solutions (2.0 and 2–6 mL, respectively) were mixed together, and the resulting solution was taken up at 20 mL with acetic acid and heated at 60 °C. Then Mn(III) acetate (0.03 and 0.05 mmol, respectively) was added once with stirring, and the reaction was run for 6 h. The results of quantitative GC analyses of the cyclization product **14** and diastereoisomers **12** allows to deduce the [12]/[14] ration (R). The mean values of R in two independent experiments with **10** were 10.2, 21.2, 32.5, 44.3, and 55.6 by using an initial styrene concentration of 0.011, 0.019, 0.030, 0.040, and 0.051 M, respectively. Least-squares analysis of these data, by using a relationship analogous to eq 3, allows to deduce a ratio $k_a/k_c = 1126 \pm 28$ ($r = 0.9991$) for **10**.

With compound **11** only lactones **13** were formed in quantitative yield also at concentrations 1/10 lower than the one used for **10**. Dihydroindene **15** was not detected even in trace amount. These results indicate a lower limit of $k_a/k_c = 5000$ for **11**.

Acknowledgment. We thank D. Lucchini for his help in the experiments and the analytical measurements and Progetto Finalizzato Chimica Fine II (CNR, Rome) for financial support.

Registry No. **1a**, 607-81-8; **1b**, 37556-13-1; **1c**, 59223-74-4; **1d**, 134260-78-9; **1e**, 59223-73-3; **1f**, 61227-48-3; **1g**, 59803-36-0; **1h**, 6432-79-7; **1i**, 37765-73-4; **1j**, 2107-84-8; **1k**, 78383-16-1; **1m**, 14618-12-3; **2a**, 74-85-1; **2b**, 111-66-0; **2c**, 107-39-1; **2d**, 110-83-8; **2e**, 1617-18-1; **2f**, 107-18-6; **2g**, 542-92-7; **2h**, 504-60-9; **2i**, 513-81-5; **2j**, 100-42-5; **2k**, 108-05-4; **2m**, 107-13-1; **2n**, 96-33-3; **2p**, 141-05-9; **2q**, 623-91-6; **2r**, 3377-20-6; **2s**, 623-70-1; **2t**, 2396-84-1; **2u**, 754-05-2; **3ab**, 134260-79-0; **3au**, 134260-80-3; **3ba**, 134260-81-4; **3bb**, 134260-82-5; **3bc**, 134260-83-6; **3bd**, 134260-84-7; **3bd'**, 134260-85-8; **3be**, 134260-86-9; **3bf** lactone derivative, 134260-87-0; **3bh**, 134260-88-1; **3bk**, 134286-48-9; **3bm**, 134260-89-2; **3bn**, 134260-90-5; **3bp**, 134286-49-0; **3bq**, 134260-91-6; **3br**, 134260-92-7; **3bs**, 134260-93-8; **3bt**, 134260-94-9; **3bt'**, 134260-95-0; **3cb**, 134260-96-1; **3db**, 134260-97-2; **3eb**, 134260-98-3; **3eb'**, 134260-99-4; **3fb**, 134261-00-0; **3fb'**, 134261-01-1; **3gb**, 134261-02-2; **3gb'**, 134261-03-3; **3hb**, 134261-04-4; **3hb'**, 134261-05-5; **3ib**, 134261-06-6; **3jb**, 134261-07-7; **3kj**, 134261-08-8; *cis*-**3mb**, 134261-09-9; *trans*-**3mb**, 134261-10-2; **4**, 118598-49-5; **5bb**, 134261-11-3; **5bb'**, 134261-12-4; **5bc**, 134261-13-5; **5bc'**, 134261-14-6; **5bh**, 134261-15-7; **5bh'**, 134261-16-8; **5bi**, 128597-41-1; **5bi'**, 128597-40-0; **5bj**, 128597-30-8; **5bj'**, 128597-31-9; **5kj**, 134261-17-9; **5kj'**, 134261-18-0; **6bb**, 134261-19-1; **6bh**, 134261-20-4; **6bi**, 134261-21-5; **6bj**, 134261-22-6; **7bb**, 134261-23-7; **8bb**, 134261-24-8; **8bc**, 134261-25-9; **9**, 134261-26-0; **10**, 26395-09-5; **11**, 6628-68-8; **12** (isomer 1), 128597-34-2; **12** (isomer 2), 128597-35-3; **13** (isomer 1), 134261-27-1; **13** (isomer 2), 134261-28-2; **14**, 115860-33-8; **15**, 115860-31-6; FEP, 13537-24-1; CAN, 16774-21-3; Mn(III) acetate, 993-02-2; 1,2-dinitratostyrene, 134261-29-3; diethyl α-(acetoxymethyl)malonate, 30379-13-6; ethyl 4-acetoxy-2-butenoate, 65330-98-5; 2-cyclohexenyl acetate, 14447-34-8.

Supplementary Material Available: Elemental analyses and proton NMR and MS spectra of tetrahydronaphthalenes **3ba–3kj**, lactones **5bb–5kj'**, dimer **9**, and olefins **7bb**, **8bb**, **8bc** (Tables IV–IX) (10 pages). Ordering information is given on any current masthead page.

Oxidation of Diethyl (Pyridylmethyl)malonates with Mn(III) Acetate, Ce(IV) Ammonium Nitrate, and Iron(III) Perchlorate in the Presence of Alkenes and Alkynes

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The oxidation of substituted diethyl 2-, 3-, or 4-picolylmalonates (**1a–g**) by Mn(III) acetate in acetic acid, Ce(IV) ammonium nitrate in methanol or acetic acid, and Fe(III) perchlorate in acetonitrile in the presence of substituted alkenes (**2**) and alkynes (**3**) affords substituted tetra- or dihydroquinolines and/or isoquinolines (**4–9**) in good to excellent yield. The influence of reaction medium on yield and isomer distribution has been investigated. A mechanism involving oxidative deprotonation of malonic esters by high-valent metal salts to malonyl radicals, their addition to olefins, and intramolecular homolytic substitution to protonated or metal-complexed heteroaromatic bases by the resulting substituted carbon radicals is suggested.

In recent years attention has been placed on the synthetic opportunities offered by high-valent metal salt oxidations of carbonyl compounds in the presence of unsaturated substrates.[1-3] Our group was specifically involved in the research of synthetic applications of homolytic aromatic alkylation promoted by these radical sources[4] and in the extention of these reactions to different metal salt and conditions.[5] In the preceding paper we have reported examples of oxidative addition–cyclization reaction of diethyl benzylmalonates and substituted olefins induced by high-valent metal salts. Now, we present the results of similar reactions between substituted diethyl picolylmalonates (**1a–g**) and alkenes (**2**) or alkynes (**3**) to

(1) Kates, S. A.; Dombroski, B. B.; Snider, B. B. *J. Org. Chem.* **1990**, *55*, 2427 and references therein.

(2) De Klein, W. J. *Organic Syntheses by Oxidation with Metal Compounds*; Mijs, W. J., De Jonge, C. R. H. I., Eds.; Plenum Press: New York, 1986; pp 261–324.

(3) Baciocchi, E.; Ruzziconi, R. *Free Radicals in Synthesis and Biology*; Minisci, F., Ed.; NATO ASI Serie, C.260; Kluver: Dordrecht, 1989; p 146.

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(5) (a) Citterio, A.; Cerati, A.; Sebastiano, R.; Finzi, C.; Santi, R. *Tetrahedron Lett.* **1989**, *30*, 1289. (b) Citterio, A.; Sebastiano, R.; Nicolini, M.; Santi, R. *Synlett* **1990**, *1*, 42.

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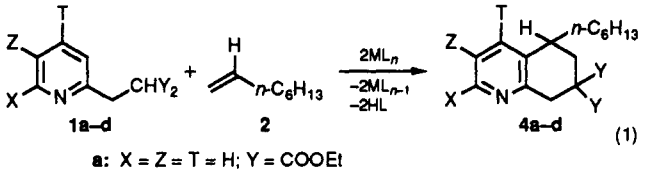
Table I. Addition–Cyclization Reaction of Substituted Picolylmalonates 1a–g and 1-Octene (2a) Induced by Mn(III) Acetate (1:2a:Mn(III) = 1:2:2; [1a] = 0.2 M, 70 °C, 12 h)

entry	1	1 (conv, %)	4–9 (yield, %)[a]
1	1a	100	90
2	1b	95	89
3	1c	89	61
4	1d	100	85
5	1e	89	83
6	1f	94	88
7	1g	100	96
8	1g[c]	48	48[b]
9	1g[d]	66 (90)[e]	62[b] (81)[b,e]

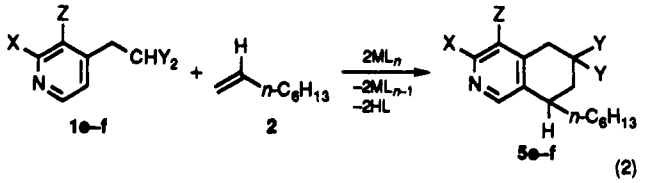
[a] Isolated product. [b] By GLC analysis. [c] Mn(III)/1a = 1/1. [d] Reaction performed in the presence of KOAc (0.4 M). [e] After 24 h.

afford substituted tetrahydro- or dihydroquinolines and/or isoquinolines (4–9) (eqs 1–4). This study was important in order to identify the influence of a basic and coordinating substrate on the kinetics and course of these metal-induced reactions.



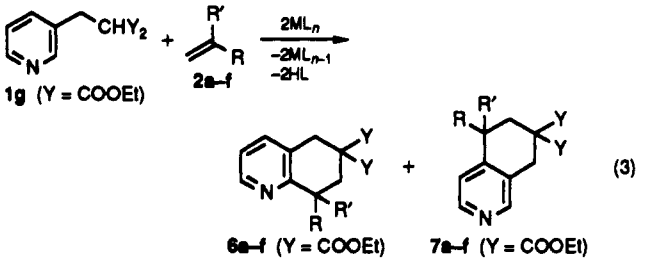
(1)

a: X = Z = T = H; Y = COOEt
b: X = T = H; Z = Et; Y = COOEt
c: X = T = Me; Z = H; Y = COOEt
d: X, Z = —CH=CHCH=CH—; T = H; Y = COOEt



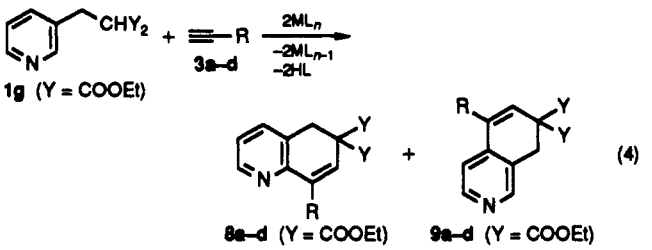
(2)

e: X = Z = H; Y = COOEt
f: X, Z = —CH=CHCH=CH—; Y = COOEt



(3)

a: R = n-C_6H_{13}; R' = H
b: R = Ph; R' = H
c: R = OAc; R' = H
d: R = n-C_5H_{11}; R' = Me
e: R = COOEt; R' = H
f: R = CN; R' = H



(4)

a: R = n-C_6H_{13}
b: R = Ph
c: R = COOEt
d: R = CN

Results

Experiments carried out with Mn(III) acetate dihydrate and diethyl 2-, 3-, and 4-picolylmalonate in the presence of 1-octene (**2a**) (Table I) indicate that the addition–cyclization reactions of eqs 1–3 are high-yield selective processes. They are significantly slower than the analogous oxidations of homocyclic substrates (8–12 h instead of 2–4 h at 70 °C) and potassium acetate further reduces the rate.

In order to study the potentiality of the reaction, we investigated more deeply the reactions of some representative terminal olefins (**2a–f**) or acetylenes (**3a, 3b**) and substrate **1g**. The choice of **1g** was suggested by the regioselectivity and reactivity problems arising from the presence of an heterocyclic nitrogen conjugated with the two possible positions of addition. Some typical results obtained in the reactions between **1g**, different metal salts, and 1-octene are reported in Table II, whereas those obtained with **1g** and different olefins are collected in Table III. $Mn(OAc)_3$ in acetic acid or in acetonitrile in the presence of trifluoroacetic acid is as efficient as Ce(IV) ammonium nitrate (CAN) in methanol or acetic acid, giving a ratio of addition–cyclization products at positions 2 and 4 ($R_{o/p}$ = 6/7) of 1.1–1.4 (Table II, entries 10, 11, 12, and 13). However, the oxidation rate with CAN is higher in methanol than in acetic acid, owing to the insolubility of the salt in the latter solvent. Fe(III) perchlorate nonahydrate (FEP) in acetonitrile is less efficient than Mn(III) and Ce(IV), and the presence of acetic acid and pyridine further decreases the conversions, keeping the selectivity high (Table II, entries 14, 16, and 17, respectively). Acetic anhydride in molar ratio to the crystallization water of FEP is strongly beneficial either as concerns the reaction rate or yield, providing an high $R_{o/p}$ (Table II, entry 15). Under these conditions, the solution remains yellow after addition of the pyridine derivative, in sharp contrast with all other metal solutions tested, which darken. Moreover, conductometric and cyclic voltametric experiments of FEP solutions in AN/Ac_2O show extensive dissociation and proton acidity combined with high oxidant power and reversibility of the couple Fe(III)/Fe(II).[6] Furthermore, $R_{o/p}$ was found to vary with

Table II. Addition–Cyclization Reaction of Diethyl 3-Picolylmalonate (1g) and 1-Octene (2a) Induced by Some Metal Oxidant ML_n (1g:2:ML_n = 1:2:2 mmol; V = 10 mL)

entry	ML_n	solvent	time (h)	T (°C)	1g conv (%)	6, 7 yield (%)[a]	$R_{o/p}$
10	$Mn(OAc)_3$	AcOH	8	70	100	95	1.4
11	$Mn(OAc)_3$	MeCN[b]	12	20	90	95	1.1
12	$Ce(NH_4)_2(NO_3)_6$	MeOH	1.5	20	95	89	0.87
13	$Ce(NH_4)_2(NO_3)_6$	AcOH	12	20	92	96	0.44
14	$Fe(ClO_4)_3$	MeCN	20	20	64	86	0.37
15	$Fe(ClO_4)_3$	MeCN[c]	1.5	20	100	95	6.6
16	$Fe(ClO_4)_3$	MeCN[d]	12	20	11	98	0.20
17	$Fe(ClO_4)_3$	MeCN[e]	4	20	20	97	0.36

[a] Based on converted 1g. [b] In the presence of trifluoroacetic acid (6 mmol). [c] In the presence of Ac_2O (9 mol for 1 mol of FEP). [d] In the presence of acetic acid (20 mmol for 1 mol of FEP). [e] In the presence of pyridine (1 mol for 1 mol of FEP).

Table III. Addition–Cyclization Reaction of Diethyl 3-Picolylmalonate (1g) and Alkenes 2b–f or Alkynes 3a–b Induced by Some Metal Oxidant ML_n (1g:2:ML_n = 1:2:2 mmol; V = 10 mL)

ML_n	solvent	2, 3	time (h)	T (°C)	1g conv (%)	6, 7 yield (%)[a]	$R_{o/p}$
$Mn(OAc)_3$	AcOH	**2b**	6	60	70	69	0.5[b]
$Fe(ClO_4)_3$	MeCN	**2b**	6	20	75	3[c]	–
$Fe(ClO_4)_3$	MeCN[d]	**2b**	1.5	20	85	–[e]	–
$Mn(OAc)_3$	AcOH	**2c**	6	60	100	92	1.14
$Ce(NH_4)_2(NO_3)_6$	MeOH	**2c**	1	20	95	33	0.75
$Fe(ClO_4)_3$	MeCN	**2c**	4	20	74	20[f]	0.4
$Fe(ClO_4)_3$	MeCN[d]	**2c**	1	20	90	–[g]	–
$Mn(OAc)_3$	AcOH	**2d**	12	60	80	93	1.17
$Fe(ClO_4)_3$	MeCN	**2d**	2	20	30	33	0.98
$Mn(OAc)_3$	AcOH	**2e**	12	60	40	50[h]	1.7[i]
$Mn(OAc)_3$	AcOH	**2f**	12	60	46	(19)[h]	1.6[i]
$Mn(OAc)_3$	AcOH	**3a**	12	60	85	80	1.85
$Fe(ClO_4)_3$	MeCN	**3a**	12	20	45	84	1.87
$Ce(NH_4)_2(NO_3)_6$	MeOH	**3a**	2	20	72	70	1.84
$Mn(OAc)_3$	AcOH	**3b**	12	60	59	74	1.94
$Fe(ClO_4)_3$	MeCN	**3b**	12	20	48	75	1.89

[a] Based on converted base. [b] Ratio of isomers **6b**/**7b**, without taking into consideration other products formed, in particular compound **8b** (11% yield). [c] The main products were γ-lactones (70% yield). [d] In the presence of acetic anhydride (6 mmol). [e] Mixture of acetamidation products. [f] A complex mixture of products was formed. [g] γ-Lactones and unsaturated addition products were formed. [h] Detected by GC–MS along with other products of further oxidation. [i] Attributed on the basis of GC–MS analysis.

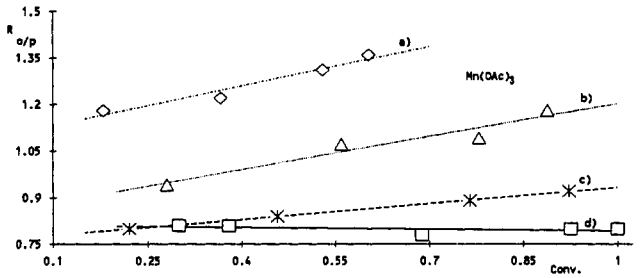


Figure 1. Dependence of the ratio of addition to positions 2 and 4 ($R_{o/p}$) on **1g** conversion in the oxidation of **1g** in the presence of 1-octene by $Mn(OAc)_3 \cdot 2H_2O$. (a) [Mn(III)] = 0.125 M; (b) [Mn(III)] = 0.20 M; (c) [Mn(III)] = 0.30 M; [Mn(III)] = 0.40 M; AcOH, 70 °C, N_2.

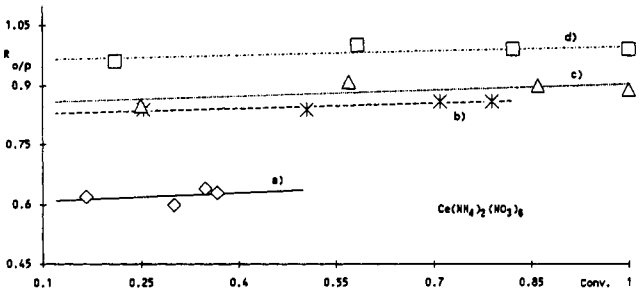


Figure 2. Dependence of the ratio of addition to positions 2 and 4 ($R_{o/p}$) on **1g** conversion in the oxidation of **1g** in the presence of 1-octene by $Ce(NH_4)_2(NO_3)_6$. (a) [Ce(IV)] = 0.10 M; (b) [Ce(VI)] = 0.20 M; (c) [Ce(IV)] = 0.30 M; (d) [Ce(IV)] = 0.40 M; MeOH, 20 °C, N_2.

the initial concentration of FEP, $Mn(OAc)_3$, and CAN and to depend on substrate conversions with the first two salts but not with the last (Figures 1–3). The slopes of least-square analysis of the data reported in Figures 1–3 correlate linearly to the initial concentration of the metal with constant (CAN) or negative slopes (–1.4 and –1.1 for $Mn(OAc)_3$ and FEP, respectively; see the Experimental Section). The acidity produced in these oxidations favors the 2-addition product, whereas high metal concentrations favor the 4-addition product.

The results of Table III indicate that alkenes are more efficient trapping agents than the similarly substituted alkynes. Apparent exceptions to this general trend are the

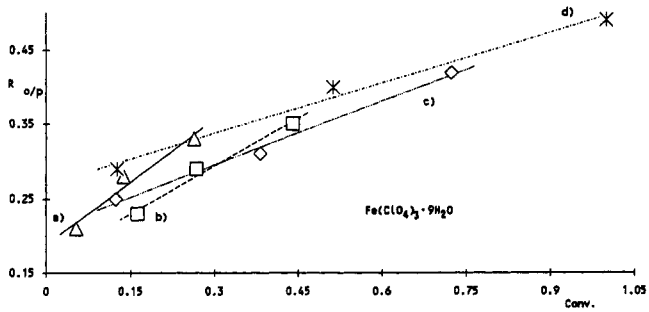


Figure 3. Dependence of the ratio of the addition to positions 2 and 4 ($R_{o/p}$) on **1g** conversion in the oxidation of **1g** in the presence of 1-octene by $Fe(ClO_4)_3 \cdot 9H_2O$. (a) [Fe(III)] = 0.10 M; (b) [Fe(III)] = 0.20 M; (c) [Fe(III)] = 0.30 M; (d) [Fe(III)] = 0.40 M; MeCN, 20 °C, N_2.

olefins substituted by electron-withdrawing COOEt or CN groups, where further oxidations or nucleophilic additions of the addition–cyclization products **6** and **7** form side products. Moreover, no significant difference is observed in reactions with alkynes **3a** or **3b** and all oxidant metal salts used, with a ratio $R_{o/p}$ = 1.85 ± 0.02, independent of the metal used.

Addition–oxidation products (i.e. γ-lactones) are observed in reactions with 1,1-disubstituted or conjugated olefins (i.e. **2c** or **2b**) in increasingly higher yield with CAN and FEP than with Mn(III). Furthermore, FEP and $Mn(OAc)_3$ oxidize **1g** in the presence of vinyl acetate to **6c** and **7c**, but again the presence of acetic anhydride is essential in experiments with FEP.

Discussion

The present study allows for the identification the following general features of the oxidative addition–cyclization reaction of α-heteroarylmethylmalonic esters and olefins promoted by high-valent metal salts: (1) the reaction is generally efficient, selective, and synthetically useful; (2) (when compared with benzylmalonates) the basic and coordinating nature of substrates **1** lowers the oxidation rate with all metals tested, and decreases or increases the yield of reactions with olefins substituted by electron-withdrawing or 1,1-dialkyl groups, respectively; (3) the regioselectivity of the intramolecular cyclization is affected by the acidity of the medium and the metal ligands. These observations can be rationalized by taking into account the homolytic nature of the reaction[4] which

(6) Kotani, E.; Kobayashi, S.; Ishii, Y.; Tobinaga, S. *Chem. Pharm. Bull.* **1984**, *32*, 4281.

Scheme I

$$ML_n + R{-}Py \rightleftharpoons ML_{n-1}Py{-}R^+ + L^- \quad (5)$$

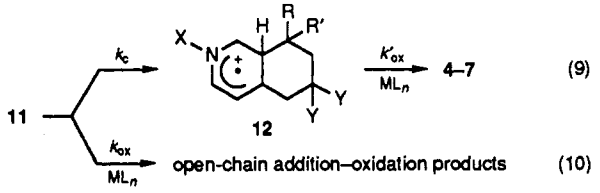
$$ML_n + HetCH_2CH(COOEt)_2 \rightleftharpoons HL + ML_{n-1}C(COOEt)_2CH_2Het \quad (6)$$

$$ML_{n-1}C(COOEt)_2CH_2Het \rightleftharpoons ML_{n-1} + HetCH_2\dot{C}(COOEt)_2 \quad (7)$$

10

$$HetCH_2\dot{C}(COOEt)_2 + CH_2{=}CRR' \longrightarrow HetCH_2C(COOEt)_2CH_2\dot{C}RR' \quad (8)$$

11

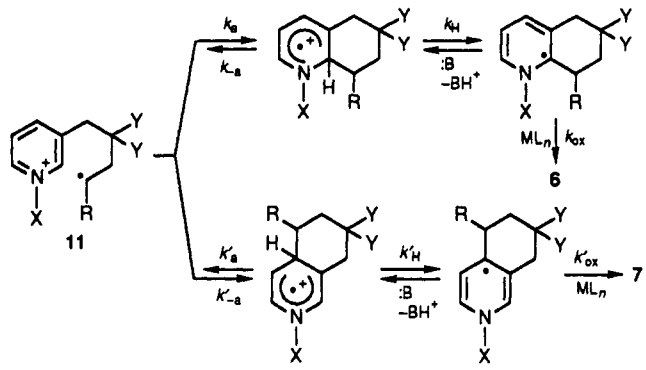


involves generation of malonyl radicals **10** from metal–malonate complexes, their efficient addition to olefins, and intramolecular trapping of the resulting substituted alkyl radicals **11** by the heteroaromatic ring with rearomatization (Scheme I).

The darkening of all solutions of metal tested after addition of **1** indicates that complexes between the metal and basic heterocycle are formed. The process is probably negligible only in experiments with FEP in AN/A_2O. The coordination to nitrogen (eq 5) competes with coordination to the β-dicarbonyl group (eq 6) and leads to a lower steady-state concentration of the intermediate metal–malonate complex responsible for the reversible generation of malonyl radicals and initiation of the homolytic stoichiometric reaction (eq 7). Nitrogen complexation is less efficient in the presence of acids, owing to the protonation of the base. Acids strongly affect these reactions, either as concerns the rate and the regioselectivity of the substitution. However, the overall process remains efficient and general owing to the high rates of the addition of malonyl radicals to olefins independently from substitution (eq 8)[7] and to the high rate of the intramolecular alkyl radical trapping by the heteroaromatic ring (eq 9).

The homolytic aromatic alkylation of heteroaromatic bases is a well-studied reaction,[8] whose rate is known to be increased by protonation and metal coordination[9] and to be decreased by steric hindrance of substituents in the ortho position to the attached carbon atom.[10,11] The lower yield of **4** and slower rate found in the reaction with substrate **1c** than with **1a** and **1b** (Table I, entry 3) can be related to the presence of the ortho methyl group. A similar steric inhibition seems to operate in controlling the regioselectivity of the addition to substrate **1g**. Previous studies[8b,c] using different alkyl radical sources led to the conclusion that the regioselectivity in the intermolecular homolytic alkylation of protonated heteroaromatic bases is the result of a complex interplay of effects of reversibility, acid–base equilibria, and oxidation properties of the medium. Extrapolation of these conclusions to the present system allows us to identify in Scheme II the possible elementary steps responsible for the regioselectivity of the addition: (1) different kinetic reactivity of position 2 and

Scheme II[a]



[a] X = H, ML_{n-1}.

4 to the heterocyclic nitrogen (k_a and k'_a); (2) different reversibility of the addition (k_a/k_{-a} and k'_a/k'_{-a}); (3) different deprotonation rate of cation radicals (k_H and k'_H); (4) different oxidation rate of 2- and 4-pyridinyl radicals by the metal (k_{ox}, k'_{ox}).

The complexity of the process helps to explain the remarkable changes in the ratio $R_{o/p} = 6/7$, reported in Table III and Figures 1–3. However, one parameter can be clearly isolated. Reactions 1–4 produce stoichiometric amounts of acid, and this causes competition between intramolecular cyclization on protonated and metal-complexed heterocyclic adduct **11** (X = H or ML_{n-1}). A previous study[9a] has reported that alkyl radicals show similar reactivity toward protonated and iron(III)-complexed heteroaromtic bases, and that the addition to position 2 in the latter case is sterically inhibited. All other parameters being the same, the steric requirements of the heterocyclic nitrogen are less important in protonation than in complexation. Therefore, substitution at position 2 increases with substrate conversion (Figures 1–3). We found that for all metals used eq 11 (where the ratio $[H^+]/[M^{n+}]$ can be deduced from eq 12) holds and the slope (α) is constant at high metal to substrate ratio and decreases in the opposite conditions. These data suggest the formation of 1:1 metal to base complex in the first case and several different complexes at high base to metal ratios.

$$R_{o/p} = \alpha[[H^+]/[M^{n+}]] + \beta \quad (11)$$

$$\frac{[H^+]}{[M^{n+}]} = \frac{[H^+]_o + 2\ \mathrm{Conv} \times [1g]_o}{[M^{n+}]_o - 2\ \mathrm{Conv} \times [1g]_o} \quad (12)$$

The effect is particularly relevant with iron(III) perchlorate in acetonitrile/acetic anhydride, because the iron(III) acetic acid solvate present in these solutions is a strong acid and a fully reversible oxidant ($E^\circ = 1.73$ V).[6] The complete protonation of the base and the high oxidation rate of the carbonyl compound results in an high value of $R_{o/p}$. On the contrary, the higher coordinating power and the lower acidity of iron(III) hexaquo complex present in solutions of FEP in AN determines the preferential formation of the 4-addition product.

$$Fe(H_2O)_6^{3+} \rightleftarrows H^+ + Fe^{2+}(H_2O)_5OH$$

$$Fe(AcOH)_6^{3+} \rightleftarrows H^+ + Fe^{2+}(AcOH)_5OAc$$

In more buffered media, i.e. $Mn(OAc)_3$ in acetic acid or CAN in methanol, $R_{o/p}$ shows lower variations, but the presence of trifluoroacetic acid in the Mn(III) acetate reactions results in similar increase of rate and changes of isomers distribution. These results lead one to formulate the following general conclusion for the best experimental

(7) Preliminary results were presented at OMCOS V Conference (Florence), 1989.

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conditions to direct the homolytic substitution on heteroaromatic bases at 2- and 4-positions: addition of carbon radicals occurs preferentially at position 2 in a high acid and oxidant medium, whereas position 4 is attached preferentially when metal complexes of the heteroaromatic base and a moderate oxidant medium are involved.

As concerns the influence of olefin substituents on the efficiency of reactions 1–4, the electron-poor nature of protonated or metal-complexed heteroaromatic bases favors the addition of nucleophilic carbon free radicals,[8] arising from olefins substituted with electron-releasing groups. The effect is more pronounced in the addition to positions 2 and 4 to the heterocyclic nitrogen of **1g**, owing to the direct conjugation with the electron-withdrawing group. Despite the intramolecular nature of the process, electrophilic carbon radicals (i.e. α-cyano and α-carbonylalkyl radicals) add inefficiently to the heterocycle, in contrast with the efficient addition–cyclization process observed with benzylmalonic esters[7] and intramolecular cyclization of diethyl (ω-arylalkyl)malonates.[4] On the contrary, tertiary alkyl radicals arising from the addition to olefin **2c** are efficiently trapped by the base without significant oxidation by $Mn(OAc)_3$, whereas they are efficiently oxidized when generated from substrates in the homocyclic series. These results agree with previous estimates of the addition rate constants of tertiary alkyl radicals to protonated heteroaromatic bases in the range 10^6–10^7 M^{-1} s^{-1} at 25–60 °C.[11] The competition between the intramolecular aromatic substitution and oxidation of carbon radical adduct to the olefin becomes more pronounced with metal salts more oxidant than $Mn(OAc)_3$ ($E°$ = 0.9 V vs NHE,[12] compared with $E°$ = 1.73 V for FEP[6] and $E°$ = 1.4 V for CAN[13]).

The metal oxidant is also responsible for the further oxidation of the addition–cyclization products **6b**, **6e**, **6f**, **7b**, **7e**, and **7f** to unsaturated compounds **8b**, **8e**, **8f** and **9f**. Control experiments of oxidation of cyclized product **6b** gave in fact **8b** in moderate yield. Therefore, benzylic protons in compounds **6** and **7** appear to be acidic enough to allows oxidative α-deprotonation by high valent metal salts, in close analogy to carbonyl and nitro derivatives.[1,13] A further support to this interpretation comes from the efficient oxidation of 2-benzylpyridine by Mn(III) acetate to the corresponding benzylic alcohol and carbonyl derivative in 15 and 55%, respectively.[14]

In conclusion, this work outlines the potentiality and limits of reactions 1–4 and points out the main factors to be considered in projecting syntheses by these addition–cyclization processes.

Experimental Section

General Methods. Separations and analysis were obtained by general methods and instruments reported in the previous article.

Materials. Mn(III) acetate dihydrate (Fluka) was tested by iodometric titration for purity. $Fe(ClO_4)_3{\cdot}9H_2O$ was tested by back-titration with a 0.1 M $TiCl_3$ solution, standardized against $Ce(SO_4)_2$. Acetic acid and acetonitrile were freshly distilled from P_2O_5; methanol was distilled from Mg turnings. All the olefins were commercial products having a purity higher than 98%; they were distilled before the use. Starting materials **1a–g** were synthesized in 50–80% yield from picolyl chloride hydrochlorides and the anion of diethyl malonate (prepared from NaH in THF), as reported in the previous article. Compounds **1b–d** and **1g** were found to be unstable to heating. The analytical data of compounds **1a–g** are collected in Table IV (supplementary material).

General Procedure for the Reaction between 1, 2, and Mn(III) Acetate. Acetic acid (10 mL) is added in a two-necked flask equipped with a N_2 inlet device and a magnetic bar. N_2 is flushed for 5 min, and then Mn(III) acetate is added. A solution of 1 (1 mmol) and 2 (2 mmol) in acetic acid is added to the resulting stirred slurry. The mixture obtained is heated at 70 °C until the color fades or for 12 h, when the mixture remains dark. The suspension is evaporated at 30 mmHg, the residue is taken up with ethyl acetate and a saturated aqueous solution of $NaHCO_3$, the layers are separated, and the water is extracted twice with ethyl acetate. The combined extracts are washed with 10% $NaHCO_3$ and water, dried, evaporated, and flash chromatographed through SiO_2 to isolate compounds **4–9**. The separation of isomers **6**, **7** or **8**, **9** was generally easy owing to quite different retention times on SiO_2. Mass spectra data of compounds **4a–d**, **5e**, **5f**, **6a–e**, **7a–e**, **8a–b**, and **9a–b** are collected in Table V (supplementary material).

7,7-Bis(ethoxycarbonyl)-5-hexyl-5,6,7,8-tetrahydroquinoline (4a). Anal. Calcd for $C_{21}H_{31}NO_4$: C, 69.78; H, 8.64; N, 3.87. Found: C, 69.6; H, 8.8; N, 3.6. MS: 361 ($M^{\bullet+}$, 39), 290 (100). ^1H NMR: 8.37 (ddd, 1 H, H_2, J = 4.5, 1.3, and 0.7 Hz), 7.53 (dd, 1 H, H_4, J = 7.7 and 1.3 Hz), 7.09 (dd, 1 H, H_3, J = 7.7 and 4.5 Hz), 4.24 and 4.11 (m, 4 H), 3.58 (dd, 1 H, H_{8a}, J = 17 and 2.3 Hz), 3.22 (dd, 1 H, H_{8b}, J = 17 and 0.6 Hz), 2.92 (m, 1 H, H_{5a}), 2.64 (ddd, 1 H, H_{6a}, J = 13.5, 6.0, and 2.3 Hz), 1.86 (dd, 1 H, H_{6b}, J = 13.5 and 11 Hz), 1.8 and 1.5 (2 m, 2 H), 1.17–1.41 (m, 8 H, aliph), 1.28 and 1.33 (2 t, 6 H), 0.89 (t, 3 H).

3-Ethyl-5-hexyl-7,7-bis(ethoxycarbonyl)-5,6,7,8-tetrahydroquinoline (4b). Anal. Calcd for $C_{23}H_{35}NO_4$: C, 70.92; H, 9.06; N, 3.60. Found: C, 71.1; H, 9.2; N, 3.5. MS: 389 ($M^{\bullet+}$, 16), 318 (100). ^1H NMR: 8.4 (d, 1 H, H_2, $J_{2,4}$ = 1.9 Hz), 7.6 (d, 1 H, H_4), 4.3–4.0 (m, 4 H), 3.6 (dd, 1 H, H_{8a}, J = 17 and 2.5), 3.2 (dd, 1 H, H_{8b}, J = 17 and 0.6 Hz), 3.0 (m, 1 H, H_{5a}), 2.6 (ddd, 1 H, H_{6a}, J = 13, 6, and 2.5 Hz), 2.1 (q, 2 H), 1.9 (dd, 1 H, H_{6b}, J = 13 and 11 Hz), 1.8 and 1.5 (2 m, 2 H), 1.4–1.1 (m, 8 H, aliph), 1.3 (t, 6 H), 1.0 (t, 3 H, Me), 0.9 (t, 3 H).

2,4-Dimethyl-5-*n*-hexyl-7,7-bis(ethoxycarbonyl)-5,6,7,8-tetrahydroquinoline (4c). Anal. Calcd for $C_{23}H_{35}NO_4$: C, 70.92; H, 9.06; N, 3.60. Found: C, 72.0; H, 9.1; N, 3.4; MS: 389 ($M^{\bullet+}$, 26), 318 (100). ^1H NMR: 7.1 (s, 1 H), 4.4–4.0 (m, 4 H), 3.7 (dd, 1 H, J = 16 and 2 Hz), 3.3 (dd, 1 H, J = 16 and 0.5 Hz), 2.9 (m, 1 H), 2.6 (ddd, 1 H, J = 14 and 2 Hz), 2.0 and 1.9 (2 s, 6 H), 1.9 (dd, 1 H, J = 14 and 11 Hz), 1.8 and 1.5 (2 m, 2 H), 1.4–1.1 (m, 8 H, aliph), 1.3 (t, 6 H), 0.9 (t, 3 H).

1-Hexyl-3,3-bis(ethoxycarbonyl)-1,2,3,4-tetrahydroacridine (4d). Anal. Calcd for $C_{25}H_{33}NO_4$: C, 72.96; H, 8.08; N, 3.40. Found: C, 73.5; H, 8.1; N, 3.5. MS: 411 ($M^{\bullet+}$, 51), 340 (100). ^1H NMR: 8.5 (s, 1 H, H_4), 8.1 (dd, 1 H, H_9, $J_{8,9}$ = 7.7 Hz, $J_{7,9}$ = 4.5 Hz), 7.5–7.0 (m, 3 H), 4.4 and 4.1 (m, 4 H), 3.6 (dd, 1 H, H_{4a}, J = 17 and 2.7), 3.2 (dd, 1 H, H_{4b}, J = 17 and 0.6 Hz), 2.9 (m, 1 H, H_{1a}), 2.64 (ddd, 1 H, H_{2a}, J = 13.5, 6, and 2.3 Hz), 1.9 (dd, 1 H, H_{2b}, J = 13.5 and 11 Hz), 1.9 and 1.5 (2 m, 2 H), 1.2–1.4 (m, 8 H, aliph), 1.3 (2 t, 6 H), 0.9 (t, 3 H).

6,6-Bis(ethoxycarbonyl)-8-hexyl-5,6,7,8-tetrahydroisoquinoline (5e). Anal. Calcd for $C_{21}H_{31}NO_4$: C, 69.78; H, 8.64; N, 3.87. Found: C, 69.8; H, 8.6; N, 3.8. MS: 361 ($M^{\bullet+}$, 25), 130 (100). ^1H NMR: 8.47 (s, 1 H, H_1), 8.30 (d, 1 H, H_3, J = 4.9 Hz), 7.03 (d, 1 H, H_4), 4.22 and 4.10 (2 q, 4 H), 3.32 (dd, 1 H, H_{5a}, J = 16.6 and 2.3 Hz), 3.08 (dt, 1 H, H_{5b}, J = 16.6 and 0.7 Hz), 2.84 (m, 1 H, H_{8a}), 2.66 (ddd, 1 H, H_{7a}, J = 13.5, 6.3, and 2.3 Hz), 1.92 and 1.61 (2 m, 2 H), 1.85 (dd, 1 H, H_{7b}, J = 13.5 and 10.8 Hz), 1.20–1.42 (m, 8 H, aliph), 1.28 and 1.15 (2 t, 6 H), 0.89 (t, 3 H).

6,6-Bis(ethoxycarbonyl)-8-hexyl-5,6,7,8-tetrahydrophenanthridine (5f). Anal. Calcd for $C_{25}H_{33}NO_4$: C, 72.96; H, 8.08; N, 3.40. Found: C, 73.7; H, 8.2; N, 3.4. MS: 411 ($M^{\bullet+}$, 42), 340 (100). ^1H NMR: 8.5 (s, 1 H, H_4), 8.1 (dd, 1 H, H_9, $J_{8,9}$ = 7.7 Hz, $J_{7,9}$ = 4.5 Hz), 7.5–7.0 (m, 3 H), 4.4 and 4.1 (m, 4 H), 3.6 (dd, 1 H, H_{4a}, J = 17, 2.7), 3.2 (dd, 1 H, H_{4b}, J = 17, 0.6 Hz), 2.9 (m, 1 H, H_{1a}), 2.64 (ddd, 1 H, H_{2a}, J = 13.5, 6, and 2.3 Hz), 1.9 (dd, 1 H, H_{2b}, J = 13.5 and 11 Hz), 1.9 and 1.5 (2 m, 2 H), 1.2–1.4 (m, 8 H, aliph), 1.3 and 1.1 (t, 3 H), 0.9 (t, 3 H).

6,6-Bis(ethoxycarbonyl)-8-hexyl-5,6,7,8-tetrahydroquinoline (6a). Anal. Calcd for $C_{21}H_{31}NO_4$: C, 69.78; H, 8.64; N, 3.87. Found: C, 69.9; H, 8.8; N, 3.7. MS: 361 ($M^{\bullet+}$, 10), 277

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(100). ^{1}H NMR: 8.43 (dd, 1 H, H_2, J = 1.6, 4.8 Hz), 7.40 (dd, 1 H, H_4, J = 1.6 and 7.6 Hz), 7.04 (ddd, 1 H, H_3, J = 0.8, 4.8, and 7.6 Hz), 4.23 and 4.11 (2 q, 4 H), 3.36 (dd, 1 H, H_{5a}, J = 16.4 and 2.4 Hz), 3.13 (ddd, 1 H, H_{5b}, J = 16.4, 6.4, and 2.4 Hz), 2.25 and 1.52 (m, 1 H), 1.94 (dd, 1 H, H_{7b}, J = 13.6 and 10.8 Hz), 1.52 (m, 1 H), 1.28 and 1.15 (m, 8 H, aliph), 0.88 (t, 3 H).

7,7-Bis(ethoxycarbonyl)-5-hexyl-5,6,7,8-tetrahydroisoquinoline (7a). Anal. Calcd for $C_{21}H_{31}NO_4$: C, 69.78; H, 8.64; N, 3.87. Found: C, 69.7; H, 8.7; N, 3.6. MS: 361 ($M^{\bullet+}$, 41), 202 (100). ^{1}H NMR: 8.35 (s, 1 H, H_1), 8.33 (d, 1 H, H_3, J = 5.2 Hz), 7,13 (d, 1 H, H_4), 4.23 and 4.10 (2 q, 4 H), 3.37 (dd, 1 H, H_{8a}, J = 16 and 2.4 Hz), 3.07 (dd, 1 H, H_{8b}, J = 16 and 1.2 Hz), 2.92 (m, 1 H, H_{5a}), 2.65 (ddd, 1 H, H_{6a}, J = 13.6, 6.4, and 2.4 Hz), 1.90 and 1.57 (2m, 2 H), 1.81 (dd, 1 H, H_{6b}, J = 13.6 and 10.8 Hz), 1.28 and 1.13 (t, 3 H), 1.18–1.32 (m, 8 H, aliph), 0.89 (t, 3 H).

6,6-Bis(ethoxycarbonyl)-8-phenyl-5,6,7,8-tetrahydroquinoline (6b). Anal. Calcd for $C_{21}H_{23}NO_4$: C, 71.37; H, 6.56; N, 3.96. Found: C, 71.5; H, 6.6; N, 3.8. MS: 353 ($M^{\bullet+}$, 56), 206 (100). ^{1}H NMR: 8.39 (dd, 1 H, H_2, $J_{2,3}$ = 4.5 Hz, $J_{2,4}$ = 1.8 Hz), 7.49 (dd, 1 H, H_4, J = 8 and 1.8 Hz), 7.04–7.35 (m, 6 H, Ar and H_3), 4.34 (dd, 1 H, H_{8b}, J = 11.2 and 6.3 Hz), 4.01–4.25 (m, 4 H), 3.47 (dd, 1 H, H_{5a}, J = 16.6 and 2.25 Hz), 3.35 (dd, 1 H, H_{5b}, J = 16.6 and 0.9 Hz), 2.94 (ddd, 1 H, H_{7a}, J = 14, 6.3, and 2.3 Hz), 2.33 (dd, 1 H, H_{7b}, J = 14 and 11.2 Hz), 1.22 and 1.20 (2 t, 6 H).

5-Phenyl-7,7-bis(ethoxycarbonyl)-5,6,7,8-tetrahydroisoquinoline (7b). Anal. Calcd for $C_{21}H_{23}NO_4$: C, 71.37; H, 6.56; N, 3.96. Found: C, 71.4; H, 6.4; N, 4.0. MS: 353 ($M^{\bullet+}$, 9), 206 (100). ^{1}H NMR: 8.44 (s, 1 H, H_1), 8.24 (d, 1 H, H_3, J = 5.3 Hz), 7.1–7.4 (m, 6 H, Ar), 6.70 (d, 1 H, H_4), 4.09–4.26 (m, 5 H), 3.53 (dd, 1 H, H_{8b}, J = 16.5 and 2.3 Hz), 3.26 (dd, 1 H, H_{8a}, J = 16.5 and 1 Hz), 2.81 (ddd, 1 H, H_{6b}, J = 13.7, 6.2, and 2.3 Hz), 2.21 (ddd, 1 H, H_{6a}, J = 13.7 and 11.7 Hz), 1.25 and 1.21 (2 t, 3 H).

6,6-Bis(ethoxycarbonyl)-8-acetoxy-5,6,7,8-tetrahydroquinoline (6c). Anal. Calcd for $C_{17}H_{21}NO_6$: C, 60.89; H, 6.31; N, 4.18. Found: C, 60.6; H, 6.5; N, 4.3. MS: 335 ($M^{\bullet+}$, 2), 29 (100). ^{1}H NMR: 8.52 (d, 1 H, H_2), 7.52 (d, 1 H, H_4), 7.21 (dd, 1 H, H_3, J = 8 and 4.5 Hz), 6.07 (t, 1 H, H_{8a}, J = 5.5 Hz), 4.1–4.3 (m, 4 H), 3.48 and 3.14 (2 d, 2 H, H_5, J = 16.5 Hz), 2.77 (dd, 1 H, H_{7a}, J = 15, 5.5 Hz), 2.68 (dd, 1 H, H_{7b}, J = 15, 5.5 Hz), 2.08 (s, 3 H), 1.25 and 1.24 (2 t, 6 H).

7,7-Bis(ethoxycarbonyl)-5-acetoxy-5,6,7,8-tetrahydroisoquinoline (7c). Anal. Calcd for $C_{17}H_{21}NO_6$: C, 60.89; 6.31; N, 4.18. Found: C, 61.0; H, 6.2; N, 4.2. MS: 335 ($M^{\bullet+}$, 1), 29 (100). ^{1}H NMR: 8.48 (s broad, 1 H, H_1), 8.43 (d broad, 1 H, H_3), 7.15 (d broad, 1 H, H_4), 6.05 (t, 1 H, H_{5a}), 4.04–4.33 (m, 4 H), 3.37 and 3.21 (d, 2 H, H_8, J = 16.5 Hz), 2.76 (dd, 1 H, H_{6a}, J = 14 and 5.5 Hz), 2.4 (dd, 1 H, H_{6b}, J = 14 and 7 Hz), 2.11 (s, 3 H), 1.25 and 1.24 (2 t, 6 H).

6,6-Bis(ethoxycarbonyl)-8-pentyl-8-methyl-5,6,7,8-tetrahydroquinoline (6d). Anal. Calcd for $C_{21}H_{31}NO_4$: C, 69.78; H, 8.64; N, 3.87. Found: C, 69.7; H, 8.8; N, 3.7. MS: 361 ($M^{\bullet+}$, 2), 291 (100). ^{1}H NMR: 8.45 (dd, 1 H, H_2, $J_{2,3}$ = 4.6 Hz, $J_{2,4}$ = 1.6 Hz), 7.41 (dd, 1 H, H_4, J = 7.3 and 1.6 Hz), 7.03 (dd, 1 H, H_3, J = 7.3 and 4.6 Hz), 4.0–4.3 (m, 4 H), 3.31 and 3.05 (dd, 2 H, H_5, J = 16.5 Hz), 2.51 (d, 1 H, H_{7b}, J = 14.5 Hz), 2.35 (dd, 1 H, H_{7a}, J = 14.5 and 2 Hz), 1.72 (m, 2 H), 1.27 and 1.21 (2 t, 6 H), 1.26 (s, 3 H), 1.1–1.4 (m, 6 H, aliph), 0.84 (t, 3 H).

7,7-Bis(ethoxycarbonyl)-5-pentyl-5-methyl-5,6,7,8-tetrahydroisoquinoline (7d). Anal. Calcd for $C_{21}H_{31}NO_4$: C, 69.78; H, 8.64; N, 3.87. Found: C, 69.8; H, 8.6; N, 3.8. MS: 361 ($M^{\bullet+}$, 11), 39 (100). ^{1}H NMR: 8.38 (s, 1 H, H_1), 8.37 (d, 1 H, H_3, J = 5.4 Hz), 7.10 (d, 1 H, H_4), 4.0–4.3 (m, 4 H), 3.33 and 2.99 (dd, 2 H, H_8, J = 16.5, 1.6 Hz), 2.39 (d, 1 H, H_{6b}, J = 14 Hz), 2.25 (dd, 1 H, H_{6a}, J = 14, 1.6 Hz), 1.5–1.6 (m, 2 H), 1.27 and 1.19 (2 t, 6 H), 1.22 (s, 3 H), 1.1–1.32 (m, 6 H, aliph), 0.84 (t, 3 H).

6,6,8-Tris(ethoxycarbonyl)-5,6,7,8-tetrahydroquinoline (6e). Anal. Calcd for $C_{18}H_{23}NO_6$: C, 61.88; H, 6.64; N, 4.01. Found: C, 62.0; H, 6.7; N, 3.9. MS: 349 ($M^{\bullet+}$, 12), 276 (100). ^{1}H NMR: 8.47 (ddd, 1 H, H_2, J = 4.7, 1.7, and 0.7 Hz), 7.49 (broad d, 1 H, H_4, J = 7.6 and 1.5 Hz), 7.24 (dd, 1 H, H_3, J = 7.6 and 4.7 Hz), 4.43, 4.33, and 4.13 (3 q, 9 H), 4.39 (d, 1 H, H_{8a}), 3.29 (dd, 1 H, H_{5a}, J = 16 and 1.5 Hz), 3.19 (dd, 1 H, H_{5b}, J = 16 and 0.7 Hz), 2.3 and 1.7 (broad, 2 H, H_7), 1.37, 1.34, and 1.13 (3 t, 9 H).

All attempts to isolate compound **7e** were unsuccessful. It was identified by GC–MS analysis of the crude reaction mixture. **7e**. MS: 349 ($M^{\bullet+}$, 28), 276 (100). It was also detected an oxidation product having the retention time of compound **8e**, independently prepared. **8e**. MS: 363 (11), 290 (100).

6,6-Bis(ethoxycarbonyl)-8-cyano-5,6,7,8-tetrahydroquinoline (6f) and 7,7-Bis(ethoxycarbonyl)-5-cyano-5,6,7,8-tetrahydroquinoline (7f). These compounds were identified by GC–MS analysis of the crude reaction mixture. **6f** (t_R 19.95). MS: 302 ($M^{\bullet+}$, 61), 257 (15), 229 (44), 228 (100), 201 (92), 183 (71), 175 (33), 173 (69). **7f** (t_R 20.74). MS: 302 ($M^{\bullet+}$, 50), 257 (15), 229 (100), 228 (29), 201 (48), 184 (32). Further oxidation products, whose analyses agree with structures **8f** and **9f**, respectively, present the following mass spectra. **8f** (t_R 19.34). MS: 300 (5), 228 (22), 227 (94), 200 (32), 199 (100), 181 (16), 150 (22). **9f** (t_R 21.05). MS: 300 (6), 227 (53), 199 (100), 155 (28).

6,6-Bis(ethoxycarbonyl)-8-hexyl-5,6-dihydroquinoline (8a). Anal. Calcd for $C_{21}H_{29}NO_4$: C, 70.11; H, 8.13; N, 3.90. Found: C, 70.3; H, 8.2; N, 4.0. MS: 359 ($M^{\bullet+}$, 62), 286 (100). ^{1}H NMR: 8.43 (dd, 1 H, H_2, J = 5 and 1.75 Hz), 7.46 (dd, 1 H, H_4, J = 7.5 and 1.75 Hz), 7.07 (dd, 1 H, H_3), 6.21 (t, 1 H, H_7, J = 1.2 Hz), 4.18 and 4.17 (q, 2 H), 3.4 (s, 2 H, H_5), 2.65 (dt, 2 H, J = 7.5 and 1.5 Hz), 1.52–1.66 (m, 2 H), 1.25–1.40 (m, 6 H, aliph), 1.23 (2 t, 6 H), 0.88 (t, 3 H).

7,7-Bis(ethoxycarbonyl)-5-hexyl-7,8-dihydroisoquinoline (9a). Anal. Calcd for $C_{21}H_{29}NO_4$: C, 70.11; H, 8.13; N, 3.90. Found: C, 69.9; H, 8.3; N, 3.7. MS: 359 ($M^{\bullet+}$, 14), 286 (100). ^{1}H NMR: 8.47 (d, 1 H, H_3, J = 5.2 Hz), 8.43 (s, 1 H, H_1), 7.13 (d, 1 H, H_4), 6.16 (t, 1 H, J = 1.25 Hz), 4.3–4.0 (m, 4 H) 3.34 (s, 2 H), 2.48 (td, 2 H, J = 7.5 and 1.25 Hz), 1.52 (m, 2 H), 1.26–1.45 (m, 6 H, aliph), 1.22 (2 t, 6 H), 0.89 (t, 3 H).

6,6-Bis(ethoxycarbonyl)-8-phenyl-5,6-dihydroquinoline (8b). Anal. Calcd for $C_{21}H_{21}NO_4$: C, 71.78; H, 6.02; N, 3.99. Found: C, 71.5; H, 6.2; N, 4.0. MS: 351 ($M^{\bullet+}$, 23), 29 (100). ^{1}H NMR: 8.42 (dd, 1 H, H_2, J = 5 and 1.8 Hz), 7.47 (dd, 1 H, H_4, J = 7.8 and 1.8 Hz), 7.3–7.5 (m, 5 H, Ar), 7.10 (dd, 1 H, H_3, J = 7.8 and 5 Hz), 6.52 (s, 1 H, H_7), 4.20 (2 q, 4 H, J = 7 Hz), 3.53 (s, 2 H, H_5), 1.24 (t, 6 H).

7,7-Bis(ethoxycarbonyl)-5-phenyl-7,8-dihydroquinoline (9b). Anal. Calcd for $C_{21}H_{21}NO_4$: C, 71.78; H, 6.02; N, 3.99. Found: C, 71.6; H, 5.9; N, 4.1. MS: 351 ($M^{\bullet+}$, 5), 29 (100). ^{1}H NMR: 8.51 (d, 1 H, H_1, J = 0.5), 8.40 (dd, 1 H, H_3, J = 5.4 and 0.5 Hz), 7.3–7.5 (m, 5 H, Ar), 6.92 (d, 1 H, H_4, J = 5.4 Hz), 6.40 (s, 1 H, H_6), 4.21 (2 q, 4 H), 3.48 (s, 2 H, H_8), 1.24 (2 t, 6 H).

General Procedure for the Reaction between 1, 2, and Fe(III) Perchlorate. In a two-necked flask, equipped with a N_2 inlet device and a magnetic stirring bar was rapidly weighed $Fe(ClO_4)_3 \cdot 9H_2O$ (2 mmol), and MeCN (8 mL) was added. N_2 was flushed for 5 min, and a solution of 1 (1 mmol), olefin **2** (2 mmol), and biphenyl, as internal standard (2 mmol) in MeCN (2 mL) was added to the deep red solution obtained. The solution was stirred at 15–20 °C for 2 h (with styrene) to 12–16 h (with octene), obtaining solutions from deep red to yellow-green, depending on the olefin. The resulting solution was evaporated to 3 mL and then added to a stirred mixture of $NaHCO_3$ saturated solution (35 mL) and Et_2O (30 mL). The organic phase was separated, and the water was extracted with Et_2O (2 × 10 mL). The combined organic extracts were washed with NaCl-saturated solution (10 mL) and water (5 mL), dried on Na_2SO_4, and analyzed by GC.

General Procedure for the Reactions between 1, 2, Fe(III) Perchlorate, and Ac_2O. In a two-necked flask, equipped with a N_2 inlet device and a magnetic stirring bar was rapidly weighed $Fe(ClO_4)_3 \cdot 9H_2O$ (2 mmol), MeCN (8 mL) was added, and N_2 was flushed for 5 min. The resulting solution was cooled at 0–2 °C, and Ac_2O (1.7 mL, 18 mmol) was dropped over 5 min. The cooling bath was removed, and the orange solution was kept at room temperature for 15–20 min, until it became yellow. Then a degassed solution of **1g** (1 mmol) and 1-octene (2 mmol) in MeCN (1 mL) was added, and the reaction was run for 1.5 h. The resulting solution was worked up as indicated above.

General Procedure for the Reaction between 1, 2, and CAN. In a two-necked flask, equipped with a N_2 inlet device and a magnetic stirring bar was weighed $Ce(NH_4)_2(NO_3)_6$ (2 mmol), and MeOH or AcOH (8 mL) was added. N_2 was flushed for 5 min, and a solution of 1 (1 mmol), olefin **2** (2 mmol), and biphenyl (as internal standard (2 mmol)) in MeOH or AcOH (2 mL) was added to the orange solution or to the heterogeneous mixture. The mixture was stirred at 20–25 °C for 2 or 12 h, respectively,

until colorless. The resulting solutions were worked up as in the iron(III) experiments.

Dependence of Isomers Ratio in the Oxidation of 1, 2, and Fe(III). Two stock solutions were made: (a) **1g** (563 mg, 2.24 mmol), 1-octene (518 mg, 6.62 mmol), and biphenyl (293 mg) in MeCN (10 mL); (b) $Fe(ClO_4)_3 \cdot 9H_2O$ (23 mmol) in MeCN (31 mL). Solution a, acetonitrile, and solution b were mixed together under N_2 in the following proportions, respectively: (1) 1.5, 1.44, and 0.45; (2) 1.5, 0.53, and 1.37; (3) 1.5, 0.1, and 1.8; (4) 1.5, 0, and 2.22. The resulting solutions were stirred at 20 °C for 1-24 h, stopped at different times, worked up as before, and analyzed by GC for the determination of the conversion, yield, and isomers ratio. The results are plotted in Figure 1 as ratios of ortho/para isomers against **1g** conversion. From these data the following slopes (correlation coefficient) were obtained: (1) 0.57 (0.9991), (2) 0.42 (0.9993), (3) 0.28 (0.9989), (4) 0.23 (0.9996). A linear correlation with a slope of -1.1 (r = 0.9988) of these data against Fe(III) concentration can be deduced.

Dependence of Isomers Ratio in the Oxidation of 1, 2, and $Mn(OAc)_3$. A stock solution was made from compound **1g** (500 mg, 1.99 mmol) and 1-octene (447 mg, 3.98 mmol) in AcOH (5 mL). $Mn(OAc)_3$ dihydrate (95% purity) was weighed in four two-necked flasks (117 mg, 218 mg, 326 mg, 429 mg, respectively); acetic acid (3 mL) was added, and the mixtures were flushed with N_2 for 5 min. The stock solution (1 mL) was added at 20 °C to the resulting mixtures, each flask was introduced in a thermostated bath at 70 °C, and the reactions were followed by withdrawing at different time samples, which were worked up and analyzed as before. The results are reported in Figure 2 as dependence of $R_{o/p}$ against the substrate conversion. The following slopes (correlation coefficient) were obtained, respectively: 0.41 (0.9988), 0.31 (0.9992), 0.19 (0.9996), 0.02 (0.9991). A linear correlation of these data against Mn(III) concentration can be deduced with a slope of -1.4 (r = 0.9992).

Dependence of Isomers Ratio in the Oxidation of 1, 2, and CAN. Two stock solutions were made: (a) compound **1g** (513 mg, 2.04 mmol), 1-octene (463 mg, 4.13 mmol) and biphenyl (286 mg) in MeOH (5 mL); (b) $Ce(NH_4)_2(NO_3)_4$ (2.886 g, 5.26 mmol) in MeOH (31 mL). Solutions a, methanol, and solution b were mixed together under N_2 in the following proportions, respectively: (1) 0.9, 2.1, and 0.70; (2) 0.9, 1.40, and 1.40; (3) 0.9, 0.7, and 2.1; (4) 0.9, 0 and 2.8. The resulting solutions were stirred at 20 °C for 1-6 h, stopped at different times, and worked up as before. The results are reported in Figure 3 as dependence of $R_{o/p}$ against the substrate conversion. The following slopes (correlation coefficient) were obtained: (1) 0.05 (0.9986), 0.04 (0.9992), 0.05 (0.9984), 0.05 (0.9992).

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Registry No. **1a**, 3243-01-4; **1b**, 134208-95-0; **1c**, 134208-96-1; **1d**, 101585-29-9; **1e**, 101829-74-7; **1f**, 134208-97-2; **1g**, 57477-12-0; **2a**, 111-66-0; **2b**, 100-42-5; **2c**, 108-05-4; **2d**, 15870-10-7; **2e**, 140-88-5; **2f**, 107-13-1; **3a**, 629-05-0; **3b**, 536-74-3; **3c**, 623-47-2; **3d**, 1070-71-9; **4a**, 134208-75-6; **4b**, 134208-76-7; **4c**, 134208-77-8; **4d**, 134208-78-9; **5e**, 134208-79-0; **5f**, 134208-80-3; **6a**, 134208-81-4; **6b**, 134208-82-5; **6c**, 134237-91-5; **6d**, 134208-85-8; **6e**, 134208-87-0; **6f**, 134208-89-2; **7a**, 134237-90-4; **7b**, 134208-83-6; **7c**, 134208-84-7; **7d**, 134208-86-9; **7e**, 134208-88-1; **7f**, 134208-90-5; **8a**, 134208-91-6; **8b**, 134208-93-8; **8c**, 134609-10-2; **9a**, 134208-92-7; **9b**, 134208-94-9; ethyl propiolate, 623-47-2.

Supplementary Material Available: Analytical data of compounds **1a-g** (Table IV) and mass spectral data of compounds **4a-d**, **5e-f**, **6a-e**, **7a-e**, **8a-e**, and **9a-b** (Table V) (4 pages). Ordering information is given on any current masthead page.

The Oxidation of Alcohols by Permanganate. A Comparison with Other High-Valent Transition-Metal Oxidants

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The results obtained from a study of the oxidation of mandelic acid and cyclobutanol by permanganate in 1.0 M KOH are best accommodated by a mechanism in which the initial reaction is the addition of a manganese-oxo bond to the α-C-H bond of the alcohol, followed by homolytic cleavage of the resulting Mn-C bond to give free-radical intermediates. A comparison with other high-valent transition-metal oxidants suggests that it is possible to systematically classify the way in which these reagents react with alcohols on the basis of the initial reaction (C-H or O-H addition) and the cleavage mode of the metal-oxygen or metal-carbon bond (homolytic or heterolytic). The approach provides a framework for understanding these reactions that is less chaotic than the current situation where distinctive mechanisms have been proposed for each individual oxidant.

Introduction

Transition-metal oxides have been widely used for the conversion of alcohols into carbonyl compounds. Permanganate,[1] manganate(VI),[2] chromic acid,[3] chlorochromate,[4] chromyl chloride,[5] molybdenum(VI) complexes,[6] pentavalent vanadium,[7] ruthenium tetroxide,[8] osmium tetraoxide,[9] perruthenate,[10] ruthenate,[11] and ferrate[12] have all proven to be useful oxidants for specific alcohols.

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