN}1$' mechanism the initial $S_H2$ abstraction of bromine by $Bu_3Sn•$ and the 5-*exo* cyclisation of radical intermediate **21** to **22** is as predicted for a 'normal' $Bu_3SnH$ cyclisation reaction. The oxidation of **22** to **8a** is more difficult to explain. The yields of many of these reactions are nearly quantitative and no dihydro products have been detected which rules out a disproportionation step in the mechanisms. Disproportionation would also break the chain reaction. Proton loss from the intermediate π-radical intermediate **22** to the π*-radical anion intermediate $(\mathbf{8a})^{-•}$ could be envisaged as favourable. $Bu_3SnH$ is not a strong base but will react with acidic protons. We have not been able to locate any data for the acidity of aromatic π-radicals but radicals in general are considerably more acidic than expected. The aromatic π*-radical anion intermediate is reasonably stable thereby facilitating single electron transfer (SET).[33] In the case of $(\mathbf{8a})^{-•}$ the unpaired electron is likely to be localised on the aldehyde group as a ketyl **23**, a very stable group

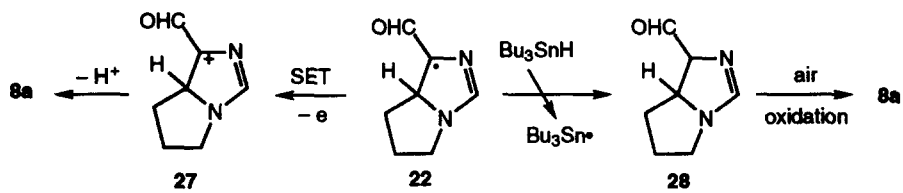



**Scheme 10.** SET and dissociative electron transfer to yield the intermediate radical **21**

of radical anions (see Scheme 10). The MO holding the unpaired electron is probably further delocalised into the aromatic ring as shown in **26**. SET between $(\mathbf{8a})^{-\bullet}$ and the bromo precursor **3a** should be facile and lead to another stable ketyl radical anion intermediate **25** as shown in Scheme 10. Intramolecular SET from the $\pi^*$ delocalised radical anion **26** to the $\sigma^*$ MO of C-Br bond will be dissociative[34] and irreversible thus yielding the alkyl radical intermediate **21** which completes the chain mechanism. SET into the $\sigma^*$ MO of alkyl bromides is dissociative. Two steps of this chain reaction are the same as observed for $S_{RN}1$ mechanisms,[32,33] *i.e.* a. SET between the radical anion of the product and starting material and, *b.* dissociation of the radical anion of the starting material into radical and anion.

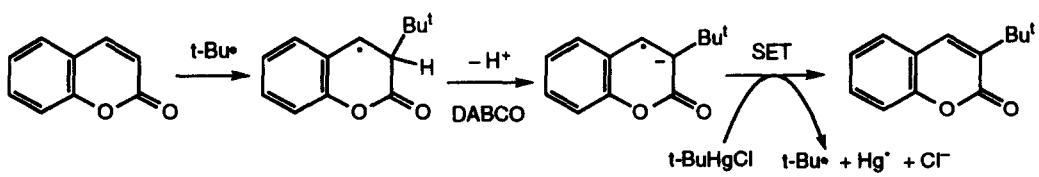
Alternative mechanisms should also be considered. Several of the reported oxidative cyclisations[8,12] require large amounts of AIBN which suggests that AIBN or 2-cyano-2-propyl radicals could act as the oxidant for the intermediate cyclised radicals.[12] This observation can also be explained by short chain lengths. AIBN has been shown to be able to act as an oxidant in radical reactions.[35] In a careful mechanistic study in the formation of biaryl compounds by this mechanism Prakhabar and co-workers[15] have shown that AIBN does not act as an oxidant and is only acting as an initiator. Similarly, Beckwith and Storey[16] have shown that di(*tert*-butyl)peroxide, which is less able to act as an oxidant, can replace AIBN as the initiator in these reactions.

Another obvious mechanistic possibility is that the intermediate radical is reduced to a dihyroimidazole **28** which undergoes air oxidation on work-up (Scheme 11). Careful study of crude product mixtures prior to work-up by GCMS, TLC and $^1$H NMR spectroscopy indicated the presence of only oxidised products. Furthermore, dihydroimidazoles are known compounds and are stable to air oxidation.



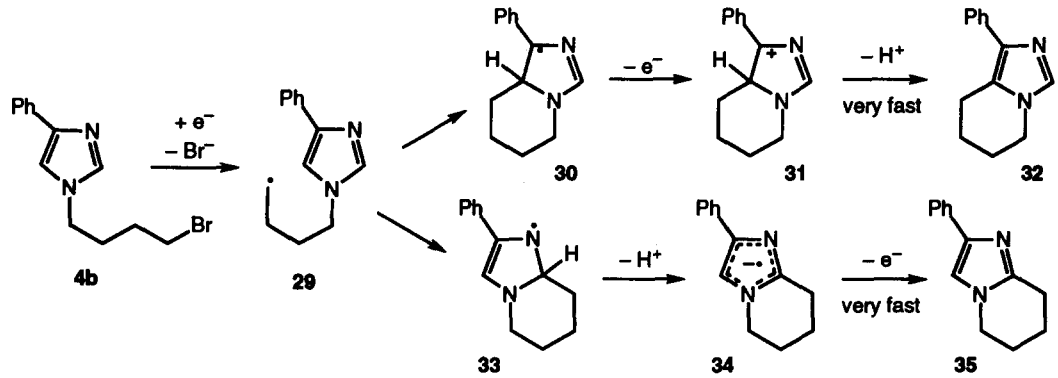

**Scheme 11.** Alternative mechanisms to explain the oxidation step

Lastly, an alternative SET chain mechanism which involves SET from the intermediate cyclised radical **22** to the starting precursor **3a** is also possible, *i.e.* SET followed by proton loss (Scheme 11) instead of proton loss followed by SET (Schemes 9 and 10). The resulting cation **27** would rapidly aromatise with loss of the proton. The cation intermediate **27** is unlikely to be favourable because of the effect of the aldehyde group even though the positive charge could be localised on 1-*N* atom of the imidazole ring. However, this alternative 'pseudo $S_{RN}1$' mechanism may well be favoured in other examples in which a strong electron withdrawing group is not present. Support for our proposals comes from the studies of Russell and co-workers[36] who have reported a series of related $S_{RN}1$ type reactions. These reactions involve the addition of alkyl radicals, generated by SET to organomercury halides and dissociation, to various substrates. When the substrate is electron poor the chain is propagated by proton loss followed by SET, *e.g.* radical addition to the 4-position of coumarins (see Scheme 12).[37] Conversely, when the radical is added to electron rich substrates, *e.g.* *N*-methylpyrrole, then SET takes place first followed by proton loss.[38]




**Scheme 12.** Oxidative radical addition to coumarone via proton loss followed by SET

In order to test the latter mechanism we studied the cyclisation of 1-(4-bromobutyl)-4-phenyl-1*H*-imidazole **4b** (Scheme 13). We predicted that the 4-phenyl group would strongly favour loss of an electron from the intermediate radical **30** to yield the intermediate stabilised cation **31** which would rapidly rearomatise with loss of a proton to yield the cyclised product **32**. The cyclisation also yielded **35** *via* cyclisation onto the electrophilic 2-position of the imidazole ring. The phenyl group unlike the aldehyde or acetyl groups does not facilitate regioselective cyclisation. Loss of an electron by SET from the radical intermediate **33** is unfavourable and loss of a proton to an intermediate radical anion **34** is more favourable suggesting that both mechanisms may be operating in one reaction. The equivalent 5-membered ring cyclisation using 1-(3-bromoproyl)-4-phenyl-1*H*-imidazole **4a** gave regioselective cyclisation to the 5-membered analogue of **32** but also yielded uncyclised reduced material.




**Scheme 13.** Alternative mechanisms to explain the oxidation step for 4-phenylimidazoles

In conclusion, the success of our radical cyclisation studies onto a range of imidazoles and pyrroles with suitable electron withdrawing groups and the studies of Moody and Norton[5] with corresponding 3-indolecarbaldehydes indicates that similar cyclisations could be carried out on other azole rings, thereby providing a useful protocol for the synthesis of bicyclic azole derivatives. Other electron withdrawing groups should also facilitate cyclisation. For instance, initial studies with methyl 1-(ω-bromoalkyl)-1*H*-2-pyrrolecarboxylates show similar results and will be published in due course.

**Acknowledgements**

We thank Loughborough University for postgraduate studentship (F.A.), the EPSRC for a 400 MHz NMR spectrometer and the EPSRC Mass Spectrometry Unit at University of Wales, Swansea for mass spectra.

## EXPERIMENTAL

### General

Commercial dry solvents were used in all reactions except for light petroleum and ethyl acetate which were distilled from $CaCl_2$ and dichloromethane was distilled over phosphorus pentoxide. Light petroleum refers to the bp 40-60 °C fraction. Sodium hydride was obtained as 60% dispersion in oil and was washed with light petroleum and 2.5 M solution of *n*-butyl lithium in hexane was used in all stated cases. Melting points were determined on a Leica Galen III hot stage melting point apparatus and are uncorrected. Elemental analyses were determined on a Perkin Elmer 2400 CHN Elemental Analyser in conjunction with a Perkin Elmer AD-4 Autobalance. Infrared spectra were recorded on a Perkin-Elmer Paragon 1000 FT-IR spectrophotometer on NaCl plates. $^1H$ (250 MHz) and $^{13}C$ (62.5 MHz) NMR spectra were recorded on a Bruker AC-250 spectrometer as solutions of $CDCl_3$ with tetramethylsilane (TMS) as the internal standard for $^1H$ NMR spectra

and deuteriochloroform the standard for $^{13}C$ NMR spectra unless otherwise specified. Chemical shifts are given in parts per million (ppm) and *J* values in hertz (Hz). Mass spectra were recorded on a Kratos MS80 spectrometer or carried out by the EPSRC Mass Spectrometry Service at University of Wales, Swansea. GCMS was carried out on Fisons 8000 series GCMS using a 15 m x 0.25 mm DB-5 column and an electron impact low resolution mass spectrometer. TLC using silica gel as absorbent was carried out with aluminium backed plates coated with silica gel (Merck Kieselgel 60 F254), and TLC using alumina as absorbent was carried out with aluminium backed plates coated with neutral aluminium oxide (Merck 150 F254,TypeT). Silica gel (Merck Kieselgel 60 H silica) was used for column chromatography unless otherwise specified. Column chromatography using alumina was carried out with Aldrich aluminium oxide, activated neutral, Brockmann 1, STD Grade, 150 mesh size. Prep-TLC was carried out using aluminium oxide (Merck 60 P F254, Type E).

**Synthesis of imidazole radical precursors**

*Standard procedure for the alkylation of imidazoles. 1-(3-Bromopropyl)-1H-4-imidazolecarbaldehyde* **3a**. Imidazole-4(5)-carbaldehyde (4.00 g, 41.6 mmol) was added to sodium hydride (1.50 g, 62.4 mmol) in dry THF (300 $cm^3$). The mixture was stirred and heated under reflux for 1 h and 1,3-dibromopropane (43.0 $cm^3$, 0.424 mol) was added. The mixture was stirred and heated under reflux for a further 2 h. The salts which were formed and unreacted imidazole were removed by filtration on a celite bed. The solution was evaporated to yield a crude oil which was purified by column chromatography using neutral alumina as absorbent with light petroleum/dichloromethane followed by ethyl acetate/methanol as eluent to yield *1-(3-bromopropyl)-1H-4-imidazole-carbaldehyde* **3a** as a yellow gummy oil (3.58 g, 40%) (Found: $M^+$, 215.9901. $C_7H_9N_2{}^{79}BrO$ requires M, 215.9899); $\upsilon_{max}/cm^{-1}$ 3110, 2961, 2824, 1682, 1538, 1497, 1454, 1381, 1327, 1249, 1162, 1046, 979, 855, 780 and 627; $\delta_H$ 2.27-2.37 (2 H, m, 2'-$CH_2$), 3.33 (2 H, t, *J* 7.5, $CH_2Br$), 4.23 (2 H, t, *J* 7.5, $NCH_2$), 7.61 (1 H, s, 2-H), 7.64 (1 H, s, 5-H) and 9.87 (1 H, s, CHO); $\delta_C$ 29.13 (2'-$CH_2$), 32.44 ($CH_2Br$), 45.60 ($NCH_2$), 124.35 (Im-2-CH), 139.21 (5-CH) and 186.58 (CHO); *m/z* 234 ($M^+$, 36%), 158 (47), 91 (27), 78 (70), 51 (45) and 41 (100).

*1-(4-Bromobutyl)-1H-4-imidazolecarbaldehyde* **3b**. Using the standard procedure for the alkylation of imidazoles, imidazole-4(5)-carbaldehyde (2.00 g, 21.0 mmol) and 1,4-bromobutane (25.1 $cm^3$, 0.210 mol) yielded: *1-(4-bromobutyl)-1H-5-imidazolecarbaldehyde* as a yellow oil (0.290 g, 6%); (Found: $M^+$, 230.0055 $C_8H_{11}N_2{}^{79}BrO$ requires M, 230.0055); $\upsilon_{max}/cm^{-1}$ 2196, 1668, 1536, 1489, 1348 and 1124; $\delta_H$ 1.84-2.00 (4 H, m, 2' and 3'-$CH_2$), 3.41 (2 H, t, *J* 6.2, $CH_2Br$), 4.34 (2 H, t, *J* 7.0, $NCH_2$), 7.68 (1 H, s, 2-H), 7.81 (1 H, s, 5-H) and 9.75 (1 H, s, CHO); $\delta_C$ 29.32 (3'-$CH_2$), 29.44 (2'-$CH_2$), 32.32 ($CH_2Br$), 46.25 ($NCH_2$), 143.43, 144.05 and 179.10 (CHO); 1-(4-bromobutyl)-1*H*-4-imidazolecarbaldehyde as a yellow oil (2.70 g, 56%); (Found: $M^+$, 230.0055 $C_8H_{11}N_2{}^{79}BrO$ requires M, 230.0055); $\upsilon_{max}/cm^{-1}$ 2945, 1686, 1541, 1497, 1450, 1349 and 1160; $\delta_H$ 1.82-1.93 (2 H, m, 3'-$CH_2$), 2.00-2.09 (2 H, m, 2'-$CH_2$), 3.42 (2 H, t, *J* 6.2, $CH_2Br$), 4.06 (2 H, t, *J* 7.0, $NCH_2$), 7.58 (1 H, s, 2-H), 7.64 (1 H, s, 5-H) and 9.88 (1 H, s, CHO); $\delta_C$ 29.16 (3'-$CH_2$), 29.32 (2'-$CH_2$), 32.02 ($CH_2Br$), 46.80 ($NCH_2$), 123.83 (Im-2-CH), 138.47 (Im-5-CH) and 186.19 (CHO); *m/z* 232 (11), 230 ($M^+$, 10%), 151(100), 123 (54), 109 (22), 95 (38), 55 (98) and 41 (29).

*1-(5-Bromopentyl)-1H-4-imidazolecarbaldehyde* **3c**. (from 1,5-dibromopentane); tan oil (63%) (Found: $MH^+$, 245.0289. $C_9H_{13}{}^{79}BrN_2O$ + H requires M, 245.0290); $\upsilon_{max}/cm^{-1}$ 2862, 1683, 1539, 1497, 1356, 1144, 1048 and 979; $\delta_H$ 1.43-1.55 (2 H, m, 3'-$CH_2$), 1.80-2.08 (4 H, m, 2' and 4'-$CH_2$), 3.43 (2 H, t, *J* 5.8, $CH_2Br$), 4.03 (2 H, t, *J* 7.1, $NCH_2$), 7.57 (1 H, s, Im-2-H), 7.64 (1 H, s, Im-5-H) and 9.88 (1 H, s, CHO); $\delta_C$ 24.95 (3'-$CH_2$), 29.99 (4'-$CH_2$), 31.78 (2'-$CH_2$), 32.85 ($CH_2Br$), 47.43 ($NCH_2$), 124.07 (Im-2-CH), 138.57 (Im-5-CH) and 186.19 (CHO); *m/z* 247 (83), 245 ($MH^+$, 82%), 219 (38), 217 (37), 165 (100) and 137 (94).

*1-(6-Bromohexyl)-1H-4-imidazolecarbaldehyde* **3d**. (from 1,6-dibromohexane); a yellow oil 60%); $\delta_H$ 1.34-1.56 (4 H, m, 3' and 4'-$CH_2$), 1.80-1.91 (4 H, m, 2'- and 5'-$CH_2$), 3.41 (2 H, t, *J* 6.5, $CH_2Br$), 4.02 (2 H, t,

*J* 7.1, $NCH_2$), 7.56 (1 H, s, 2-H), 7.63 (1 H, s, 5-H) and 9.88 (1 H, s, CHO); $\delta_C$ 25.99 (4'-$CH_2$), 27.71, 31.05, 32.58, 34.08 ($CH_2Br$), 47.94 ($NCH_2$), 124.56 (Im-2-CH), 139.04 (5-CH), 142.94 (4-C) and 185.60 (CHO).

*1-(12-bromododecyl)-1H-4-imidazolecarbaldehyde* **3e**. (from 1,12-dibromododecane); cream coloured needles (77%), mp 41-43 °C (Found: $M^+$, 342.1307. $C_{16}H_{27}{}^{79}BrN_2O$ requires M, 342.1307); $\delta_H$ 1.26 (16 H, m, 3'-10'-$CH_2$), 1.80-1.88 (4 H, m, 2' and 11'-$CH_2$), 3.38-3.44 (2 H, m, $CH_2Br$), 3.99 (2 H, t, *J* 7.1, $NCH_2$), 7.54 (1 H, s, 2-H), 7.62 (1 H, s, 5-H) and 9.88 (1 H, s, CHO); $\delta_C$ (62.5 MHz) 26.31, 28.02, 28.60, 28.85, 29.21, 29.24, 29.29, 30.71, 32.68, 34.00 ($CH_2Br$), 47.63 ($NCH_2$), 124.20 (2-CH), 138.61 (5-CH), 143.33 (4-C) and 186.15 (CHO); *m/z* 342 ($M^+$, 1%), 263 (34), 137 (13), 110 (23) and 55 (100).

*1-(2-Bromobenzyl)-1H-4-imidazolecarbaldehyde* **3f**. (from 2-bromobenzyl bromide); yellow oil (45%); (Found: $M^+$, 263.9898. $C_{11}H_9{}^{79}BrN_2O$ requires M, 263.9899); $\upsilon_{max}/cm^{-1}$ 2251, 2229, 1688, 1539, 1442, 1152, 1030 and 909; $\delta_H$ 5.26 (2 H, s, $NCH_2$), 7.09-7.12 (1 H, m, Ar-H), 7.22-7.37 (2 H, m, Ar-H), 7.60-7.62 (1 H, m, Ar-H), 7.64 (1 H, s, 2- or 5-H), 7.65 (1 H, s, 2- or 5-H) and 9.85 (1 H, s, CHO); $\delta_C$ (62.5 MHz) 51.37 ($NCH_2$), 123.59, 124.68, 128.27, 129.88, 130.58, 133.43, 134.00, 139.04, 142.39 (2-C) and 186.04 (CHO); *m/z* 266 ($M^+$, 13%), 264 ($M^+$), 263 (6), 185 (34), 171 (100), 169 (98), 157 (46), 90 (73), 89 (76) and 63 (32).

*1-(3-Bromopropyl)-2-methyl-1H-4-imidazolecarbaldehyde* **10**. [2-methylimidazole-4(5)-carbaldehyde and 1,3-dibromopropane]; yellow oil (45%) (Found: $M^+$, 230.0055. $C_8H_{11}{}^{79}BrN_2O$ requires M, 230.0055); $\upsilon_{max}/cm^{-1}$ 3125, 1678, 1547, 1418, 1351, 1254, 1163, 1102, 991 and 812; $\delta_H$ 2.28-2.33 (2 H, m, 2'-$CH_2$), 2.48 (3 H, s, $CH_3$), 3.37 (2 H, t, *J* 6.0, $CH_2Br$), 4.13 (2 H, t, *J* 6.7, $NCH_2$), 7.59 (1 H, s, 5-H) and 9.81 (1 H, s, CHO); $\delta_C$ 13.53 ($CH_3$), 29.21, 33.05 ($CH_2Br$), 44.83 ($NCH_2$), 125.81 (5-CH), 141.13 (2-C), 147.34 (4-C) and 185.94 (CHO); *m/z* 232 (30), 231 (19), 230 ($M^+$, 23%), 150 (48), 149 (48), 121 (44), 81 (35), 79 (28) and 41 (100).

*1-(3-Bromopropyl)-5-methyl-1H-4-imidazolecarbaldehyde* **11**. [4(5)-methylimidazole-4(5)-carbaldehyde and 1,3-dibromopropane]; yellow oil (34%) (Found: $M^+$, 230.0062. $C_8H_{11}{}^{79}BrN_2O$ requires M, 230.0055); $\upsilon_{max}/cm^{-1}$ 3081, 1668, 1556, 1510, 1407, 1382, 1310, 1272, 1234, 1213, 1102 and 806; $\delta_H$ 2.24-2.35 (2 H, m, 2'-$CH_2$), 2.58 (3 H, s, $CH_3$), 3.37 (2 H, t, *J* 6.0, $CH_2Br$), 4.14 (2 H, t, *J* 6.8, $NCH_2$), 7.59 (1 H, s, Im-2-H) and 9.96 (1 H, s, CHO); $\delta_C$ 9.75 ($CH_3$), 29.23, 32.98 ($CH_2Br$), 42.77 ($NCH_2$), 135.25 (5-C), 137.95 (2-CH), 138.42 (4-C) and 187.88 (CHO); *m/z* 232 (27), 230 ($M^+$, 27%), 151 (100), 124 (35), 109 (14), 96 (24) and 41 (54).

*1-[3-(Phenylselanyl)propyl]-1H-4-imidazolecarbaldehyde*. Diphenyl diselenide (2.53 g, 8.1 mmol) was dissolved in absolute ethanol (600 $cm^3$) at room temperature. Sodium borohydride (0.67 g, 17.7 mmol) was added slowly to the stirred solution at 0 °C. After 30 min, 1-(3-bromopropyl)-1*H*-4-imidazolecarbaldehyde **3a** (1.92 g, 8.89 mmol) in absolute ethanol (100 $cm^3$) was added and the mixture was stirred at room temperature for 16 h. The solution was evaporated to dryness and 2 M hydrochloric acid (100 $cm^3$) added and the acidic solution was washed with light petroleum to remove selenide residues. The solution was basified to pH 8 with saturated sodium carbonate solution followed by the addition of 2 M sodium hydroxide solution to pH 14. The hydroxide solution was extracted with dichloromethane and the organic extracts dried and evaporated to dryness to yield a brown solid, which was recrystallised (EtOAc) to yield the {1-[3-(phenylselanyl)propyl]-1*H*-4-imidazolyl}methanol as yellow crystals (1.08 g, 41%) (Found: $M^+$, 296.0427. $C_{13}H_{16}N_2OSe$ requires M, 296.0428); $\upsilon_{max}/cm^{-1}$ 3054, 1709, 1579, 1503, 1478, 1438, 1265 and 1161; $\delta_H$2.08-2.15 (2 H, m, 2'-$CH_2$), 2.81 (2 H, t, *J* 6.8, $CH_2SePh$), 4.03 (2 H, t, *J* 6.6, $NCH_2$), 4.58 (2 H, s, $CH_2OH$), 6.80 (1 H, s, 5-H), 7.24-7.29 (3 H, m, Ph-H), 7.37 (1 H, s, 2-H) and 7.47-7.51 (2 H, m, Ph-H); $\delta_C$ 24.41, 31.28 ($CH_2SePh$), 46.49 ($NCH_2$), 58.34 ($CH_2OH$), 116.47 (5-CH), 127.74, 129.66, 133.57, 137.33 (2-CH), 143.27 and (4-C); *m/z* 296 ($M^+$, 98%), 157 (49), 138 (62), 121 (72), 109 (100), 82 (97) and 41 (81). {1-[3-(Phenylselanyl)propyl]-1*H*-4-imidazolyl}methanol (0.879 g, 3.0 mmol) and activated manganese dioxide (2.70 g, 31.1 mmol) were stirred at room temperature in dry dichloromethane (200 $cm^3$) for 48 h. The mixture was filtered on a celite bed and

evaporated to an oil which was purified by column chromatography using neutral alumina as absorbent with EtOAc/MeOH as eluent to yield 1-[3-(phenyl-selanyl)propyl]-1*H*-4-imidazolecarbaldehyde as a yellow oil (0.635 g, 72%) (Found: $M^+$, 294.0275. $C_{13}H_{14}N_2OSe$ requires M, 294.0271); $\upsilon_{max}/cm^{-1}$ 3054, 1684, 1539, 1478, 1438, 1266, 1160, 1022 and 910; $\delta_H$ 2.10-2.21 (2 H, m, 2'-$CH_2$), 2.82 (2 H, t, *J* 6.8, $CH_2SePh$), 4.14 (2 H, t, *J* 6.8, $NCH_2$), 7.26-7.31 (3 H, m, Ph-H), 7.48-7.52 (3 H, m, Ph-H and Im-2-H), 7.55 (1 H, s, Im-5-H) and 9.86 (1 H, s, CHO); $\delta_C$ 25.40, 32.33 ($CH_2SePh$), 48.21 ($NCH_2$), 125.30, 131.02, 134.94, 140.43, 145.78 and 187.73 (CHO); *m/z* 294 ($M^+$, 100%), 157 (48), 137 (38), 109 (56), 84 (67), 77 (57), 49 (65) and 41 (62).

*1-(3-Bromopropyl)-4-phenyl-1H-imidazole* **4a**. 4(5)-Phenyl-1*H*-imidazole (1.50 g, 10.40 mmol) and 1,3-dibromopropane (10.6 $cm^3$, 0.104 mol) were reacted using the standard conditions for alkylation of imidazoles to yield 1-(3-bromopropyl)-4-phenyl-1*H*-imidazole **4a** as a colourless oil (1.350 g, 49%); (Found: $M^+$, 264.0262. $C_{12}H_{13}{}^{79}BrN_2$ requires M, 264.0263); $\upsilon_{max}/cm^{-1}$ 1605, 1482, 1368, 1280, 1195, 1067, 1046 and 941; $\delta_H$ 2.26-2.37 (2 H, m, 2'-$CH_2$), 3.36 (2 H, t, *J* 6.1, $CH_2Br$), 4.17 (2 H, t, *J* 6.5, $NCH_2$), 7.22 (1 H, s, 5-H), 7.23-7.27 (1 H, m, Ph-H), 7.35-7.41 (2 H, m, Ph-H), 7.56 (1 H, s, 2-H) and 7.76-7.79 (2 H, m, Ph-H); $\delta_C$ 29.36, 33.28 ($CH_2Br$), 44.67 ($NCH_2$), 114.47, 124.70, 126.70, 126.83, 128.55 and 137.44; *m/z* 266 (22%), 264 ($M^+$, 23), 184 (10), 158 (32), 157 (50), 143 (33), 130 (97), 103 (93), 102 (70), 89 (100), 77 (35), 51 (45) and 41 (100).

*1-(4-Bromobutyl)-4-phenyl-1H-imidazole* **4b**. [from 4(5)-phenyl-1*H*-imidazole and 1,4-dibromobutane]; colourless oil (40%); (Found: $M^+$, 278.0419. $C_{13}H_{15}N_2{}^{79}Br$ requires M, 278.0419); $\upsilon_{max}/cm^{-1}$ 1606, 1554, 1501, 1483, 1444, 1195 and 1068; $\delta_H$ 1.81-1.88 (2 H, m, $CH_2$), 1.94-2.01 (2 H, m, $CH_2$), 3.39 (2 H, t, *J* 6.2, $CH_2Br$), 3.96 (2 H, t, *J* 6.7, $NCH_2$), 7.19-7.21 (1 H, m, 5-H), 7.24-7.28 (1 H, m, Ph-H), 7.34-7.41 (2 H, m, Ph-H), 7.48-7.49 (1 H, m, 2-H) and 7.75-7.79 (2 H, m, Ph-H); $\delta_C$ 28.97, 29.92, 32.92 ($CH_2Br$), 48.68 ($NCH_2$), 116.81, 127.02, 129.13, 130.93, 131.58, 131.90, 136.37, 139.55 and 144.69; *m/z* 280 (47%), 278 ($M^+$, 42), 199 (100), 145 (39), 133 (33), 89 (88), 77 (31) and 55 (78).

*1-(4-Bromobutyl)-4-nitro-1H-imidazole* **5**. 4(5)-Nitro-1*H*-imidazole (1.622 g, 14.3 mmol) and 1,4-dibromobutane (17.0 $cm^3$, 0.143 mmol) were reacted using the standard conditions for alkylation of imidazoles to yield yellow needles of 1-(4-bromobutyl)-4-nitro-1*H*-imidazole **7** (1.55 g, 44%), mp 34-35 °C (Found: $M^+$, 246.9957. $C_7H_{10}{}^{79}BrN_2O_2$ requires M, 246.9957); $\upsilon_{max}/cm^{-1}$ 2949, 1638, 1544 ($NO_2$), 1490, 1403, 1383 and 1335; $\delta_H$ 1.87-1.95 (2 H, m, 3'-$CH_2$), 2.00-2.09 (2 H, m, 2'-$CH_2$), 3.44 (2 H, t, *J* 6.1, $CH_2Br$), 4.09 (2 H, t, *J* 7.0, $NCH_2$), 7.45 (1 H, d, *J* 1.6, 2-H) and 7.79 (1 H, d, *J* 1.6, 5-H); $\delta_C$ 29.54, 29.68, 32.48 ($CH_2Br$), 47.99 ($NCH_2$), 119.49 (2-CH), 136.32 (5-CH) and 148.64 (4-C); *m/z* 248 ($M^+$, 9%), 168 (100), 137 (14), 135 (13), 122 (36) and 55 (91).

*1-[3-(Phenylselanyl)propyl]-1H-5-imidazolecarbaldehyde* **6a**. Imidazole-4(5)-carbaldehyde (1.230 g, 12.8 mmol) was added to 3-iodo-1-(phenylselanyl)propane (4.168 g, 12.8 mmol) in THF (200 $cm^3$) and the mixture was stirred and heated under reflux for 54 h. The solution was evaporated to yield a crude slurry, which was purified by column chromatography using neutral alumina as absorbent with light petroleum/dichloromethane followed by ethyl acetate/methanol as eluent to yield a yellow oil of 1-[3-(phenylselanyl)-propyl]-1*H*-5-imidazolecarbaldehyde **6a** (0.414 g, 11%) (Found: $M^+$, 294.0268. $C_{13}H_{14}N_2OSe$ requires M, 294.0271); $\upsilon_{max}/cm^{-1}$ 3054, 1670, 1579, 1537, 1479, 1436, 1346, 1207, 1123 and 1022; $\delta_H$ 2.01-2.20 (2 H, m, 2'-$CH_2$), 2.82 (2 H, t, *J* 6.8, $CH_2SePh$), 4.40 (2 H, t, *J* 6.8, $NCH_2$), 7.26-7.29 (3 H, m, Ph-H), 7.47-7.50 (2 H, m, Ph-H), 7.61 (1 H, s, 2-H), 7.79 (1 H, s, 4-H) and 9.72 (1 H, s, CHO); $\delta_C$ 22.81 (2'-$CH_2$), 28.81 ($CH_2SePh$), 44.73 ($NCH_2$), 125.69, 127.44, 127.59, 129.29, 131.40, 142.14, 142.50 and 177.42 (CHO); *m/z* 294 ($M^+$, 17%), 157 (10), 137 (100), 109 (13) and 100 (21). Further elution with ethyl acetate/methanol yielded a yellow oil of 1-[3-(phenylselanyl)propyl]-1*H*-4-imidazolecarbaldehyde (0.188 g, 5%).

*1-[4-(Phenylselanyl)butyl]-1H-5-imidazolecarbaldehyde* **6b**. Using the same procedure as for the synthesis of **6a**, reaction between imidazole-4(5)-carbaldehyde and 4-iodo-1-(phenylselanyl)butane yielded a yellow oil of **6b** (13%); (Found: $M^+$, 308.0428. $C_{14}H_{16}N_2OSe$ requires M, 308.0427); $\upsilon_{max}/cm^{-1}$ 2253, 1675, 1644, 1536, 1478, 1347 and 1126; $\delta_H$ (400 MHz) 1.69-1.76 (2 H, m, 3'-$CH_2$), 1.91-1.98 (2 H, m, 2'-$CH_2$), 2.92 (2 H, t, *J* 6.0, $CH_2SePh$), 4.32 (2 H, t, *J* 7.2, $NCH_2$), 7.27-7.31 (3 H, m, Ph-H), 7.48-7.51 (2 H, m, Ph-H), 7.60 (1 H, s, 2-H), 7.82 (1 H, s, 4-H) and 9.76 (1 H, s, CHO); $\delta_C$ 27.24 (3'-$CH_2$), 27.46 (2'-$CH_2$), 31.11 ($CH_2SePh$), 47.03 ($NCH_2$), 127.49, 129.53, 130.16, 133.28, 133.39, 144.31 and 179.52 (CHO); *m/z* 308 ($M^+$, 90%), 279 (5), 253 (10), 151 (100), 123 (40), 109 (62), 97 (66) and 55 (58).

*1-[3-(Phenylselanyl)propyl]-1H-2-imidazolecarbaldehyde* **7**.

*1-(Triphenylmethyl)-1H-2-imidazolecarb-aldehyde*.[26] 1-(Triphenylmethyl)imidazole[26,27] (10.0 g, 32.2 mmol) was dissolved in THF (200 $cm^3$) and a solution of *n*-butyllithium (14 $cm^3$, 35.2 mmol) added dropwise to the stirred solution at -78 °C. The solution which gradually turned red was stirred at 0 °C for a further 20 min and DMF (5.4 $cm^3$, 64.4 mmol) added dropwise. The solution was stirred overnight at room temperature and evaporated to dryness. Saturated ammonium chloride and water was added to the residue and extracted with dichloromethane. The organic extracts were washed with brine, dried and evaporated to dryness to yield yellow crystals which were recrystallised (EtOAc) to give yellow needles of the 1-(triphenylmethyl)-1*H*-2-imidazolecarbaldehyde (8.0 g, 74%), mp 184-185 °C (lit.[27], mp 189-190 °C); (Found: C, 81.9; H, 5.1; N, 8.3. $C_{23}H_{18}N_2O$ requires C, 81.7; H, 5.3; N, 8.3%).

*Imidazole-1H-2-carbaldehyde*.[27] The triphenylmethyl group was removed from 1-(triphenyl-methyl)-1*H*-2-imidazolecarbaldehyde by hydrolysis in MeOH and hydrochloric acid to yield imidazole-1*H*-2-carbaldehyde (26%), mp 208-212 °C (lit.[27] mp 204-205 °C); $\upsilon_{max}/cm^{-1}$ 1692, 1424, 1411, 1342 and 1136; $\delta_H$ ([$^2H_6$] $Me_2SO$) 7.44 (2 H, brs, Im-4(5)-H) and 9.66 (1 H, s, CHO).

*2-(Diethoxymethyl)imidazole*.[29] Imidazole-1*H*-2-carbaldehyde (0.80 g, 3.7 mmol) was dissolved in dry ethanol (150 $cm^3$), and concentrated sulfuric acid (0.5 $cm^3$) added. The solution was stirred and heated under reflux for 4 h, cooled, neutralised with solid sodium carbonate, filtered and the filtrate evaporated to dryness. The residue was purified by column chromatography using neutral alumina as absorbent with ethyl acetate as the eluent to yield colourless needles of 2-(diethoxymethyl)imidazole (1.22 g, 86%); mp 114-116 °C (lit.[29], mp 115-116 °C); $\delta_H$ 1.25 (6 H, t, *J* 7.5, $CH_3$), 3.58-3.73 (4 H, m, $CH_2$), 5.61 (1 H, s, C*H*$(OEt)_2$) and 7.05 (2 H, brs, Im-H); $\delta_C$ 15.10 ($CH_3$), 62.00 ($CH_2$), 96.71 [*C*H$(OEt)_2$], 115.22 (4- or 5-CH), 128.94 (4- or 5-CH) and 145.80 (2-C).

*2-(Diethoxymethyl)-1-[3-(phenylselanyl)propyl]-1H-imidazole*. Using the standard procedure for the alkylation of imidazoles, 2-(Diethoxymethyl)imidazole and 3-iodo-1-(3-phenylselanyl)-propane gave 2-(diethoxymethyl)-1-[3-(phenylselanyl)propyl]-1*H*-imidazole as a colourless oil (64%); (Found: $M^+$, 368.1003. $C_{17}H_{24}N_2O_2Se$ requires M, 368.1002); $\upsilon_{max}/cm^{-1}$ 2978, 2246, 1579, 1498, 1478, 1438, 1105, 1060, 910 and 732; $\delta_H$ 1.20 (6 H, t, *J* 7.0, $CH_3$), 2.11-2.23 (2 H, m, 2'-$CH_2$), 2.88 (2 H, t, *J* 7.3, $CH_2SePh$), 3.46-3.58 (2 H, m, diastereotopic-*C*$H_2CH_3$), 3.68-3.77 (2 H, m, diastereotopic-$CH_2$C$H_3$), 4.26 (2 H, t, *J* 7.0, $NCH_2$), 5.57 [1 H, s, C*H*$(OEt)_2$], 6.68 (1 H, s, Im-H), 6.97 (1 H, s, Im-H), 7.26-7.28 (3 H, m, Ph-H) and 7.47-7.51 (2 H, m, Ph-H); $\delta_C$ 15.39 ($CH_3$), 24.65 (2'-$CH_2$), 31.64 ($CH_2SePh$), 46.12 ($NCH_2$), 63.55 (*C*$H_2CH_3$), 99.29 [*C*H$(OEt)_2$], 121.22, 127.45, 127.63, 129.49, 129.90, 133.28 (Ph-CH) and 145.10; *m/z* 368 ($M^+$, 7%), 295 (21), 199 (60), 157 (68), 137 (54), 121 (100), 109 (59), 77 (71), 47 (70) and 41 (61).

*1-[3-(Phenylselanyl)propyl]-1H-2-imidazolecarbaldehyde* **7**. 2-(Diethoxymethyl)-1-[3-(phenylselanyl)-propyl]-1*H*-imidazole (0.444 g, 1.21 mmol) was dissolved in ethanol (300 $cm^3$), concentrated hydrochloric acid (5 $cm^3$) and water (100 $cm^3$). The solution was heated under reflux for 2 h, cooled, neutralised with solid sodium carbonate and filtered. The filtrate was evaporated to *ca.* 100 $cm^3$ of solution which was extracted with dichloromethane. The organic extracts dried and evaporated to dryness to yield **7** as a yellow oil (0.207 g, 58%), (Found: $M^+$, 294.0271. $C_{13}H_{14}N_2OSe$ requires M, 294.0271); $\upsilon_{max}/cm^{-1}$ 2936, 1684, 1475, 1437, 1335, 1157, 771 and 737; $\delta_H$ 2.03-2.11 (2 H, m, 2'-$CH_2$), 2.75 (2 H, t, *J* 7.1, $CH_2SePh$), 4.40 (2 H, t, *J* 6.9, $NCH_2$), 7.05 (1 H, s, Im-H), 7.17-7.19 (4 H, m, Im-H and Ph-H) and 7.37-7.41 (2 H, m, Ph-H); $\delta_C$ 23.73 (2'-

$CH_2$), 30.80 ($CH_2$SePh), 47.01 ($NCH_2$), 126.47, 127.19, 129.13, 131.50, 132.93, 137.08, 143.14 and 181.75 (CHO); *m/z* 294 ($M^+$, 16%), 265 (5), 157 (29), 137 (100) and 77 (66).

**Cyclisation studies of imidazoles**

*6,7-Dihydro-5H-pyrrolo[1,2-c]imidazole-1-carbaldehyde* **8a**. *Standard procedure for reactions using $Bu_3SnH$.* A solution of $Bu_3SnH$ (2.9 $cm^3$, 10.8 mmol) and AIBN (0.593 g, 3.6 mmol) in toluene (50 $cm^3$) was added to 1-(3-bromopropyl)-1*H*-4-imidazolecarbaldehyde **3a** (1.560 g, 7.2 mmol) in acetonitrile (750 $cm^3$) at reflux over 5 h. The solution was stirred and heated under reflux for a further 1 h. After cooling to room temperature the solution was evaporated to dryness. Hydrochloric acid solution (2 M) was added and the acidic solution was washed with light petroleum, basified to pH 8 with saturated sodium carbonate solution and to pH 14 with sodium hydroxide solution (2 M) and extracted with dichloromethane. The organic extracts were dried and evaporated to dryness to yield a brown oil. TLC and $^1H$ NMR spectroscopic analysis of the crude oil showed a complete consumption of the starting bromide. Purification by column chromatography using neutral alumina as absorbent with ethyl acetate/methanol as eluent yielded **8a** as colourless needles (0.411 g, 3.02 mmol 42%); mp 137-139 °C; (Found: $M^+$, 136.0637. $C_7H_8N_2O$ requires M, 136.0637); $\upsilon_{max}/cm^{-1}$ 3223, 1672 (C=O), 1618, 1471, 1446, 1345, 1300, 1281, 1134 and 744; $\delta_H$ 2.66-2.80 (2 H, m, 6-$CH_2$), 3.10 (2 H, t, *J* 7.5, 7-$CH_2$), 4.06 (2 H, t, *J* 7.2, $NCH_2$), 7.48 (1 H, s, 3-H), and 9.83 (1 H, s, CHO); $\delta_C$ 23.43 (6-$CH_2$), 29.22 (7-$CH_2$), 45.09 ($NCH_2$), 132.21 (3-CH), 133.52 (7a-C), 145.05 (1-C) and 186.95 (CHO); *m/z* 136 ($M^+$, 40%), 135 (39), 108 (36), 107 (52), 81(29), 80 (100), 79 (27), 53 (84), 52 (82), 41 (36) and 39 (42). Further elution with ethyl acetate/methanol yielded 1-propyl-1*H*-4-imidazole-carbaldehyde **9a** as a colourless oil (0.100 g, 10%) (Found: $M^+$, 138.0795. $C_7H_{10}N_2O$ requires M, 138.0793); $\delta_H$ 0.96 (3 H, t, *J* 7.4, $CH_3$), 1.81-1.93 (2 H, m, 2'-$CH_2$), 3.97 (2 H, t, *J* 7.1, $NCH_2$), 7.55 (1 H, s, 2-H), 7.62 (1 H, s, 5-H) and 9.87 (1 H, s, CHO); $\delta_C$ 11.40 ($CH_3$), 24.59 (2'-$CH_2$), 49.75 ($NCH_2$), 124.49 (2-CH), 139.07 (5-CH), 142.92 and 186.77 (CHO); *m/z* 138 ($M^+$, 100%), 121 (12), 110 (46), 95 (61), 81 (13), 68 (25) and 43 (47).

*5,6,7,8-Tetrahydroimidazo[1,5-a]pyridine-1-carbaldehyde* **8b**. (from **3b**) yellow needles (49%) mp 51-53 °C, (Found: $M^+$, 150.0793. $C_8H_{10}N_2O$ requires M, 150.0793); $\upsilon_{max}/cm^{-1}$ 2957, 1672, 1553, 1514, 1266 and 1151; $\delta_H$ 1.86-2.05 (4 H, m, 6- and 7-$CH_2$), 3.10 (2 H, t, *J* 6.4, 8-$CH_2$), 4.03 (2 H, t, *J* 6.0, $NCH_2$), 7.42 (1 H, s, 3-H) and 9.89 (1 H, s, CHO); $\delta_C$ (62.5 MHz) 20.35, 22.67, 23.18 (8-$CH_2$), 44.18 ($NCH_2$), 137.29 (3-CH) and 187.90 (CHO); *m/z* 151 ($MH^+$, 100%), 150 ($M^+$, 69), 149 (56), 121 (19), 94 (9) and 67 (31).

*6,7,8,9-Tetrahydro-5H-imidazo[1,5-a]azepine-1-carbaldehyde* **8c**. (from **3c**) colourless needles of (14%) mp 86-88 °C, (Found: $M^+$, 164.0950. $C_9H_{12}N_2O$ requires M, 164.0950); $\upsilon_{max}/cm^{-1}$ 2857, 1666, 1555, 1524, 1392 and 1353; $\delta_H$ 1.65-1.89 (6 H, m, 6-, 7- and 8-$CH_2$), 3.20-3.22 (2 H, m, 9-$CH_2$), 4.01-4.05 (2 H, m, $NCH_2$), 7.39 (1 H, s, 3-H) and 9.92 (1 H, s, CHO); $\delta_C$ 24.52, 26.76, 29.07, 30.89, 48.38 ($NCH_2$), 137.80 (9a-C), 138.19 (3-CH), 141.76 (1-C) and 187.95 (CHO); *m/z* 165 ($MH^+$, 24%), 164 ($M^+$, 100), 163 (45), 149 (18), 135 (91), 121 (34), 107 (43) and 81 (31). Further elution of the chromatography column with ethyl acetate/methanol yielded 1-pentyl-1*H*-4-imidazolecarbaldehyde **9c** as a colourless oil (8%); (Found: $M^+$, 166.1106. $C_9H_{14}N_2O$ requires M, 166.1106); $\delta_H$ 0.91 (3 H, t, *J* 6.9, $CH_3$), 1.25-1.40 (4 H, m, 7- and 8-$CH_2$), 1.77-1.88 (2 H, m, 6-$CH_2$), 3.99 (2 H, t, *J* 7.1, $NCH_2$), 7.62 (1 H, s, 2-H), 7.63 (1 H, s, 5-H) and 9.88 (1 H, s, CHO); $\delta_C$ 14.17 ($CH_3$), 22.45 (4'-$CH_2$), 28.98, 30.89, 48.12 ($NCH_2$), 124.39 (2-CH), 139.00 (5-CH), 142.96 (4-C) and 186.77 (CHO); *m/z* 166 ($M^+$, 24%), 137 (61), 110 (25), 109 (20), 95 (26), 81 (34), 68 (16), 55 (28) and 41 (100).

*Attempted cyclisation of 1-(6-bromohexyl)-1H-4-imidazolecarbaldehyde* **3d**. 1-Hexyl-1*H*-4-imidazole-carbaldehyde **9d** was obtained as a colourless oil (56%); $\delta_H$ 0.89 (3 H, t, *J* 6.5, $CH_3$), 1.28-1.31 (6 H, m, 3'-, 4'-, and 5'-$CH_2$), 1.79-1.84 (2 H, m, 2'-$CH_2$), 3.99 (2 H, t, *J* 7.2, $NCH_2$), 7.55 (1 H, s, 2-H), 7.63 (1 H, s, 5-H) and 9.87 (1 H, s, CHO); $\delta_C$ 14.26 ($CH_3$), 22.76, 26.48, 31.08, 31.06, 48.14 ($NCH_2$), 124.48 (2-CH), 139.01 (5-CH), 142.89 (4-C) and 186.72 (CHO).

*Attempted cyclisation of 1-(12-bromododecyl)-1H-4-imidazolecarbaldehyde* **3e**. 1-Dodecyl-1*H*-4-imidazolecarbaldehyde **9e**; an oil (70%); (Found: M+, 264.2202. $C_{16}H_{28}N_2O$ M, 264.2202); $\upsilon_{max}/cm^{-1}$ 2854, 1689, 1540, 1466, 1378, 1158 and 910; $\delta_H$ 0.88 (3 H, t, *J* 6.6, $CH_3$), 1.25-1.38 (18 H, m, 3'-11'-$CH_2$), 1.79-1.82 (2 H, m, 2'-$CH_2$), 3.99 (2 H, t, *J* 7.1, $NCH_2$), 7.54 (1 H, d, *J* 0.9, 2-H), 7.63 (1 H, d, *J* 0.9, Im-5-H) and 9.88 (1 H, s, CHO); $\delta_C$ 14.45 ($CH_3$), 23.02, 26.80, 29.32, 29.66, 29.77, 29.83, 29.92, 31.18, 31.31, 32.24, 48.10 ($NCH_2$), 124.52 (2-CH), 139.03 (5-CH), 142.88 (4-C) and 186.65 (CHO); *m/z* 264 (M+, 57%), 235 (44), 221 (23), 207 (29), 151 (36), 137 (37), 110 (81), 97 (48), 55 (73) and 41 (100).

*(E)-4-(3-methyl-6,7-dihydro-5H-pyrrolo[1,2-c]imidazol-1-yl)-3-buten-2-one* **11**. 1-(3-Bromopropyl)-2-methyl-1*H*-4-imidazolecarbaldehyde **10** was reacted using the standard procedure. 3-Methyl-6,7-dihydro-5*H*-pyrrolo[1,2-*c*]imidazole-1-carbaldehyde which was not isolated. Aqueous hydrochloric acid (2 M) and acetone was added and stirred. The acidic solution was washed with light petroleum, basified to pH 8 with saturated sodium carbonate solution and to pH 14 with sodium hydroxide solution (2 M) and extracted with dichloromethane. The organic extracts were dried and evaporated to dryness to yield a tan solid which was purified by column chromatography with ethyl acetate/methanol as eluent to yield **11** as a yellow oil (75%) (Found: M+, 190.1106. $C_{11}H_{14}N_2O$ requires M, 190.1106); $\upsilon_{max}/cm^{-1}$ 2961, 1661, 1422, 1363 and 1254; $\delta_H$ (400 MHz) 2.28 (3 H, s, 3-$CH_3$), 2.88 (3 H, s, $CH_3$), 2.64-2.69 (2 H, m, 6-$CH_2$), 2.93 (2 H, t, *J* 7.4, 7-$CH_2$), 3.88 (2 H, t, *J* 7.1, $NCH_2$), 6.60 (1 H, d, *J* 15.8, 1'-*trans*-H) and 7.38 (1 H, d, *J* 15.8, 2'-*trans*-H ); $\delta_C$ 13.51 (3-$CH_3$), 23.32 (6-$CH_2$), 28.28 ($CH_3$), 29.58 (7-$CH_2$), 44.28 ($NCH_2$), 123.02 (1'-CH), 127.81, 135.83 (2'-CH), 141.32 (3-C) and 198.92 (CHO); *m/z* 190 (M+, 86%), 175 (100), 147 (88), 106 (34) and 77 (59).

*Attempted cyclisation of 1-(3-bromopropyl)-5-methyl-1H-4-imidazolecarbaldehyde* **12**. 5-Methyl-1-propyl-1*H*-4-imidazolecarbaldehyde **13**; yellow oil (46%); $\upsilon_{max}/cm^{-1}$ 3111, 2876, 1674, 1557, 1510, 1456, 1381, 1259, 1209, 1170 and 1109; $\delta_H$ 0.95 (3 H, t, *J* 7.4 , $CH_3$), 1.74-1.83 (2 H, m, 2'-$CH_2$), 2.53 (3 H, s, 5-$CH_3$), 3.85 (2 H, t, *J* 7.2, $NCH_2$), 7.44 (1 H, s, 2-H) and 9.92 (1 H, s, CHO); $\delta_C$ 9.34 (5-$CH_3$), 11.06 ($CH_3$), 23.72 (2'-$CH_2$), 46.24 ($NCH_2$), 137.53 (2-CH) and 187.54 (CHO).

*Attempted cyclisation of 1-[3-(phenylselanyl)propyl]-1H-5-imidazolecarbaldehyde* **6a**. 1-Propyl-1*H*-5-imidazolecarbaldehyde **15a** was obtained as a yellow oil (73%); (Found: M+, 138.0793. $C_7H_{10}N_2O$ requires M, 138.0793); $\upsilon_{max}/cm^{-1}$ 1676, 1466, 1383, 1347 and 1214; $\delta_H$ 0.94 (3 H, t, $CH_3$), 1.76-1.82 (2 H, m, 2'-$CH_2$), 4.26 (2 H, t, *J* 7.2, $NCH_2$), 7.79 (1 H, s, 2- or 4-H), 7.80 (1 H, s, 2- or 4-H) and 9.87 (1 H, s, CHO); *m/z* 139 ($MH^+$, 100%), 121 (30), 97 (34) and 41 (38).

*5,6,7,8-Tetrahydroimidazo[1,2-a]pyridine-3-carbaldehyde* **14b**. (from **6b**); yellow oil (53%); (Found: M+, 150.0793. $C_8H_{10}N_2O$ requires M, 150.0793); $\upsilon_{max}/cm^{-1}$ 1686, 1637, 1489, 1406, 1364 and 1265; $\delta_H$ 1.92-2.03 (4 H, m, 6- and 7-$CH_2$), 2.98 (2 H, t, *J* 6.2, $CH_2$), 4.33 (2 H, t, *J* 5.7, $NCH_2$), 7.75 (1 H, s, Im-2-H) and 9.66 (1 H, s, CHO); $\delta_C$ 20.04 (7-$CH_2$), 22.76 (6-$CH_2$), 25.20 ($CH_2$), 46.08 ($NCH_2$), 142.62 (2-H) and 179.11 (CHO); *m/z* 150 (M+, 100), 149 (60), 135 (16), 122 (25) and 84 (62).

*Attempted cyclisation of 1-[3-(phenylselanyl)propyl]-1H-2-imidazolecarbaldehyde* **7**. Extensive decomposition took place and 1-[3-(phenylselanyl)propyl]imidazole was obtained as the only product (22%); yellow oil (Found: M+, 266.0328. $C_{12}H_{14}N_2Se$ requires M, 266.0322); $\upsilon_{max}/cm^{-1}$ 3424, 2089, 1644, 1579, 1509, 1478, 1438, 1229 and 1080; $\delta_H$ 2.04-2.13 (2 H, m, 2'-$CH_2$), 2.79 (2 H, t, *J* 6.9, $CH_2Se$), 4.05 (2 H, t, *J* 6.8, $NCH_2$), 6.86 (1 H, s, 5-H), 7.06 (1 H, s, 4-H), 7.25-7.29 (3 H, m, Ph-H), 7.44-7.48 (2 H, m, Ph-H) and 7.49 (1 H, s, 2-H); $\delta_C$ 23.93 (2'-$CH_2$), 30.90 ($CH_2SePh$), 45.97 ($NCH_2$), 127.34, 129.21, 129.47 and 133.06; *m/z* 266 (M+, 89%), 185 (26), 157 (28), 109 (72) and 81 (100). The product was also synthesised by alkylation of the anion of imidazole with 1-iodo-3-(phenylselanyl)propane for comparison purposes.

**Synthesis of pyrrole radical precursors**

The standard procedure for the alkylation of imidazoles was used for the alkylation of pyrroles.

*Alkylations of 1H-3-pyrrolyl-1-ethanone.* 3-Acetylpyrrole was prepared using a literature procedure.[39] *1-(3-Bromopropyl)-1H-3-pyrrolyl-1-ethanone* **16a**. (from 1,3-dibromopropane) yellow oil (51%); (Found: $M^+$, 229.0103. $C_9H_{12}{}^{79}BrNO$ requires M, 229.0103); $\upsilon_{max}/cm^{-1}$ 1652, 1530 and 1255; $\delta_H$ 2.23-2.33 (2 H, m, 2'-$CH_2$), 2.40 (3 H, s, $CH_3$), 3.32 (2 H, t, *J* 6.1, $CH_2Br$), 4.11 (2 H, t, *J* 6.4, $CH_2N$), 6.58-6.60 (1 H, m, 4- and 5-H), 6.64-6.66 (1 H, m, 2-H) and 7.29-7.31[1 H, m, 2-H]; $\delta_C$ 27.45 ($CH_3$), 29.93 (2'-$CH_2$), 33.99 ($CH_2Br$), 48.00 ($NCH_2$), 110.11 (pyrrole-CH), 122.73 (pyrrole-CH), 126.13 (pyrrole-CH), 126.77 (3-C) and 193.75 (C=O); *m/z* 232 ($MH_2^+$, 96%), 217 (100), 150 (97), 135 (98), 121 (19), 106 (54), 94 (72) and 80 (21).

*1-(4-Bromobutyl)-1H-3-pyrrolyl-1-ethanone* **16b**. (from 1,4-dibromobutane) yellow oil (56%); (Found: $M^+$, 243.0256. $C_{10}H_{14}{}^{79}BrNO$ requires M, 243.0259); $\upsilon_{max}/cm^{-1}$ 1654, 1530, 1201 and 933; $\delta_H$ 1.81-1.86 (2 H, m, 3'- $CH_2$), 1.94-2.00 (2 H, m, 2'-$CH_2$), 2.39 (3 H, s, $CH_3$), 3.40 (2 H, t, *J* 6.6, $CH_2Br$), 3.93 (2 H, t, *J* 6.7, $CH_2N$), 6.58-6.62 [2 H, m, 4- and 5-H] and 7.26-7.27 (1 H, m, 2-H); $\delta_C$ (62.5 MHz) 28.98 ($CH_3$), 29.41 (3'-$CH_2$), 29.54 (2'-$CH_2$), 32.54 ($CH_2Br$), 49.19 ($NCH_2$), 109.51 (pyrrole-CH), 121.98 (pyrrole-CH) and 125.44 (pyrrole-CH); *m/z* 245 ($MH_2^+$, 39%), 228 (88), 164 (100), 135 (25), 122 (57), 109 (14), 94 (75) and 80 (23).

*1-(5-Bromopentyl)-1H-3-pyrrolyl-1-ethanone* **16c**. (from 1,5-dibromopentane); yellow oil (63%); $\upsilon_{max}/cm^{-1}$ 1652, 1531, 1453, 1386, 1251, 1103 and 933; $\delta_H$ 1.45-1.51 (2 H, m, 3'-$CH_2$ 1.79-1.91 (4H, m, 2' and 4'-$CH_2$), 2.39 (3 H, s, $CH_3$), 3.40 (2 H, t, *J* 6.6, $CH_2Br$), 3.91 (2 H, t, *J* 7.0, $CH_2N$), 6.57-6.62 [2 H, m, 4- and 5-H] and 7.26-7.28 (1 H, m, 2-H); $\delta_C$ (62.5 MHz) 25.09, 26.98 ($CH_3$), 30.25, 32.01 (2'-$CH_2$), 33.10 ($CH_2Br$), 49.81 ($NCH_2$), 109.31 (pyrrole-CH), 122.02 (pyrrole-CH), 125.48 (pyrrole-CH) and 193.35.

*Alkylations of pyrrole-2-carbaldehyde. 1-(3-Bromopropyl)-1H-2-pyrrolecarbaldehyde* **19a**. (from 1,3-dibromopropane); yellow oil (71%), (Found: $M^+$, 214.9946. $C_8H_{10}{}^{79}BrNO$ requires M, 214.9946); $\upsilon_{max}/cm^{-1}$ 2805, 1526, 1661, 1369 and 885; $\delta_H$ 2.19-2.29 (2 H, m, 2'-$CH_2$), 3.23 (2 H, t, *J* 6.2, $CH_2Br$), 4.40 (2 H, t, *J* 6.4, $NCH_2$), 6.15-6.18 (1 H, m, 4-H), 6.68-6.90 (1 H, m, 5-H), 6.97 (1 H, m, 3-H) and 9.45 (1 H, s, CHO); $\delta_C$ 30.57 (2'-$CH_2$), 33.78, ($CH_2Br$), 47.45 ($NCH_2$), 110.09 (5-CH), 125.66 (4-CH), 131.56 (3-CH), 132.38 (2-C) and 179.63 (CHO); *m/z* 215 ($M^+$, 18%), 186 (11), 136 (100), 108 (92), 94 (89) and 80 (100).

*1-(4-Bromobutyl)-1H-2-pyrrolecarbaldehyde* **19b**. (1,4-dibromobutane); yellow oil (62%); (Found: $M^+$, 229.0099. $C_9H_{12}{}^{79}BrNO$ requires M, 229.0103); $\upsilon_{max}/cm^{-1}$ 2800, 1603, 1525, 1444 and 609; $\delta_H$ 1.85-1.92 (4 H, m, 2' and 3'-$CH_2$), 3.40 (2 H, t, *J* 6.2, $CH_2Br$), 4.36 (2 H, t, *J* 6.6, $CH_2N$), 6.22-6.25 (1 H, m, 4-H), 6.93-6.95 (2 H, m, 3 and 5-H) and 9.53 (1 H, s, CHO); $\delta_C$ 29.33 (3'-$CH_2$), 29.37 (2'-$CH_2$), 32.58 ($CH_2Br$), 47.82 ($NCH_2$), 109.52 (5-CH), 124.71 (4-CH), 130 87 (3-CH), 131.08 (2-C) and 179.06 (CHO); *m/z* 229 ($M^+$, 73%), 202 (27), 150 (92), 122 (100), 108 (66), 94 (56) and 80 (85).

*1-(5-Bromopentyl)-1H-2-pyrrolecarbaldehyde* **19c**. (1,5-dibromopentane); yellow oil (45%); (Found: $M^+$, 245.0234. $C_{10}H_{14}{}^{79}BrNO$ requires M, 245.0238); $\upsilon_{max}/cm^{-1}$ 2805, 1660, 1572, 1321, 885, 838 and 763; $\delta_H$ 1.38-1.48 (2 H, m, 3'-$CH_2$), 1.72-1.93 (4 H, m, 2' and 4'-$CH_2$), 3.39 (2 H, t, *J* 6.7, $CH_2Br$), 4.31 (2 H, t, *J* 7.2, $NCH_2$), 6.21-6.23 (1 H, m, 4-H), 6.92-6.94 (2 H, m, 3 and 5-H) and 9.52 (1 H, s, CHO); $\delta_C$ 24.25 (3'-$CH_2$), 30.49 (4'-$CH_2$), 32.13 (2'-$CH_2$), 33.52 ($CH_2Br$), 48.24 ($NCH_2$), 109.36 (5-CH), 109.93 (4-CH), 124.95 (3-CH), 131.31 (2-C) and 179.28 (CHO); *m/z* 245 ($M^+$, 89%), 229 (17), 217 (22), 165 (60), 137 (100), 123 (38), 109 (59), 95 (32) and 81 (52).

**Cyclisation studies of pyrroles**

The cyclisations were carried out using the general procedures for the cyclisation of imidazoles except that toluene was used as the solvent for dissolving the $BuSn_3H$ as well as the radical precursor. Extraction into dilute hydrochloric acid could not be used as for the imidazole reactions and all purifications were carried out using by column chromatography with silica gel as absorbent and mixtures of light petroleum and dichloromethane as eluent. Uncyclised reduced products were less polar and were eluted before cyclised products in each case.

*1-(2,3-Dihydro-1H-7-pyrrolizinyl)-1-ethanone* **17a**. (from **16a**); *1-propyl-1H-3-pyrrolyl-1-ethanone* **20a**: yellow oil (10%); (Found: M+, 151.0995. $C_9H_{13}NO$ requires M, 151.0997); $\upsilon_{max}/cm^{-1}$ 1651, 1531, 1199 and 1102; $\delta_H$ 0.93 (3 H, t, *J* 7.4, $CH_3$), 1.77-1.86 (2 H, m, 2'-$CH_2$), 2.40 (3 H, s, $COCH_3$), 3.85 (2 H, t, *J* 7.1, $NCH_2$), 6.57-6.62 (2 H, m, 4- and 5-H) and 7.27-7.28 (1 H, m, 2-H); $\delta_C$ 11.05 ($CH_3$), 24.37 (2'-$CH_2$), 26.98 ($COCH_3$), 51.76 ($NCH_2$), 109.17 (4-CH), 122.07 (5-CH) and 125.59 (2-CH); *m/z* 151 ($M^+$, 45%), 136 (100), 94 (48) and 43 (21). *1-(2,3-dihydro-1H-7-pyrrolizinyl)-1-ethanone* **17a**: yellow oil (46%); (Found: M+, 149.0841. $C_9H_{11}NO$ requires M, 149.0841); $\upsilon_{max}/cm^{-1}$ 1646, 1535, 1430, 1371, 1294, 1245 and 1206; $\delta_H$ 2.37 (3 H, s, $COCH_3$), 2.48-2.62 (2 H, m, 2-$CH_2$), 3.10 (2 H, t, *J* 7.5, 1-$CH_2$), 3.98 (2 H, t, *J* 7.2, $NCH_2$), 6.55-6.56 (1 H, m, 5- or 6-H) and 6.61-6.62 (1 H, s, 5- or 6-H); $\delta_C$ (62.5 MHz) 23.55 (2-$CH_2$), 26.09 (1-$CH_2$), 27.08 ($COCH_3$), 46.63 ($NCH_2$), 113.29 (5- or 6-CH) and 114.82 (5- or 6-CH), 7- and 7a- were not detected; *m/z* 149 ($M^+$, 43%), 134 (100), 106 (15), 77 (7), 51 (7) and 43 (9).

*1-(5,6,7,8-Tetrahydro-1-indolizinyl)-1-ethanone* **17b**. (from **16b**); yellow oil (45%); (Found: M+, 163.0997. $C_{10}H_{13}NO$ requires M, 163.1000); $\upsilon_{max}/cm^{-1}$ 1647, 1535, 1504, 1319, 1228 and 1206; $\delta_H$ 1.78-1.88 (2 H, m, 7-$CH_2$), 1.86-1.99 (2 H, m, 6-$CH_2$), 2.37 (3 H, s, $COCH_3$), 3.10 (2 H, t, *J* 6.4, 8-$CH_2$), 3.93 (2 H, t, *J* 5.9, $NCH_2$), 6.43 (1 H, d, *J* 3.1, 2- or 3-H) and 6.49 (1 H, d, *J* 3.1, 2- or 3-H); $\delta_C$ 20.53, 23.88, 24.66, 28.46 ($COCH_3$), 46.02 ($NCH_2$), 110.43 (2- or 3-CH), 119.56 (2- or 3-CH), 120.47 (8a-C), 136.74 (1-C) and 194.63 (CO); *m/z* 164 ($M^+$, 17%), 163 (48), 149 (21), 148 (100), 122 (22), 120 (30) and 43 (39).

*6,7,8,9-Tetrahydro-5H-pyrrolo[1,2-a]azepine-3-carbaldehyde* **17c**. (from **16c**); *1-pentyl-1H-3-pyrrolyl-1-ethanone* **18c**; yellow oil (18%); (Found: M+, 179.1310. $C_{11}H_{17}NO$ requires M, 179.1310); $\upsilon_{max}/cm^{-1}$ 1652, 1531, 1454, 1439, 1386, 1348 and 1251; $\delta_H$ 0.90 (3 H, t, *J* 6.2, $CH_3$), 1.23-1.36 (4 H, m, 7- and 8-$CH_2$), 1.72-1.84 (2 H, m, 6-$CH_2$), 2.39 (3 H, s, $COCH_3$), 3.87 (2 H, t, *J* 7.1, $NCH_2$), 6.56-6.58 (1 H, m, 2- or 3-H), 6.59-6.61 (1 H, m, 2- or 3-H) and 7.25-7.27 (1 H, m, 2-H); $\delta_C$ 14.27 ($CH_3$), 22.99 (4'-$CH_2$), 27.85 ($COCH_3$), 29.06 (3'-$CH_2$), 31.23 (2'-$CH_2$), 50.75 ($NCH_2$), 109.57 (3-CH), 122.53 (2- or 5-CH), 126.25 (2- or 5-CH) and 193.92 (CO); *m/z* 179 ($M^+$, 19%), 164 (49), 136 (15), 134 (10), 94 (36), 80 (28) and 43 (100). *6,7,8,9-Tetrahydro-5H-pyrrolo[1,2-a]azepine-3-carbaldehyde* **17c**; yellow oil (54%); (Found: M+, 177.1154. $C_{10}H_{15}NO$ requires M, 177.1154); $\upsilon_{max}/cm^{-1}$ 1648, 1535, 1501, 1438, 1347, 1260, 1251 and 1221; $\delta_H$ 1.55-1.85 (6 H, m, 6-, 7- and 8-$CH_2$), 2.40 (3 H, s, $COCH_3$), 3.28-3.32 (2 H, m, 9-$CH_2$), 3.91-3.95 (2 H, m, $NCH_2$), 6.38 (1 H, d, *J* 3.0, 2- or 3-H) and 6.42-6.43 (1 H, *J* 3.0, 2- or 3-H); $\delta_C$ 22.79, 24.54, 25.87 ($COCH_3$), 28.02 (6-$CH_2$), 30.42 (9-$CH_2$), 46.02 ($NCH_2$), 108.50 (2- or 3-CH), 119.86 (2- or 3-CH), 120.11 (9a-C) and 194.80 (CO) (1-C was not observed); *m/z* 177 ($M^+$, 14%), 162 (26), 134 (15), 55 (16) and 43 (100).

*2,3-Dihydro-1H-5-pyrrolizinecarbaldehyde* **20a**. (from **19a**); yellow oil, (28%); (Found: M+, 135.0683. $C_8H_9NO$ requires M, 135.0684); $\upsilon_{max}/cm^{-1}$ 1652, 1472 and 804; $\delta_H$ 2.24-2.60 (2 H, m, 2-$CH_2$), 2.85 (2 H, t, *J* 7.4, 1-$CH_2$), 4.29 (2 H, t, *J* 7.2, $NCH_2$), 5.97 (1 H, d, *J* 3.8, 7-H), 6.93 (1 H, d, *J* 3.8, 6-H) and 9.40 (1 H, s, CHO); $\delta_C$ 24.43 (2-$CH_2$), 27.54 (1-$CH_2$), 47.90 ($NCH_2$), 103.50 (7-CH), 128.68 (6-CH) and 178.49 (CHO), (5-C and 7a-C were not observed); *m/z* 135 ($M^+$, 100%), 120 (17), 106 (55), 79 (51) and 65 (16).

*5,6,7,8-Tetrahydro-3-indolizinecarbaldehyde* **20b**. (from **19b**); yellow oil (55%); (Found: M+, 149. 0841. $C_9H_{11}NO$ requires M, 149. 0841); $\upsilon_{max}/cm^{-1}$ 1652, 1573 and 1301; $\delta_H$ 1.63-1.85 (2 H, m, 7-$CH_2$), 1.95-1.97 (2 H, m, 6-$CH_2$), 2.84 (2 H, t, *J* 6.3, 8-$CH_2$), 4.38 (2 H, t, *J* 6.1, $NCH_2$), 5.97 (1 H, d, *J* 3.8, 1-H), 6.87 (1 H, d, *J* 3.8, 2-H) and 9.41 (1 H, s, CHO); $\delta_C$ 19.77 (7-$CH_2$), 22.92 (6-$CH_2$), 23.75 (8-$CH_2$), 45.60 ($NCH_2$), 107.93 (1-CH), 124.01 (2-CH), 131.13 (3- or 8a-C), 133.40 (3- or 8a-C) and 178.17 (CHO); *m/z* 149 ($M^+$, 100%), 134 (18), 120 (52), 108 (34), 93 (24), 80 (10) and 65 (12).

*6,7,8,9-Tetrahydro-5H-pyrrolo[1,2-a]azepine-3-carbaldehyde* **20c**. (from **19c**); yellow oil (40%); (Found: M+, 163.0997. $C_{10}H_{13}NO$ requires M, 163.0994); $\upsilon_{max}/cm^{-1}$ 1649, 1573 and 1472; $\delta_H$ 1.62-1.83 (6 H, m, 6-, 7- and 8-$CH_2$), 2.73-2.78 (2 H, m, 9-$CH_2$), 4.66-4.71 (2 H, m, $NCH_2$), 5.98 (1 H, d, *J* 3.9, 1-H), 6.76

(1 H, d, *J* 3.9, 2-H) and 9.39 (1 H, s, CHO); $\delta_C$ 27.28, 28.58, 29.00, 31.48, 46.73 ($NCH_2$), 109.66 (1-CH), 125.46 (2-CH), 131.77 (3- or 9a-C), 148.01 (3- or 9a-C) and 179.32 (CHO); *m/z* 163 ($M^+$, 100%), 155 (6), 146 (20), 135 (61), 120 (11), 106 (25), 93 (9) and 80 (9).

*Radical Cyclisation of 1-(4-bromobutyl)-4-phenyl-1H-imidazole* **4b**. The cyclisation was carried out using the general procedure for the cyclisation of imidazoles except that toluene was used as the solvent for dissolving the $BuSn_3H$ as well as the radical precursor. A yellow oil was obtained which contained two cyclised products, 1-phenyl-5,6,7,8-tetrahydroimidazo[1,5-*a*]pyridine **35** and 2-phenyl-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine **32**, which were inseparable by chromatography. No uncyclised reduced product was detected. The two products were analysed as a mixture. 1-Phenyl-5,6,7,8-tetrahydroimidazo[1,5-*a*]pyridine **35** (35%): (Found: $M^+$, 198.1157. $C_{13}H_{14}N_2$ requires M, 198.1157); $\delta_H$ 1.92-2.01 (4 H, m, 6- and 7-$CH_2$), 3.01 (2 H, t, *J* 6.4, 8-C), 4.04 (2 H, t, *J* 5.6, $NCH_2$), 7.24-7.76 (5 H, m, Ph-H) and 7.48 (1 H, s, 3-H); *m/z* 198 ($M^+$, 74%), 197 (100), 170 (34), 169 (58), 157 (22), 115 (31), 103 (24) and 77 (22); 2-phenyl-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine **32** (14%): (Found: $M^+$, 198.1157. $C_{13}H_{14}N_2$ requires M, 198.1157); $\delta_H$ 1.87-1.90 (4 H, m, 6- and 7-$CH_2$), 2.96 (2 H, t, *J* 5.7, 5-C), 3.98 (2 H, t, *J* 6.1, $NCH_2$), 7.06 (1 H, s, 1-H) and 7.24-7.76 (5 H, m, Ph-H); *m/z* 198 ($M^+$, 100%), 197 (39), 170 (20), 169 (20), 130 (24), 104 (26) and 77 (27).

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