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Dipolar cycloadditions of imidazoline 3-oxides with *N*-arylmaleimides. Synthesis and diethylamine induced ring-opening of *exo* and *endo* hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-diones

Necdet Coşkun,* Habibe Mert and Nevin Arıkan

Department of Chemistry, Uludağ University, 16059 Görükle Bursa, Turkey

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Abstract—1,4-Diarylimidazoline 3-oxides react with *N*-arylmaleimides in benzene to give predominantly the corresponding *endo* adducts. Chiral imidazoline 3-oxides react diastereospecifically (cis configuration of the tetrahydroimidazo ring) and diastereoselectively to give *cis–endo* adducts. The effects of substituents on the aromatic ring of the maleimide was investigated. The presence of electron-withdrawing or releasing groups have minor effect on the total yields but more pronounced is the effect on the ratio of *exo* and *endo* diastereomers. The adducts undergo an interesting and unprecedented ring-opening in the presence of secondary amines to give deoxygenated 3-imidazoline 3-oxides instead of the expected double cis elimination products. Tertiary amines did not induce any reaction.

1. Introduction

Nitrones are well-known 1,3-dipoles in thermal cycloaddition reactions with multiple bond systems to provide various heterocyclic five membered ring systems.[1] The cycloadducts of di- and triarylimidazoline 3-oxides[2] with a variety of dipolarophiles[3] give bicyclic compounds with potentially interesting biological activity.[4] On the other hand, they are source of new heterocyclic compounds via interesting ring-opening reactions.[5] In our previous work, the 1,3-dipolar cycloadditions of imidazoline 3-oxides was shown to proceed regio- and diastereoselectively and interesting reactions of these adducts under a variety of conditions especially the double cis elimination they undergo in the presence of dialkylamines was reported.[3d–e,5] *exo* Adducts of *N*-methyl and *N*-phenylmaleimides with chiral 1-benzyl-4-phenyl-2-imidazoline 3-oxide were reported recently.[6] As a continuation of our interest in the synthesis of imidazoisoxazolidines with potential anticancer activity and in the stereochemistry of dipolar cycloadditions of 1,4-diaryl and 1,2,4-triarylimidazoline 3-oxides with different dipolarophiles, we planned to react a series of *N*-arylmaleimides with imidazoline 3-oxides[7] **1** and to subject them to ring-opening in the presence of secondary and tertiary amines.[8] The latter reaction would serve as an important entry into the synthesis of chiral 3-hydroxypyrrolidines, which have attracted attention after the discovery of the glycosidase inhibitor activity of the natural product nojirimycin.[9] The retrosynthetic plan related to the synthesis of chiral pyrrolidin-3-ols is depicted in Scheme 1. (*S*)-Nitrone would give the *exo* and *endo* adducts; the ring-opening of the *exo* adduct would give (*S*)-pyrrolidin-2,5-diones while *endo* would give (*R*), and the reduction of both would give the corresponding chiral pyrrolidin-3-ols. The reverse will be true if we start from (*R*)-nitrone.

For the most widely studied nitrone, *C*-phenyl-*N*-methylnitrone, the frontier orbital energies indicate HOMO control for electron-deficient dipolarophiles.[10] Our observations on the cycloadditions of compounds **1** with electron deficient dipolarophiles corroborate the conclusion that the process is HOMO controlled. In this investigation we were also interested in the effect of substituents on the *N*-aryl group of the maleimide on the reaction yield and the *exo–endo* selectivity of the cycloaddition reaction with cyclic nitrones **1**. The problem of *endo–exo* selectivity in 1,3-dipolar cycloadditions is far from definitively assessed and the *endo–exo* selectivity of the cycloaddition of 3,4-dihydroisoquinoline 2-oxide with different types of dipolarophiles was reported.[11a] The *exo–endo* selectivity of 1,3-dipolar cycloaddition of *C*,*N*-diphenylnitrone to

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* Corresponding author. Tel.: +90 44292561308; fax: +90 4428022; e-mail: coskun@uludag.edu.tr

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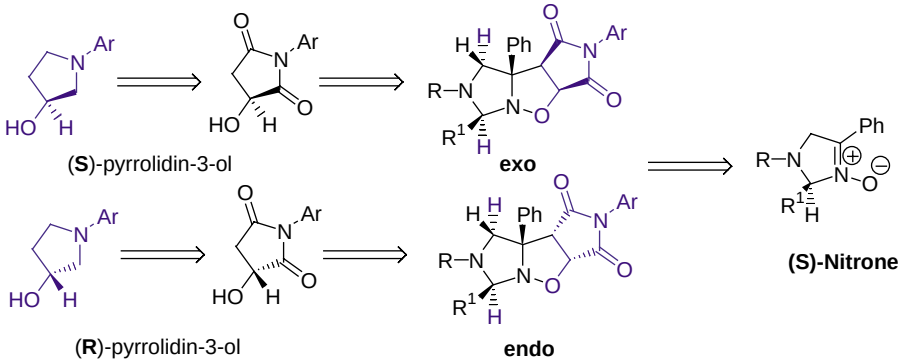


Scheme 1. Retrosynthetic analysis for the asymmetric synthesis of pyrrolidin-3-ols.

tert-butyl vinyl ether in the presence of chiral Ti(IV) species was recently reported.[11]

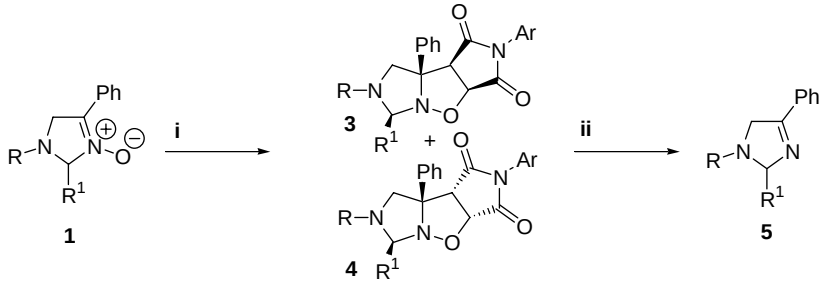
We report herein the synthesis and ring-opening reactions of a new class of compounds, namely hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-diones. The reaction of nitrones **1a–i** with *N*-arylmaleimides **2** in benzene and toluene was shown to proceed selectively to give the *endo* adducts as major products. The *exo–endo* ratio increases when electron-donating groups are present on the N-2 aryl, and decreases when the groups are electron-withdrawing. The reaction of adducts **3** and **4** separately or their mixture with diethylamine led to a so far unobserved interesting ring-opening to give di- and triaryl-3-imidazolines **5** instead of the expected double cis elimination products. The mechanism of this reaction is also briefly discussed.

2. Results and discussions

To elucidate the solvent effect on the rate and product ratio of the dipolar cycloaddition, nitrone **1a** was refluxed in different solvents in the presence of 4 equiv of *N*-phenyl-maleimide (Scheme 2 and Table 1). The reaction was observed to proceed much faster in solvents such as benzene, acetonitrile and toluene. The reaction proceeds with higher *endo* selectivity in toluene while the cyclo-addition in dichloromethane, THF and acetonitrile was unselective. The reaction is too slow in DCM, 39% yield was achieved after 48 h reflux.

At first we decided to develop the model reaction starting with racemic nitrones **1**. Compounds **1a–i** were reacted with maleimides **2** in benzene to give adducts **3** and **4** in high total yields (Scheme 2 and Table 2).

The cycloaddition nearly completes within 10 h in the cases where C-2 of the nitrone is unsubstituted, while in the cases of C-2 aryl substituted nitrones **1c–e** the reaction time was five times longer to achieve the same yields due to the steric hindrance of the aryl groups. The *exo–endo* ratio is approximately the same in the cycloaddition of nitrones **1a–d** with *N*-phenylmaleimide. The ratio is close to 1:1 in the case of **1e** (C-2 substituent is 3-nitrophenyl group) the steric hindrance of which probably does not support the formation of the transition state leading to the *endo* adduct. To understand the role of the substituents on the *N*-aryl group of **2** it is useful to compare the *exo–endo* ratio of cycloadditions with **1a**,**f–i** (Table 2). It is seen that the electron-donating groups favor the formation of *endo* adducts, while electron-withdrawing groups do not. Beside the steric effects contributing to the *exo–endo* ratio, secondary orbital interactions between the aryl rings at N-2 and N-5 and may be between N-5 and the carbonyls at the pyrrolidine ring are probably also responsible for the stabilization of the transition state leading to *endo* adduct. The effect of substituents on the total yields of adducts **3** and **4** are of the same magnitude independent of their nature. This means electron-donating groups somewhat increase the LUMO energy of the electron deficient maleimide and thus decelerate the *exo* adduct formation. Computations of the HOMO and LUMO energies for maleimides **2** confirmed this. On the other hand, computation of the HOMO and LUMO energies for nitrone **1a** and comparison with the corresponding HOMO and LUMO energies of maleimides **2** clearly revealed that the cycloaddition should be a HOMO controlled process. The same electron-donating substituent probably raises the energy of N-2 phenyls HOMO to give a better π interaction between the N-5 aryl. Conversely, electron-withdrawing groups decrease the LUMO energy of the electron deficient maleimide thus accelerating the *exo*



Scheme 2. Reagents and reaction conditions; (i) 4 equiv *N*-arylmaleimide **2**; benzene, reflux; (ii) Diethylamine, reflux, 23 h.

Table 1. Solvent effect on the 1,3-dipolar cycloaddition of **1a** with *N*-phenylmaleimide

Solvent	Reaction time (h)	Total yield (%)	Yield (%)	
			3a	**4a**
Benzene	10	100	35	65
Toluene	10	80	24	57
THF	10	56	23	33
DCM	48[a]	39	19	20
Acetonitrile	10	86	45	41

[a] The yield of the reaction for 10 h reaction time is 12% and the ratio of *exo* and *endo* isomers is 1:2.

adduct formation but lower the π interaction between the N-5 aryl.

Some characteristic assignments for adducts **3** and **4** based on extensive 1D and 2D NMR experiments are given in Table 3.

The *exo* stereochemistry of adducts **3a–b**,**f–i** was confirmed by NOESY1D experiments performed on compound **3a** (Fig. 1) as follows:

Irradiation of proton at C-7a enhanced the signal of 3aH (1%). Irradiation of the doublet of 6Ha enhanced the signals of 6Hb (12.72%) and *ortho* protons of *N*-tolyl group (6.66%). The irradiation of 6Hb enhances the signal of 6Ha (13.62%) and the *ortho* protons' signals of *N*-tolyl (3.92%) and 3b-phenyl (2.93%). Irradiation of 4Hb, enhanced the signals of 4Ha, and the *ortho* protons of both phenyls at N-5 and C-3b by 19.0, 6.81, and 9.13%, respectively. The irradiation of 3aH enhances the signals of 7aH (3.3%), 4Ha (3.09%) and *ortho* protons of 3b-phenyl by 0.5%. Irradiation of 4Ha enhances the signals of 4Hb (18.7%), 3aH (6.17%), 7a (1%), and *ortho* protons of *N*-tolyl group. 7aH was irradiated to give enhancement for 3aH (1.75%) and the *ortho* protons of *N*-phenyl group at 7.04 ppm (4.0%).

Table 2. Synthesis of hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-diones **3a–i** and **4a–i**

Entry	R	R[1]	Ar	Total yield	Yield (%) of		*exo–endo*[a]
					3	**4**	
a	4-MeC_6H_4	H	Ph	100[b]	35	65	1:1.86
b	4-$MeOC_6H_4$	H	Ph	100[b]	38	62	1:1.63
c	4-MeC_6H_4	4-$MeOC_6H_4$	Ph	90[c]	33	57	1:1.73
d	4-$MeOC_6H_4$	4-$MeOC_6H_4$	Ph	92[c]	32	60	1:1.87
e	4-$MeOC_6H_4$	3-$NO_2C_6H_4$	Ph	74[c]	33	41	1:1.24
f	4-MeC_6H_4	H	4-$MeOC_6H_4$	93[b]	24	69	1:2.88
g	4-MeC_6H_4	H	4-$NO_2C_6H_4$	85[b]	35	50	1:1.43
h	4-MeC_6H_4	H	4-ClC_6H_4	88[b]	36	52	1:1.44
i	4-MeC_6H_4	H	4-MeC_6H_4	88[b]	28	60	1:2.14

[a] The ratio of the isolated adducts.
[b] Reaction time 10 h.
[c] Reaction time 51 h.

Table 3. Characteristic ^{1}H NMR spectroscopic data for *exo* and *endo* adducts **3** and **4**

	exo							*endo*					
	3aH	4Ha	4Hb	6Ha	6Hb	7aH		3a	4Ha	4Hb	6Ha	6Hb	7aH
3a	3.98	3.80	4.17	4.79	4.53	5.17	**4a**	4.02	3.11	4.60	4.49	4.66	5.15
3b	3.98	3.79	4.12	4.76	4.53	5.17	**4b**	4.01	3.05	4.56	4.44	4.63	5.15
3c	3.92	3.96	4.61		5.81	5.17	**4c**	4.04	4.77	3.87		5.64	5.16
3d	3.92	3.96	4.61		5.76	5.19	**4d**	4.04	4.71	3.85		5.63	5.17
3e	3.92	3.96	4.70		5.85	5.21	**4e**	4.06	4.69	3.95		5.76	5.22
3f	3.96	3.79	4.16	4.78	4.52	5.15	**4f**	4.01	3.10	4.58	4.49	4.65	5.15
3g	4.02	3.81	4.19	4.79	4.54	5.21	**4g**	4.05	3.08	4.62	4.47	4.59	5.19
3h	3.97	3.79	4.16	4.78	4.52	5.16	**4h**	4.01	3.08	4.59	4.48	4.63	5.15
3i	3.95	3.78	4.15	4.78	4.52	5.14	**4i**	4.01	3.10	4.59	4.49	4.65	5.14

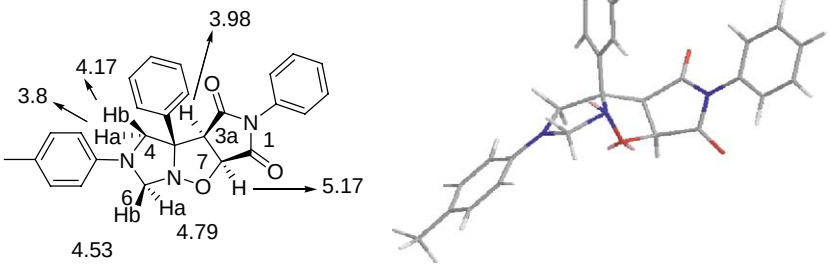


Figure 1. Some selected chemical shifts assignments for **3a** and its energy minimised 3D model (total energy 99.4078 kcal/mol).

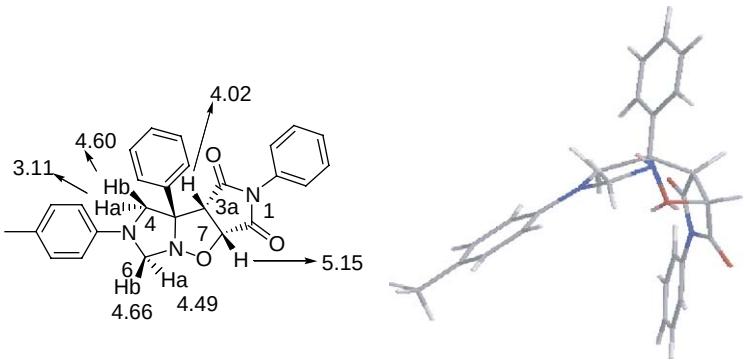


Figure 2. Some selected chemical shifts assignments for **4a** and its energy minimised 3D model (total energy 99.0050 kcal/mol).

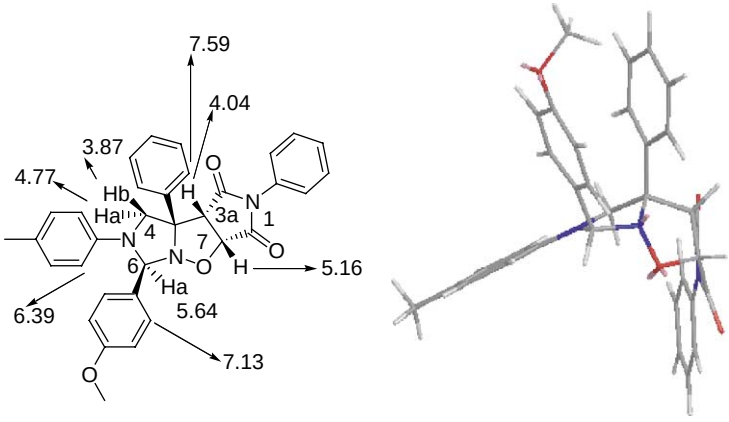


Figure 3. Some selected chemical shifts for *cis–endo* adduct **4c** and its energy minimised 3D model (total energy 27.2092 kcal/mol).[12]

Finally, the *ortho* protons of 3b-phenyl were irradiated to give enhancements for the signals of 4Hb (2.11%) and 6Hb (0.5%). The energy minimised conformations of compounds **3a**, **4a** and **4c** (see Figs. 1–3) are supporting the observed correlations by NOESY1D experiments. On the other hand, the total energy of **3a** was by 0.4028 kcal/mol higher than that of **4a**.

The NOESY1D experiment results for *endo* adduct **4a** are as follows: irradiation of 6Ha enhanced the signals of 6Hb (17.2%), the *ortho* protons of *N*-tolyl group (3.07%) and 4Ha (0.66%). The irradiation of 4Ha enhanced the signals of 4Hb (19.18%), *ortho* protons of *N*-tolyl and 3b-phenyl by 1.69 and 0.9%, respectively. Irradiation of 3aH enhanced the signals of 7aH and 3b-phenyls *ortho* protons by 3.3 and 2.66%, respectively. Irradiation of 4Hb enhances the signal of 4Ha by 17.71% and the *ortho* protons of *N*-tolyl and 3b-phenyl by 7.30 and 2.59%. Irradiation of *ortho* protons of 3b-phenyl enhances the signals of 4Hb and 3aH by 1.5 and 1%, respectively.

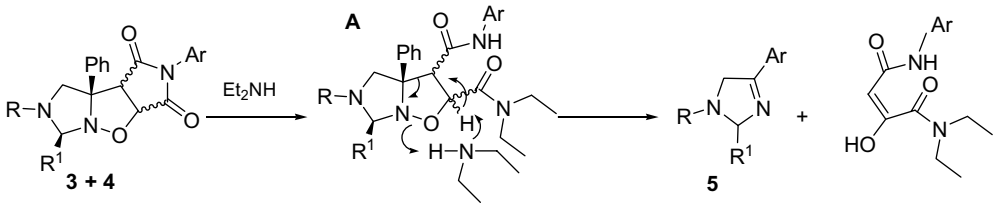
To prove the cis orientation of the phenyls at C-3b and C-6 we have irradiated the corresponding protons at the imidazolidine and isoxazolidine rings of **4c** as follows: the proton at C-3a was irradiated to give enhancements for the C-3b-phenyls' *ortho* protons (3.61%) and for the 7aH (3.98%). 4Hb was irradiated to give enhancements for 4Ha (27.0%) and the *ortho* protons of the phenyls at C-3b, N-5 and C-6 by 2.84, 2.58 and 4.13%, respectively. Irradiation of 4Ha enhanced the signals of 4Hb (27.8%) and the signals of *N*- and C-3b-phenyls' *ortho* protons by 10.0 and 2.71%, respectively. The irradiation of C-6H enhanced the signals of C-6 phenyls and N-5 phenyls *ortho* protons. This unequivocally proves the *cis–endo* configuration of compounds **4c–e**.

According to the developed procedure isolated, compounds **3** and **4** or their mixture were refluxed in diethylamine in order to prepare the racemic mixtures of pyrrolidin-3-ols as in Scheme 1, however, this treatment led to the formation of new 3-imidazolines **5a–e** (Scheme 2 and Table 4). The compounds were easily characterized by elemental analyses and spectral methods. The characteristic IR frequencies for C=N appears at ca.1630 cm^{-1}. The methylenes at C-2 and C-5 in the cases of **5a–b** appear as two proton triplets as a results of long range coupling between them. The long range

Table 4. Synthesis of 3-imidazolines **5a–e**

Starting material	Product	Yield (%)	Mp (°C)
3a+4a	**5a**	90	117–119
3b+4b	**5b**	100[a]	129–130
4c	**5c**	92	176–178
3c	**5c**	98	176–178
3d+4d	**5d**	88	152–153
3e	**5e**	92	182–184
4e	**5e**	92	182–184

[a] The reaction time was 23 h for all entries except for entry 2 where the reaction time is 39 h.



Scheme 3. Proposed mechanism for the conversion of adducts **3** and **4** into **5**.

coupling is observed between the protons at C-2 and the AB system at C-5 in the cases of **5c–d**.

The probable mechanism for the ring-opening of compounds **3** and **4** in diethylamine is depicted in Scheme 3. The nucleophilic attack of diethylamine leads to intermediate **A** (isolated in the case of **4b**), which probably undergo diethylamine assisted synchronous ring-opening to give imidazolines **5** and the corresponding oxaloacetic acid amides. The isolated and characterized **A** (5-(4-methoxyphenyl)-3a-phenyl-hexahydroimidazo[1,5-*b*]isoxazole-2,3-dicarboxylic acid 2-diethylamide 3-phenylamide **4b′**, was isolated from the reaction of **3b** and **4b** in diethylamine for 23 h) was refluxed in diethylamine for 23 h to give imidazoline **5b** in 92% yield.

To prove the structure of 5-(4-methoxyphenyl)-3a-phenyl-hexahydroimidazo[1,5-*b*]isoxazole-2,3-dicarboxylic acid 2-diethylamide 3-phenylamide **4b′** we have performed NOESY1D experiments as follows: irradiation of C-4Hb proton led to enhancement of the signals of C-4Ha (18.05%), *p*-anisyl (3.58%) and C-3b phenyls (4.27%) *ortho* protons. While the irradiation of C-4Ha enhances the signals of C-4Hb (16.34%), *N*-*p*-anisyl (7.20%) and C-3b phenyls *ortho* protons (1.3%). Irradiation of C-3H enhanced the signals of C-2H (4.09%), C-3b phenyls *ortho* protons (2%) and the amide proton at 8.89 ppm. The latter correlation was indicative for the determination of the right regioisomer. Thus, all these experiments allowed us to assign the configuration shown in Figure 4.

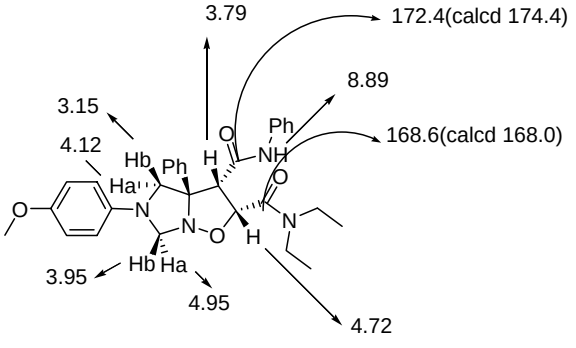


Figure 4. Some characteristic chemical shifts for intermediate bisamide **4b′**.

exo Adduct **3a** was shown to give nucleophilic addition product faster than *endo* adduct **4a**. The reaction times for the disappearance of the corresponding adducts (TLC controls) were 1.5 and 6 h, respectively.

Compounds **3a**,**c** and **4a**,**c** were refluxed in triethylamine for 48 h but no conversion was observed, the starting materials were recovered unchanged.

3. Conclusions

In conclusion, we studied the reaction of imidazoline 3-oxides **1** with of *N*-arylmaleimides **2**. The reactions of nitrones **1a–b**,**f–i** with *N*-arylmaleimides **2** in benzene give predominantly the corresponding *endo* adducts **4a–b**,**f–i**. Chiral imidazoline 3-oxides **1c–e** react diastereospecifically with respect to the cis configuration in the tetrahydroimidazo ring and diastereoselectively to give *cis–endo* adducts **4c–e**.The effect of substituents on the phenyl ring of the maleimide was investigated. The presence of electron-withdrawing or releasing groups have minor effects on the total yields but the effect on the ratio of *exo* and *endo* diastereomers is more pronounced. The *exo–endo* ratio increases when electron-donating groups are present on the N-2 aryl, and decreases when the groups are electron-withdrawing. Adducts **3** and **4** undergo an interesting ring-opening in the presence of secondary amines to give the deoxygenated 3-imidazoline 3-oxides **5** instead of the expected double cis elimination products. This reaction will serve as a convenient method for the synthesis of otherwise inaccessible 3-imidazolines. Tertiary amines did not induce any reaction.

4. Experimental

4.1. General

Melting points were recorded on an Electrothermal Digital melting point apparatus. Infrared spectra were recorded on a Mattson 1000 FTIR. 1D and 2D NMR experiments were performed on a Varian Mercury Plus 400 MHz spectrometer. Visualisation was effected with UV light. Imidazoline 3-oxides **1a–e** were prepared according to the method we have recently reported.[7] The elemental analyses were performed on a EuroEA 3000 CHNS analyser. The total energies of compounds **3a**, **4a**, **4c**, *cis–exo* **3c** and the FMO energy calculations for maleimides **2** and nitrone **1a** were performed using CS MOPAC Pro in ChemOffice 6.

4.1.1. 1,2-Bis-(4-methoxyphenyl)-4-phenyl-2,5-dihydro-1*H*-imidazole 3-oxide 1d. Yield, 2.0 g, 23%; white needles; mp 200–201.5 °C; IR (KBr) $\nu_{C=N}$ 1610 cm^{-1}; ^{1}H NMR δ 3.73 (3H, s), 3.80 (3H, s), 4.81 (1H, dd, J=14.0, 3.2 Hz), 5.14 (1H, dd, J=14.0, 5.6 Hz), 6.10 (1H, dd, J=5.6, 3.2 Hz), 6.57 (2H, d, J=8.8 Hz), 6.82 (2H, d, J=8.8 Hz),

6.94 (2H, d, $J=8.4$ Hz), 7.45–7.49 (3H, m), 7.56 (2H, d, $J=8.4$ Hz), 8.34 (2H, dd, $J=7.6$, 3.6 Hz). ^{13}C NMR δ 53.4; 55.6; 55.9; 90.0; 113.9; 114.6; 115.3; 127.2; 128.9; 129.0; 129.6; 131.1; 134.5; 136.9; 138.8; 153.0; 161.2. Anal. Calcd for $C_{23}H_{22}N_2O_3$ (374.43) C, 73.78; H, 5.92; N, 7.48; found C, 73.75; H, 5.90; N, 7.45.

4.1.2. 1-(4-Methoxyphenyl)-2-(3-nitrophenyl)-4-phenyl-2,5-dihydro-1*H*-imidazole 3-oxide 1e. Yield 2.38 g, 26%; yellow needles; mp 190–191 °C; $\nu_{C=N}$ 1610 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.80 (3H, s), 4.86 (1H, dd, $J=14.0$, 3.2 Hz), 5.26 (1H, dd, $J=14.0$, 5.6 Hz), 6.25 (1H, dd, $J=5.6$, 3.2 Hz), 6.55 (2H, d, $J=9.2$ Hz), 6.84 (2H, d, $J=9.2$ Hz), 7.48–7.52 (3H, m), 7.65 (1H, t, $J=7.6$ Hz), 8.06 (1H, d, $J=8.0$ Hz), 8.29–8.33 (3H, m), 8.51 (1H, t, $J=2.0$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 53.9; 55.9; 89.1; 114.2; 115.5; 123.2; 123.4; 126.9; 127.2; 129.1; 130.1; 131.7; 134.9; 135.6; 138.3; 138.5; 148.0; 153.7. Anal. Calcd for $C_{22}H_{19}N_3O_4$ (389.40) C, 67.86; H, 4.92; N, 10.79; found C, 67.83; H, 4.90; N, 10.75.

The maleimides used were prepared according to a method known in the literature.[13a] Maleimide **2g** was prepared according to a modified literature procedure:[13b] to a mixture of 4-nitroaniline (5.1 mmol, 0.772 g) and maleic anhydride (6.04 mmol, 0.592 g) PPA (7 g) was added and the mixture stirred for 15 h at 80 °C on a water bath. The mixture was poured into cold water and the product precipitated was filtered and dried in a vacuum oven. Yield 0.598 g, 54%; yellow amorphous solid; mp 163–164 °C; IR (KBr) $\nu_{C=O}$ 1724 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.93 (2H, s), 7.68 (2H, d, $J=9.6$ Hz), 8.34 (2H, d, $J=9.6$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 124.7; 125.7; 134.9; 137.3; 146.4; 168.8.

4.2. Synthesis of hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-diones 3a–i and 4a–i. General procedure

To a solution of imidazoline 3-oxide **1** (0.12 mmol) in benzene (10 mL) maleimide (0.48 mmol) was added and the reaction mixture stirred for the specified time. The solvent was evaporated and the mixture was separated by column chromatography using silica gel as an adsorbent and petroleum ether ethyl acetate as a solvent mixture. The compounds were recrystallized from ether or ethanol.

4.2.1. *exo*-2,3b-Diphenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 3a. Yield 0.018 g, 35%; white needles; mp 177–178 °C; IR (KBr) $\nu_{C=O}$ 1713 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.24 (3H, s), 3.80 (1H, d, $J=8.8$ Hz), 3.98 (1H, d, $J=7.6$ Hz), 4.17 (1H, d, $J=8.8$ Hz), 4.53 (1H, d, $J=11.2$ Hz), 4.79 (1H, d, $J=11.2$ Hz), 5.17 (1H, d, $J=7.6$ Hz), 6.42 (2H, d, $J=8.0$ Hz), 7.00–7.05 (4H, m), 7.31–7.40 (6H, m), 7.57 (2H, d, $J=7.2$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 56.7; 56.8; 71.0; 80.7; 112.3; 126.2; 126.6; 126.9; 129.0; 129.2; 129.3; 129.4; 130.1; 131.3; 136.0; 143.6; 171.2; 174.1. Anal. Calcd for $C_{26}H_{23}N_3O_3$ (425.48) C, 73.39; H, 5.45; N, 9.88; found C, 73.34; H, 5.40; N, 9.95.

4.2.2. *exo*-5-(4-Methoxyphenyl)-2,3b-diphenyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 3b. Yield 0.020 g, 38%; white needles; mp 120–121 °C; IR (KBr) $\nu_{C=O}$ 1716 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.74 (3H, s), 3.79 (1H, d, $J=8.4$ Hz), 3.98 (1H, d, $J=7.2$ Hz), 4.12 (1H, d, $J=8.8$ Hz), 4.53 (1H, d, $J=11.2$ Hz), 4.76 (1H, d, $J=11.2$ Hz), 5.17 (1H, d, $J=7.2$ Hz), 6.46 (2H, d, $J=8.8$ Hz), 6.83 (2H, d, $J=9.2$ Hz), 6.99 (2H, d, $J=7.6$ Hz), 7.30–7.40 (6H, m), 7.56 (2H, d, $J=7.2$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 56.1; 56.9; 57.2; 71.5; 77.3; 80.8; 113.3; 115.4; 126.2; 126.5; 129.0; 129.1; 129.2; 129.4; 131.3; 136.1; 140.5; 152.3; 171.2; 174.1. Anal. Calcd for $C_{26}H_{23}N_3O_4$ (441.48) C, 70.73; H, 5.25; N, 9.52; found C, 70.80; H, 5.40; N, 9.42.

4.2.3. *exo*-6-(4-Methoxyphenyl)-2,3b-diphenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza cyclopenta[*a*]pentalene-1,3-dione 3c. Yield 0.021 g, 33%; white needles; mp 167–168 °C; IR (KBr) $\nu_{C=O}$ 1712 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.23 (3H, s), 3.70 (3H, s), 3.92 (1H, d, $J=7.6$ Hz), 3.96 (1H, d, $J=9.2$ Hz), 4.61 (1H, d, $J=9.2$ Hz), 5.17 (1H, d, $J=7.6$ Hz), 5.81 (1H, s), 6.43 (2H, d, $J=8.8$ Hz), 6.58 (2H, d, $J=8.4$ Hz), 6.89–7.18 (10H, m), 7.18–7.51 (4H, m). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 55.5; 57.5; 57.7; 77.0; 79.7; 85.5; 113.4; 113.5; 126.1; 127.0; 127.4; 128.2; 128.6; 128.9; 129.1; 129.3; 129.9; 130.2; 131.3; 135.3; 144.0; 159.5; 171.1; 174.1. Anal. Calcd for $C_{33}H_{29}N_3O_4$ (531.60) C, 74.56; H, 5.50; N, 7.90; found C, 74.60; H, 5.60; N, 7.78.

4.2.4. *exo*-5,6-Bis-(4-methoxyphenyl)-2,3b-diphenyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 3d. Yield 0.021 g, 32%; white needles; mp 165–166 °C; IR (KBr) $\nu_{C=O}$ 1712 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.70 (3H, s), 3.72 (3H, s), 3.92–3.96 (2H, two overlapping d, $J=7.6$, 8.8 Hz), 4.61 (1H, d, $J=8.8$ Hz), 5.19 (1H, d, $J=7.6$ Hz), 5.76 (1H, s), 6.46 (2H, d, $J=8.4$ Hz), 6.58 (2H, d, $J=8.0$ Hz), 6.78 (2H, d, $J=8.4$ Hz), 6.95–6.99 (3H, m), 7.08–7.14 (3H, m), 7.21–7.25 (2H, m), 7.30–7.35 (4H, m). ^{13}C NMR (100 MHz, $CDCl_3$): δ 55.5; 55.9; 57.6; 57.8; 77.0; 79.7; 85.4; 113.5; 114.4; 115.1; 126.1; 127.0; 127.4; 128.3; 128.7; 128.9; 129.1; 129.3; 129.6; 135.3; 144.7; 152.6; 159.5; 171.1; 174.1. Anal. Calcd for $C_{33}H_{29}N_3O_5$ (547.60) C, 72.38; H, 5.34; N, 7.67; found C, 72.32; H, 5.40; N, 7.60.

4.2.5. *exo*-5-(4-Methoxyphenyl)-6-(3-nitrophenyl)-2,3b-diphenyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]-pentalene-1,3-dione 3e. Yield 0.022 g, 33%; yellow needles; mp 173–174 °C; IR (KBr) $\nu_{C=O}$ 1715 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.73 (3H, s), 3.92 (1H, d, $J=7.1$ Hz), 3.96 (1H, d, $J=8.8$ Hz), 4.70 (1H, d, $J=8.8$ Hz), 5.21 (1H, d, $J=7.1$ Hz), 5.85 (1H, s), 6.44 (2H, d, $J=8.8$ Hz), 6.80 (2H, d, $J=8.8$ Hz), 7.01–7.09 (5H, m), 7.18–7.38 (6H, m), 7.52 (1H, d, $J=7.6$ Hz), 7.79 (1H, s), 7.96 (1H, d, $J=7.6$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 55.9; 57.2; 57.4; 77.1; 80.0; 85.3; 114.5; 115.3; 122.9; 123.2; 125.9; 126.9; 128.5; 129.0; 129.2; 129.3; 129.4; 131.2; 134.1; 134.3; 140.0; 140.2; 148.2; 153.1; 170.8; 173.8. Anal. Calcd for $C_{32}H_{26}N_4O_6$ (562.57) C, 68.32; H, 4.66; N, 9.96; found C, 68.30; H, 4.60; N, 9.98.

4.2.6. *exo*-2-(4-Methoxyphenyl)-3b-phenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 3f. Yield 0.013 g, 24%; white needles; mp 187–188 °C; IR (KBr) $\nu_{C=O}$ 1716 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.23 (3H, s), 3.78 (3H, s), 3.79 (1H, d, J=8.6 Hz), 3.96 (1H, d, J=7.4 Hz), 4.16 (1H, d, J=8.6 Hz), 4.52 (1H, d, J=10.9 Hz), 4.78 (1H, d, J=10.9 Hz), 5.15 (1H, d, J=7.4 Hz), 6.41 (2H, d, J=8.2 Hz), 6.87–6.94 (4H, m), 7.03 (2H, d, J=8.2 Hz), 7.31 (1H, t, J=7.2 Hz), 7.37 (2H, t, J=7.2 Hz), 7.55 (2H, t, J=7.2 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 55.7; 56.7; 56.8; 71.0; 77.2; 80.7; 112.3; 114.7; 123.8; 126.5; 126.8; 127.4; 129.2; 129.3; 130.1; 136.0; 143.6; 159.8; 171.5; 174.4. Anal. Calcd for $C_{27}H_{25}N_3O_4$ (455.51) C, 71.19; H, 5.53; N, 9.22; found C, 71.21; H, 5.50; N, 9.27.

4.2.7. *exo*-2-(4-Nitrophenyl)-3b-phenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 3g. Yield 0.020 g, 35%; yellow needles; mp 175 °C; IR (KBr) $\nu_{C=O}$ 1728 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.24 (3H, s), 3.81 (1H, d, J=8.8 Hz), 4.02 (1H, d, J=7.2 Hz), 4.19 (1H, d, J=8.8 Hz), 4.54 (1H, d, J=10.8 Hz), 4.79 (1H, d, J=10.8 Hz), 5.21 (1H, d, J=7.2 Hz), 6.40 (2H, d, J=8.4 Hz), 7.04 (2H, d, J=8.4 Hz), 7.24–7.26 (3H, m), 7.35–7.41 (2H, m), 7.54 (2H, d, J=8.0 Hz), 8.23 (2H, d, J=9.2 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 56.8; 56.9; 71.0; 77.2; 80.8; 112.4; 124.6; 126.4; 126.6; 127.1; 129.3; 129.5; 130.2; 135.8; 136.6; 143.5; 147.3; 170.5; 173.4. Anal. Calcd for $C_{26}H_{22}N_4O_5$ (470.48) C, 66.37; H, 4.71; N, 11.91; found C, 66.40; H, 4.76; N, 11.90.

4.2.8. *exo*-2-(4-Chlorophenyl)-3b-phenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 3h. Yield 0.020 g, 36%; white needles; mp 186–187 °C; IR (KBr) $\nu_{C=O}$ 1720 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.24 (3H, s), 3.79 (1H, d, J=8.4 Hz), 3.97 (1H, d, J=7.6 Hz), 4.16 (1H, d, J=8.4 Hz), 4.52 (1H, d, J=11.2 Hz), 4.78 (1H, d, J=11.2 Hz), 5.16 (1H, d, J=7.6 Hz), 6.41 (2H, d, J=8.6 Hz), 6.95–6.98 (2H, m), 7.04 (2H, d, J=8.6 Hz), 7.31–7.40 (5H, m), 7.54 (2H, d, J=8.6 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 56.7; 56.8; 71.0; 77.2; 80.7; 112.3; 126.5; 127.0; 127.4; 129.2; 129.3; 129.6; 129.7; 130.1; 134.8; 135.9; 143.6; 171.0; 173.8. Anal. Calcd for $C_{26}H_{22}ClN_3O_3$ (459.92) C, 67.90; H, 4.82; N, 9.14; found C, 68.05; H, 4.96; N, 9.27.

4.2.9. *exo*-3b-Phenyl-2,5-di-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 3i. Yield 0.015 g, 28%; white needles; mp 194–195 °C; IR (KBr) $\nu_{C=O}$ 1716 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.23 (3H, s), 2.30 (3H, s), 3.78 (1H, d, J=8.19 Hz), 3.95 (1H, d, J=7.4 Hz), 4.15 (1H, d, J=8.19 Hz), 4.52 (1H, d, J=10.9 Hz), 4.78 (1H, d, J=10.9 Hz), 5.14 (1H, d, J=7.4 Hz), 6.41 (2H, d, J=8.0 Hz), 6.88 (2H, d, J=8.0 Hz), 7.03 (2H, d, J=8.0 Hz), 7.17 (2H, d, J=8.0 Hz), 7.30–7.37 (3H, m), 7.55 (2H, d, J=7.6 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 21.4; 55.7; 56.8; 71.0; 77.0; 80.7; 112.3; 126.0; 126.6; 126.8; 128.6; 129.1; 129.2; 130.0; 130.1; 136.0; 139.1; 143.6; 173.3; 174.2. Anal. Calcd for $C_{27}H_{25}N_3O_3$ (439.51) C, 73.78; H, 5.73; N, 9.56; found C, 73.75; H, 5.70; N, 9.50.

4.2.10. *endo*-2,3b-Diphenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4a. Yield 0.033 g, 65%; white needles; mp 185–186 °C; IR (KBr) $\nu_{C=O}$ 1709 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.28 (3H, s), 3.11 (1H, d, J=10.1 Hz), 4.02 (1H, d, J=8.6 Hz), 4.49 (1H, d, J=9.4 Hz), 4.60 (1H, d, J=10.1 Hz), 4.66 (1H, d, J=9.4 Hz), 5.15 (1H, d, J=8.6 Hz), 6.52 (2H, d, J=8.6 Hz), 6.88 (2H, d, J=7.0 Hz), 7.08 (2H, d, J=8.6 Hz), 7.19–7.25 (3H, m), 7.35 (1H, t, J=7.4 Hz), 7.44 (2H, t, J=7.4 Hz), 7.66 (2H, d, J=7.4 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.7; 54.2; 59.8; 75.3; 80.6; 80.9; 115.0; 125.8; 126.5; 128.4; 128.9; 129.2; 129.3; 129.8; 130.2; 131.4; 141.5; 142.9; 173.0; 174.1. Anal. Calcd for $C_{26}H_{23}N_3O_3$ (425.48) C, 73.39; H, 5.45; N, 9.88; found C, 73.40; H, 5.33; N, 10.05.

4.2.11. *endo*-5-(4-Methoxyphenyl)-2,3b-diphenyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4b. Yield 0.033 g, 62%; white needles; mp 182–183 °C; IR (KBr) $\nu_{C=O}$ 1712 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 3.05 (1H, d, J=10.4 Hz), 3.75 (3H, s), 4.01 (1H, d, J=8 Hz), 4.44 (1H, d, J=9.6 Hz), 4.56 (1H, d, J=10.0 Hz), 4.63 (1H, d, J=9.6 Hz), 5.15 (1H, d, J=8.0 Hz), 6.57 (2H, d, J=8.5 Hz), 6.81 (2H, d, J=8.5 Hz), 6.90 (2H, d, J=7.4 Hz), 7.2–7.25 (3H, m), 7.34 (1H, t, J=7.41 Hz), 7.43 (2H, t, J=7.4 Hz), 7.66 (2H, d, J=7.4 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 54.8; 55.9; 59.8; 75.9; 80.8; 81.0; 115.2; 116.3; 125.8; 126.6; 128.4; 128.9; 129.2; 129.3; 131.4; 139.3; 141.58; 154.1; 173.0; 174.3. Anal. Calcd for $C_{26}H_{23}N_3O_4$ (441.48) C, 70.73; H, 5.25; N, 9.52; found C, 70.85; H, 5.33; N, 9.48.

4.2.12. *endo*-6-(4-Methoxyphenyl)-2,3b-diphenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4c. Yield 0.036 g, 57%; white needles; mp 189–191 °C; IR (KBr) $\nu_{C=O}$ 1720 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.22 (3H, s), 3.74 (3H, s), 3.87 (1H, d, J=10.0 Hz), 4.04 (1H, d, J=8.4 Hz), 4.77 (1H, d, J=10.0 Hz), 5.16 (1H, d, J=8.4 Hz), 5.64 (1H, s), 6.38 (2H, d, J=8.6 Hz), 6.76 (2H, d, J=8.6 Hz), 6.80 (2H, d, J=7.4 Hz), 6.93 (2H, d, J=8.2 Hz), 7.12 (2H, d, J=8.6 Hz), 7.19–7.32 (4H, m), 7.37 (2H, t, J=7.4 Hz), 7.60 (2H, d, J=7.4 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 52.7; 55.4; 59.4; 79.9; 80.3; 84.6; 114.2; 114.3; 126.0; 126.3; 127.9; 128.3; 128.7; 128.8; 129.0; 129.2; 129.9; 131.2; 131.5; 141.3; 141.6; 159.6; 172.9; 174.0. Anal. Calcd for $C_{33}H_{29}N_3O_4$ (531.60) C, 74.56; H, 5.50; N, 7.90; found C, 74.45; H, 5.63; N, 7.85.

4.2.13. *endo*-5,6-Bis-(4-methoxyphenyl)-2,3b-diphenyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4d. Yield 0.039 g, 60%; white needles; mp 159–160 °C; IR (KBr) $\nu_{C=O}$ 1716 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 3.70 (3H, s), 3.73 (3H, s), 3.85 (1H, d, J=10.0 Hz), 4.04 (1H, d, J=8.4 Hz), 4.71 (1H, d, J=10.0 Hz), 5.17 (1H, d, J=8.4 Hz), 5.63 (1H, s), 6.41 (2H, d, J=9.0 Hz), 6.69 (2H, d, J=9.0 Hz), 6.74 (2H, d, J=8.6 Hz), 6.85–6.87 (2H, m), 7.09 (2H, d, J=8.6 Hz), 7.21–7.33 (4H, m), 7.38 (2H, t, J=7.8 Hz), 7.60 (2H, d, J=7.8 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 53.0; 55.4; 55.9; 59.4; 79.9; 80.4; 85.0; 114.1; 115.0; 115.6; 126.0; 126.2; 128.3; 128.8; 128.8; 129.1; 129.2; 131.2; 131.4; 137.7; 141.7; 152.9; 159.5; 172.9; 174.1. Anal. Calcd for

$C_{33}H_{29}N_3O_5$ (547.60) C, 72.38; H, 5.34; N, 7.67; found C, 72.35; H, 5.53; N, 7.51.

4.2.14. *endo*-5-(4-Methoxyphenyl)-6-(3-nitrophenyl)-2,3b-diphenyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta-[*a*]pentalene-1,3-dione 4e. Yield 0.028 g, 41%; yellow needles; mp 119–120 °C; IR (KBr) $\nu_{C=O}$ 1714; 1724 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 3.70 (3H, s), 3.95 (1H, d, J=10.0 Hz), 4.06 (1H, d, J=8.0 Hz), 4.69 (1H, d, J=10.0 Hz), 5.22 (1H, d, J=8.0 Hz), 5.76 (1H, s), 6.41 (2H, d, J=8.8 Hz), 6.71 (2H, d, J=9.2 Hz), 6.90 (2H, d, J=8.8 Hz), 7.25–7.57 (10H, m), 8.05–8.08 (2H, m). ^{13}C NMR (100 MHz, $CDCl_3$): δ 53.1; 55.9; 59.5; 80.0; 80.3; 84.5; 115.2; 115.7; 122.7; 123.5; 125.8; 126.1; 126.3; 129.0; 129.2; 129.3; 129.4; 131.1; 133.7; 134.4; 140.8; 141.5; 148.6; 153.4; 172.7; 173.6. Anal. Calcd for $C_{32}H_{26}N_4O_6$ (562.57) C, 68.32; H, 4.66; N, 9.96; found C, 68.43; H, 4.59; N, 9.90.

4.2.15. *endo*-2-(4-Methoxyphenyl)-3b-phenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4f. Yield 0.038 g, 69%; white needles; mp 187–187.4 °C; IR (KBr) $\nu_{C=O}$ 1705 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.27 (3H, s), 3.10 (1H, d, J=10.0 Hz), 3.75 (3H, s), 4.01 (1H, d, J=8.4 Hz), 4.49 (1H, d, J=9.6 Hz), 4.58 (1H, d, J=10.0 Hz), 4.65 (1H, d, J=9.6 Hz), 5.15 (1H, d, J=8.4 Hz), 6.51 (2H, d, J=8.2 Hz), 6.71 (2H, d, J=8.9 Hz), 6.8 (2H, d, J=8.9 Hz), 7.05 (2H, d, J=8.2 Hz), 7.34 (1H, t, J=7.02 Hz), 7.43 (2H, t, J=7.4 Hz), 7.66 (2H, d, J=7.4 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.7; 54.2; 55.7; 59.7; 75.3; 80.5; 80.8; 114.5; 115.0; 123.9; 125.8; 127.8; 128.3; 129.3; 129.7; 130.2; 141.6; 143.0; 159.7; 173.2; 174.3. Anal. Calcd for $C_{27}H_{25}N_3O_4$ (455.51) C, 71.19; H, 5.53; N, 9.22; found C, 71.09; H, 5.70; N, 9.25.

4.2.16. *endo*-2-(4-Nitrophenyl)-3b-phenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4g. Yield 0.028 g, 50%; yellow needles; mp 176–177 °C; IR (KBr) $\nu_{C=O}$ 1716 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.29 (3H, s), 3.08 (1H, d, J=10.0 Hz), 4.05 (1H, d, J=8.0 Hz), 4.47 (1H, d, J=9.6 Hz), 4.59 (1H, d, J=9.6 Hz), 4.62 (1H, d, J=10.0 Hz), 5.19 (1H, d, J=8.0 Hz), 6.50 (2H, d, J=8.2 Hz), 7.05 (2H, d, J=8.2 Hz), 7.14 (2H, d, J=9.0 Hz), 7.36 (1H, t, J=7.4 Hz), 7.43 (2H, t, J=7.4 Hz), 7.65 (2H, d, J=7.4 Hz), 7.54 (2H, d, J=9.0 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.7; 54.2; 59.9; 75.4; 80.7; 81.4; 115.1; 124.4; 125.8; 127.1; 128.6; 129.4; 130.4; 130.5; 136.8; 141.0; 142.6; 147.2; 172.3; 173.5. Anal. Calcd for $C_{26}H_{22}N_4O_5$ (470.48) C, 66.37; H, 4.71; N, 11.91; found C, 66.30; H, 4.65; N, 11.85.

4.2.17. *endo*-2-(4-Chlorophenyl)-3b-phenyl-5-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4h. Yield 0.029 g, 52%; white needles; mp 158–160 °C; IR (KBr) $\nu_{C=O}$ 1712 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.28 (3H, s), 3.08 (1H, d, J=10.0 Hz), 4.01 (1H, d, J=8.0 Hz), 4.48 (1H, d, J=9.6 Hz), 4.59 (1H, d, J=10.0 Hz), 4.63 (1H, d, J=9.6 Hz), 5.15 (1H, d, J=8.0 Hz), 6.50 (2H, d, J=8.4 Hz), 6.83 (2H, d, J=9.2 Hz), 7.05 (2H, d, J=8.4 Hz), 7.17 (2H, d, J=9.2 Hz), 7.31–7.38 (1H, m), 7.42–7.46 (2H, m), 7.64–7.67 (2H, m). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.7; 54.2; 59.8; 75.3; 80.6; 81.0; 115.0; 125.8; 127.8; 128.4; 129.4; 129.4; 129.8; 130.0; 130.3; 134.7; 141.4; 142.8; 172.8; 174.0. Anal. Calcd for $C_{26}H_{22}ClN_3O_3$ (459.92) C, 67.90; H, 4.82; N, 9.14; found C, 68.00; H, 4.80; N, 9.22.

4.2.18. *endo*-3b-Phenyl-2,5-di-*p*-tolyl-hexahydro-7-oxa-2,5,6a-triaza-cyclopenta[*a*]pentalene-1,3-dione 4i. Yield 0.032 g, 60%; white needles; mp 178–179 °C; IR (KBr) $\nu_{C=O}$ 1706 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.28 (3H, s), 2.29 (3H, s), 3.10 (1H, d, J=10.0 Hz), 4.01 (1H, d, J=8.4 Hz), 4.49 (1H, d, J=9.2 Hz), 4.59 (1H, d, J=10.0 Hz), 4.65 (1H, d, J=9.2 Hz), 5.14 (1H, d, J=8.4 Hz), 6.52 (2H, d, J=8.0 Hz), 6.76 (2H, d, J=8.0 Hz), 7.02 (2H, d, J=8.0 Hz), 7.06 (2H, d, J=8.0 Hz), 7.35 (1H, t, J=7.6 Hz), 7.43 (2H, t, J=7.2 Hz), 7.66 (2H, d, J=7.2 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 21.1; 54.0; 59.5; 75.0; 80.4; 80.6; 114.8; 125.6; 126.1; 128.1; 128.5; 129.0; 129.5; 129.6; 130.0; 138.8; 141.4; 142.8; 172.9; 174.0. Anal. Calcd for $C_{27}H_{25}N_3O_3$ (439.51) C, 73.78; H, 5.73; N, 9.56; found C, 73.70; H, 5.70; N, 9.50.

4.2.19. 5-(4-Methoxyphenyl)-3a-phenyl-hexahydro-imidazo[1,5-*b*]isoxazole-2,3-dicarboxylic acid 2-diethyl-amide 3-phenylamide 4b′. Yield 0.023 g, 18%; white needles; mp 166–167 °C; IR (KBr) ν_{NH} 3445 cm^{-1}; $\nu_{C=O}$ 1691 and 1620 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 0.92 (6H, t, J=7.6 Hz), 2.58 (4H, q, J=7.6 Hz), 3.17 (1H, d, J=10.0 Hz), 3.70 (3H, s), 3.79 (1H, d, J=7.2 Hz), 3.95 (1H, d, J=10.8 Hz), 4.12 (1H, d, J=10.0 Hz), 4.72 (1H, d, J=7.2 Hz), 4.95 (1H, d, J=10.8 Hz), 6.50 (2H, d, J=8.6 Hz), 6.70 (2H, d, J=8.6 Hz), 6.94 (1H, t, J=7.0 Hz), 7.09 (2H, t, J=7.0 Hz), 7.21–7.35 (6H, m), 7.59 (2H, d, J=7.8 Hz), 8.90 (1H, s). ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.3; 42.2; 55.8; 58.3; 66.7; 72.7; 79.4; 80.5; 115.0; 116.0; 120.1; 124.1; 125.9; 127.7; 128.7; 129.0; 138.2; 140.5; 144.7; 153.2; 168.6; 172.4. Anal. Calcd for $C_{30}H_{34}N_4O_4$ (514.62) C, 70.02; H, 6.66; N, 10.89; found C, 70.10; H, 6.60; N, 10.85.

4.3. Base catalysed ring-opening of compounds 3 and 4. Synthesis of 2,5-dihydro-1*H*-imidazole 5a–e. General procedure

Method A. Compound **3** or **4** (0.25 mmol) were refluxed in diethylamine (5 mL) for 23 h. The solvent was evaporated and the product was purified by preparative TLC using petroleum ether ethyl acetate as eluent (2:1). The products were recrystallized from ethanol or ether. *Method B*. The mixture of adducts **3** and **4** from the cycloaddition of nitrones **1** (0.25 mmol) with maleimides (1 mmol) **2** was dissolved in diethylamine (5 mL) and refluxed for 23 h. The solvent was evaporated and the isolation of the product **5** is as in Method A.

4.3.1. 4-Phenyl-1-*p*-tolyl-2,5-dihydro-1*H*-imidazole 5a. Method B; yield 0.053 g, 90%; white needles; mp 117–119 °C; IR (KBr) $\nu_{C=N}$ 1631 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.28 (3H, s), 4.57 (2H, t, J=5.2 Hz), 5.43 (2H, t, J=5.2 Hz), 6.52 (2H, d, J=8.4 Hz), 7.11 (2H, d, J=8.4 Hz), 7.38–7.53 (3H, m), 7.82–7.89 (2H, m). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.6; 55.3; 79.0; 112.2; 121.5; 127.6; 129.0; 130.3; 131.6; 136.0; 143.4; 169.3. Anal. Calcd for

$C_{16}H_{16}N_2$ (236.31) C, 81.32; H, 6.82; N, 11.85; found C, 81.30; H, 6.85; N, 11.90.

4.3.2. 1-(4-Methoxyphenyl)-4-phenyl-2,5-dihydro-1*H*-imidazole 5b. Method B; yield 0.063 g, 100%; white needles; mp 129–130 °C; IR (KBr) $\nu_{C=N}$ 1631 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 3.78 (3H, s), 4.55 (2H, t, $J=5.2$ Hz), 5.41 (2H, t, $J=5.2$ Hz), 6.56 (2H, d, $J=9.2$ Hz), 6.91 (2H, d, $J=8.4$ Hz), 7.45–7.51 (3H, m), 7.87 (2H, d, $J=8.0$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 55.7; 56.1; 79.4; 113.0; 115.5; 127.6; 129.0; 131.7; 132.5; 140.4; 152.0; 169.7. Anal. Calcd for $C_{16}H_{16}N_2O$ (252.31) C, 76.16; H, 6.39; N, 11.10; found C, 76.20; H, 6.30; N, 11.05.

4.3.3. 2-(4-Methoxyphenyl)-4-phenyl-1-*p*-tolyl-2,5-dihydro-1*H*-imidazole 5c. Method B; yield 0.080 g, 93%; white needles; mp 176–178 °C; IR (KBr) $\nu_{C=N}$ 1623 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 2.23 (3H, s), 3.79 (3H, s), 4.72 (1H, dd, $J=15.2$, 3.6 Hz), 4.99 (1H, dd, $J=15.2$, 6.0 Hz), 6.45 (1H, dd, $J=6.0$, 3.6 Hz), 6.51(2H, d, $J=8.8$ Hz), 6.89 (2H, d, $J=8.6$ Hz), 7.02 (2H, d, $J=8.8$ Hz), 7.39–7.48 (5H, m), 7.88 (2H, d, $J=7.8$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5; 55.5; 57.5; 91.6; 113.0; 114.5; 126.6; 127.9; 128.3; 128.9; 130.0; 131.6; 132.4; 133.1; 143.3; 159.7; 166.8. Anal. Calcd for $C_{23}H_{22}N_2O$ (342.43) C, 80.67; H, 6.48; N, 8.18; found C, 80.60; H, 6.40; N, 8.20.

4.3.4. 1,2-Bis-(4-methoxyphenyl)-4-phenyl-2,5-dihydro-1*H*-imidazole 5d. Method B; yield 0.079 g, 88%; white needles; mp 152–153 °C; IR (KBr) $\nu_{C=N}$ 1623 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 3.73 (3H, s), 3.79 (3H, s), 4.69 (1H, dd, $J=14.8$, 4.0 Hz), 4.99 (1H, dd, $J=14.4$, 6.0 Hz), 6.40 (1H, dd, $J=6.0$, 4.0 Hz), 6.55 (2H, d, $J=9.2$ Hz), 6.81 (2H, d, $J=9.2$ Hz), 6.9 (2H, d, $J=8.8$ Hz), 7.4–7.5 (5H, m), 7.87–7.89 (2H, m). ^{13}C NMR (100 MHz, $CDCl_3$): δ 55.5; 56.0; 57.9; 91.9; 113.8; 114.5; 115.2; 127.9; 128.3; 128.9; 131.5; 132.4; 133.2; 140.2; 152.0; 159.6; 166.9. Anal. Calcd for $C_{23}H_{22}N_2O_2$(358.43) C, 77.07; H, 6.19; N, 7.82; found C, 77.09; H, 6.10; N, 7.87.

4.3.5. 1-(4-Methoxyphenyl)-2-(3-nitrophenyl)-4-phenyl-2,5-dihydro-1*H*-imidazole 5e. Method A (from **3e**) yield 0.086 g, 92%; Method A (from **4e**) yield 0.086 g, 92%; yellow needles; mp 182–184 °C; IR (KBr) $\nu_{C=N}$ 1623 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 3.74 (3H, s), 4.74 (1H, dd, $J=14.8$, 4.0 Hz), 5.08 (1H, dd, $J=14.8$, 5.6 Hz), 6.49–6.54 (coincident 2H, d, $J=9.0$ Hz, 1H, dd, $J=5.6$, 4.0 Hz), 6.83 (2H, d, $J=9.0$ Hz), 7.44–7.57 (4H, m), 7.86–7.88 (3H, m), 8.16–8.19 (1H, m), 8.37 (1H, t, $J=2.0$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ 55.6; 58.5; 91.5; 114.1; 115.4; 122.44; 123.5; 127.9; 129.1; 130.1; 131.9; 132.0; 133.5; 139.7; 143.5; 149.0; 152.7; 168.4. Anal. Calcd for $C_{22}H_{19}N_3O_3$ (373.40) C, 70.76; H, 5.13; N, 11.25; found C, 70.80; H, 5.10; N, 11.14.

4.4. The treatment of compounds 3 and 4 with triethylamine

Compound **3** or **4** (0.25 mmol) was dissolved in triethylamine (5 mL) and the mixture refluxed for 48 h. The solvent was evaporated and the starting material was recovered unchanged.

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