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ARTICLE

A facile one-pot synthesis of 2-amino-1,3,4-oxadiazole tethered peptidomimetics by molecular-iodine-mediated cyclodeselenization

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Synthesis of 2-amino-1,3,4-oxadiazole tethered peptidomimetics through the reaction of N^{α}-protected amino acid hydrazides with isoselenocyanato esters in one-pot is described. The molecular-iodine-mediated cyclodeselenization of in situ generated selenosemicarbazide intermediates resulted in the facile formation of 2-amino-1,3,4-oxadiazoles under mild conditions in excellent yields. The method employs environmentally benign iodine as the cyclizing agent and thereby avoids the harsh conditions that are being employed in the existing routes.

Introduction

Peptidomimetics is a thriving area of research with multitude of applications in diverse fields. Especially peptidomimetics based drug design has been at the forefront of pharma research with increasing number of molecules in clinical trials stage as well as foraying into the market.[1] Molecular combinations of peptides and heterocycles have been investigated with the goal of blending the desirable properties of peptides with those of heterocycles to obtain highly bioactive and still metabolically stable and membrane-permeable molecules. They possess properties that are dictated by the chemical and physical properties of the constituent heterocycle.

1,3,4-Oxadiazole derivatives are formidable class of compounds with a broad spectrum of biological activities including anti-inflammatory and anti-infective (Fig. 1a),[2a] inhibition of tubulin polymerization (Fig. 1b),[2b] antibacterial and antifungal (Fig. 1c),[2c] antitubercular (Fig. 1d),[2d] and other activities.[2e-k] They also form constituents of agrochemicals with insecticidal, herbicidal and fungicidal characteristics.[3] In particular, marketed antihypertensive agents such as tiodazosin[4] and nesapidil[5] as well as antibiotics such as furamizole[6] contain the oxadiazole unit. Their peptidomimetic ability has been explored in muscarinic receptor agonists[7] and in the development and biological evaluation of Phe-Glymimetics of dermorphin (Tyr-D-Ala-Phe-Gly-Tyr-Pro-Ser-NH_2) and substance P (Arg-Pro-Lys-Pro-Gln-Gln-Phe-Phe-Gly-Leu-Met-NH_2, SP).[8] Results have shown that 1,3,4-oxadiazoles as Phe-Glymimetics in dermorphin displayed high affinities for the μ-receptor and retained their agonist activity. They have also been utilized as bioisosteres of carboxamide moiety in benzodiazepine receptor agonists,[9] NK1 receptor antagonists.[10] Due to their potential to mimic the peptide turn conformations, 1,3,4-oxadiazole peptidomimetics have been considered as "universal peptidomimetics".[11,12]

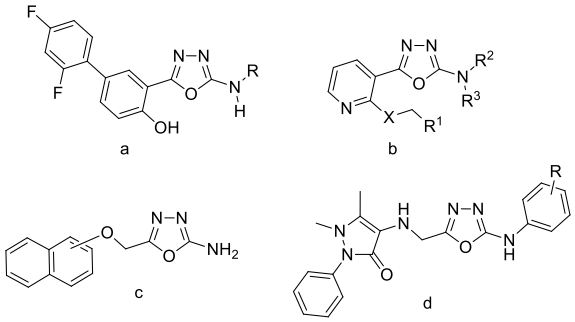

Figure 1 Selected representative examples of biologically active 2-amino-1,3,4-oxadiazole derivatives

However, reports on 1,3,4-oxadiazoles bearing peptidomimetics are rather scant in the literature. This might be due to the fact that most of the synthetic methods reported in the literature for the construction of 2-amino-1,3,4-oxadiazoles involve rather forcing conditions and/or elevated

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temperatures which are quite unsuitable for use with the amino acids and peptides having sensitive functionalities.

Most of the literature protocols for the synthesis of 2-amino-1,3,4-oxadiazole derivatives involve mainly two routes. These are cyclodehydration of semicarbazides[13] using reagents like $POCl_3$, H_2SO_4, Burgess type reagents or cyclodesulfurization of thiosemicarbazides[14] using toxic mercury or lead salts, I_2/NaOH, p-tosyl chloride, carbodiimides (DCC or EDC). Invariably harsh reaction conditions and long reaction hours have been employed in these protocols and also stoichiometric amount of undesirable by-products from cyclization reagents are generated (Fig. 2). Recently, we developed a mild synthesis of 2-amino-1,3,4-oxadiazoles through the cyclodesulfurization of thiosemicarbazides mediated by *o*-iodoxybenzoic acid (IBX) at room temperature.[15] IBX was also found to be efficient for the cyclization of selenosemicarbazide as well.[15] The efficacy of selenosemicarbazide moiety for the preparation of 2-amino-1,3,4-oxadiazoles has also been demonstrated by Xie's group which involved heating of selenosemicarbazides in DMF for 3-4 h.[16a] It was observed that longer reaction time up to 24 h is required for the cyclization of selenosemicarbazides at lower temperatures. Pieczonka et al. reported the imidazole linked 2-amino-1,3,4-oxadiazole derivatives from selenosemicarbazides by refluxing them in DMF at 100 °C.[16b] However, both these reports involved higher temperatures as well as the presence of aromatic or electron withdrawing groups (R^1 & R^2; Fig. 2) which are deemed necessary for the efficient cyclization of selenosemicarbazides to oxadiazoles. Recent literature reports also suggest that synthesis of 2-amino-1,3,4-oxadiazole derivatives required higher temperatures and longer reaction durations.[17] We reasoned that if cyclodeselenization can be effected at low temperature under mild conditions, it can be efficiently utilized in peptidomimetic chemistry.

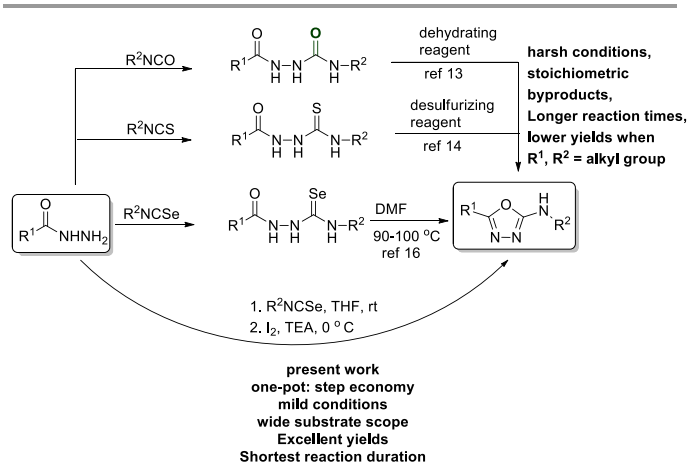

Figure 2 Literature protocols and present protocol for the preparation of 2-amino-1,3,4-oxadiazole derivatives

Substitution of the carbonyl oxygen in a molecule with progressively heavier atoms viz. S or Se reportedly changes its physicochemical properties substantially.[18] Due to the larger polarizabilities of heavier chalcogens, they accommodate more charge density than anticipated based on their electronegativity. Hence, a larger dipole moment and higher acidity for the amide proton in chalcogen substituted congeners of peptides has been reported.[18d] Based on the above rationale, we hypothesized that the selenosemicarbazide intermediate on account of high polarizability of C=Se bond might have a greater tendency for C=Se bond activation and subsequent cyclodeselenization. Thus, though the electronegativities of sulfur and selenium are nearly identical, on bonding with iodine, a base can trigger a facile deselenization by deprotonation leading to a carbodiimide intermediate. Thus formed carbodiimide can be cyclized in situ by the intramolecular nucleophilic attack of amide oxygen of selenosemicarbazide to form the desired 2-amino-1,3,4-oxadiazole.

Molecular iodine has played a pivotal role as a catalyst and stoichiometric reagent in many organic reactions,[19] and it was opted for deselenization because of its benignant nature, selenophilicity and solubility in organic solvents. This way we can eliminate the harsh conditions that were frequently employed for desulfurization in such organic transformations. Similar desulfurization reactions using iodine[20a] and more reactive IBX[20b] were rather inefficient in case of substrates with alkyl amine substituents attached to the thiocarbonyl carbon. This has been ascribed to lower pKa of alkyl amines and a lesser acidity of NH protons attached to the thiocarbonyl carbon. With our best interest in synthesis of heterocycle tethered peptidomimetics using deselenizing chemistry employing molecular iodine,[21] we herein report the synthesis of 2-amino-1,3,4-oxadiazole tethered peptidomimetics.

Results and discussion

Initially, several Boc and Cbz-protected amino acids were converted to the corresponding hydrazides **1** by the reported protocol.[22] Isoselenocyanato esters **2** were prepared by a protocol previously developed by us. The isoselenocyanato esters have been efficiently utilized by our group for the synthesis of selenoureidopeptides, unsymmetrical selenoureas, and hydantoins.[23] With both the substrates **1** and **2** in hand, the insertion of 2-amino-1,3,4-oxadiazole into the peptide backbone was undertaken.

In a typical experiment, a solution of Cbz-Ala-$CONHNH_2$ **1a** in THF was treated with SeCN-Val-OMe **2a** at room temperature (Table 1). The reaction mixture was stirred for 1-2 h until the TLC showed complete disappearance of the reactants (1a and 2a). The in situ generated selenosemicarbazide was then treated with triethylamine (TEA) (2 equiv.) followed by the addition of molecular iodine (1 equiv.) portion-wise over a period of 5 min. The precipitation of reddish brown selenium powder was observed. TLC analysis after 30 min indicated that the incomplete reaction of intermediate (as small amount of selenosemicarbazide remained unreacted) and formation of small amount of few unidentified side products along with good yield of the desired compound (Table 1, entry a). Since deselenization with I_2 and Et_3N being slightly exothermic, it is expected to show these undesired results. The studies on

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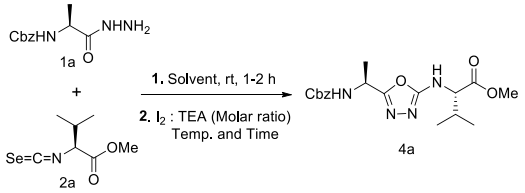
reaction with respect to the solvent, temperature and molar equivalents of iodine and TEA were then carried out. Importantly no product was observed in the absence of molecular iodine with TEA alone (Table 1, entry b). Also, yields were negligible under reflux conditions and when the reaction was sonicated in THF at 50 °C for 1 h (Table 1, entry c and d). The solvent influence on the reaction was also studied; during which only aprotic solvents were preferred as it is well known that protic solvents react with I_2 to form iodides and hypoiodites,[19f]unavailing stoichiometric I_2 as a deselenizing agent. Screening of various solvents such as dichloromethane (CH_2Cl_2), acetonitrile (CH_3CN), ethyl acetate (EtOAc) and N, N-dimethylformamide (DMF) revealed THF to be the best solvent (Table 1, entries e-h) and it can be from the complete solubility of N^{α}-protected amino acid hydrazides in it.

Table 1 Optimization of conditions for the synthesis of 2-amino-1,3,4-oxadiazole tethered peptidomimetics 4[a]



Entry	Solvent	Molar ratio I_2:TEA	Temp. (°C)	Time (min)	Yield (%)[b]
a	THF	1:2	rt	30	86
b	THF	0:2	rt	60	--
c	THF	0:2	reflux	120	nd
d	THF	0:2	50[c]	60	nd
e	CH_2Cl_2	1:2	rt	45	80
f	CH_3CN	1:2	rt	60	78
g	EtOAc	1:2	rt	120	70
h	DMF	1:2	rt	120	65
i	THF	1:3	rt	30	86
j	THF	1.2:2	rt	30	84
k	THF	1:1.5	rt	60	65
l	THF	1:2	0 °C	15	92

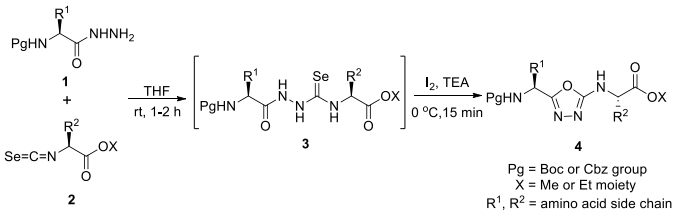
[a]Reactions were monitored by TLC. [b]Isolated yield after column chromatography. [c] sonication. nd = not determined

Higher equivalents of iodine and TEA did not improve the output of the reaction (Table 1, entries i and j), whereas lesser equivalent of TEA led to a decrease in the yield of the product (Table 1, entry k).

Though screening revealed THF to be a suitable solvent, further improvement were desired to avoid aforementioned undesired results. Mild reaction condition was then maintained by carrying out reaction of deselenization of selenosemicarbazide at 0 °C (Table 1, entry l). Gratifyingly, the reaction was completed within 15 min and there was only a formation of expected product (by TLC analysis). The precipitated selenium powder was filtered off. The desired 2-amino-1,3,4-oxadiazole **4a** was isolated in 92% yield after simple aqueous work up followed by column chromatography on silica gel.

The optimized protocol was then generalized to reaction of different N^{α}-Boc/Cbz-protected amino acid hydrazides **1** with isoselenocyanato esters **2** to obtain N^{α}-Boc/Cbz-protected 2-amino-1,3,4-oxadiazole bearing dipeptidomimetics **4** (Table 2, entries 4a-j). In all the cases clean reaction was observed and the products were obtained in good yields.

The structures of the peptidyl 2-amino-1,3,4-oxadiazoles **4** were confirmed by ^{1}H NMR, ^{13}C NMR and mass spectrometric analyses.



Scheme 1 Synthesis of Boc/Cbz-protected 2-amino-1,3,4-oxadiazole tethered peptidomimetics **4**

Though the present reaction conditions were mild, the possibility of racemization was studied in the case of two epimeric 1,3,4-oxadiazoles Cbz-Phe-ψ-[C_2N_2O]-NH-L-Ala-OMe **4g** and Cbz-Phe-ψ-[C_2N_2O]-NH-D-Ala-OMe **4g*.** The analytical RP-HPLC profiles of oxadiazoles **4g** and its epimer **4g*** showed distinct retention times of Rt 19.557 and 18.544 min respectively, thus confirming the absence of racemization.

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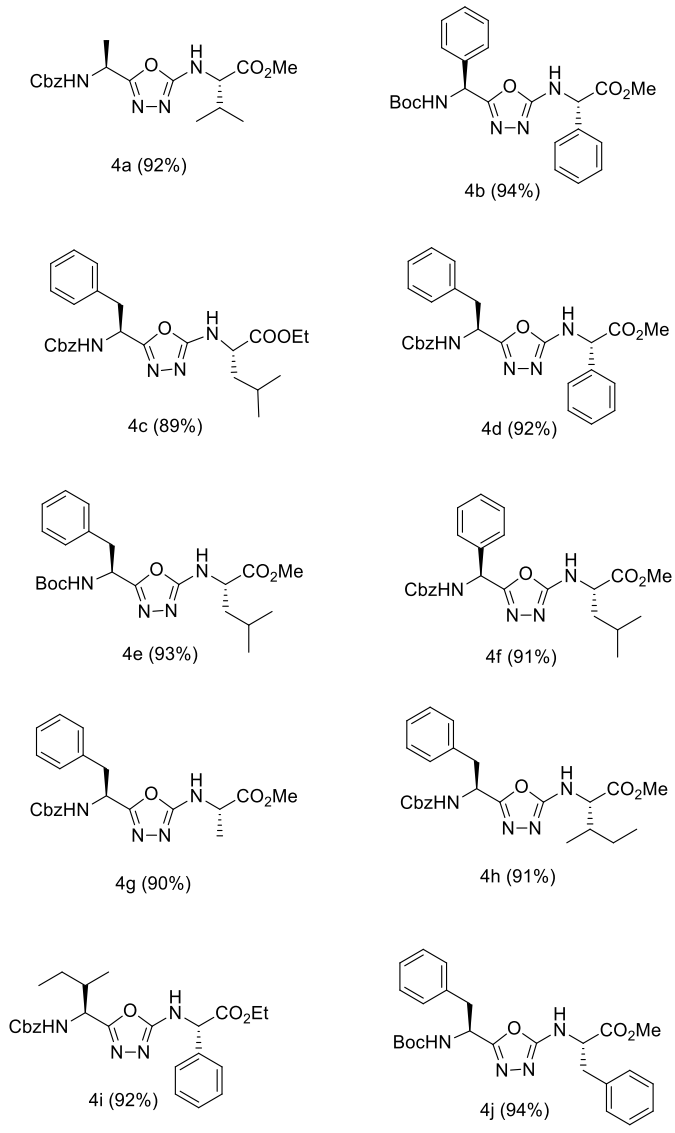
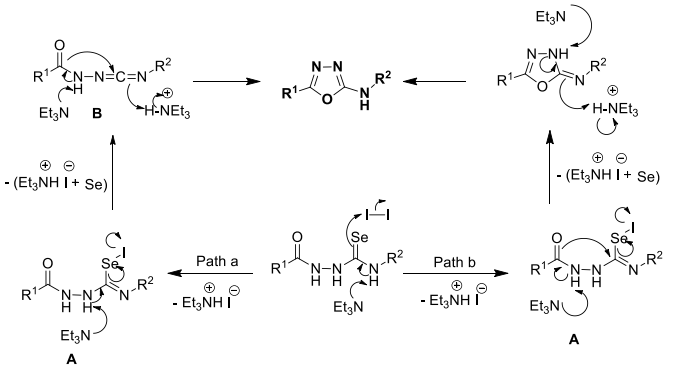
Table 2 Synthesis of 2-amino-1,3,4-oxadiazole tethered peptidomimetics



Isolated yields are given in the parenthesis

A plausible mechanism has been proposed based on our results and literature precedents[15,18,21] (Scheme 2). Initially the nucleophilic attack of Se on the molecular iodine will form the intermediate **A**. Then TEA assisted deselenization (path a) leads to the carbodiimide intermediate **B**. The subsequent cyclization involving the nucleophilic attack of carbonyl oxygen onto the carbodimide results in 2-amino-1,3,4-oxadiazole. However, a second pathway b involving cyclization via direct nucleophilic attack of carbonyl oxygen assisted by TEA cannot be ruled out. It is noteworthy to mention that the mechanism was also derived from the stoichiometric amount of TEA and I_2 added for the cyclization via deselenization. In the reaction, 1 equiv. of I_2 and 2 equiv. of TEA were consumed for the formation of 2-amino-1,3,4-oxadiazole from its corresponding selenosemicarbazide, the same stoichiometric amounts are reflected in the proposed mechanism. Though our protocol is one-pot, to supplement the proposed reaction mechanism, selenosemicarbazide (3e) was isolated and characterized by Mass and NMR studies, which gave a conclusive evidence of in situ formed selenosemicarbazide.



Scheme 2 Plausible mechanism for the formation of 2-amino-1,3,4-oxadiazole **4** from selenosemicarbazide **3**

Conclusions

In summary, synthesis of N^{α}-Cbz/Boc-protected 2-amino-1,3,4-oxadiazole tethered peptidomimetics by molecular iodine mediated cyclodeselenization of in situ generated peptidyl selenosemicarbazides in one-pot is developed. The present method is mild and effective than the previously reported methods (from semicarbazides or thiosemicarbazides) in the literature and uses environmentally benign iodine as the cyclization reagent. Other advantages of the method include high product yields, mild reaction conditions and short reaction time. The precipitation of elemental selenium and formation of triethylammonium iodide largely simplifies the purification procedure and the concern on precipitated selenium can be diminished by reusing it for the preparation of isoselenocyanato esters. We expect that the mild synthetic route described here should increase the utility of this amide/ester bioisostere in the synthesis of pseudopeptides for the molecular recognition studies and in drug development.

Experimental section

All chemicals were used as obtained from Sigma Aldrich Company, USA. All the solvents were dried and purified using recommended procedures in the literature whenever necessary. High resolution mass spectra were recorded on a Micromass Q-TOF micromass spectrometer using electron spray ionization mode.^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker AMX 400 MHz and 100 MHz spectrometer, respectively. Melting points were determined in an open capillary and are uncorrected. TLC experiments were done using MERCK TLC aluminum sheets (silica gel 60 F254) and chromatograms were visualized by exposing in iodine chamber and in UV-lamp. Column chromatography was

performed on silica gel (100-200 mesh) using ethyl acetate and hexane mixture as eluent.

General procedure

Synthesis of 2-amino-1, 3, 4-oxadiazole peptidomimetics 4;

To a solution of N^{α}-protected amino acid hydrazide **1** (1.0 mmol) in THF (8 mL) was added a solution of isoselenocyanato ester **2** (1.0 mmol) and the reaction mixture was stirred for 1-2 h at room temperature till the complete conversion of starting materials (TLC analysis). Then the mixture is cooled to 0 ^{o}C and then TEA (2.0 mmol) was added followed by addition of iodine (1.0 mmol) portion-wise over 5 min. Stirring was continued for 15 min and during the reaction precipitation of reddish brown selenium powder was observed. After the reaction was completed (monitored by TLC), the selenium powder was filtered off and washed with THF (10 mL). The combined filtrate was concentrated under vacuum and the residue was diluted with EtOAc and washed with Sat. $Na_2S_2O_3$, 10% citric acid, 5% Na_2CO_3, brine solution and finally dried over Na_2SO_4, and solvent was evaporated under reduced pressure, the resulting crude product was purified by column chromatography on silica gel (n-hexane-EtOAc = 7:3).

Acknowledgements

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Notes and references

1 M. Castanho and N. C. Santos, Eds.; *Peptide Drug Discovery and Development*, Wiley-VCH Verlag, GmbH & Co. KGaA, Weinheim, Germany, 2011.

2 (a) S. G. Kucukguzel, I. Kucukguzel, E. Tatar, S. Rollas, F. Sahin, M. Gulluce, E. De Clercq and L. Kabasakal, *Eur. J. Med. Chem*., 2007, **42**, 893-901; (b) X. Ouyang, E. L. Piatnitski, V. Pattaropong, X. Chen, H. Y. He, A. S. Kiselyov, A. Velankar, J. Kawakami, M. Labelle, L. Smith, J. Lohman, S. P. Lee, A. Malikzay, J. Fleming, J. Gerlak, Y. Wang, R. L. Rosler, K. Zhou, S. Mitelman, M. Camara, D. Surguladze, J. F. Doody and M. C. Tuma, *Bioorg. Med. Chem. Lett*., 2006, **16**, 1191-1196; (c) G.Sahin, E. Palaska, M. Ekizoglu and M. Ozalp, *Il Farmaco*, 2002, **57**, 539-542; (d) M. J. Ahsan, J. G. Samy, C. B. Jain, K. R. Dutt, H. Khalilullah and M. S. Nomani, *Bioorg. Med. Chem. Lett*., 2012, **22**, 969-972;(e)J. Bostrom, A. Honger, A. Llinas, E. Wellner and A. T. Plowright, *J. Med. Chem.*,2012, **55**, 1817-1830;(f) C. B. Chapleo, P. L. Myers, M. Myers, J. F. Saville, A. C. B. Smith, M. R. Stilling, I. F. Tulloch, D. S. Walter and A. P. Welbourn, *J. Med. Chem.*, 1986, **29**, 2273-2280; (g) H. L. Yale and K. Losee, *J. Med. Chem.*, 1966, **9**, 478-483; (h) D. Ghirian, I. Schwatz and I. Smiti, *Farmacia*, 1974, **22**, 141; (i) N. K. Chudgar, S. N. Shah and R. A. Vora, *Mol. Cryst. Liq. Cryst*.,1989, **172**, 51-56; (j) Y. Choi, H. Ishikawa, J. Velcicky, G. I. Elliott, M. M. Miller and D. L. Boger, *Org. Lett.*,2005, **7**, 4539-4542; (k) H. Ishikawa, G. I. Elliott, J. Velcicky, Y. Choi and D. L. Boger, *J. Am. Chem. Soc.*, 2006, **128**, 10596-10612.

3 (a) X. Zheng, Z. Li, Y. Wang, W. Chen, Q. Huang, C. Liu and G. Song, *J. Fluorine Chem*., 2003, **123**, 163-169; (b) X. J. Zou, L. H. Lai, G. Y. Jin and Z. X. Zhang, *J. Agric. Food Chem.*, 2002, **50**, 3757-3760.

4 S. Vardan, H. Smulyan, S. Mookherjee and R. Eich, *Clin. Pharm. Ther.*, 1983, **34**, 290-296.

5 R. Schlecker and P. C. Thieme, *Tetrahedron*, 1988, **44**, 3289-3294.

6 M. Ogata, H. Atobe, H. Kushida and K. Yamamoto, *J. Antibiot*., 1971, **24**, 443-451.

7 B. S. Orlek, F. E. Blaney, F. Brown, M. S. G. Clark, M. S. Hadley, J. Hatcher, G. J. Riley, H. E. Rosenberg, H. J. Wadsworth and P. Wyman, *J. Med. Chem*., 1991, **34**, 2726-2735.

8 (a) S. Borg, R. C. Vollinga, M. Labarre, K. Payza, L. Terenius and K. Luthman, *J. Med. Chem*., 1999, **42**, 4331-4342; (b) S. Borg, G. Estenne-Bouhtou, K. Luthman, I. Csoeregh, W. Hesselink and U. Hacksell, *J. Org. Chem*., 1995, **60**, 3112-3120.

9 W. R. Tully, C. R. Gardner, R. J. Gillespie and R. J. Westwood, *J. Med. Chem*., 1991, **34**, 2060-2067.

10 T. Ladduwahetty, R. Baker, M. A. Cascieri, M. S. Chambers, K. Haworth, L. E. Keown, D. E. MacIntyre, J. M. Metzger, S. Owen, W. Rycroft, S. Sadowski, E. M. Seward, S. L. Shepheard, C. J. Swain, F. D. Tattersall, A. P. Watt, D. W. Williamson and R. J. Hargreaves, *J. Med. Chem*., 1996, **39**, 2907-2914.

11 (a) E. Ko, J. Liu, L. M. Perez, G. Lu, A. Schaefer and K. Burgess, *J. Am. Chem. Soc*., 2011, **133**, 462-477; (b) E. Ko, J. Liu and K. Burgess, *Chem. Soc. Rev*., 2011, **40**, 4411-4421.

12 (a) J. I. Gavrilyuk, A. J. Lough and R. A. Batey, *Tetrahedron* Lett, 2008, **49,** 4746-4749; (b) R. S. Lamani, G. Nagendra and V. V. Sureshbabu, *Tetrahedron Lett*., 2010, **51**, 4705-4709; (c) G. Nagendra, R. S. Lamani, N. Narendra and V. V. Sureshbabu, *Tetrahedron Lett*., 2010, **51**, 6338-6341; (d) Z. Jakopin and M. S. Dolenc, *Curr. Org. Chem.*,2008, **12**, 850-898; (e) A. Pace and P. Pierro, *Org. Biomol. Chem*., 2009, **7**, 4337-4348; (f) N. R. Rivera, J. Balsells and K. B. Hansen, *Tetrahedron Lett*., 2006, **47**, 4889-4891; (g) C. G. Levins and Z. K. Wan, *Org. Lett*., 2008, **10**, 1755-1758.

13 For cyclodehydrationapproach see: (a) G. S. Poindexter, M. A. Bruce, J. G. Breitenbucher, M. A. Higgins, S. Y. Sit, J. I. Romine, S. W. Marin, S. A. Ward, R. T. McGovern, W. Clarke, J. Russell and I. Antal-Zimanyi, *Bioorg. Med. Chem*., 2004, **12**, 507-521; (b) G. D. Wilkie, G. I. Elliott, B. S. J. Blagg, S. E. Wolkenberg, D. R. Soenen, M. M. Miller, S. Pollack and D. L. Boger, *J. Am. Chem. Soc*., 2002, **124**, 11292-11294; (c) C. T. Brain, J. M. Paul, Y. Loong and P. J. Oakley, *Tetrahedron Lett*., 1999, **40**, 3275-3278; (d) R. Appel, *Angew. Chem., Int. Ed.* Engl, 1975, **14**, 801-811; (e) J. Kosmrlj, M. Kocevar andS. Polanc, *Synlett*, 1996,**7**, 652-654; (f) T. P. Tran, N. Patel, P. Samas and J. B. Schwarz, *Org. Biomol. Chem*., 2009, **7**, 5063-5066.

14 For cyclodesulfurization approach, see: (a) K. M. L. Rai and N.Linganna, *IIFarmaco*, 2000, **55**, 389-392; (b) E. L. P. Chekler, A. M. Elokdah and J. Butera, *Tetrahedron Lett*., 2008, **49**, 6709-6711; (c) S. J. Dolman, F. Gosselin, P. D. Shea and I. W. Davies, *J. Org. Chem*., 2006, **71**, 9548-9551; (d) O. M. AboulWafa and A. M. M. E. Omar, *SulfurLett.,* 1992, **14**, 181-188; (e) F. T. Coppo, K. A. Evans, T. L. Graybill and G. Burton, *Tetrahedron Lett*., 2004, **45**, 3257-3260; (f) I. R. Baxendale, S. V. Ley and M. Martinelli, *Tetrahedron*, 2005,**61**, 5323-5349; (g) R. Severinsen, J. P. Kilburn and J. F. Lau, *Tetrahedron*, 2005, **61**, 5565-5575; (h) X. Wang, Z. Li, B. Wei and J. Yang, *Synth. Commun.*,2002, **32**, 1097-1103; (i) S. J. Yang, S. H. Lee, H. J. Kwak and Y. D. Gong, *J. Org. Chem*., 2013, **78**, 438-444.

15 G. Prabhu and V. V. Sureshbabu, *Tetrahedron Lett*., 2012, **53**, 4232-4234.

16 (a) Y. Xie, J. Liu, P. Yang, X. Shi and J. Li, *Tetrahedron*, 2011, **67**, 5369-5374; (b) A. M. Pieczonka, K. Ciepielowski, Z.

View Article Online
DOI: 10.1039/C7NJ02278F

Cebulska, G. Mloston, A. Linden and H. Heimgartner, *Helv. Chim. Acta*., 2013, **96**, 397-407.
17 S. J. Yang, J. H. Choe, A. Abdildinova and Y. D. Gong, *Acs Comb. Sci*., 2015, **17** , 732-741; (b) P. Niu, J. Kang, X. Tian, L. Song, H. Liu, J. Wu and W. Yu, *J. Org. Chem*., 2015, **80**, 1018-1024.
18 (a) T. Olszewska, A. Pyszno, M. J. Milewska, M. Gdaniec and T. Polonski, *Tetrahedron: Asymmetry*,2005, **16**, 3711-3717; (b) S. Niu, G. M. Li, R. A. Zingaro, J. H. Reibenspies and T. Ichiye, *Heteroatom Chem*., 2002, **13**, 380-386; (c) E. D. Glendening and J. A. Hrabal II, *J. Am. Chem. Soc*., 1997, **119**, 12940-12946; (d) Y. Huang, G. Jahreis, G. Fischer and C. Lucke, *Chem. Eur. J.*, 2012, **18**, 9841-9848; (e) Y. Huang, G. Jahreis, C. Lucke, D. Wildermann, G. Fischer,*J. Am. Chem. Soc*., 2010, **132**, 7578-7579.
19 (a) H. Togo and S. Iida, *Synlett*, 2006, **14**, 2159-2175;(b) M. Krishnamurthy, T. M. Vishwanatha, N. R. Panguluri, V. Panduranga and V. V. Sureshbabu, *Synlett*, 2015, **26**, 2565-2569; (c) T. Kaiho, Ed.;*Iodine Chemistry and Applications*, Wiley: Hoboken, NJ, 2015; (d) Y. M. Ren, C. Cai and R. C. Yang, *RSC Adv*., 2013, **3**, 7182-7204; (e) Q. Gao, C. Liu, X. Wu, J. Zhang and A. Wu, *Org. Lett*., 2015, **17**, 2960-2963; (f) M. Breugst, E. Detmar and D. Von der Heiden, *ACS Catal*., 2016, **6**, 3203-3212.
20 (a) A. R. Ali, H. Ghosh and B. K. Patel,*Tetrahedron Lett*.,2010, **51**, 1019-1021; (b) P. S. Chaudhari, P. S. Dangate and K. G. Akamanchi, *Synlett*, 2010, **20**, 3065-3067.
21 G. Prabhu, L. Santhosh, G. Nagendra, V. Panduranga and V. V. Sureshbabu, *ChemistrySelect*, 2017, **2**, 1202-1206.
22 R. G. Strachan, W. J. Paleveda, R. F. Nutt, R. A. Vitali, D. F. Veber, M. J. Dickinson, V. Grasky, J. E. Deak, E. Walton, S. R. Jenkins, F. W. Holly and R. Hirschmann, *J. Am. Chem. Soc*., 1969, **91**, 503-505.
23 (a) H. P. Hemantha and V. V. Sureshbabu, *J. Pept. Sci*., 2010, **16**, 644-651; (b) G. Chennakrishnareddy, G. Nagendra, H. P. Hemantha, U. Das, T. N. Guru Row andV. V. Sureshbabu, *Tetrahedron*, 2010, **66**, 6718-6724.