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The Mild Oxidation of Nitrile Oxides affords a Convenient Entry to Nitrosocarbonyl Intermediates, Versatile Tools in Organic Syntheses.

P. Quadrelli, M. Mella, A Gamba Invernizzi and P. Caramella

Dipartimento di Chimica Organica dell'Università degli Studi di Pavia
Viale Taramelli, 10 I-27100 Pavia Italy

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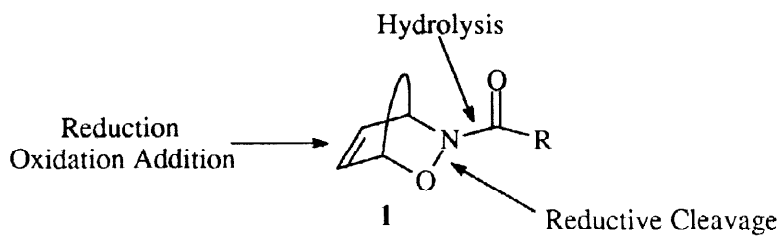
Abstract: Nitrile oxides are oxidized by tertiary amine N-oxides in different solvents at room temperature to afford in the presence of dienes nitrosocarbonyl adducts in fair yields. The mild conditions used in oxidizing a variety of nitrile oxides promise a wide application of this method in synthetic processes.

Keywords:Diels-Alder reactions, Nitrile Oxides, Nitroso compounds, N-Oxides, Solvents.

Nitrosocarbonyls are fleeting intermediates and versatile synthetic tools, which gained wide acceptance because of their high reactivity in Hetero Diels-Alder (HDA) cycloadditions and the synthetic potential of their HDA cycloadducts.

The initial studies of G. W. Kirby, who generated nitrosocarbonyl intermediates by periodate oxidation of hydroxamic acids and trapped them with dienes, paved the way for synthetic applications of nitrosocarbonyls and many authors in recent years have utilized their high dienophilic power.[1-3] In spite of their lability, nitrosocarbonyls can be easily trapped with dienes to give dihydro-1,2-oxazines in an efficient HDA cycloaddition. The HDA cycloadditions have been extensively investigated because of their high stereo- and regio-selective outcome and the HDA adducts **1** have been used in a variety of synthetic operations, which allow for a flexible introduction of multifunctionality. Several methods are available to cleave reductively the N-O bond of the adducts allowing for the required stereocontrol in several natural products syntheses.[4-6]



Dedicated to Prof. G. Tacconi on the occasion of his 67th birthday and his retirement.

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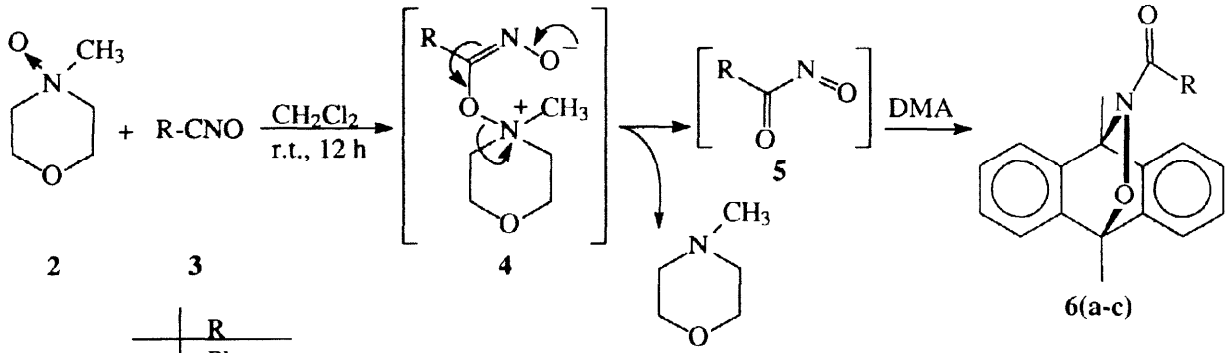
The classical method to generate nitrosocarbonyls is the oxidation of hydroxamic acids with various periodate salts.[1-4] A few other oxidations of hydroxamic acids have been reported. Good results have been obtained with silver oxide and lead oxide in ethyl acetate[7] and with oxalyl chloride / dimethyl sulfoxide in dichloromethane at –78 °C, a procedure known as the Swern-Moffat protocol.[8] Other methods were proposed in the literature,[9] but they often require specific reaction conditions not always suitable in natural product syntheses where sensitive functionalities exist. Quite recently we discovered a clean photochemical entry to nitrosocarbonyl intermediates, which are formed in the photochemical cleavage of 1,2,4-oxadiazole 4-oxides.[10]

We detail here our studies on a new efficient and mild method for the generation of nitrosocarbonyl intermediates by the mild oxidation of nitrile oxides with tertiary amine oxides. The paper gives a more complete account on the oxidation of nitrile oxides and extends the results discussed in our preliminary communication.[11]

Results

Oxidation of nitrile oxides.

Nitrile oxides are easily oxidized to nitrosocarbonyls by tertiary amine N-oxides (Scheme 1). The nucleophilic oxygen[12] of the tertiary amine *N*-oxide **2** adds to the electrophilic carbon[13] of the nitrile oxide **3** affording a zwitterionic adduct **4** whose fragmentation lead to the tertiary amine and the nitrosocarbonyl intermediate **5**. The latter can be trapped with 9,10-dimethylanthracene (DMA), which is a good quencher of nitrosocarbonyls, affording the HDA adduct **6**.

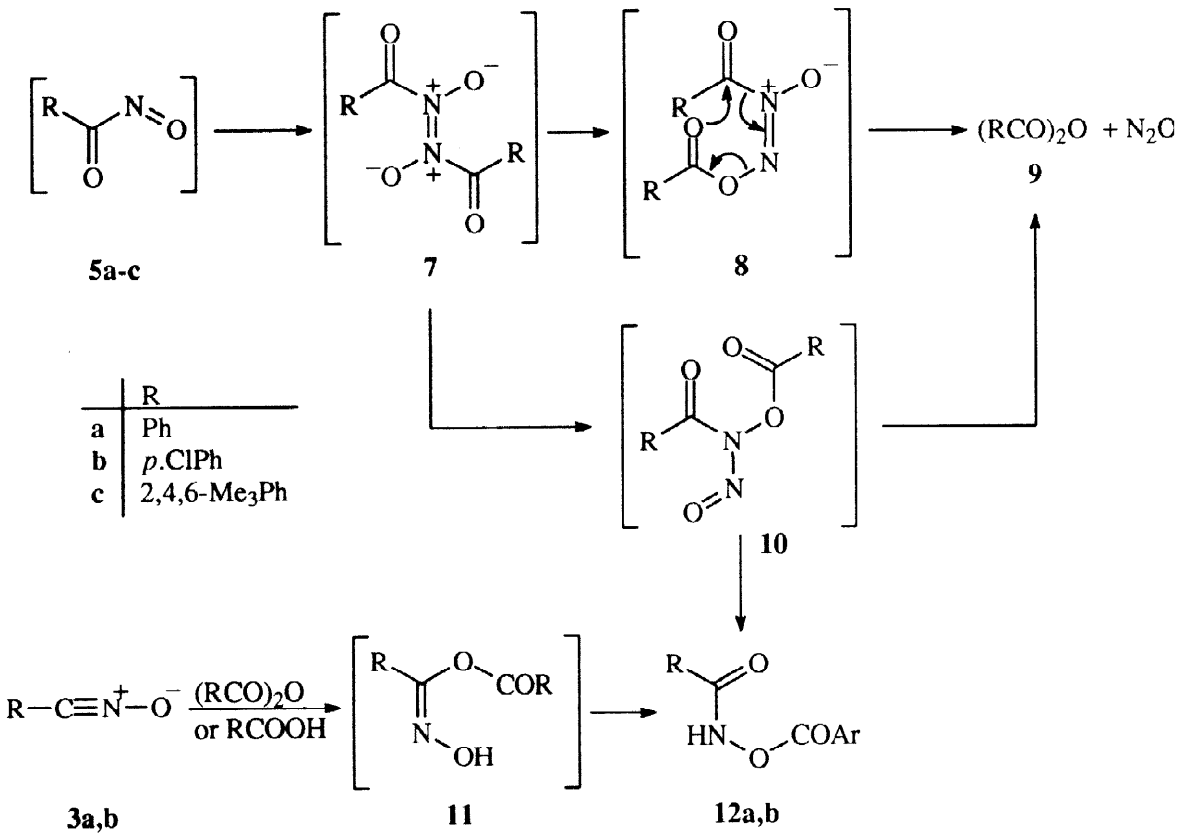


	R
a	Ph
b	*p*.Cl-Ph
c	2,4,6-Me_3-Ph

Scheme 1

In a typical experiment (Procedure A), *N*-methyl morpholine *N*-oxide (NMO, 1.1 equiv.) was added to a nitrile oxide R-CNO solution in dichloromethane at room temperature in the presence of a slight excess (1.5 equiv.) of DMA. After keeping overnight at r.t. the organic solution was washed with water, dried and evaporated. By column chromatography excess DMA was recovered and the HDA adducts **6(a-c)** were isolated in excellent yields. Adduct **6a** (mp 125-6 °C from petroleum ether, 82%) is identical to an authentic sample prepared according to the literature procedure.[14] Adducts **6b** (mp 128-9 °C dec. from ligroin, 95%) and **6c** (mp 183-5 °C from ethanol, 60%) were obtained in a similar way.

The oxidation step takes place readily at r.t. and is complete in 1-2 h in the case of benzonitrile oxide (BNO) **3a** and in 12 h in the case of the more sterically hindered mesitonitrile oxide (MNO) **3c**. The progress of the reactions can be monitored by tlc following the disappearance of the nitrile oxide or, more quantitatively, by trapping the unconsumed 1,3-dipole with a highly reactive dipolarophile, norbornene (20 equiv.), after appropriate intervals of time and determining the ratios of the HDA adducts **6** and the nitrile oxide adduct to norbornene by nmr. Under the experimental conditions listed above the half-lives of the nitrile oxide **3a** can be estimated at 3-4 minutes and the half-life of **3c** at 1.5 h.



Scheme 2

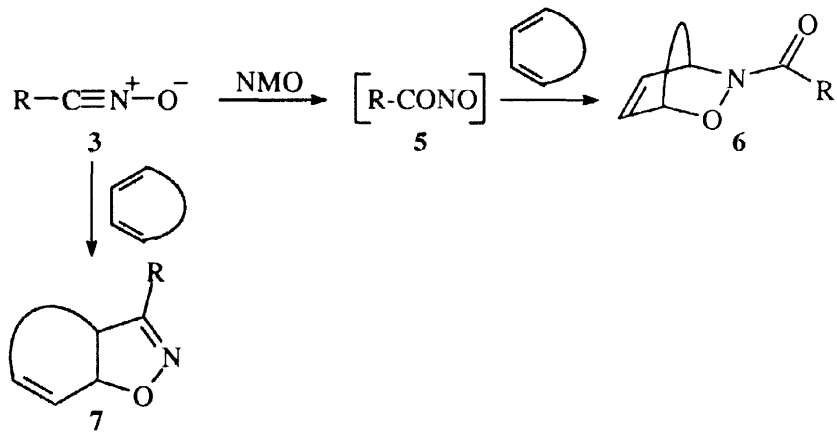
In the absence of the trapping agent (DMA), the main product isolated from the runs was the mesitoic anhydride **9c** (35%) in the case of MNO **3c** and the *N,O*-diaroylhydroxylamines **12a,b** in the case of **3a,b** (Scheme 2). The mesitoic anhydride has been observed in the oxidation of mesitohydroxamic acid with periodate salts[15] and a mechanism of its formation proposed by Kirby involves the dimerization of the nitrosocarbonyl to the azo *N,N*-dioxide **7**, a 1,2 shift of the acyl to the acyloxy azo *N*-oxide **8**, which collapses to the anhydride with loss of nitrous oxide. The *N,O*-diaroylhydroxylamines **12** have been frequently observed in the oxidation of benzohydroxamic acids and their formation is usually ascribed to the reaction of then nitrosocarbonyls with their precursors.[16] In our procedure the *N,O*-diaroyl derivatives **12a,b** derive presumably from the reaction of the anhydrides **9a,b** with the nitrile oxides **3a,b**. Nitrile oxides are known[17] to react with acids and anhydrides under

basic conditions (N-methyl morpholine) affording the labile adducts **11** which evolve to the stable *O*-acyl derivatives **12a,b**. A conceivable alternative is a 1,3-acyl shift[18] in the rearrangement of the azo *N,N*-dioxide **7** to afford *N*-nitroso *O*-benzoyl benzohydroxamic acid intermediates **10** which may evolve to the anhydride **9** or the *N,O*-diaroylhydroxylamines **12** depending upon the experimental conditions.

In situ generation of nitrile oxides.

The HDA reactions can be more conveniently performed starting from the hydroximoyl halides **13** and generating the nitrile oxides *in situ*. In this case (Procedure B), triethylamine (1 equiv. or even a catalytic amount) was added to a dichloromethane solution of the hydroximoyl chloride **13** and NMO (1.1 equiv.) in the presence of a suitable diene (1.5 equiv.) affording the nitrosocarbonyl cycloadducts **6(a-t)** in fair yield.

Table 1 reports the results obtained from a variety of aromatic nitrile oxides generated according to procedure B. Besides DMA, 1,3-cyclohexadiene and cyclopentadiene display good activity as trapping agents of nitrosocarbonyls. Under these conditions, oxidation of the nitrile oxide is much faster than the 1,3-dipolar cycloaddition of the nitrile oxide to the dienes and low yields (1-7%) of the nitrile oxide cycloadducts **7(d-m)** to 1,3-cyclohexadiene and cyclopentadiene were observed (Scheme 3).



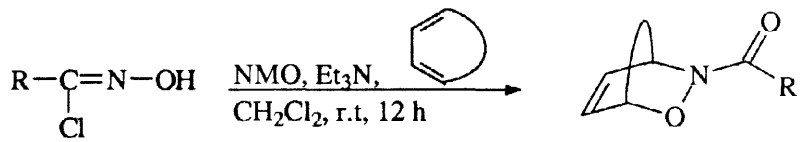
Scheme 3

The method also performs very well with aliphatic nitrile oxides. A variety of methods are reported in the literature[13] to convert aldoximes into hydroximoyl chlorides; among these we found very attractive the protocol proposed by G. Tacconi[19] which makes use of the easy and controlled generation of chlorine from hydrochloric acid and sodium hypochlorite. With this protocol several aliphatic hydroximoyl chlorides can be prepared from the aldoximes, including some hydroximoyl halides containing unsaturated substituents.

The results obtained in the oxidation of some aliphatic nitrile oxides as well as a few examples of other nitrile oxides containing C=C and C=O bonds, generated *in situ* from the corresponding hydroximoyl chlorides (Procedure B) are included in Table 1. The HDA adducts of aliphatic nitrile oxides to 1,3-cyclohexadiene were isolated in fair yield. The low yield of adduct **6s** is counterbalanced by the good result for adduct **6t**, where the

same nitroso carbonyl [Ph-CO-CONO] is trapped more efficiently with cyclopentadiene. Adducts deriving from the competing 1,3-dipolar cycloaddition reaction of aliphatic nitrile oxides were observed as by-products.

Table 1



13 **6(a-t)**

R	Adduct (yield %)	R	Adduct (yield %)
Aromatic Nitrile Oxides		**Aliphatic Nitrile Oxides**	
DMA			
Ph	**6a** (90)		
p.Cl-Ph	**6b** (97)		
2,4,6-Me_3-Ph[a]	**6c** (60)		
Cyclohexadiene			
Ph	**6d** (81)	CH_3-	**6n** (57)
p.ClPh	**6e** (77)	CH_3-$(CH_2)_2$-	**6o** (86)
p.Br-Ph	**6f** (79)	CH_3-$(CH_2)_5$-	**6p** (82)
p.Me-Ph	**6g** (72)	Ph-CH_2-	**6q** (54)
p.MeO-Ph	**6h** (77)	Ph-CH=CH-	**6r** (81)
p.NO_2-Ph	**6i** (86)	Ph-C=O	**6s** (27)
m.NO_2-Ph	**6j** (70)		
2,4,6-Me_3-Ph[a]	**6k** (65)		
Cyclopentadiene			
Ph	**6l** (68)	Ph-C=O	**6t** (61)
2,4,6-Me_3-Ph[a]	**6m** (60)		

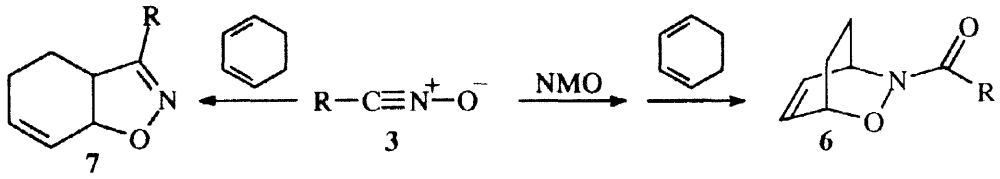
(a). Procedure A.

The ^{1}H-nmr spectra of adducts **6(d-t)** are in complete agreement with the assigned structures. The olefinic protons are in the range 6.3-6.9 δ and the bridge-head protons are in the range 4.2-5.6 δ and appear as broad signals because of the hindered rotation at the carboxamide moiety. Only in the case of the bulky 2,4,6-trimethylphenyl adducts **6k,m** and the benzoyl adducts **6s,t** the spectra show well separated signals for the bridge-head protons of both rotamers.

Tuning the reactions.

The HDA trapping of nitrosocarbonyls performs well under the conditions listed above. A few experiments performed with BNO and 1,3-cyclohexadiene show however a remarkable dependence of the reaction outcome on the changes in the reactant ratios (Table 2).

Table 2. Dependence of the product distribution upon the reactant ratios.



Entry	NMO equiv.	Diene equiv.	6 / 7
R = Ph		*Cyclohexadiene*	
1	1.5	1.5	96 : 4
2	1.5	3	94 : 6
3	1.5	6	90 : 10
4	1.5	15	75 : 25
5	1.5	30	52 : 48
6	3	30	81 : 19
7	6	30	93 : 7
8	18	30	100 : 0
R = Mes			
9	1.5	1.5	98 : 2
10	1.5	3	96 : 4
11	1.5	6	94 : 6
12	1.5	15	87 : 13
13	1.5	30	76 : 24

Upon increasing the excess of the diene the 1,3-dipolar cycloaddition competes more effectively with the oxidation step, as expected. Table 2 shows the steady increase of the 1,3-dipolar cycloadduct **7** with the increase of the diene equivs. (entries 1-5). Almost equal amounts of the nitrosocarbonyl adduct **6** and the 1,3-dipolar cycloadduct **7** are formed with 30 equiv of cyclohexadiene.

On the other hand an increase in NMO equivalents speeds the oxidation rate of the nitrile oxide. Entries 6-8 of Table 2 show the increase of the nitrosocarbonyl adduct **6** with increasing NMO equivs without any apparent shortcomings.

The ratios of the products **6** and **7** shown in Table 2 are consistent with the higher reactivity of BNO toward oxidation rather than cycloaddition to cyclohexadiene. From the ratios BNO can be estimated 50-60 fold more reactive toward NMO than towards cyclohexadiene

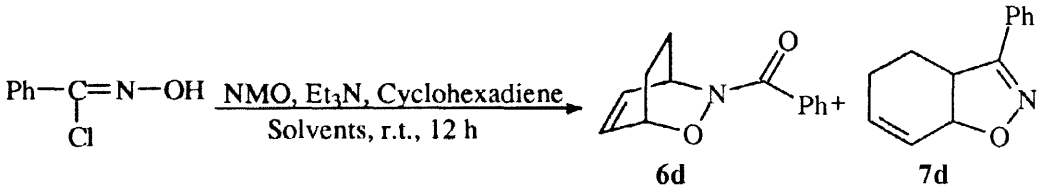
Mesitonitrile oxide behaves in much the same way as BNO. The reactions proceed more slowly and a greater discrimination between oxidation and cycloaddition is exercised. The last entries (9-13) of Table 2 show that the increase in the 1,3-dipolar cycloadduct **7** upon increasing the number of cyclohexadiene equivalents is qualitatively similar but approximately half of that observed with BNO. The hindrance of mesitonitrile oxide apparently slows down the cycloaddition more than the oxidation. The oxidation of the nitrile oxide and the trapping with diene looks like a tunable reaction and an excess of the tertiary amine *N*-oxide allows for some additional useful control element favoring the nitrosocarbonyl adducts.

Solvents and other N-oxides.

We have briefly investigated the two remainig variables of our procedure: reaction solvents and the use of different N-oxides.

Oxidation of benzonitrile oxide (BNO) in the presence of 1,3-cyclohexadiene under the usual conditions (Procedure B) was employed to check the influence of some common solvents on the reaction outcome as reported in Table 3.

Table 3



Entry	Solvents	**6d** Yield %	**7d** Yield %
1	Chloroform	73	9
2	Acetonitrile	87	/
3	Acetone	85	1
4	Ethyl Acetate	77	3
5	DMSO	89	1
6	DMF	82	1
7	THF	75	8
8	Dioxane	87	5
9	Benzene	68	24
10	Toluene	46	37
11	Cyclohexane	3	68
12	Carbon tetrachloride	24	47
13	Methanol	34	52
14	Ethanol	44	40
15	$CH_3OCH_2CH_2OH$	46	29

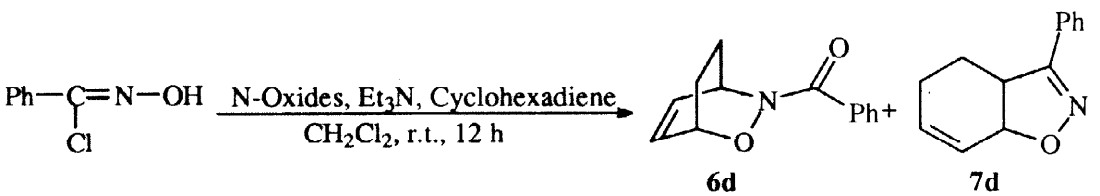
Polar solvents (entries 1-8) stabilize the zwitterionic intermediate **4** giving uniformly excellent yields of adducts **6d** and negligible amounts of the competing cycloadduct **7d** (<10%). With aromatic solvents (entries 9,10) the amounts of the cycloadduct **7d** increase sizeably while in apolar solvents (entries 11,12) adduct **7d** becomes eventually the major product. Diethyl ether gave erratic results presumably because of the low solubility of NMO which depends on the variable amounts of water present. In general NMO shows low solubility in all non-polar solvents.

Somewhat surprisingly in alcoholic solvents (entries 13-15) comparable amounts of the two adducts are formed. Presumably alcohols slow down the oxidation step by decreasing the nucleophilicity of the NMO oxygen because of its H-bonding with the solvent. As a matter of fact, the oxidation of nitrile oxides with tertiary amine

N-oxides works well in different common polar solvents, *i.e.* the generation of nitroso carbonyl intermediates is adaptable to the different conditions required in synthetic operations. Table 4 reports the results obtained in the same test reaction in the presence of some different aliphatic and aromatic N-oxides.

Aliphatic N-oxides (entries 1-3) give results similar to those obtained with NMO and the best yields of adduct **6d** while with aromatic N-oxides (entries 4-7) the 1,3-dipolar cycloaddition process prevails.

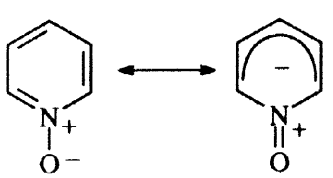
Table 4



Entry	N-Oxides	pK_a[(a)]	**6d** Yield %	**7d** Yield %
1	$Me_3N\rightarrow O$[(b)]	4.65	70	10
2	$Et_3N\rightarrow O$	5.13	77	8
3	Ph-Me_2-N→O	4.21	70	8
4	Py→O	0.79	2	68
5	*p*.NO_2-Py→O	-1.7	/	86
6	*p*.Ph-Py→O	0.83	5	73
7	*p*.MeO-Py→O	2.05	24	52

(a) Experimental pK_a values in water at 20-25 °C; (b) The commercial dihydrate form was used.

This agrees with the differences in basicity and nucleophilicity between aliphatic and aromatic N-oxides. In aliphatic N-oxides, pK_a values are in the range of 4-5[20] while the pK_as of aromatic N-oxides are significantly lower.[21] This is ascribed to the appreciable interactions between the N-O group and the aromatic ring, which make the oxygen less basic as shown in **14**.



14

Substituents in position (4) on the pyridine *N*-oxide affect the basicity and nucleophilicity of the *N*-oxide in a regular way. A methoxy substituent increases the basicity and the nucleophilicity of the pyridine *N*-oxide (entry 7) while a nitro group decrease them sizeably (entry 5) and no oxidation of the nitrile oxide to nitrosocarbonyl occurs. We have earlier reported the easy deoxygenation of 1,2,4-oxadiazole 4-oxides in the presence of nitrile oxides to afford 1,2,4-oxadiazoles and nitrosocarbonyls, which were trapped with DMA.[22] This deoxygenation reaction has some relevance in the regioselection of the nitrile oxide dimerization, which takes place in

deceptively regiospecific fashion affording 1,2,5-oxadiazole 5-oxides (furoxans). Minor amounts of 1,2,4-oxadiazoles were noted in the dimerization as by-products[23] and derive from deoxygenation of the regioisomeric 1,2,4-oxadiazole 4-oxides.

Conclusion

We have described here an efficient entry to nitrosocarbonyl intermediates by the mild oxidation of nitrile oxides with tertiary amine *N*-oxides. The reaction is tunable and takes place readily in different common solvents. The method looks promising because of the easy conversion of aldoximes to hydroximoyl halides and the mild conditions of the oxidation, widening the access to a wide array of nitrosocarbonyls, versatile tools in organic synthesis.

Experimental

All melting points are uncorrected. Elemental analyses were done on a C. Erba 1106 elemental analyzer. ^{1}H-nmr spectra were recordered on a Bruker AC 300 spectrometer in $CDCl_3$ solutions. Chemical shifts are expressed in ppm from internal tetramethylsilane (δ). IR spectra (nujol mulls) were recordered on an FT-IR Perkin-Elmer Paragon 1000. Column chromatography and tlc: silica gel H60 and GF_{254} (Merck), respectively, eluant cyclohexane/ethyl acetate 9:1 to 5:5. The identification of samples from different experiments was secured by mixed mps and superimposable IR spectra.

Materials. The aromatic hydroximoyl chlorides **13** (R=Ph, *p*.MePh, *p*.MeOPh, *p*.ClPh and *p*.NO_2Ph) were prepared according to well-known procedures.[17] Aceto- (R=CH_3) and butyro- [R= CH_3-$(CH_2)_2$-] hydroximoyl chlorides were prepared by treatment of the oximes with chlorine[24] and glyoxylo (R=PhCO-) hydroximoyl chloride from phenacyl chloride and butyl nitrite.[25] The other aliphatic hydroximoyl chlorides **13** were prepared according to the protocol of Tacconi[19] in fair yields: R= CH_3-$(CH_2)_5$-, 73%, mp 37-39°C, (lit.[26] mp 38-40°C); R=$PhCH_2$-, 80%, mp 87-88°C dec., (lit.[27] mp 89-91°C) and R=PhCH=CH-, 61%, mp 91-2°C, (lit.[28] mp 98°C).

Benzonitrile oxide **3a.** was obtained with the procedure of Quilico and Speroni.[29] *p*.Chlorobenzonitrile oxide **3b**, colorless crystals mp 82-3°C,[17] was obtained by dehydrohalogenation of the hydroximoyl chloride in diethyl ether. To a stirred and ice-cooled solution of 1.9 g (10 mmol) of *p*-chlorobenzhydroximic acid chloride in anhydrous diethyl ether a stoichiometric amount of triethylamine in 10 ml of diethyl ether was added dropwise over 2-3 minutes. After stirring 5 min. at 0°C, triethylamine hydrochloride was filtered off and the filtrate was evaporated under vacuum leaving quantitatively the nitrile oxide **3b** which was crystallized by dissolving in ethanol at 45-50°C and cooling in ice. The stable mesitonitrile oxide **3c** was prepared by oxidation of 2,4,6-trimethylbenzaldoxime with bromine.[30] The tertiary amine *N*-oxides are commercially available except *N,N*-

dimethylaniline *N*-oxide, which was obtained by oxidation of *N,N*-dimethylaniline with *m*-chloroperbenzoic acid in $CHCl_3$.[31]

Trapping reactions of nitrosocarbonyls with dienes.

Procedure A- *N*-methyl morpholine *N*-oxide (NMO, 1.1 equiv.) was added to a nitrile oxide R-CNO solution in dichloromethane at room temperature in the presence of a slight excess (1.5 equiv.) of DMA. After keeping overnight at r.t. the organic solution was washed with water, dried and evaporated. By column chromatography excess DMA was recovered and the HDA adducts **6(a-c)** were isolated in excellent yields. Adduct **6a** (mp 125-6 °C from petroleum ether, 82%) is identical with an authentic sample prepared according to the literature procedure (mp 127-8 °C).[14] Adduct **6b** was isolated in a 95% yield; mp 128-9°C from ligroin (found: C, 73.40; H, 4.81; N, 3.71. $C_{23}H_{18}NO_2Cl$ requires C, 73.50; H, 4.83; N, 3.73%); IR: $\nu_{C=O}$ 1635 cm^{-1}; ^{1}H-nmr: 2.05 and 2.75 (s, 3H+3H, *CH*$_3$); 7.1-7.6 (m, *aromatics*). Adduct **6c** was isolated in a 60% yield, mp 183-5°C from ethanol (found: C, 81.3; H, 6.4; N, 3.6. $C_{26}H_{25}NO_2$ requires C, 81.5; H, 6.5; N, 3.7%); IR: $\nu_{C=O}$ 1645 cm^{-1}; ^{1}H-nmr: 1.7 and 2.0 (s, 6H+3H, 2,4,6-*Me*$_3$Ph); 2.2 and 2.9 (s, 3H+3H, *CH*$_3$); 6.7 (s, 2H, 2,4,6-Me$_3$*Ph*); 7.2-7.6 (m, *aromatics*). In experiments performed in the absence of the trapping agent (DMA), column chromatography of the reaction mixtures afforded the *N,O*-diaroyl hydroxylamines **12a** (32%), mp 161 °C (mp 161 °C)[32] and **12b** (26%), mp 172-4 °C (mp 172-4 °C)[33] and 2,4,6-trimethylbenzoic anhydride **9c** (35%), mp 106-7 °C (mp 106-7 °C),[34] respectively, identical with authentic specimens.

Procedure B- Hydroximoyl halides **13** (10 mmol) were added to a stirred dichloromethane solution of NMO (1.1 equiv.), Et_3N (1 equiv.) and the appropriate diene (1.5 equiv.). After keeping overnight at r.t., the organic solutions were washed with water, dried on $MgSO_4$ and evaporated. The residues were submitted to column chromatography to separate the adducts **6(d-t)** from the cycloadducts **7(d-t)**. The adducts **6** were crystallized from diisopropyl ether or distilled. Adducts **6d**, 81%, mp 105-7 °C (mp 108-110 °C)[15] and **6l**, 68%, mp 75-6 °C (mp 78-9 °C)[15] are identical to samples prepared according to the literature procedures. The analytical and spectroscopic data of all other unreported 2-oxa-3-aza-bicyclo[2.2.2]oct-5-en-3-yl and 2-oxa-3-aza-bicyclo[2.2.1]hept-5-en-3-yl derivatives **6** are given below.

6e (77%), mp 88-90 °C; (found: C, 62.7; H, 4.8; N, 5.6. $C_{13}H_{12}NO_2Cl$ requires C, 62.6; H, 4.8; N, 5.6%); $\nu_{C=O}$ 1630 cm^{-1}; δ_H 1.55, 2.3 (m, 2H+2H, *H-7*, *H-8*); 4.8, 5.4 (bs, 1H+1H, *H-1*, *H-4*); 6.5, 6.7 (bs, 1H+1H, *H-5*, *H-6*); 7.3, 7.6 (m, 2H+2H, *arom.*).

6f (79%), mp 68-69 °C; (found: C, 53.4; H, 4.1; N, 4.7. $C_{13}H_{12}NO_2Br$ requires C, 53.1; H, 4.1; N, 4.8%); $\nu_{C=O}$ 1643 cm^{-1}; δ_H 1.6, 2.3 (m, 2H+2H, *H-7*, *H-8*); 4.8, 5.4 (bs, 1H+1H, *H-1*, *H-4*); 6.5, 6.7 (bs, 1H+1H, *H-5*, *H-6*); 7.6 (m, 4H, *arom.*).

6g (72%), mp 97-8 °C; (found: C, 73.2; H, 6.6; N, 6.1. $C_{14}H_{15}NO_2$ requires C, 73.4; H, 6.6; N, 6.1%); $\nu_{C=O}$ 1605 cm^{-1}; δ_H 1.5, 2.3 (m, 2H+2H, *H-7*, *H-8*); 2.35 (s, 3H, CH_3); 4.8, 5.3 (bs, 1H+1H, *H-1*, *H-4*); 6.6, 6.7 (bs, 1H+1H, *H-5*, *H-6*); 7.2, 7.6 (m, 2H+2H, *arom.*).

6h (77%), mp 68-70 °C; (found: C, 68.8; H, 6.2; N, 5.7. $C_{14}H_{15}NO_3$ requires C, 68.6; H, 6.1; N, 5.7%); $\nu_{C=O}$ 1640 cm^{-1}; δ_H 1.6, 2.3 (m, 2H+2H, *H-7*, *H-8*); 3.8 (s, 3H, OCH_3); 4.8, 5.3 (bs, 1H+1H, *H-1*, *H-4*); 6.5, 6.7 (bs, 1H+1H, *H-5*, *H-6*); 6.9, 7.7 (m, 2H+2H, *arom.*).

6i (86%), mp 128-9 °C; (found: C, 59.7; H, 4.6; N, 10.7. $C_{13}H_{12}N_2O_4$ requires C, 60.0; H, 4.7; N, 10.8%); $\nu_{C=O}$ 1643 cm^{-1}; δ_H 1.6, 2.3 (m, 2H+2H, *H-7*, *H-8*); 4.8, 5.5 (bs, 1H+1H, *H-1*, *H-4*); 6.6, 6.8 (bs, 1H+1H, *H-5*, *H-6*); 7.8, 8.2 (m, 2H+2H, *arom.*).

6j (70%), oil; (found: C, 59.7; H, 4.6; N, 10.5. $C_{13}H_{12}N_2O_4$ requires C, 60.0; H, 4.7; N, 10.8%); $\nu_{C=O}$ 1640 cm^{-1}; δ_H 1.6, 2.3 (m, 2H+2H, *H-7*, *H-8*); 4.8, 5.5 (bs, 1H+1H, *H-1*, *H-4*); 6.6, 6.8 (bs, 1H+1H, *H-5*, *H-6*); 7.5-8.6 (m, 4H, *arom.*).

6k (65%), mp 98-100 °C; (found: C, 74.3; H, 7.5; N, 5.4. $C_{16}H_{19}NO_2$ requires C, 74.7; H, 7.4; N, 5.4%); $\nu_{C=O}$ 1601 cm^{-1}; δ_H 1.5 (m, 2H, CH_2); 2.0-2.4 (m, 11H, CH_2 and 2,4,6-Me_3Ph); 4.2, 4.57, 5.0, 5.6 (m, 2H, *H-1*, *H-4*); 6.5-6.9 (m, 4H, *H-5*, *H-6* and *Mes*).

6m (60%), mp 109-110 °C; (found: C, 74.1; H, 7.1; N, 5.8. $C_{15}H_{17}NO_2$ requires C, 74.1; H, 7.0; N, 5.8%); $\nu_{C=O}$ 1632 cm^{-1}; δ_H 1.8-2.3 (m, 11H, CH_2 and 2,4,6-Me_3Ph); 4.55, 5.23, 5.48, 5.62 (m, 2H, *H-1*, *H-4*); 6.3-6.9 (m, 4H, *H-5*, *H-6* and *Mes*).

6n (57%), bp 90 °C/$_{0.1mmHg}$; (found: C, 62.8; H, 7.3; N, 9.1. $C_8H_{11}NO_2$ requires C, 62.7; H, 7.2; N, 9.1%); $\nu_{C=O}$ 1654 cm^{-1}; δ_H 1.5, 2.15 (m, 2H+2H, *H-7*, *H-8*); 1.96 (s, 3H, CH_3CO); 4.76, 5.27 (bs, 1H+1H, *H-1*, *H-4*); 6.52, 6.63 (m, 1H+1H, *H-5*, *H-6*).

6o (86%), bp 110 °C/$_{0.1mmHg}$; (found: C, 66.1; H, 8.2; N, 7.5. $C_{10}H_{15}NO_2$ requires C, 66.3; H, 8.3; N, 7.7%); $\nu_{C=O}$ 1651 cm^{-1}; δ_H 0.91 (m, 3H, CH_3); 1.4-1.7 (m, 4H, $2CH_2$); 2.0-2.4 (m, 4H, $2CH_2$); 4,75, 5,27 (bs, 1H+1H, *H-1*, *H-4*); 6.55, 6.65 (m, 1H+1H, *H-5*, *H-6*).

6p (82%), bp 180 °C/$_{0.5mmHg}$; (found: C, 69.8; H, 9.4; N, 6.3. $C_{13}H_{21}NO_2$ requires C, 69.9; H, 9.5; N, 6.3%); $\nu_{C=O}$ 1653 cm^{-1}; δ_H 0.9 (m, 3H, CH_3); 1.3-1.7 (m, 10H, $5CH_2$); 2.0-2.4 (m, 4H, $2CH_2$); 4.75, 5.3 (bs, 1H+1H, *H-1*, *H-4*); 6.5, 6.65 (m, 1H+1H, *H-5*, *H-6*).

6q (54%), mp 71-2 °C; (found: C, 73.5; H, 6.4; N, 6.1. $C_{14}H_{15}NO_2$ requires C, 73.3; H, 6.6; N, 6.1%); $\nu_{C=O}$ 1641 cm^{-1}; δ_H 1,49 (m, 2H, CH_2); 2.1 (m, 2H, CH_2); 3.55, 3.71 (d, 2H, CH_2Ph, J=14Hz); 4.75, 5,38 (bs, 1H+1H, *H-1*, *H-4*); 6.47, 6.62 (m, 1H+1H, *H-5*, *H-6*); 7,28 (m, 5H, *arom.*).

6r (81%), oil; (found: C, 74.5; H, 6.1; N, 5.7. $C_{15}H_{15}NO_2$ requires C, 74.6; H, 6.3; N, 5.8%); $\nu_{C=O}$ 1649 cm^{-1}; δ_H 1.55 (m, 2H, *CH_2*); 2.2 (m, 2H, *CH_2*); 4.9, 5.38 (bs, 1H+1H, *H-1, H-4*); 6.5-6.8 (m, 2H, *H-5, H-6*); 6.92, 7.75 (d, 1H+1H, *CH=CH*, J=16Hz), 7.3-7.6 (m, 5H, *arom.*).

6s (27%), mp 105-6 °C; (found: C, 68.5; H, 5.3; N, 5.8. $C_{14}H_{13}NO_3$ requires C, 69.1; H, 5.4; N, 5.8%); $\nu_{C=O}$ 1641, 1669 cm^{-1}; δ_H 1.55 (m, 2H, *CH_2*); 2.26 (m, 2H, *CH_2*); 4.65, 4.71, 5.02, 5.37 (m, 2H, *H-1, H-4*); 6.5-6.8 (m, 2H, *H-5, H-6*); 7.4-8.1 (m, 5H, *arom.*).

6t (61%), mp 80-2 °C; (found: C, 68.0; H, 4.7; N, 6.0. $C_{13}H_{11}NO_3$ requires C, 68.1; H, 4.8; N, 6.1%); $\nu_{C=O}$ 1649, 1672 cm^{-1}; δ_H 1.9-2.1 (m, 2H, *CH_2*); 5.17, 5.31, 5.50, 5.54, (m, 2H, *H-1, H-4*); 6.4-6.8 (m, 2H, *H-5, H-6*); 7.4-8.1 (m, 5H, *arom.*).

The cycloadducts **7** were isolated as by-products in the trapping reactions of nitrosocarbonyls with dienes. Cycloadduct **7d**, oil[35] and **7l**, mp 47-8 °C[36] are identical to samples prepared according to the literature. Samples of the other cycloadducts **7** were similarly obtained by generating the nitrile oxides in the presence of excess diene (5 equiv.) for the purpose of tlc comparison. A few of them **7e,f,i,j,t** were isolated by column chromatography and fully characterized: **7e**, mp 78-81 °C from *i*Pr_2O; (found: C, 66.5; H, 5.3; N, 6.1. $C_{13}H_{12}NOCl$ requires C, 66.8; H, 5.2; N, 6.0%); δ_H 1.4-2.2 (m, 4H, 2*CH_2*); 3.45 (m, 1H, *CH*); 4.84 (m, 1H, *CH-O*); 6.0, 6.2 (m, 1H+1H, *CH=CH*); 7.3-7.7 (m, 2H+2H, *arom.*); **7f**, mp 91-3 °C from *i*Pr_2O; (found: C, 56.2; H, 4.3; N, 5.1. $C_{13}H_{12}NOBr$ requires C, 56.1; H, 4.4; N, 5.0%); δ_H 1.4-2.2 (m, 4H, 2*CH_2*); 3.45 (m, 1H, *CH*); 4.84 (m, 1H, *CH-O*); 6.0, 6.2 (m, 1H+1H, *CH=CH*); 7.5-7.7 (m, 4H, *arom.*); **7i**, mp 149-150 °C from *i*Pr_2O; (found: C, 64.1; H, 4.8; N, 11.4. $C_{13}H_{12}N_2O_3$ requires C, 63.9; H, 4.9; N, 11.5%); δ_H 1.4-2.2 (m, 4H, 2*CH_2*); 3.55 (m, 1H, *CH*); 4.91 (m, 1H, *CH-O*); 6.05, 6.32 (m, 1H+1H, *CH=CH*); 7.8-8.3 (m, 2H+2H, *arom.*); **7j**, mp 108-110 °C from *i*Pr_2O; (found: C, 64.0; H, 4.7; N, 11.5. $C_{13}H_{12}N_2O_3$ requires C, 63.9; H, 4.9; N, 11.5%); δ_H 1.4-2.2 (m, 4H, 2*CH_2*); 3.55 (m, 1H, *CH*); 4.9 (m, 1H, *CH-O*); 6.05, 6.23 (m, 1H+1H, *CH=CH*); 7.5-8.5 (m, 4H, *arom.*); **7t**, mp 108-110 °C from EtOH; (found: C, 73.0; H, 5.0; N, 6.1. $C_{13}H_{11}NO_2$ requires C, 73.2; H, 5.2; N, 6.6%); δ_H 1.4-2.7 (m, 4H, 2*CH_2*); 3.2 (m, 1H, *CH*); 4.6 (m, 1H, *CH-O*); 5.6, 5.7 (m, 1H+1H, *CH=CH*); 7.3-8.2 (m, 4H, *arom.*).

Timing and influence of reactant ratios in the trapping of nitrosocarbonyls 5a,c with 1,3-cyclohexadiene.

Nitrosocarbonyl **5a** was generated according to procedure B in the presence of 1.5 equiv of 1,3-cyclohexadiene. After appropriate intervals of time an excess of norbornene (20 equiv) was added. After stirring 2h at r.t. the organic solution was washed with water , dried and evaporated. The ratios of the nitrosocarbonyl adduct **6d** and the BNO cycloadduct to norbornene[37] were determined by nmr and found to increase with the delay in the addition of norbornene: 2:3 (2 min), 4:1 (4 min.), 9:1 (9 min). In similar experiments nitrosocarbonyl

5c was generated according to Procedure A and the ratios of the nitrosocarbonyl adduct **6k** and the MNO adduct to norbornene[38] were: 1:4 (0.5 h), 3:7 (1 h), 2:1 (2 h).

Nitrosocarbonyls **5a** and **5c** were generated in the presence of variable amounts of 1,3-cyclohexadiene and NMO. After keeping overnight, washing with water, drying and evaporation, the ratios of the adducts **6** and **7** were determined by nmr and are given in Table 2.

Solvent effect. Procedure B was used to perform the experiments on a 2 mmol scale in different solvents. After 12 h at room temperature, the solutions were evaporated and the residues taken up with dichloromethane and washed with water. The dried ($MgSO_4$) organic solutions were evaporated and the residues submitted to chromatographic separation affording products **6d** and **7d**. The isolated yields are reported in Table 3.

Experiments in the presence of different N-oxides. The reactions were performed according to Procedure B. After keeping the reaction mixtures 12 h at room temperature, the solutions were evaporated. The residues were taken up with dichloromethane and washed with water. The dried ($MgSO_4$) organic solutions were evaporated and the residues submitted to chromatographic separation affording products **6d** and **7d**. The isolated yields are reported in Table 4.

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