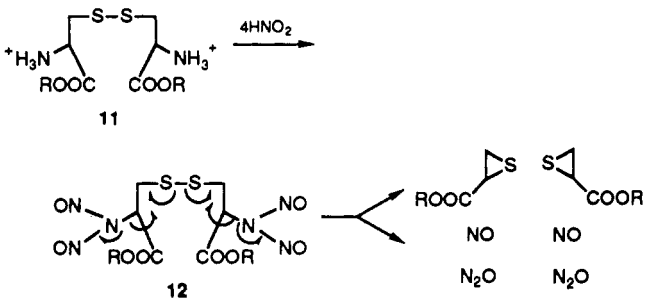
Scheme IV



icals begin to depart (step 3a). The hybridization approaches sp^2 p. The expanding lobes eventually overlap to form the new S–C bond as the leaving groups separate completely (step 3b) and sp^3 hybridization is established anew. Inversion is mandated by the endergonic nature of the homolyses and the need for the energy of formation of the new bond to compensate in a concerted process.

The reaction of cystine ester 11 follows a similar course (Scheme IV). The bis dinitrosamine 12 formed by reaction with excess nitrite can undergo electrocyclic collapse producing 2 mol of episulfide per mol, nitric and nitrous oxides again being produced. Alternatively, one of the half-cystine residues may depart as thiyl radical, to be trapped by nitric oxide or in other side reactions. In either case, formation of episulfide is well accounted for.

Experimental Section

^{1}H NMR spectra were obtained in $CDCl_3$/TMS. Dichloromethane was stripped at ~25 °C, 30–40 mmHg. Epithioesters were volatilized at 40–45 °C and trapped at –60 °C. Microanalyses were by Atlantic Microlab, Norcross, GA. Methyl and ethyl thioglycidates (1, R = Me and R = Et) were identified by NMR spectra and optical activities which were as previously reported[4] and gave satisfactory elemental analyses (CHNS). The NMR spectra of polymers were similar to those of monomers except that the SCH_2 and SCH multiplets were displaced downfield to δ 3.2 and 3.85, respectively.

Reaction of L-Cysteine Ethyl Ester Hydrochloride with Nitrous Acid. (a) Anaerobic Reaction with 3 Equiv of Nitrite (Optimum Conditions). Solid $NaNO_2$ (2.07 g, 30 mmol) was added in one portion to stirred, ice-chilled L-cysteine ethyl ester·HCl (1.85 g, 10 mmol) in deaerated HCl (50 mL, 1 M) under nitrogen. A deep red color developed and faded. Extraction (CH_2Cl_2) after 5 min gave a pale yellow oil (1.34 g) from which ethyl thiiranecarboxylate (1.05 g, 80%) was volatilized at 3 mmHg. The residue after 24 h (0.25 g), a viscous yellow oil, contained no monomer.

(b) Aerobic Reaction with 3 Equiv of Nitrite (Literature Procedure[4]). Procedure a was carried out in ordinary (air-saturated) hydrochloric acid. The red color faded and a red-brown coloration was observed in the air space above the mixture. Extraction after 5 min gave 1.18 g of oil from which 0.53 g (40%) of epithioester and 0.58 g of polymer were obtained. Further extraction after 2 h gave additional material (0.14 g) which contained about 30% of monomer (NMR).

(c) Aerobic Reaction with Less Than 3 Equiv of Nitrite. When procedure b was carried out with 2 equiv (0.14 g) of sodium nitrite, the red color faded more slowly (10–15 min). Extraction after 5 min gave oil (0.33 g) from which epithioester (0.13 g, 10%) was volatilized. Extraction after 2 h gave further oil (0.9 g) which contained additional epithioester (0.22 g, 17%). With 1 equiv of nitrite (0.7 g), the red color did not fade noticeably during 2 h. Extraction after 5 min gave an oil (0.1 g) which contained (NMR) about 0.07 g (5%) of epithioester. Extraction after 2 h gave further oil (0.45 g) containing 0.13 g (10%) of volatile product.

Reaction of L-Cystine Dimethyl Ester Hydrochloride with Nitrous Acid. $NaNO_2$ (0.6 g, 9 mmol) was added to a solution of L-cystine dimethyl ester·HCl (1.0 g, 3 mmol) in HCl (15 mL, 0.2 M) as in procedure b. No color developed. Extraction afforded an oil (0.40 g) from which volatization at 10 mmHg gave methyl thiiranecarboxylate (1, R = Me) (0.18 g, 52% or 26%).

Acknowledgment. Support for this research was provided in part from the Petroleum Research Fund administered by the American Chemical Society.

α-Selective Coupling Reactions of Allylic Alcohols with Aldehydes Using $Me_3SiCl/NaI/H_2O$–Sn

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It is well established that additions of allylic organometallic reagents to aldehydes lead to branched homoallylic alcohols (γ-adducts).[1] However, despite the synthetic importance of linear homoallylic alcohols (α-adduct), obtaining them from regioinverted additions of allylic metals to aldehydes has remained an unsolved problem in organic synthesis.

During the last decade, some α-selective coupling reactions using allylic tin compounds have been reported.[2] For instance, 1-buten-3-yldibutyltin chloride, which was generated from 2-butenyltributyltin and Bu_2SnCl_2, reacts with propanal to give only the (*Z*)-linear alcohol.[3] Treatment of tributylcrotyltin with aldehydes in the presence of $AlCl_3$–^{i}PrOH affords α-adducts, but the nature of the aldehydes significantly influences the selectivity in the adducts produced.[4] More recently, a highly α-selective allylation has been achieved by the reaction of allylic barium[5] and allylic cerium reagents[6] with aldehydes.

Previously, we showed that a $Me_3SiCl/NaI/H_2O$ system was a useful method for in situ generation of hydrogen iodide.[7,8] In a continuation of our study on the utilization of $Me_3SiCl/NaI/H_2O$ in synthetic reactions, we have found that α-selective coupling reactions of allylic alcohols with aldehydes are efficiently mediated by the $Me_3SiCl/NaI/H_2O$–Sn system.[9]

Metallic tin was treated with $Me_3SiCl/NaI/H_2O$ in acetonitrile at room temperature. (E)-2-Hexen-1-ol (1) was added, and, 1 h later, butanal (2) was added. The resulting solution was stirred at ambient temperature to produce homoallylic alcohols 3 and 4 in a combined yield of 76% with remarkably high α-selectivity with an α:β ratio of 98:2 (eq 1).[10] Most coupling reactions of allylic organometals with aldehydes take place at the γ-carbon rather than the α-carbon of the allylic metals to afford branched homoallylic alcohols (γ-adducts).[1] Therefore, it is interesting

(1) Courtois, G.; Miginiac, L. *J. Organomet. Chem.* **1974**, *69*, 1.
(2) (a) Pereyre, M.; Quintard, J-P.; Rahm, A. *Tin in Organic Synthesis*: Butterworth: London, 1987. (b) Yamamoto, Y. *Aldrichimica Acta* **1987**, *20*, 45.
(3) Gambaro, A.; Marton, D.; Tagliavini, G. *J. Organomet. Chem.* **1982**, *231*, 307.
(4) Yamamoto, Y.; Maeda, N.; Maruyama, K. *J. Chem. Soc., Commun.* **1983**, 742.
(5) Yanagisawa, A.; Habaue, S.; Yamamoto, H. *J. Am. Chem. Soc.* **1991**, *113*, 8955.
(6) Guo, B.-S.; Doubleday, W.; Cohen, T. *J. Am. Chem. Soc.* **1987**, *109*, 4710.
(7) Kanai, T.; Kanagawa, Y.; Ishii, Y. *J. Org. Chem.* **1990**, *55*, 3274.
(8) Kamiya, N.; Chikami, Y.; Ishii, Y. *Synlett* **1990**, 675.
(9) Recently, allylation of carbonyl compounds with allylic compounds using metallic tin has been reported. (a) Mukaiyama, T.; Harada, T. *Chem. Lett.* **1981**, 1527. (b) Nokami, J.; Otera, T.; Sudo, T.; Okawara, R. *Organometallic* **1983**, *2*, 191. (c) Petrier, C.; Einnhorn, J.; Luche, J. L. *Tetrahedron Lett.* **1985**, *26*, 1449.
(10) The coupling constants of the vic-vinyl protons for (*E*)- and (*Z*)-3 were 14.8 and 10.0 Hz, respectively.
(11) In our previous paper, we showed that the reactions of 1, 12, and 13 with the $Me_3SiCl/NaI/H_2O$ reagent forms the same iodide, 1-iodo-2-hexene.[12]

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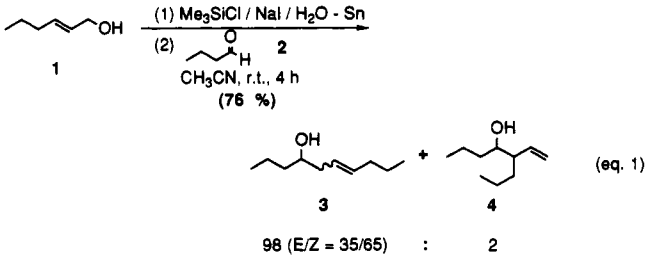


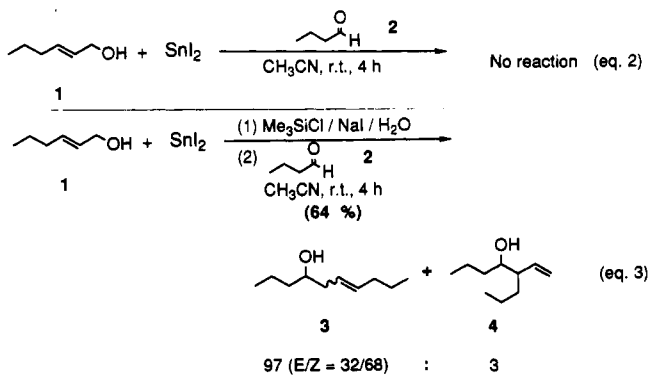
(eq. 1)

to note that the present system gives linear homoallylic alcohols (i.e., α-adducts) predominantly.

In order to obtain the optimum ratio of metallic tin to $Me_3SiCl/NaI/H_2O$ in the reaction, the coupling of 1 with 2 was chosen for study, and the reaction conditions were varied (Table I). The yield of homoallylic alcohol was considerably affected by the ratio of $Me_3SiCl/NaI/H_2O$ to Sn. The reaction was satisfactorily achieved when 4 equiv of $Me_3SiCl/NaI/0.5H_2O$ and 1 equiv of Sn were used (run 5). In the absence of water, allylic iodide **5** was the principal product (run 6).

To extend the scope of the reaction, the allylation of aldehydes with several allylic alcohols was examined by using 4 equiv of $Me_3SiCl/NaI/0.5\ H_2O$ and 1 equiv of Sn (Table II). In the reactions of 1 with aliphatic aldehydes such as 2 and 6, the allylation proceeded with high α-selectivity to give linear homoallylic alcohols 3 and 7 in 98% selectivity (74% yield) and 97% selectivity (70% yield), respectively (runs 1 and 2). When (*Z*)-2-hexen-1-ol (10) was used as an allylic source, the distribution of products was almost the same as that when 1 was used (run 4). This result suggests that 1 and 10 react with the $Me_3SiCl/NaCl/H_2O$–Sn reagent to form the same allylic tin intermediate, which subsequently couples with 2 to produce homoallylic alcohols 3 and 4. The reaction of 1-hexen-3-ol (11) with 2 gave 3 in slightly lower yield, although the reaction seems to proceed through a reaction path similar to that of 1 or 10 with 2 (run 5). The coupling of 1 and 12 with benzaldehyde (8) resulted in the formation of the γ-adduct in preference to the α-adduct (9 and 15) (runs 3 and 7). This may be due to the high electrophilicity of 8 compared with that of aliphatic aldehydes.

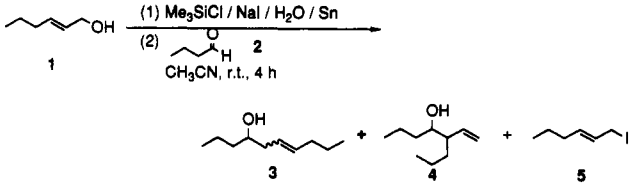
In order to determine the reaction course in the present coupling reaction, 1 was allowed to react with 2 under several reaction conditions. The coupling reaction of 1 with 2 in the presence of stannous iodide (SnI_2) instead of the $Me_3SiCl/NaI/H_2O$ agent did not take place, and starting materials were recovered (eq 2). However, when 1 was treated with 2 in the presence of SnI_2 (1 equiv) and $Me_3SiCl/NaI/0.5\ H_2O$ (2 equiv), 3 was obtained in 97% selectivity (62% yield) (eq 3).



(eq. 3)

We have already shown that the reaction of allylic alcohols with the $Me_3SiCl/NaI/H_2O$ reagent gives the corresponding allylic iodides in good yields.[12] In fact, allylic iodide is a byproduct of this allylation. These results indicate that the allylic tin iodide species, generated in situ from the allylic alcohol, $Me_3SiCl/NaI/H_2O$, and tin, may react with the aldehyde to give the corresponding homoallylic alcohol. The reaction of 1-iodo-2-hexene with 2 in the presence of SnI_2 produced small amounts of 3 (3%) and 4 (1%), together with an unidentified byproduct (28%) (eq 4).[13] Quite suprisingly, the treatment of 1-iodo-2-hexene with 2 in the presence of 1 equiv of SnI_2 and

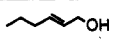
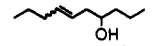
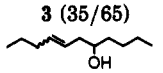
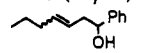
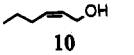
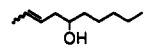
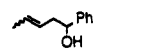
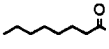
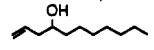
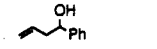
Table I. Allylation of Butyraldehyde with 2-Hexen-1-ol and Various Amounts of $Me_3SiCl/NaI/H_2O$ to Sn[a]



run	$Me_3SiCl/NaI/H_2O$ (mmol)	homoallylic alcohols: yield, %[b]	selectivity, %: 3 (*E*/*Z*)	4	iodide, % 5
1	5/5/2.5	6	98 (35/65)	2	0.1
2	10/10/5	10	99 (31/69)	1	0.5
3	20/20/10	36	94 (46/54)	6	3
4	30/30/15	61	97 (38/62)	3	5
5	40/40/20	76	98 (35/65)	2	6
6	40/40/0	5	98 (31/69)	2	41

[a] 1 (10 mmol), CH_3CN (40 mL), and 2 (20 mmol) were used. [b] Based on 1.

Table II. Allylation of Aldehydes with Allylic Alcohols Using $Me_3SiCl/NaI/H_2O$–Sn System[a]

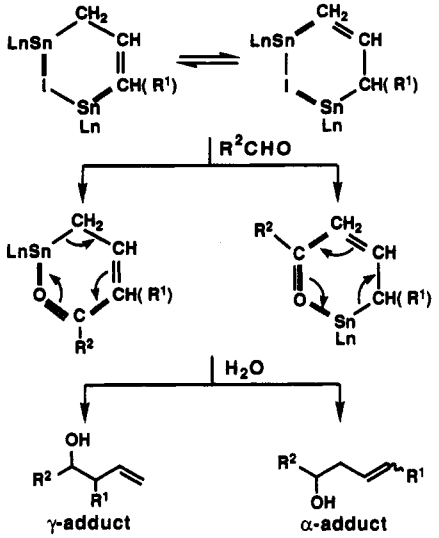
run	alcohol	aldehyde	product (*E*/*Z*)[b]	yield, %[c,d]	selectivity (α-/γ-adduct)
1	 1	 2	 3 (35/65)	74	98/2
2	2	 6	 7 (34/66)	70	97/3
3	1	PhCHO (8)	 9 (23/77)	20	32/68
4	 10	2	3 (39/61)	72	97/3
5	 11	2	3 (39/61)	70	97/3
6	 12	 13	 14 (25/75)	71	97/3
7	12	8	 15 (21/79)	21	35/65
8	 16	 17	 18	80	
9	16	8	 19	89	

[a] Reaction conditions were the same as those of run 5 in Table I. [b] *E* and *Z* ratios were determined by GC. [c] Based on the alcohols used. [d] Yields were determined by GC using internal standard techniques.

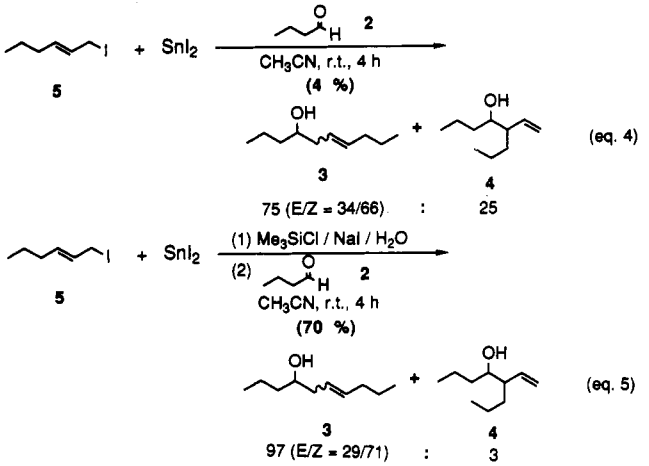
(12) Irifune, S.; Kibayashi, T.; Ishii, Y.; Ogawa, M. *Synthesis* **1988**, 366.

(13) Mukaiyama and co-workers have shown that allyl iodide couples with aldehydes in the presence of SnF_2 to form homoallylic alcohols in good yields. See: Mukaiyama, T.; Harada, T.; Shoda, S. *Chem. Lett.* **1980**, 1507.

Scheme I



2 equiv of $Me_3SiCl/NaI/0.5\ H_2O$ gave **3** in 97% selectivity (68% yield, E/Z = 29/71) (eq 5).



To gain the further insight into the identity of the allylic tin species, crotyl alcohol was allowed to react with the $Me_3SiCl/NaI/H_2O$–Sn system in CD_3CN. The ^1H NMR spectrum of the reaction solution consisted of several allylic tin species.[14] From the characteristic splitting of the terminal vinyl protons, we believe that a branched allylic tin species such as 1-buten-3-yltin iodide is formed. Gambaro et al. reported that the redistribution reaction of 2-butenyltributyltin and Bu_2SnCl_2 at 30 °C resulted in a mixture of $Bu_2ClSnCH_2CH{=}CHCH_3$ (84–86%) and $Bu_2ClSnCH(CH_3)CH{=}CH_2$ (14–16%). Subsequent coupling with aldehydes led to linear homoallylic alcohols predominantly.[15] Gambaro et al. also assumed that this redistribution reaction proceeded via the bimolecular cyclic transition state. Therefore, we believe that the present allylation proceeds by the mechanism shown in Scheme I. A branched allylic tin species, which is in equilibrium with a linear one formed by the reaction of allylic alcohol with $Me_3SiCl/NaI/H_2O$–Sn, couples preferentially with aldehydes to form α-adducts (Scheme I).

The present coupling reaction has the following characteristic: (1) the reaction provides mixtures of Z and E linear homoallylic alcohols in which the Z alcohols predominate, (2) allylic alcohols, available from commercial suppliers, are used as the allyl source without the use of allylic tin derivatives, and (3) reactions can be carried out with ease using metallic tin under mild conditions.

(14) ^1H NMR of allylic tin species was measured by treating **1** with $Me_3SiCl/NaI/0.5\ H_2O$ (4 equiv) and Sn (1 equiv) in CD_3CN. Terminal vinyl protons attributed to the γ-allylic tin species appeared at δ 4.93 and 4.87 with J = 1.1 Hz, which are assigned to geminal vinyl protons. See: Fishwick, M.; Wallbridge, M. G. H. *J. Organomet. Chem.* **1970**, *25*, 69.

(15) Gambaro, A.; Marton, D.; Tagliavini, G. *J. Organomet. Chem.* **1981**, *210*, 57.

Experimental Section

Instruments. ^1H and ^{13}C NMR spectra were recorded at 400 and 100 MHz, respectively. Infrared spectra were obtained on a FT-IR. GC analyses were performed using a 0.2 mm × 25 m glass column packed with Silicon OV-7 or PEG 20M.

Materials. Allylic alcohols, aldehydes, sodium iodide (NaI), metallic tin, stannous iodide (SnI_2), and chlorotrimethylsilane (Me_3SiCl) were purchased from commercial sources and were used without purification. Acetonitrile (CH_3CN) was purchased from commercial sources and purified by distillation over CaH_2. 1-Iodo-2-hexene (**5**) was prepared according to the reported procedure.[12]

General Procedures for the Synthesis of Homoallylic Alcohols. To an acetonitrile (40 mL) solution of NaI (6.00 g, 40 mmol) was added Me_3SiCl (5.07 mL, 40 mmol). Then H_2O (0.36 mL, 20 mmol) was added, and the mixture was stirred at room temperature for 0.5 h. Metallic tin (1.19 g, 10 mg atom) was added to the resulting mixture. After the mixture stirred for 1 h at room temperature, the allylic alcohol (10 mmol) was added. After 1 h the aldehyde (20 mmol) was added. The solution was stirred for 4 h at ambient temperature, quenched with water (30 mL), and extracted with diethyl ether (30 mL × 3). The combined extracts were washed with sodium bisulfite solution (30 mL × 2). The organic layer was dried over $MgSO_4$ and analyzed by GLC using an internal standard. Removal of the solvent under reduced pressure afforded a pink liquid, which was purified by column chromatography on silica gel with *n*-hexane/ethyl acetate (10/2) to give the corresponding homoallylic alcohol.

7-Undecen-5-ol (7): ^1H NMR (mixture of E- and Z-isomers) ($CDCl_3$) δ 0.89 (t, J = 7.3 Hz, 3 H), 0.91 (t, J = 7.3 Hz, 3 H), 1.32–1.50 (m, 8 H), 1.65 (bs, 1 H), 1.98–2.10 (m, 2 H), 2.20–2.26 (m, 2 H), 2.24 (t, J = 6.9 Hz, 2 H), 3.56–3.63 (m, 2 H), 5.39–4.43 (m, 1 H), 5.51–5.59 (m, 1 H); ^{13}C NMR (mixture of E- and Z-isomers) ($CDCl_3$) δ 13.5, 13.7, 13.9, 22.5, 22.6, 22.7, 22.8, 27.9, 28.0, 29.5, 34.6, 34.7, 35.5, 36.5, 36.7, 40.8, 71.1, 71.6, 125.4, 126.2, 133.0, 134.2; IR (neat) 3356, 2957, 2872, 1465, 1378, 1037, 970, 873, 730 cm^{-1}.

1-Phenyl-3-hepten-1-ol (9): ^1H NMR (mixture of E- and Z-isomers) ($CDCl_3$) δ 0.87 and 0.88 (t, J = 7.3 Hz, 3 H), 1.32 and 1.37 (sextet, J = 7.3 Hz, 2 H), 1.59 and 1.60 (s, 1 H), 2.00–2.02 (m, 2 H), 2.44–2.49 (m, 2 H), 4.68 (t, J = 7.3 Hz, 1 H), 5.39 and 5.40 (dt, J = 14.4 and 7.3 Hz for δ 5.4, dtt, J = 11.0, 7.3, 2.2 Hz for δ 5.40, 1 H), 5.56 and 5.57 (ddt, J = 14.4, 7.3, and 1.8 Hz for δ 5.56, J = 11.0, 7.3, and 2.2 Hz for δ 5.57, 1 H), 7.25–7.28 (m, 3 H), 7.32–7.38 (m, 2 H); ^{13}C NMR (E-isomer) ($CDCl_3$) δ 13.6, 22.5, 34.7, 42.8, 73.4, 125.6, 125.8, 127.4, 128.3, 135.0, 144.0; ^{13}C NMR (Z-isomer) ($CDCl_3$) δ 13.7, 22.7, 29.4, 37.3, 73.9, 124.8, 125.8, 127.5, 128.4, 133.6, 144.1; IR (neat) 3354, 3017, 2956, 2930, 2859, 1654, 1456, 1404, 1377, 1033, 967, 935, 911, 704 cm^{-1}.

2-Decen-5-ol (14): ^1H NMR (mixture of E- and Z-isomers) ($CDCl_3$) δ 0.89 (t, J = 7.0 Hz, 3 H), 0.90 (t, J = 7.0 Hz, 3 H), 1.21–1.50 (m, 6 H), 1.65 (dd, J = 5.9 and 0.7 Hz, 2 H), 1.74 (bs, 1 H), 2.23 (t, J = 7.0 Hz, 2 H), 5.41–5.48 (m, 1 H), 5.61–5.69 (m, 1 H); ^{13}C NMR (mixture of E- and Z-isomers) ($CDCl_3$) 13.7, 13.8, 14.1, 22.6, 22.8, 22.9, 27.9, 28.0, 29.5, 34.8, 35.4, 36.4, 36.6, 40.8, 71.0, 71.5, 125.5, 126.1, 133.1, 134.4; IR (neat) 3384, 2956, 2930, 2859, 1718, 1458, 1378, 1123, 1033, 968, 758, 704 cm^{-1}.

Typical Procedure for the Reaction of 1 or 5 with 2 in the Presence of SnI_2 and $Me_3SiCl/NaI/H_2O$. To an acetonitrile (40 mL) solution of NaI (3.00 g, 20 mmol) was added Me_3SiCl (2.53 mL, 20 mmol). H_2O (0.18 mL, 10 mmol) was then added, and the mixture was stirred at room temperature for 0.5 h. Stannous iodide (3.73 g, 10 mmol) was added to the resulting mixture. After the reaction mixture stirred for an additional 1 h at room temperature, allylic alcohol (**1**) or allylic iodide (**5**) (10 mmol) was added to the mixture. After 1 h the aldehyde (20 mmol) was added. The resulting solution was stirred for 4 h at ambient temperature. Workup and isolation of the products were performed in the same manner described in the General Procedures for the Synthesis of Homoallylic Alcohols.

Supplementary Material Available: ^1H NMR spectra for compounds **3**, **7**, **9**, **14**, **15**, **18**, and **19** and spectral data for com-

pounds 3, 15, 18, and 19 (11 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

Novel [3 + 2] and [3 + 3] 4-Quinolone Annulations by Tandem Claisen–Cope-Amidoalkylation Reaction

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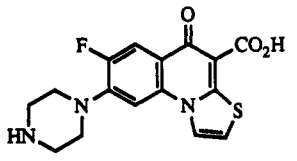
The thermal rearrangement of 4-(allyloxy)-2,3-dimethylquinoline (1) to produce 2-(3-butenyl)-1,4-dihydro-3-methyl-4-oxoquinolone (4) was first described by Makisumi over 25 years ago and was thought to proceed by a mechanism involving an initial Claisen rearrangement to give dienone 2 and a subsequent Cope rearrangement via the tautomeric enamine 3 (Scheme I).[1] As an interesting and potentially useful reaction for the introduction of functionalized side chains into the C-2 position of the 4-quinolone nucleus, we sought to apply it to the synthesis of novel tricyclic quinolone antibacterial agents[2] containing carbocyclic rings fused between N-1 and C-2 and patterned after the potent thiazolo-fused quinolone 5.[3] We now wish to report a convenient one-pot annulation method leading to the formation of 5- and 6-membered ring-fused 4-quinolones 6 and 7 in which migrating allyl/propargyl groups in the tandem Claisen–Cope rearrangement undergo further reaction at the quinolone nitrogen.



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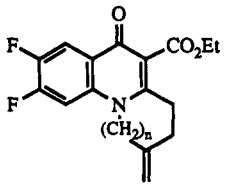

6: n = 0; 7: n = 1

4-(Allyloxy)quinolines 11 and 13 and 4-(propargyloxy)quinoline 12 were prepared as substrates for the tandem Claisen–Cope rearrangement as shown in Scheme II. The chloroimidate derived from treatment of 3,4-difluoroacetanilide (8) with PCl_5 was condensed with diethyl sodiomalonate to give an intermediate enamino diester, which was cyclized thermally in Dowtherm to afford a regioisomeric mixture of difluoroquinolones 9 and 10, with the desired 6,7-difluoro isomer 9 predominating by ≈3.3:1. Alkylation of the mixture of 9 and 10 under standard conditions with allyl bromide, propargyl bromide, and (β-chloromethyl)allyl chloride, respectively, provided quinolines 11–13. In each case the undesired 5,6-difluoroquinoline derived from 10 could be cleanly separated by flash chromatography. Although pure 9 could be obtained by two recrystallizations from EtOH, it was just as convenient to alkylate the mixture of 9 and 10. It is interesting to note that the 2-methyl group of 9 and 10 steers the alkylation onto the quinolone carbonyl; alkylation of the corresponding *des*-2-methyl derivatives is known to occur on nitrogen.[4]

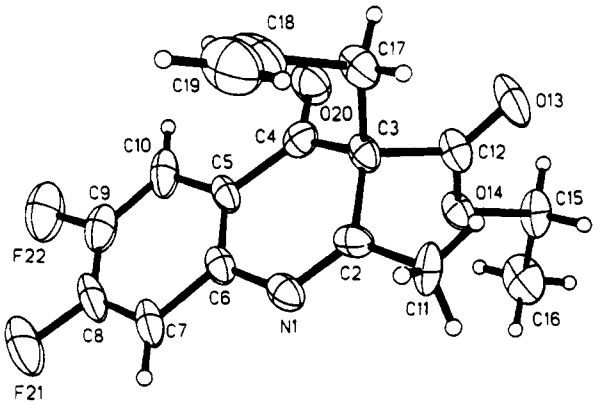

Figure 1. ORTEP drawing of the X-ray structure of dienone 14. Two crystalline forms were found; only one is shown for clarity.

To see if the tandem Claisen–Cope rearrangement was compatible with the 3-carbethoxy and 6,7-difluoro substitution in the quinoline ring, which is required for elaboration to quinolone antibacterials, (allyloxy)quinoline 11 was subjected to thermolysis in refluxing chlorobenzene (bp 132 °C), smoothly affording the expected 2-(3-butenyl)-4-quinolone 16 in 85% yield (Scheme III). Interestingly, when the reaction was performed in refluxing xylenes (bp 139–141 °C), the putative dienone intermediate 14 could be detected by TLC and was isolated by careful flash chromatography.[5] As one of the rare examples of a nonaromatic Claisen product to be isolated in the aromatic Claisen rearrangement,[6] an X-ray structure[7] of 14 was obtained (Figure 1) and, to our knowledge, is the first of such a species. The isolation of 14 and its smooth conversion to 16 upon resubjection to the reaction conditions now provides the first direct evidence of Makisumi's mechanism. It also should be noted that 14 exists as the imine tautomer, as shown, and hence conversion to the enamine tautomer 15 requires thermal equilibration.

The synthesis of pyrrolo[1,2-*a*]quinolone 6 was carried out initially by treatment of 16 with NBS to give tricycle 17 and subsequent dehydrobromination with ethanolic KOH (Scheme III). Alternatively, 6 could be obtained in a more direct fashion and in 54% overall yield by simple thermolysis of 4-(propargyloxy)quinoline 12 in refluxing *o*-dichlorobenzene (bp 179–180 °C). Presumably, 2-(3-butynyl)quinolone 19 is the penultimate intermediate, generated via allene 18, which cyclizes to 6 by intramo-

† To whom correspondence should be sent concerning the X-ray determination of dienone 14.

(1) Makisumi, Y. *J. Org. Chem.* **1965**, *30*, 1989.

(2) For a recent review on quinolone antibacterials, see: Rosen, T. In *Progress in Medicinal Chemistry*; Ellis, G. P., West, G. B., Eds.; Elsevier Science: Amsterdam, New York, Oxford, 1990; Vol. 27, p 235.

(3) Matsumura, S.; Kise, M.; Ozaki, M.; Tada, S.; Kazuno, K. Watanabe, H.; Kunimoto, K., Tsuda, M. U.S. Patent 4,426,381; *Chem. Abstr.* **1983**, *98*, 53877w.

(4) For a general review of quinolone chemistry, including the synthesis of N-substituted quinolones, see: Albrecht, R. *Prog. Drug. Res.* **1977**, *21*, 9.

(5) The detection of 14 in refluxing xylenes and not in chlorobenzene could be due to the difference in dielectric constant between the two solvents, which could change the free energy profile of the reaction and therefore alter the stability of 14 relative to 15 and 16. The dielectric constants of xylenes and chlorobenzene are 2.3–2.6 and 5.7, respectively, at 20 °C.

(6) For examples of other dienones which have been isolated from the aromatic Claisen rearrangement, see: Bender, D. R.; Kanne, D.; Frazier, J. D.; Rapoport, H. *J. Org. Chem.* **1983**, *48*, 2709 and references cited therein (footnote 29).

(7) The author has deposited atomic coordinates for this structure with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

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