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Asymmetric Synthesis of Polyfunctionalized Pyrrolidines and Related Alkaloids

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Abstract: This account describes our recent studies on the development of a general method of preparing polyfunctionalized pyrrolidine, indolizidine, pyrrolizidine and pyrrolo[1,2-a]azepines and their related alkaloids.

1 Introduction

In early 2000, we started a project concerned with developing a general synthesis of polyfunctional pyrrolidines with the initial intention of developing a synthesis of the Stemona alkaloid, croomine (1). This project was given to a fresh PhD student, Karl Lindsay, who was keen to tackle a challenging natural product target. Our general retrosynthetic analysis is outlined in Scheme 1. The key reactions of this analysis were the ring-closing metathesis (RCM) reaction of the diene 3 and the regioselective aminolysis of the vinyl epoxides 4 or 7 with the chiral allylic amines 5 and 6, respectively. At the start of this project the regioselective ring-opening of vinyl epoxides with ammonia and benzyl and cyclohexyl amine had been reported by Somfai’s group.1,2 However, the regioselectivity of the aminolysis of more complex chiral vinyl epoxides and more hindered amines was uncertain at the time, and required closer examination. The RCM reaction was well established as a versatile and efficient process for making heterocyclic rings.3,4 While both these key reactions had been well documented, we thought that their application in tandem appeared to be a novel way to allow ready access to our target molecule.

In the first year of Karl’s project we realized that this tandem-methodology could also be applied to the synthesis of the relatively less complex polyhydroxylated indolizidine and pyrrolizidine alkaloids like swainsonine 8 and australine 9 (Scheme 2 and Scheme 3, respectively). Thus, Karl temporarily stopped working on croomine and instead focused on the synthesis of swainsonine (8).

Key words: vinyl epoxides, aminolysis, oxazolidinones, ring-closing metathesis, pyrrolidines, indolizidine, pyrrolizidine and pyrrolo[1,2-a]azepines, Petasis reaction

Scheme 1 Retrosynthetic analysis of croomine (1)
Stephen Pyne was born in Melbourne, Australia. He obtained his BSc (Hons) degree from the University of Adelaide in 1975 and his PhD in 1979 at the Australian National University under the supervision of Prof. Lew Mander. After postdoctoral fellowships at Purdue (with Phil Fuchs) and Harvard (with E. J. Corey) Universities he started his academic career as a lecturer at the University of Wollongong in 1985 and was appointed to Professor of Chemistry at the same institution in 1998. He was a Von Humboldt Research Fellow (Marburg University, 1992–1993), Young Researcher of the Year Award for 1992 (offered by the Australian Research Council and the Von Humboldt Foundation) a Rhone Poulenc Fellow (University Louis Pasteur, Strasbourg, 1994), a visiting Professor, Max Planck Institute für Kohlenforschung, Mülheim, Germany in 1998, an ARC Senior Research Fellow in 1994–1999 and Subprogram Leader for Organic and Petrochemistry, Thai-Australian Science and Engineering Assistance Program (TASEAP), 1998–2000. His early research interests were in the areas of chiral sulfur chemistry and their rearrangement reactions with Pd(0), the asymmetric synthesis of nonproteinogenic amino acids and chiral organometallic chemistry. In 2000 his research interests changed to the asymmetric synthesis of bioactive natural products, especially alkaloids, phytochemistry of Thai medicinal plants and medicinal and fullerene chemistry.

Andrew Davis was born in Sydney, Australia and obtained his BSc (Hons) degree from the University of Wollongong in 2000. He has worked as a research assistant at the University of Wollongong, 2001–2002 and is currently pursuing a PhD degree under Prof. Stephen Pyne.

Nicole Gates was born in Wollongong, Australia in 1981. She joined the research group of Professor Stephen Pyne in 2002 for a third year research project. After completing her BSc (Hons) in 2003 at the University of Wollongong, she began a PhD in 2004 in the same group working towards the synthesis of polyhydroxylated pyrrolidines.

Joseph Hartley was born in Bournemouth, England in 1977. His undergraduate chemistry studies at the University of Bath, England included a year spent at Rhone-Poulenc Rorer’s Dagenham Research Centre, and he obtained his MChem (Hons) degree in 1999. He stayed on at the University of Bath for postgraduate studies on the use of indium(III) salts as catalysts for electrophilic aromatic substitution reactions, under the supervision of Chris Frost, and was awarded his PhD in 2002. In 2003, he moved Down Under to Australia to begin a postdoctoral research fellowship with Stephen Pyne at the University of Wollongong.

Karl Lindsay was born in Invercargill, New Zealand and obtained his BSc (Hons) degree from the University of Otago in 1998 under the supervision of David Larsen. In 1999 he joined the Pyne group as a research assistant for one year and then commenced his PhD in 2000. In 2003 he submitted his PhD degree and he will formally graduate in July 2004. In early 2004 he took up a post-doctoral position in the Department of Chemistry, University of Aarhus in Denmark.

Theeraphan Machan was born in Phitsanulok, Thailand. He obtained his BSc (Hons) degree from Rajabhat Institute Pibulsongkram, Thailand in 1996 and MSc degree from Chiang Mai University in 2000. He is currently studying a PhD in the Faculty of Pharmacy, Chiang Mai University under The Royal Golden Jubilee PhD program. In 2003 he has joined the Pyne group as a visiting fellow for 1 year to work on natural products chemistry and synthesis.

Minyan Tang was born in Jingdezhon, China. She obtained her BSc (1995) and MSc (1998) degrees at the Jiangxi Normal University, China from which she obtained two academic awards. In 1998–2000 she was employed at the same University in the Department of Chemistry as a lecturer in organic chemistry and a researcher in natural products chemistry. In 2001 she moved to the University of Wollongong, Australia, to start a PhD in the Pyne group. She has just submitted her PhD thesis.
In early 2001, Minyan Tang joined my research group as a PhD student and she was given the task of synthesizing australine (9) and its epimers. These target molecules required access to both chiral trans- and cis-vinyl epoxides.

Scheme 2 Retrosynthetic analysis of swainsonine (8)

Scheme 3 Retrosynthesis of australine (9)

2 Tandem Vinyl Epoxide Aminolysis/Ring-Closing Metathesis

In order to test our proposed synthetic strategy, Karl and Minyan prepared a number of chiral vinyl epoxides using the Sharpless asymmetric epoxidation (SAE) to introduce the epoxide functions on E- and Z-allylic alcohols. These were readily obtained from the differentially protected propargyl alcohols 10, by either REDAL reduction to the E-allylic alcohols (Scheme 4) or Lindlar reduction to give the Z-allylic alcohols (Scheme 5). The resulting epoxy alcohols were then converted to chiral vinyl epoxides via TPAP or Swern oxidation followed by Wittig olefination.

Scheme 4 Asymmetric synthesis of trans-vinyl epoxides

Initial vinyl epoxide ring-opening studies using allyl amine employed the methodology reported by Somfai. A typical reaction involved heating a solution of the vinyl epoxide (e.g. 17, Scheme 6) in the presence of allyl amine (10.0 equiv) and p-TsOH·H2O (0.1 equiv) in a sealed tube for 3 days at 105 °C. Surprisingly, these seemingly harsh conditions provided the desired 1,2-amino alcohols (e.g. 18) in good to excellent yields. Furthermore, these reactions were highly regioselective and gave the expected SN2 products. We later found that these reactions were accelerated by changing the protic acid catalyst p-TsOH·H2O for the Lewis acid catalyst LiOTf (1.0–1.5 equiv) without any detrimental effects on the regioselectivities or chemical yields. With the combination of LiOTf and microwave heating then these aminolysis reactions were complete after 1 hour of heating at 110 °C. The purchase of a microwave reactor in 2002 allowed us to perform aminolysis reactions of vinyl epoxides using aqueous ammonia which was difficult to perform in a sealed tube and often resulted in only cleavage of primary OTBS groups on the vinyl epoxide. Prior to this purchase we had to prepare amino alcohols like 22 in two steps, first vinyl epoxide aminolysis with allyl amine followed by regioselective N-deallylation with Pd(0) and N,N-dimethylbarbituric acid (NDMBA, Scheme 7).

Scheme 5 Asymmetric synthesis of cis-vinyl epoxides

With 1,2-amino alcohols in hand we were in a position to attempt RCM reactions. These were first converted to their corresponding N-Boc derivatives and not unexpectedly their RCM reactions proceeded readily using Grubbs’ first generation catalyst [benzylidene bis(tricyclohexylphosphine)-dichlororuthenium, Grubbs’ I, 5–10 mol%] and high dilution in dichloromethane solution at reflux for 18–20 hours (Scheme 8).
All Routes Lead to Oxazolidinones

When Minyan attempted to protect the amino group of more hindered amino alcohols like 25 we found that DMAP was required to enhance the rate of reaction. Under these conditions we obtained a mixture of the desired N-Boc derivative 26 (71%) and the oxazolidinone 27 (15%, Scheme 9). The oxazolidinone 27 could be obtained as the exclusive product by treating 25 with triphosgene under basic conditions (Scheme 9). The RCM reaction of 26 gave the expected 2,5-di-hydrodipyrrrole 28 but upon treatment with TBSOTf, for the purpose of preparing the corresponding secondary TBS ether, we obtained the oxazolidinone 29 in 42% yield (Scheme 10).

Since all Minyan’s reactions were producing oxazolidinones we thought we should ‘go with the flow’ and use the oxazolidinone as a protecting group for the 1,2-amino alcohol moiety. Fortunately, this proved to be a viable protecting group and allowed us to perform much more diastereoselective syn-dihydroxylations on the resulting pyrrolo[1,2-c]oxazol-3-ones (e.g. 29). At about this time Nicole Gates joined my group in 2002 to start a laboratory based 3rd year chemistry subject. Her project initially involved the synthesis of the 3-allyl-4-vinyloxazolidinones 30a, b and an examination of their RCM reactions. Compound 30a had been prepared before, however, it was claimed to not undergo the RCM reaction with Grubbs’ I catalyst in benzene at room temperature. We had thought that by running this reaction in refluxing dichloromethane then we would obtained the pyrrolo[1,2-c]oxazol-3-one 31 (Scheme 11). In the event, heating a dilute dichloromethane solution of 30a and Grubbs’ I catalyst (10 mol%) at reflux for 24 hours resulted in only 50% conversion to 31 by GC analysis. Indeed the RCM reaction of 30a was slow compared to that of dienes like 23. However, a yield of 73% could be obtained for 31, after 24 hours, when the more reactive, and expensive, Grubbs’ II catalyst (10 mol%) was employed. The styrene derivative 30b underwent a RCM reaction under the same conditions to give 31 in 82% yield.

The more heavily substituted 3-allyl-4-vinyloxazolidinones like 32 were even more sluggish in their RCM reactions than 30a and 30b. For example, the RCM reaction of 32 required a total catalyst (Grubbs’ I) loading of 40 mol% and heating for 48 hours. The yield of the pyrrolo[1,2-c]oxazol-3-one 33, however, was an acceptable 73% (Scheme 12).
4  Syn-Dihydroxylation Reactions of 2,5-Dihydropyrroles, Indolizidines and Pyrrolo[1,2-c]oxazol-3-ones

Syn-dihydroxylation (DH) of 2-substituted-2,5-dihydropyrroles like 24 with catalytic potassium osmate dihydrate (K₂OsO₄·2H₂O) and stoichiometric NMO in acetone–water is a highly diastereoselective reaction (dr >98:<2) with the C-2 substituent acting as the stereochemical control element (Scheme 13).¹⁰  Syn-dihydroxylations of indolizidines 36a–d were less diastereoselective under similar conditions. For example, we found the DH reaction of 36a gave a 67:33 mixture of diastereomers in favor of the diastereomer 37a, having the same absolute stereochemistry as swainsonine (8). Other investigators have found similar diastereoselectivities for the DH reactions of 36b–d (Scheme 13).¹¹–¹³ Surprisingly, the TIPS derivative 36c is reported to undergo DH to give a mixture in favor of 1,2-diepi-37c (structure not shown). The diastereoselectivities of these reactions are greatly enhanced using the Sharpless asymmetric DH conditions. Under these conditions using AD-mix-a the diastereoselectivities for the DH of 36a by us¹⁰ and 36d by Blechert’s group¹³ were enhanced to 98:2 and 95:5, respectively. The stereochemical outcomes for these reactions were consistent with addition of the osmium reagent to the less hindered α-face of 36. Approach to the β-face being hindered by the pseudo-axial allylic protons H₈α and H₃β (Scheme 14).¹⁰–¹³

The DH reaction of Minyan’s pyrrolo[1,2-c]oxazol-3-one 33 using K₂OsO₄·2H₂O/NMO was highly diastereoselective (dr >95:<5) and gave the pure 6,7-a,a-diol 38 in 82% yield (Scheme 15).⁸

The DH reaction of Nicole’s pyrrolo[1,2-c]oxazol-3-one 31 using K₂OsO₄·2H₂O/NMO was also highly diastereoselective (dr >95:<5) and gave the pure 6,7-a,a-diol 39 in 76% yield (Scheme 16). This diol resulted from attack of the oxidizing agent from the concave face of the molecule (Figure 1) due to the pseudo-axial allylic protons H₅β and H₇a that sterically hinder the β-face to attack by the osmium reagent (Figure 1). This argument is similar to that proposed to account for the facial selectivity of DH reactions on the related indolizines 36 (Scheme 14). Thus, the C-5 β-benzyloxyethyl substituent in 33 was not entirely responsible for the facial selectivity in the DH reaction of 33.
Asymmetric Synthesis of Swainsonine and Epiaurstalines

Polyhydroxylated indolizidines [e.g. (−)-swainsonine (8)] and pyrrolizidine natural products [e.g. australine (9)] are potent glycosidase inhibitors and have potential applications as anti-cancer, anti-viral and anti-retroviral drugs. These interesting biological properties coupled with the polyfunctional and stereochemically rich nature of these compounds have attracted the attention of synthetic chemists resulting in many total syntheses of these and related compounds.\(^1\,\text{4,15}\)

In 2002 we reported Karl’s successful synthesis of (−)-swainsonine (8) from the deprotection of the diol 37a and (+)-1,2-diepi-swainsonine by intramolecular N-alkylation of the activated primary alcohol of 35 after removal of the N-Boc and O-PMB groups (Scheme 17).\(^10\) In principle, the tandem vinyl epoxide aminolysis/RCM method could allow the synthesis of all possible stereoisomers of swainsonine. For example, we also reported the synthesis of (+)-1,2,8-triepi-swainsonine (Scheme 17) by starting from the cis-vinyl epoxide 16 (n = 1). Karl also extended his method to the preparation of the novel 1H-pyrrolo[1,2-a]azepine analogue 44 of swainsonine by starting with 43 the homologue of 41 (Scheme 17).\(^16\)

In 2003 Karl developed an alternative synthesis of (−)-swainsonine that was inspired by the success of Nicole and Minyan’s DH reactions of the pyrrolo[1,2-c]oxazol-3-ones 31 and 33, respectively.\(^17\) Base-catalyzed cyclization of 24 gave the pyrrolo[1,2-c]oxazol-3-one 45. With 45 in hand, Karl next examined its DH reactions. To this end 45 was treated with K2OsO4·2H2O/NMO in acetone-water, which gave a 3:1 inseparable mixture of the diols 46 and 6,7-diepi-46 (structure not shown) in 85% yield. A pure sample of the major diol 46 was isolated by careful crystallization from hot dichloromethane and petroleum spirit. This crystallization was not necessary, however, because benzylolation of the mixture of diols gave the corresponding bis-benzyl ethers 47 and 6,7-diepi-47 (structure not shown) in quantitative yield, and these were readily separable by column chromatography. Conducting the same DH reaction at 0 °C resulted in an improved diastereoselectivity and yield (3.5:1 and 92%, respectively). Thus, the diastereoselectivities for the DH reaction of 46 were similar to those found for the DH reactions of indolizidine 36. These DH reactions, however, were far less diastereoselective than those of the unsubstituted pyrrolo[1,2-c]oxazol-3-one 31. The C-1 α-substituent present in 45 is most likely responsible for this reduced α-face diastereoselectivity. With the aim of increasing the steric bulk of the oxidant, and perhaps the diastereoselectivity, the DH reaction was repeated in the presence of the coordinating ligand pyridine (10.0 equiv). Unfortunately, the use of pyridine extended the reaction time to 7 days and resulted in a significant reduction in the diastereoselectivity to 1.5:1. When AD-mix-α was used at room temperature the reaction did not go to completion within 6 days, and the diastereoselectivity was only slightly improved (3.7:1). Surprisingly, when AD-mix-β was used a 20:1 ratio of diastereoisomers was obtained, albeit at low conversion after 6 days at room temperature, giving a 46% yield of product diols 46 and 6,7-diepi-46 (and 45% recovered starting material). We attribute the disparities between the α- and β-AD-mixes to be a result of a matched/mismatched situation.\(^18\)

Conversion of 47 into (−)-swainsonine (8) proved to be relatively straightforward (Scheme 19).

In 2003 we reported Minyan’s synthesis of (+)-1,7-diepiaurstaline (48) and (−)-7-epiaurstaline (51) and from the diol 38 (Scheme 19).\(^8\) The synthesis of (−)-7-epiaurstaline (51) required us to invert the stereochemistry at C-1 (aurstaline numbering) in the diol 38. This was achieved in a regioselective manner via ring-opening of the derived cyclic sulfone 49 with cesium benzoate. The regioselectivity being controlled by the C-3 (aurstaline numbering)
benzyloxymethyl group in 49 (Scheme 19). In 2004 we reported Minyan’s synthesis of the natural product (+)-1-epiaustraline (53) and her attempted synthesis of australine (9, Scheme 20).19 Starting with the cis-vinyl epoxide 16 (n = 0) we prepared the C-4 epimer of 25 which eventually provided the diol 52. This was readily converted to the alkaloid (+)-1-epiaustraline (53). Compound 52 was converted to the amino tetraol 56 using similar chemistry as shown in Scheme 19. Cyclization of 56 was anticipated to give 57, the O-benzyl ether of our target australine 9 (Scheme 20). Unexpectantly, the cyclization of 56 under the Mitsunobu reaction conditions, which had provided 48, 51 and 53, failed to work in this case. Unfortunately, we had run out of time and compound to try this cyclization again as Minyan had to commence the writing of her PhD thesis in March 2004. The reasons why this molecule failed to cyclize are not clear, however, this step had been a relatively low yielding process in our synthesis of 48, 51 and 53. In contrast, we have had relatively little difficulty preparing analogous 5,6- and 5,7-bicyclic heterocyclic systems [c.f. Scheme 13 (conversion of 35 to 36a) and Scheme 17] by formation of the heterocyclic 6- or 7-membered ring using the Appel cyclization conditions (Ph3P, CBr4, Et3N).20 Unfortunately, this method has not been successful in our hands to prepare pyrrolizidines.

6 Synthesis of 1,2-Amino Alcohols and Putative Uniflorine A Using the Petasis Reaction

While we had successfully demonstrated the tandem aminolysis of vinyl epoxides/RCM stategy in the synthesis of several alkaloids, we were not happy that the required 1,2-amino alcohols required seven synthetic steps from commercially available alkynes. A novel one-pot, three-component method of preparing 1,2-amino alcohols is the Petasis reaction (boronic acid-Mannich reaction).21 Indeed, Nicole used the Petasis reaction in her synthesis of the 1,2-amino alcohol 30b (Scheme 21).

To test this method for alkaloid synthesis we targeted the synthesis of the polyhydroxyindolizidine alkaloid, uniflorine A (59), which was isolated in 2000 from the leaves of the tree Eugenia uniflora L.22–24 The water-soluble extract of these leaves has been used as an antidiabetic agent in Paraguayan traditional medicine. Uniflorine A was found to be an inhibitor of the α-glucosidases, maltase and sucrase, with IC50 values of 12 and 3.1 μM, respectively. The structure of uniflorine A was deduced from NMR
The proposed structure of uniflorine A is similar to that of castanospermine 60, except for the stereochemistry at C-1 and the extra hydroxyl substitution at C-2 (Figure 2).

**Scheme 22** Retrosynthetic analysis of 59

In April 2003 Andrew Davis joined our group as a new PhD student to work on the synthesis of uniflorine A and related alkaloids. Our retrosynthetic analysis of 59 (Scheme 22) suggested that the target compound could be acquired from the precursor 61 using a RCM reaction and N-alkylation to prepare the 5- and 6-membered rings of 59, respectively.25 The 1,2-anti-amino alcohol 61 would be expected to be readily obtained from the Petasis reaction of L-xylose, allylamine and (E)-styrene boronic acid, followed by chemo- and regioselective N- and O-protection reactions.

In the event, the requisite Petasis reaction gave the desired amino-tetraol 62 in 73% yield as a single diastereomer after purification by ion-exchange chromatography (Scheme 23). The amino-tetraol 62 was converted to its N-Boc derivative 63 (51% yield) and then the primary alcohol was regioselectively protected as its O-trityl compound 64 (68% yield). A RCM reaction of 64 using Grubbs’ I catalyst (10 mol%) smoothly gave the 2-substituted-2,3-dihydropyrrole 65 in 86% yield. Syn-dihydroxylation of 65 furnished the pentaol 66 as a single diastereomer in 88% yield. The stereochemical outcome of this DH reaction was expected due to the stereodirecting effect of the C-2 substituent in 65 and was later confirmed from the single crystal X-ray analysis of the pentaacetate derivative of 59 (70). The pentaol 66 was readily converted to its penta-O-benzyl derivative 67 (76%) under standard conditions. Selective liberation of the secondary amino and primary hydroxyl groups of 67 was achieved by exposure of 67 to TFA in the presence of anisole, as a cation scavenger, at room temperature. Surprisingly, this reaction gave a mixture of the desired amino-alcohol 68 (37%) and the indolizidine 69 (54%, Scheme 23). When this reaction was performed at 0 °C a
mixture of 68 and the mono-deprotected trityl derivative of 67 was obtained. Treatment of this compound or 68 with TFA/anisole at room temperature gave only a very poor yield (<5% from $^1$H NMR analysis) of 69 after 2 days. We suggested that 69 arises by cyclization of an incipient amide anion A with activation of the O-trityl group by protonation by TFA, as shown in Scheme 24. The amino-alcohol 68 underwent smooth cyclization to give the same indolizidine 69 using Ph$_3$P/CBr$_4$/Et$_3$N (54%). Debenzylation of 11 under hydrogenolysis conditions using PdCl$_2$/H$_2$ gave 59 in 63% yield after ion-exchange chromatography and then recrystallization in a total of 8 synthetic steps from L-xylose. The structure of 59 was unequivocally established by a single-crystal X-ray study of its pentaacetate derivative 70. The $^1$H NMR and $^{13}$C NMR data for synthetic 59, however, did not match with those reported for uniflorine A; the latter showed many more downfield peaks in the $^1$H NMR, perhaps consistent with the amine salt. The $^1$H NMR of the hydrochloride salt of synthetic 59, however, did not match the literature spectral data either. We therefore concluded that the structure assigned to uniflorine A was not correct.

In 2003 Theeraphan joined our group for 12 months as a visiting scientist from Thailand. He and Andrew have prepared the pyrrolo[1,2-c]oxazol-3-ones 71 from the tetraol 62 which they are attempting to convert to castanospermine (60, Scheme 25).

In 2002 Karl returned to the croomine synthesis project. As model studies to test the viability of our proposed synthesis he prepared the chiral allylic amine 22, a structurally simpler analogue of 6, and the vinyl epoxide 72, the nor-methyl analogue of 7, and used them as building blocks to prepare a molecule having the tricyclic B,C,D-ring core structure of croomine (1).

Heating a mixture of 22 (ee 92%) and 72 (ee >82%) and lithium triflate (1.5 equiv) in acetonitrile solution at 130 °C for 4 days in a sealed tube provided the amino alcohol 73 in 78% yield. The ee of this compound was
estimated ca 95% due to removal of most of the undesired enantiomers of 22 and 72 as the diastereomer of 73, since 73 and its diastereomer (not shown, 17%) were readily separated by column chromatography (Scheme 26). The unwanted diastereomer (a mixture of enantiomers) arises from the reaction of 22 with 22 and with 72. Treatment of 73 with triphosgene at –40 °C in the presence of base (Et3N) gave the oxazolidinone 74 in 84% yield, along with an aziridine 80 (14%, Scheme 27) that arises from reaction of triphosgene with the secondary hydroxyl group of 73 followed by intramolecular S-O displacement by the nitrogen atom at the carbon bearing the activated hydroxyl. The low temperature was required to minimize the formation of this aziridine. The oxazolidinone 74 underwent a RCM reaction with Grubbs’ I catalyst. The reaction was slow requiring 7 days of heating at reflux and high catalyst loading (50 mol%), however, the yield of the 2,5-dihydropyrrole 75 was excellent (93%). Compound 75 was converted to the 1H-pyrrolo[1,2-a]azepine (76) in seven synthetic steps. Oxidation of this triol to give the desired keto-lactone 79 proved difficult. For example, the use of TPAP/NMO, a reagent combination that we have used successfully before to prepare a lactone from a related 1,4-diol,2 gave a mixture of products including ones that showed aldehyde signals in the 1H NMR spectra. When the oxidizing system 2,2,6,6-tetramethyl-1-piperidinylloxyl (TEMPO, catalytic)/bis-acetoxy iodobenzene (BAIB, stoichiometric)27 was employed in acetic acid as solvent, the unexpected product 78 was isolated in 28% yield having a novel 5,9-epoxy-1H-pyrrolo[1,2-a]azepine tricyclic ring structure. This structure was thought to arise from oxidation of the tertiary amine to the corresponding cyclic iminium ion 77 followed by ring closure through the secondary hydroxyl in the azepine ring.

In 2003 Joe Hartley joined our group as a post-doctoral research fellow to work on the croomine project. In light of Karl’s work described in Scheme 26 we went back to the drawing board and planned a modified approach to croomine that would carry the extra methyl substituents required for the natural product syntheses and would avoid oxidation reactions in the presence of the free tertiary amino group in the azepine ring. Joe will soon have epoxides 4 and 7 in hand (Scheme 1) and be in a position to prepare 3 and hopefully croomine before Christmas 2004.

In conclusion, we have demonstrated the successful application of the tandem aminolysis of chiral vinyl epoxides/RCM reaction for the synthesis of both natural and unnatural products. We have demonstrated that 3-allyl-4-vinyl-oxazolidinones undergo slow but efficient RCM reactions to give pyrrolo[1,2-c]oxazol-3-ones that are useful substrates for diastereoselective manipulations because of their bicyclic nature. The combination of the Petas reaction and the RCM allows more rapid access to these molecules and this tandem process is being keenly examined by Andrew, Nicole and Theraphan for use in alkaloid synthesis.

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