N-(α-Ethoxyallyl)benzotriazole: A Novel Propenoyl Anion Synthon Route to Vinyl Ketones

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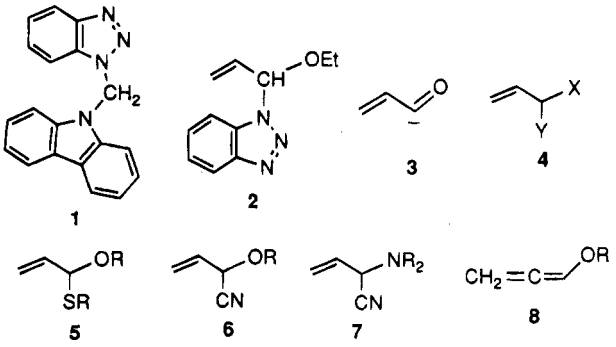
Received April 24, 1995[⊗]

Lithiation with butyllithium of *N*-(α-ethoxyallyl)benzotriazole (**2**) (readily prepared in quantitative yield on a large scale from benzotriazole and acrolein diethyl acetal (**9**)) followed by reaction of lithio derivative **14** with halides, α,β-unsaturated esters, α,β-unsaturated ketones, and aldehydes gave exclusively α-alkylation adducts. These adducts are hydrolyzed under extremely mild conditions, enabling convenient syntheses of vinyl ketones **16** and functionalized vinyl ketones **21**, **22**, **24**, and **27**.

The use of masked acyl anion equivalents has been proven to be a powerful strategy in the synthesis of carbonyl compounds.[1a-c] Consequently, it is not surprising that many precursors have been investigated for the generation of acyl anion synthons. We have previously described 1-(carbazol-9-ylmethyl)benzotriazole (**1**) as a precursor of heterocycle-stabilized acyl anion equivalents[2a-c] and called attention to their attractive and advantageous usage in the syntheses of α-functionalized aldehydes and ketones, which combine a single step procedure and mild hydrolytic conditions without the need for exotic reagents. We now report that the similar heterocyclic system, *N*-(α-ethoxyallyl)benzotriazole (**2**), provides a novel and versatile propenoyl anion synthon equivalent (**3**).



1 2 3 4 5 6 7 8

Propenoyl anion **3** synthons are three-carbon homologating reagents for the preparation of propenoyl ketones. In previously published work, a common strategy for their generation has involved metalation of 3,3-diheteroatom-substituted propenes **4** followed by α-alkylation with electrophiles to give intermediates with labile diheteroatom substituents which were then hydrolyzed to the vinyl ketones.[3a-c] Regiochemical selectivity is crucial to the utility of the ambient anion of **4**,[3c,4] since alkylation with an electrophile may occur at either end of the allylic anion; the ratio of α to γ attack has been found to be dependent on many factors, and there seems as yet to be no general rule for predicting this ratio. Lithio derivatives of α,α-bis(alkylthio)allyl sulfides (**4**, X = Y = SR),[5a,b] α-alkoxyphosphine oxides (**4**, X = P(O), Y = OR),[6a-c] acrolein diethyl acetal (**4**, X = Y = OEt),[7] and α-alkoxyallyl trimethylsilyl ethers (**4**, X = OR, Y = $SiMe_3$),[3a] when reacted with an electrophile, give predominantly products of γ-alkylation. α-Alkylation of the heteroatom-stabilized homoenolate anions with high regioselectivity is less common, possibly because of steric factors. Lithio derivatives of α-alkoxyallyl sulfides **5** were reported to undergo α-alkylation with halides to give α-alkylated hemithio ketals which, on oxidation and subsequent hydrolysis, formed vinyl ketones.[8a,b] However, the synthetic applications of compounds **5** are somewhat limited by their instability and difficulty of preparation;[9a,b] for example, the direct conversion of α,β-unsaturated acetals to the corresponding hemithio acetals **5** has not been reported. The cyano group, which serves as a good activating group in the well-known benzoin condensation, has been demonstrated to be an effective substituent at one of the two heteroatom positions in **4** for the activation of metalation. Thus, silyl- and ethoxyethyl-protected cyanohydrins **6** and α-(dialkylamino)nitriles **7** have been successfully employed as precursors of the vinyl ketone anion equivalent **3**.[3a,10a-e] However, the use of reagents **6** and **7** involves acid-

[⊗] Abstract published in *Advance ACS Abstracts,* November 1, 1995.

(1) (a) Seebach, D. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 239. (b) Martin, S. F. *Synthesis* **1979**, 633. (c) Gschwend, H. W.; Rodriguez, H. R. *Org. React.* **1979**, *26*, 1.

(2) (a) Katritzky, A. R.; Yang, Z.; Lam, J. N. *J. Org. Chem.* **1991**, *56*, 2143. (b) Katritzky, A. R.; Yang, Z.; Lam, J. N. *J. Org. Chem.* **1991**, *56*, 6917. (c) Katritzky, A. R.; Yang, Z.; Cundy, D. J. *Aldrichim. Acta* **1994**, *27*, 31.

(3) (a) Hoppe, D. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 932. (b) Werstiuk, N. H. *Tetrahedron* **1983**, *39*, 205. (c) Yamamoto, Y. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: New York, 1990; Vol. 2, p 55.

(4) Altenbach, H. J. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: New York, 1991; Vol. 6, p 829.

(5) (a) Oida, T.; Tanimoto, S.; Terao, H.; Okano, M. *J. Chem. Soc., Perkin Trans. 1* **1986**, 1715. (b) Fang, J.-M.; Liao, L.-F.; Hong, B.-C. *J. Org. Chem.* **1986**, *51*, 2828.

(6) (a) Devchand, D. K.; Murray, A. W.; Smeaton, E. *Tetrahedron Lett.* **1986**, *27*, 4635. (b) Ironside, M. D.; Murray, A. W. *Tetrahedron Lett.* **1989**, *30*, 1691. (c) Birse, R. F.; McKenzie, A.; Murray, A. W. *J. Chem. Soc., Perkin Trans. 1* **1988**, 1039.

(7) Seyferth, D.; Mammarella, R. E.; Klein, H. A. *J. Organomet. Chem.* **1980**, *194*, 1.

(8) (a) Mandai, T.; Takeshita, M.; Kawada, M.; Otera J. *Chem. Lett.* **1984**, 1259. (b) Mandai, T.; Arase, H.; Otera, J.; Kawada, M. *Tetrahedron Lett.* **1985**, *26*, 2677.

(9) (a) Mandai, T.; Takeshita, M.; Mori, K.; Kawada, M.; Otera, J. *Chem. Lett.* **1983**, 1909. (b) Kim, S.; Park, J. H.; Lee, J. M. *Tetrahedron Lett.* **1993**, *34*, 5769.

(10) (a) Albright, J. D. *Tetrahedron* **1983**, *39*, 3207. (b) Singh, P.; Hodgson, D. J. *J. Am. Chem. Soc.* **1974**, *96*, 5272. (c) Jacobson, R. M.; Lahm, G. P.; Clader, J. W. *J. Org. Chem.* **1980**, *45*, 395. (d) Jacobson, R. M.; Lahm, G. P. *J. Org. Chem.* **1979**, *44*, 462. (e) Hertenstein, U.; Hunig, S.; Oller, M. *Synthesis* **1976**, 416.

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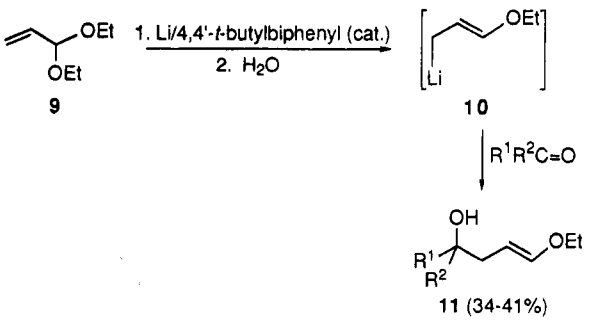
Scheme 1



promoted decyanation with the generation of HCN, and their preparation utilizes HCN or, in the case of **6** (R = $SiMe_3$ or R = CH_2CH_2OEt), ZnI_2 and expensive (trimethylsilyl)carbonitrile, all problematic on a large scale.

An alternative strategy for the production of synthon equivalent **3** has been to use α-lithiated alkoxyallenes **8.** This methodology has been used to prepare aryl vinyl ketones from aryl halides in the presence of $ZnCl_2$ and palladium catalysts.[11] However, metalation of alkoxyallenes **8** with $NaNH_2$ followed by alkylation with a primary alkyl group gave mixtures of α- and γ-alkylated alkoxyallenes,[12] while the corresponding lithio derivatives of **8** generated with butyllithium gave α-alkylation products which were isomerized to 2-methoxybutadienes.[13] There are no syntheses reported in the literature of alkyl vinyl ketones from alkoxyallenes **8.** α-Alkylation adducts of alkoxyallenes **8** with aldehydes and ketones do not give vinyl ketones on hydrolysis.[14]

Acrolein acetals have many reported synthetic applications based on elaboration of either the alkoxy group or the C=C double bond. Lithiation of **9** is difficult. As stated in ref 7, the temperature range for successful preparation of the lithio derivative of **9** is narrow: below −100 °C the metalation reaction is very slow; above −85 °C, the lithiated species begins to decompose; and at −65 °C the decomposition is rapid. Recently, Yus *et al.*[15] also mentioned the extreme instability of the lithiated species which decomposes spontaneously *via* an intramolecular nucleophilic process to give a cyclopropanolate. Details were also reported of an arene-catalyzed conversion of acrolein diethyl acetal (**9**) to a homoenolate anion **10** which reacted with ketones and aldehydes to give γ-alkylation products in 34−41% yields (Scheme 1); no examples of α-alkylation were found.[7,15] We have previously demonstrated that commercially available and inexpensive benzotriazole can be readily converted into a range of derivatives and that the benzotriazolyl group is easily displaced by nucleophiles.[16a−c] We now report that acrolein diethyl acetal (**9**) is conveniently converted to benzotriazolyl derivative **2** in which lithiation proceeds smoothly with butyllithium or LDA to form allylic anions which undergo α-alkylation almost exclusively with a number of electrophiles. Subsequent hydrolysis gives the desired vinyl ketones in good yields.

Results and Discussion

Preparation of *N*-(α-Ethoxyallyl)benzotriazole (2) and *in Situ* Preparation of Lithio Derivative 14. *N*-(α-Ethoxyallyl)benzotriazole (**2**) was prepared quantitatively on a large scale by reacting benzotriazole with acrolein diethyl acetal (**9**) in performance fluid (PF 5070, bp 80 °C, basic formula C_7H_{16}, an inert fluorocarbon medium available from the 3M Co.[17]) in an inverse Dean−Stark apparatus. The product was exclusively allylic ether **2.** No detectable amount of the vinyl ether derived from rearrangement of the C=C bond was evident from alkenic signals in the ^1H NMR spectrum, although, as we shall show later, such rearrangement can be induced quantitatively with $ZnBr_2$.[18] By contrast, previously documented reactions of acrolein acetals with nucleophiles such as Grignard reagents were reported[19a−c] to form mixtures of allyl ethers and vinyl ethers. Compound **2** thus prepared was pure and was used directly in further reactions. While **2** partially decomposed on silica gel during column chromatography, it is stable to prolonged storage and was fully characterized by NMR and elemental analysis. The allylic CH proton appears at *ca.* 6.6 ppm as a multiplet, and the two CH_2O protons resonate at fields of approximately 3.30 and 3.60 ppm, respectively.

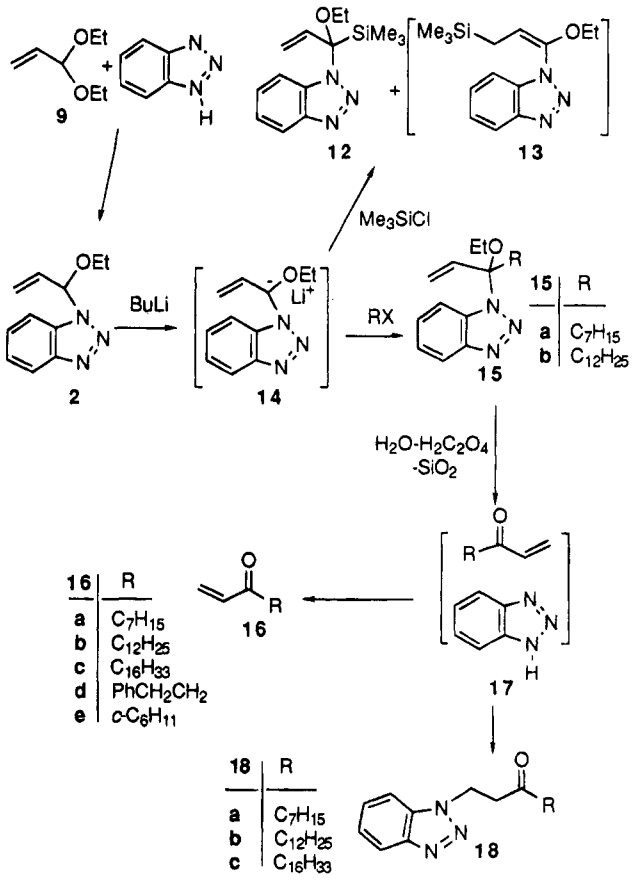
Allylic anion **14** was prepared *in situ* as a deep green solution in THF by stirring compound **2** with butyllithium at −78 °C for *ca.* 5 min (Scheme 2). A strictly oxygen-free atmosphere is required for the preparation of **14** as demonstrated by control experiments in which a brown solution was obtained when the reaction was protected by a normal nitrogen atmosphere. Reactions of this brown solution with alkyl halides gave product mixtures exhibiting complex NMR spectra.

Nucleophilic Substitution Reactions of Anion 14 with Halides: Preparation of Alkyl Vinyl Ketones. Treatment of the deep green solution of **14** prepared *in situ* with halides at −78 °C for 4 h and subsequently at 20 °C for a few hours gave adducts **15.** The alkylation reactions were complete at −78 °C as indicated by the simultaneous change in color of the solutions from green to brown within 2 min of the halide addition. As a result, the reactions could be quenched with water either at −78 °C or at 20 °C without influencing the yields. Alkylation of anion **14** by halides presumably proceeds *via* an S_N2 reaction, although anion **14** is sterically hindered.

This procedure worked very well for primary halides and gave fairly clean crude products. With long chain halides (**15b**, **16b**, and **16c**), some unreacted halide was recovered even when an excess of anion **14** was used. Higher yields of **15b**, **16b**, and **16c** were achieved when **14** was stirred with 2 equiv of HMPA for half an hour at −78 °C prior to the addition of halide. Cyclohexyl bromide, as an example of a secondary halide, gave **16e** in low yield even in the presence of HMPA, presumably because some of the halide was consumed in elimination reactions in which anion **14** behaved as a base. *t*-Butyl bromide gave no alkylation products. Adducts **15** are stable on storage; while they decomposed partially on

(11) Russell, C. E.; Hegedus, L. S. *J. Am. Chem. Soc.* **1983**, *105*, 943.
(12) Hoff, S.; Brandsma, L.; Arens, J. F. *Recl. Trav. Chim. Pays-Bas* **1968**, *87*, 916.
(13) Kucerovy, A.; Neuenschwander, K.; Weinreb, S. M. *Synth. Commun.* **1983**, *13*, 875.
(14) Zimmer, R. *Synthesis* **1993**, 165.
(15) Gil, J. F.; Ramon, D. J.; Yus, M. *Tetrahedron* **1994**, *50*, 3437.
(16) (a) Katrizky, A. R.; Rachwal, S.; Hitchings, G. J. *Tetrahedron* **1991**, *47*, 2683. (b) Katritzky, A. R.; Lan, X.; Fan, W. Q. *Synthesis* **1994**, 445. (c) Katritzky, A. R.; Lan, X. *Chem. Soc. Rev.* **1994**, 363.
(17) Zhu, D.-W. *Synthesis* **1993**, 953.
(18) Katritzky, A. R.; Wu, H.; Xie, L. *Synthesis*, in press.
(19) (a) Mioskowski, C.; Manna, S.; Falck, J. R. *Tetrahedron Lett.* **1984**, *25*, 519. (b) Quelet, R.; Bercot, P.; d'Angelo, J. *Bull. Soc. Chim. Fr.* **1966**, 3258. (c) Quelet, R.; d'Angelo, J. *Bull. Soc. Chim. Fr.* **1967**, 1503.

Scheme 2



column chromatography, pure adducts **15a** and **15b** were thus obtained for characterization purposes in 48% and 45% yields, respectively (cf. Table 1). However, in general, intermediates **15** were used directly in the subsequent hydrolysis reactions.

Primary, secondary, and tertiary alkyl halides all gave no detectable quantities of γ-alkylation products according to the NMR spectra of the crude products even though attack at the γ-position should be sterically more favorable. Hence, we do not believe that the regioselectivity of the alkylation of anion **14** is controlled by steric factors. The NMR spectra of the product mixture derived from the reaction of anion **14** with trimethylsilyl chloride, however, showed both α- and γ-silylated products **12** and **13** (*ca.* 3:1), indicating that the nature of the electrophile can affect the regioselectivity. Compound **12** was isolated in 43% yield.

Hydrolysis of adducts **15** was readily achieved at ambient temperature by treatment with $H_2C_2O_4$–SiO_2–H_2O in CH_2Cl_2. Thus, stirring compounds **15** with silica gel in the presence of small amounts of $H_2C_2O_4$ and H_2O for *ca.* 30 min gave alkyl vinyl ketones **16** in 48–71% overall yield along with small quantities of the rearranged products **18**. Contact with the hydrolysis medium for a longer period increased the proportion of rearranged ketones **18,** and stirring for 12 h led to the sole isolation of **18,** indicating that the rearrangement **15** → **18** is stepwise, i.e., hydrolysis to form alkyl vinyl ketones **16** and benzotriazole is followed by Michael addition of benzotriazole to the resulting ketone **16** to give **18.** Rapid hydrolysis and much slower Michael addition under the present conditions allowed vinyl ketones **16** to be separated from benzotriazole by washing with 2 N NaOH before the reaction between **16** and benzotriazole had occurred to any great extent. Alkyl vinyl ketones **16** thus prepared were purified by column chromatography to remove traces of the rearranged side products **18.**

The use of oxalic acid seems crucial for the successful formation of **16a–e** as demonstrated by comparison experiments: hydrolysis by 2 N HCl in methanol or by a strong acidic resin in the presence of a small amount of H_2O in THF gave only the rearranged products **18** presumably because both the hydrolysis and the Michael addition were fast under the strongly acidic conditions. By contrast, hydrolysis assisted by acetic acid or a weak acidic resin for 2 days led to recovery of most of the starting materials **15.**

Previously reported synthetic methods for vinyl ketones have included one carbon homologation by carbon monoxide,[20a,b] two-carbon homologation by vinyl metallics,[21a,b] and three-carbon homologation by vinyl acyl anion equivalents[10c,22a] (other work discussed above[3a,8a,b,10a–e] was concerned with vinyl ketones in which the vinyl group was substituted). The present three-carbon homologation combines simple procedures, readily accessible reagents, and mild hydrolysis conditions and compares favorably with the previous methodology.

1,4-Addition of Anion 14 to α,β-Unsaturated Carbonyl Compounds: Preparation of γ-Propenoyl-Substituted Esters 22 and Ketones 21 and 24. Many masked acyl anions such as lithioalkoxyallene react with α,β-unsaturated ketones to give either 1,2-adducts or a mixture of 1,2- and 1,4-adducts.[14] We examined reactions of anion **14** with α,β-unsaturated esters and α,β-unsaturated ketones, with the hope that the sterically congested anion **14** would favor 1,4-addition. Treatment of anion **14** with ethyl acrylate followed by quenching with H_2O at −78 °C gave exclusively 1,4-addition adduct **19a**, as shown by H_2O–$H_2C_2O_4$–SiO_2 mediated hydrolysis to give compound **22a** in 63% overall yield. Both the alkylation of anion **14** and the quenching with water must be carried out at −78 °C; higher temperatures resulted in isolation neither of **19a,** nor consequently of **22a,** but gave completely different products.[23] Hydrolysis of **19a** by H_2O–$H_2C_2O_4$–SiO_2 appears to be more rapid than the hydrolysis of compounds of type **15** as completion of the reaction of **19a** was observed after 5–10 min at room temperature. Longer periods (*ca.* 20 min) resulted in the formation of mixtures containing considerable amounts of rearranged benzotriazole derivatives similar to **18.** The γ-methyl substituent of methyl crotonate did not cause any detectable 1,2-addition of anion **14** to the ester group, and compound **22b** was similarly prepared without isolation of the intermediate from methyl crotonate in 70% overall yield (Scheme 3).

Intermediates **19** are stable under basic and neutral conditions and can be purified by column chromatography if desired; however, direct hydrolysis of the crude intermediates **19** provides the most efficient method for the production of compounds of type **22.** We characterized intermediates **19a** and **19b**; compared with **19a**, compound **19b** showed twice as many signals as required in both the ^1H and ^{13}C NMR spectra. Thus, ^{13}C signals at

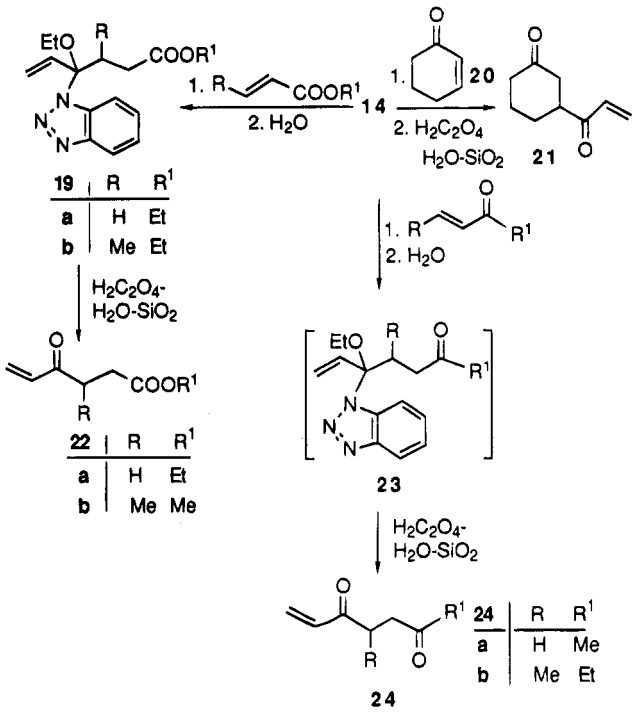
(20) (a) Goure, W. F.; Wright, M. E.; Davis, P. D.; Labadie, S. S.; Stille, J. K. *J. Am. Chem. Soc.* **1984**, *106*, 6417. (b) Ryu, I.; Kusano, K.; Yamazaki, H.; Sonoda, N. *J. Org. Chem.* **1991**, *56*, 5003.

(21) (a) Trost, B. M.; Kunz, R. A. *J. Am. Chem. Soc.* **1975**, *97*, 7152. (b) Labadie, J. W.; Tueting, D.; Stille, J. K. *J. Org. Chem.* **1983**, *48*, 4634.

(22) Stork, G.; Maldonado, L. *J. Am. Chem. Soc.* **1971**, *93*, 5286.

(23) Katritzky, A. R.; Jiang, J. *J. Org. Chem.* **1995**, *60*, 6; Katritzky, A. R.; Jiang, J. *J. Org. Chem.* **1995**, *60*, 7597.

Scheme 3



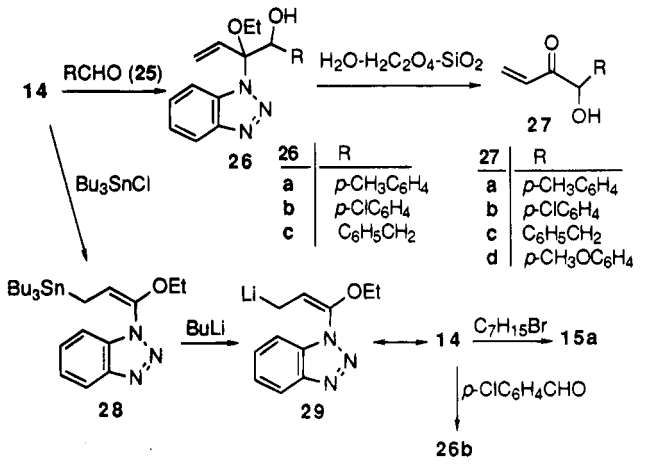
171 and 172 ppm for the carbonyl carbon and at 96.5 and 97 ppm for the carbon connected to the benzotriazolyl group demonstrated the presence of two diastereomers.

A similar procedure allows the efficient preparation of γ-propenoyl-substituted ketones. Products **21** and **24a,b** were synthesized in 40–62% overall yields by reaction of anion **14** with 2-cyclohexenone, methyl vinyl ketone, and ethyl 1-propenyl ketone, respectively. No 1,2-addition was observed in the reaction with methyl vinyl ketone, but for 2-cyclohexenone and ethyl 1-propenyl ketone, byproducts of 1,2-addition were detected at the *ca.* 20% level by ^{1}H NMR. Apparently, the γ-substituents of the α,β-unsaturated ketones induce some γ-attack by anion **14**. The minor amounts of 1,2-addition byproducts were readily removed by column chromatography, and their structures were not completely characterized.

Structures **21, 22a,b** and **24a,b** were assigned on the basis of NMR spectra, and new compounds **21**, **22a,b** and **24b** were confirmed by elemental analyses. In the ^{13}C NMR spectra of **22a,b** the two carbonyl signals appeared at *ca.* 172 and 200 ppm and those of **24a,b** at *ca.* 200 and 208 ppm. Proton signals typical for the terminal vinyl groups were observed in all compounds: the proton signals appeared as two doublets at *ca.* 5.9 and 6.3 ppm and as a doublet of doublets at 6.4 ppm; the carbon signals appeared at *ca.* 128 and 136 ppm. Compounds **22a** and **24a** showed the expected spectra, while the two CH_2 protons β to the ester or ketone group in **22b** and **24b** resonated at different fields in the ^{1}H NMR spectra.

1,4-Dicarbonyl compounds are valuable synthetic precursors,[24] but few methods are available for the preparation of compounds of types **22** and **24** containing an additional vinyl group. Lithiation of the protected cyanohydrins derived from α,β-unsaturated aldehydes followed by reaction with α,β-unsaturated ketones gives 1,4-addition adducts;[10b] however, their transformation to 1,4-dicarbonyl compounds similar to **21** was reported as a three-step procedure. By contrast, the hydrolysis of **19** and **23** by the present method is a simple one-step procedure.

Scheme 4



Reaction of Anion 14 with Aldehydes: Preparation of (1-Hydroxyalkyl) Vinyl Ketones. Anion **14** reacted with aldehydes to afford the expected secondary alcohols **26a-c** (Scheme 4). Only moderate yields (46–48%) of **26** were obtained following isolation by column chromatography as the adducts partially decomposed during purification. These compounds showed some tendency to revert back to the starting materials if the reaction mixture was heated. Hydrolysis of the isolated pure compounds **26a–c** (derived from aryl aldehydes) by H_2O–$H_2C_2O_4$–SiO_2 gave the corresponding vinyl ketone derivatives **27a–c** in quantitative yields. However, the overall yields of compounds **27** given in Table 2 (average 51%) are the result of direct hydrolysis of the crude intermediates **26**, thus providing a convenient approach to **27**. Hydrolysis of compounds of type **26** is slower than that observed for **15**, **19**, and **23**, but after 2.5 h hydrolysis of **26** to **27** was complete without significant formation of rearranged products similar to **18**.

Compounds similar to **27** derived from ketones rather than from aldehydes were previously prepared by reaction of the lithio species derived from cyanohydrin derivatives **6**[10c] (our own work with ketones is considered in the following paper[25]). Similar reactions of cyanohydrin anions of type **6** with aldehydes in THF gave α-alkylated products which reacted further with another equivalent of the anion of **6** to give mixtures of products.[26] We have found that compounds **27a–d** are not stable at temperatures above 60 °C and even decompose during solvent removal under reduced pressure in a water bath at 60 °C. However, the use of low boiling point solvents such as CH_2Cl_2 or petroleum ether (30–50 °C) for the hydrolysis and column chromatography allowed **27** to be isolated readily without decomposition. Compound **27c** derived from phenylacetaldehyde is even less stable, and a lower yield (30%) of the pure compound was obtained under the same conditions. The successful preparation of compounds **27a–d** by the present method is attributed to the use of mild conditions under which compounds **27** are not rapidly decomposed.

Reactions of Anion 14 with Tributyltin Chloride and Anion 29 with Electrophiles. Unlike the reaction

(24) Lu, X.; Ji, J.; Ma, D.; Shen, W. *J. Org. Chem.* **1991**, *56*, 5774.
(25) Katritzky, A. R.; Jiang, J. *J. Org. Chem.* **1995**, *60*, 7597.
(26) Hunig, S.; Marschner, C.; Peters, K.; von Schnering, H. G. *Chem. Ber.* **1989**, *122*, 2131.
(27) Satoh, T.; Kumagawa, T.; Sugimoto, A.; Yamakawa, K. *Bull. Chem. Soc. Jpn.* **1987**, *60*, 301.
(28) Stetter, H.; Landscheidt, A. *Chem. Ber.* **1979**, *112*, 1410.

Table 1. Preparation of Benzotriazole Derivatives 2, 12, 15, 18, 19, 26, and 28

compd	R (Ar)	yield (%)	mp (°C)	molec formula	CHN analysis, found (required) C	H	N
2		95	oil	$C_{11}H_{13}N_3O$	65.18 (64.99)	6.56 (6.45)	20.67 (20.68)
12		43	69–70	$C_{14}H_{21}N_3OSi$	60.98 (61.05)	7.72 (7.69)	15.38 (15.26)
15a	C_7H_{15}	48	oil	$C_{18}H_{27}N_3O$	71.99 (71.72)	9.07 (9.03)	13.55 (13.94)
15b	$C_{12}H_{25}$	45	oil	$C_{23}H_{37}N_3O$	74.04 (74.33)	10.09 (10.04)	14.48 (14.31)
18a	C_7H_{15}	70	oil	$C_{16}H_{23}N_3O$	70.65 (70.30)	8.67 (8.48)	15.03 (15.37)
18b	$C_{12}H_{25}$	5[a]	79–80	$C_{21}H_{33}N_3O$	73.61 (73.43)	9.71 (9.68)	12.22 (12.33)
18c	$C_{16}H_{33}$	5[a]	90–91	$C_{25}H_{41}N_3O$	75.47 (75.41)	10.60 (10.34)	10.17 (10.52)
19a[b]	H	70	oil	$C_{16}H_{21}N_3O_3$	63.56 (63.35)	7.05 (6.98)	13.80 (13.85)
19b[b]	Me	65	oil	$C_{17}H_{23}N_3O_3$	64.45 (64.33)	7.40 (7.30)	13.33 (13.24)
26a	*p*-$CH_3C_6H_4$	46	134–135	$C_{19}H_{21}N_3O_2$	70.51 (70.57)	6.58 (6.55)	13.08 (12.99)
26b	*p*-ClC_6H_4	48	123–124	$C_{18}H_{18}N_3O_2Cl$	63.21 (62.88)	5.36 (5.28)	11.86 (12.22)
26c	$C_6H_5CH_2$	48	130–131	$C_{19}H_{21}N_3O_2$	70.54 (70.57)	6.57 (6.55)	13.05 (12.99)
28		85	oil	$C_{23}H_{39}N_3OSn$	56.21 (55.96)	8.05 (7.97)	8.68 (8.52)

[a] The byproducts isolated from the preparation of **16b** and **16c**. [b] R^1 = Et.

Table 2. Preparation of Vinyl Ketones 16, 21, 22, 24, and 27

compd	R(Ar)	$R^1(Ar^1)$	yield (%)	time[a] (min)	molec formula	CHN analysis, found (required) C	H
16a	C_7H_{15}		64	30	$C_{10}H_{18}O$	77.59 (77.87)	11.66 (11.66)
16b	$C_{12}H_{25}$		66	30	$C_{15}H_{28}O$	80.06 (80.28)	12.58 (12.59)
16c	$C_{16}H_{33}$		69	30	$C_{19}H_{36}O$	81.11 (81.36)	13.26 (12.94)
16d	$PhCH_2CH_2$		71	30	$C_{11}H_{12}O$	82.18 (82.45)	7.65 (7.55)
16e[b]	*c*-C_6H_{11}		48	30	$C_9H_{14}O$	ref[27]	
21			40	5	$C_9H_{12}O_2$	71.42 (71.03)	8.19 (7.95)
22a	H	Et	63	5	$C_8H_{12}O_3$	61.41 (61.52)	7.95 (7.74)
22b	Me	Me	70	5	$C_8H_{12}O_3$	61.23 (61.52)	7.91 (7.74)
24a[c]	H	Me	62	5	$C_7H_{12}O_2$	ref[28]	
24b	Me	Et	44	5	$C_9H_{14}O_2$	70.14 (70.10)	9.18 (9.15)
27a	*p*-$CH_3C_6H_4$		70	150	$C_{11}H_{12}O_2$	74.76 (74.98)	7.00 (6.86)
27b	*p*-ClC_6H_4		43	150	$C_{10}H_9O_2Cl$	60.78 (61.08)	4.70 (4.61)
27c	$PhCH_2$		30	150	$C_{11}H_{12}O_2$	74.69 (74.96)	6.97 (6.87)
27d	*p*-$MeOC_6H_4$		61	150	$C_{11}H_{12}O_3$	68.42 (68.74)	6.27 (6.29)

[a] For hydrolysis. [b] Identical NMR data to that reported in the lit.[27] [c] Identical NMR data to that reported in the lit.[28]

of allyl anion **14** with tertiary alkyl halides described above which gave neither α-alkylated nor γ-alkylated products, treatment of anion **14** with tributyltin chloride at −78 °C for 2 h then at 20 °C for 10 h gave qualitatively the γ-adduct **28** (Scheme 4). Presumably, because of the high instability of the α-alkylated product, no α-reaction was observed as indicated by the ^{1}H NMR spectra which showed no signals for the terminal alkenyl group. The characteristic triplet of the CH=C group of **28** appears at around 5.5 ppm in the ^{1}H NMR spectrum. We investigated reactions of **28** with butyllithium, anticipating that anion **29** thus generated might undergo γ-alkylation with halides or aldehydes. Thus, treatment of compound **28** with butyllithium at −78 °C gave a green solution which presumably contained carbanion **29**. However, treatment of this solution with heptyl bromide and with *p*-chlorobenzaldehyde exclusively gave the α-alkylated adducts **15a** and **26b**, respectively, which were identical to the products of the reactions of allyl anion **14** with the corresponding halide and aldehyde (Schemes 1 and 4). This indicates that a rapid equilibrium occurs between anions **14** and **29**. This result also suggests that the regioselectivity of reactions of anion equivalents **14** and **29** with electrophiles is not related to initial formation at the α-terminus or the γ-terminus but represents typical characteristics of homoenolate anions. The high selectivity of anion **14** or **29** toward α-alkylation is presumably connected to the higher electron density at the α-end, some of which is provided by the electron pair of the adjacent ethoxy group.

Conclusions

In summary, we have developed a new heterocycle-stabilized propenoyl anion equivalent or homoenolate anion which, because of α-alkylation, provides synthon equivalent **3** for the convenient synthesis of vinyl ketones **16**, and functionalized vinyl ketones **21**, **22**, **24**, and **27**. The benzotriazolyl group in *N*-(α-ethoxyallyl)benzotriazole (**2**) makes two additional essential contributions to the utility of **2**: (i) the lithiation of acrolein diethyl acetal (**9**) by butyllithium is rendered possible under normal conditions and (ii) protection of the ketonic carbonyl group. Compared with similar reagents, the use of *N*-(α-ethoxyallyl)benzotriazole exhibits a number of advantages: high regioselectivity of α-alkylation, mild conditions for hydrolysis of the resulting α-alkylation adducts, easy removal of (and if desired, easy recovery of) the benzotriazole, no requirement for the use of HCN or sulfur compounds, readily available reagents, and simple procedures. Many of the compounds synthesized by the present method are of synthetic interest and are either novel or have not previously been conveniently prepared.

Experimental Section

^{1}H and ^{13}C NMR spectra were recorded on a 300 MHz spectrometer in $CDCl_3$. THF was freshly distilled from sodium–benzophenone ketyl immediately prior to use. All lithiations were carried out in an argon atmosphere created by purging the air and refilling with argon several times. (Argon was used for convenience, pure nitrogen would certainly be satisfactory). Use of either butyllithium or LDA as the base for lithiations gave equal yields of the products.

Preparation of *N*-(α-Ethoxyallyl)benzotriazole (2). Acrolein diethyl acetal (**9**, 10.0 g, 72 mmol) and benzotriazole (7.15 g, 60 mmol) were heated under reflux in performance fluid (82 °C, 70 mL) in a round bottom flask for 2 h. The flask was then equipped with a reverse Dean–Stark trap and the reaction mixture was refluxed for another 3 h to remove the ethanol generated. The mixture was cooled to 20 °C and a separatory funnel used to collect the upper layer. Removal of the small amount of performance fluid under vacuum gave an oil (12.0 g, 95%): ^{1}H NMR δ 1.14 (t, J = 7.0 Hz, 3 H), 3.25-3.40 (m, 1 H), 3.56-3.68 (m, 1 H), 5.45 (d, J = 10.5 Hz, 1 H), 5.58 (d, J = 17.0 Hz, 1 H), 6.14-6.27 (m, 1 H), 6.58-6.62 (m, 1 H), 7.35-7.50 (m, 2 H), 7.73 (d, J = 8.0 Hz, 1 H), 8.08 (d, J = 8.0 Hz, 1 H); ^{13}C NMR δ 14.4, 64.3, 88.6, 111.4, 119.3, 119.7, 124.1, 127.2, 131.1, 132.6, 146.6.

Preparation of Benzotriazole Derivatives 15. Representative Procedure for *N*-(1-Ethoxy-1-heptylallyl)benzotriazole (15a). To a solution of *N*-(α-ethoxyallyl)benzotriazole (**2**, 2.03 g, 10 mmol) in THF (100 mL) was added butyllithium (11 mmol) via syringe at −78 °C to give a green solution (**14**). The mixture was stirred at −78 °C for 5 min, and 1-iodoheptane (2.26 g, 10.0 mmol) was added at −78 °C. The stirring was continued at −78 °C for 4 h and then at 20 °C for 12 h. The reaction was quenched with water (30 mL) and extracted with ether (3 × 50 mL) (the reaction can also be quenched at −78 °C before warming to rt without influencing the yield). The extract was washed with NaOH (2 N, 25 mL) (the benzotriazole is removed in this wash and if desired can be recovered) and dried ($MgSO_4$) and the solvent removed to give an oil which was purified by column chromatography (silica gel, hexane/ether, 10:1), yield 48%: ^{1}H NMR δ 0.88 (t, J = 7.1 Hz, 3 H), 1.08 (t, J = 7.1 Hz, 3 H), 1.18–1.50 (m, 10 H), 2.54–2.72 (m, 2 H), 2.93–3.05 (m, 1 H), 3.25–3.40 (m, 1 H), 5.42 (d, J = 10.9 Hz, 1 H), 5.52 (d, J = 17.4 Hz, 1 H), 6.22 (dd, J = 17.4, 10.9 Hz, 1 H), 7.34–7.45 (m, 2 H), 7.80 (d, J = 8.3 Hz, 1 H), 8.05 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 14.0, 14.8, 22.6, 22.8, 29.1, 29.5, 31.7, 36.1, 57.9, 94.5, 113.1, 117.4, 119.7, 123.9, 126.9, 132.1, 136.8, 146.6.

***N*-(1-Dodecyl-1-ethoxyallyl)benzotriazole (15b)** was prepared as described above with the exception that the green solution (**14**) was stirred with 2 equiv of HMPA for 0.5 h prior to the addition of 1-bromododecane. Purification by column chromatography (silica gel, EtOAc/hexane, 1:5) afforded an oil, yield 45%: ^{1}H NMR δ 0.88 (t, J = 6.9 Hz, 3 H), 1.09 (t, J = 7.0 Hz, 3 H), 1.20–1.45 (m, 20 H), 2.50–2.70 (m, 2 H), 2.92–3.03 (m, 1 H), 3.30–3.40 (m, 1 H), 5.43 (d, J = 10.8 Hz, 1 H), 5.49 (d, J = 17.3 Hz, 1 H), 6.23 (dd, J = 17.3, 10.8 Hz, 1 H), 7.30–7.47 (m, 2 H), 7.80 (d, J = 8.3 Hz, 1 H), 8.07 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 14.0, 14.8, 22.6, 22.7, 29.2, 29.3, 29.4, 29.5, 29.6, 31.8, 36.0, 57.9, 94.5, 113.0, 117.3, 119.6, 123.8, 126.9, 132.1, 136.8, 146.6.

***N*-[(1-Ethoxy-1-(trimethylsilyl)allyl)]benzotriazole (12)** was prepared from trimethylsilyl chloride according to the procedure given for **15** and isolated by column chromatography (silica gel, EtOAc/hexane, 1:5) as a white solid, yield 43%: mp 69–70 °C; ^{1}H NMR δ 0.34 (s, 9 H), 1.06 (t, J = 7.0 Hz, 3 H), 3.15–3.25 (m, 1 H), 3.40–3.52 (m, 1 H), 5.26 (d, J = 17.3 Hz, 1 H), 5.37 (d, J = 10.9 Hz, 1 H), 6.12 (dd, J = 17.3, 10.9 Hz, 1 H), 7.32–7.43 (m, 2 H), 7.76 (d, J = 8.3 Hz, 1 H), 8.06 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 1.3, 15.3, 60.8, 92.8, 113.2, 116.2, 119.7, 123.9, 126.8, 132.8, 136.0, 146.2.

Preparation of Alkyl Vinyl Ketones 16. Representative Procedure for 1-Decen-3-one (16a). *N*-(α-Ethoxyallyl)-benzotriazole (**2**, 3.03 g, 15 mmol) was stirred with butyllithium (17 mmol) in THF (100 mL) at −78 °C for 5 min to give a green solution (**14**). 1-Iodoheptane (2.9 g, 13.5 mmol) was added and the mixture stirred at −78 °C for 4 h. The reaction was quenched with water (30 mL) and extracted with ether. The extract was washed with NaOH (2 N, 25 mL) and dried ($MgSO_4$) and the solvent removed to give an oil which was stirred with silica gel (40 g) in CH_2Cl_2 (80 mL) containing $H_2C_2O_4$ (0.7 g) and H_2O (0.7 mL) for 30 min. After the silica gel and $H_2C_2O_4$ were filtered off, the filtrate was washed with NaOH (2 N, 40 mL) and dried ($MgSO_4$) and the solvent removed to give an oily product which was purified by column chromatography (silica gel, EtOAc/hexane, 1:5), overall yield 64%: ^{1}H NMR δ 0.89 (t, J = 7.0 Hz, 3 H), 1.23–1.41 (m, 8 H), 1.57–1.61 (m, 2 H), 2.59 (t, J = 7.2 Hz, 2 H), 5.82 (d, J = 10.3 Hz, 1 H), 6.22 (d, J = 17.7 Hz, 1 H), 6.37 (dd, J = 17.7, 10.3 Hz, 1 H); ^{13}C NMR δ 13.9, 22.5, 23.9, 29.0, 29.1, 31.6, 39.6, 127.6, 136.5, 200.9.

1-Pentadecen-3-one (16b) was prepared as described above with the exception that the green solution (**14**) was stirred with 2 equiv of HMPA for 0.5 h prior to the addition of 1-bromododecane. Purification by column chromatography (silica gel, EtOAc/hexane, 1:5) afforded an oil, yield 66%: ^{1}H NMR δ 0.88 (t, J = 6.9 Hz, 3 H), 1.22–1.36 (m, 18 H), 1.57–1.70 (m, 2 H), 2.58 (t, J = 7.3 Hz, 2 H), 5.82 (d, J = 10.3 Hz, 1 H), 6.23 (d, J = 17.7 Hz, 1 H), 6.36 (dd, J = 17.7, 10.3 Hz, 1 H); ^{13}C NMR δ 14.0, 22.6, 24.0, 29.2, 29.3, 29.4, 29.5, 29.6, 31.9, 39.6, 127.7, 136.6, 200.9.

1-Nonadecen-3-one (16c) was prepared as described above with the exception that the green solution (**14**) was stirred with 2 equiv of HMPA for 0.5 h prior to the addition of 1-bromohexadecane. Purification by column chromatography (silica gel, AcOEt/hexane, 1:5) afforded a white solid, yield 69%: mp 47–48 °C; ^{1}H NMR δ 0.87 (t, J = 7.0 Hz, 3 H), 1.20–1.35 (m, 26 H), 1.55–1.67 (m, 2 H), 2.57 (t, J = 7.3 Hz, 2 H), 5.81 (d, J = 10.4 Hz, 1 H), 6.20 (d, J = 17.7 Hz, 1 H), 6.35 (dd, J = 17.7, 10.3 Hz, 1 H); ^{13}C NMR δ 14.1, 22.7, 24.0, 29.2, 29.3, 29.4, 29.5, 29.6, 29.7, 31.9, 39.7, 127.7, 136.6, 201.0.

5-Phenyl-1-penten-3-one (16d) was prepared as an oil from 1-bromo-2-phenylethane and purified by column chromatography (silica gel AcOEt/hexane, 1:5), overall yield 71%: ^{1}H NMR δ 2.85–3.00 (m, 4 H), 5.81 (d, J = 10.4 Hz, 1 H), 6.19 (d, J = 17.7 Hz, 1 H), 6.35 (dd, J = 17.7, 10.3 Hz, 1 H), 7.15–7.26 (m, 3 H), 7.26–7.33 (m, 2 H); ^{13}C NMR δ 29.7, 41.1, 126.0, 128.0, 128.2, 128.4, 136.4, 141.0, 199.5.

Cyclohexyl vinyl ketone (16e) was prepared as an oil from bromocyclohexane and purified by column chromatography (silica gel, AcOEt/hexane, 1:5), overall yield 48%: ^{1}H NMR δ 1.21–1.45 (m, 5 H), 1.65–1.75 (m, 1 H), 1.75–1.92 (m, 4 H), 2.59–2.68 (m, 1 H), 5.76 (d, J = 10.4 Hz, 1 H), 6.27 (d, J = 17.4 Hz, 1 H), 6.46 (dd, J = 17.4, 10.3 Hz, 1 H); ^{13}C NMR δ 25.6, 25.8, 28.4, 48.0, 127.5, 134.8, 203.2.

Preparation of β-(Benzotriazol-1-yl) Ketones 18. Representative Procedure for 1-(Benzotriazol-1-yl)decan-3-one (18a). *N*-(α-Ethoxyallyl)benzotriazole (**2**, 3.03 g, 15 mmol) was stirred with butyllithium (17 mmol) in THF (100 mL) at −78 °C for 5 min to give a green solution (**14**). 1-Iodoheptane (2.9 g, 13.5 mmol) was added and the mixture stirred at −78 °C for 4 h. The reaction was quenched with water (30 mL) and extracted with ether. The extract was washed with NaOH (2 N, 25 mL) and dried ($MgSO_4$) and the solvent removed to give an oil which was stirred with 2 N HCl (10 mL) in methanol (30 mL). After most of the methanol was removed, the residue was extracted with $CHCl_3$ (2 × 50 mL). The extract was dried ($MgSO_4$) and the solvent removed to give an oil. The product was purified by column chromatography (silica gel, AcOEt/hexane, 1:5), yield 70%. **18a** was also isolated in 5% yield in the preparation of vinyl ketone **16a**: ^{1}H NMR δ 0.85 (t, J = 6.7 Hz, 3 H), 1.15–1.30 (m, 8 H), 1.45–1.57 (m, 2 H), 2.40 (t, J = 7.4 Hz, 2 H), 3.22 (t, J = 6.5 Hz, 2 H), 4.83 (t, J = 6.5 Hz, 2 H), 7.32 (t, J = 8.2 Hz, 1 H), 7.45 (t, J = 7.9 Hz, 1 H), 7.63 (d, J = 8.3 Hz, 1 H), 7.98 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 13.6, 22.1, 23.1, 28.5, 31.1, 41.1, 41.8, 42.5, 109.4, 119.1, 123.4, 126.8, 132.7, 145.3, 207.2.

1-(Benzotriazol-1-yl)pentadecan-3-one (18b) was isolated as a white solid by column chromatography in the preparation of vinyl ketone **16b**, yield 5%: mp 79–80 °C; ^{1}H NMR δ 0.88 (t, J = 6.7 Hz, 3 H), 1.17–1.35 (m, 18 H), 1.48–1.60 (m, 2 H), 2.42 (t, J = 7.4 Hz, 2 H), 3.24 (t, J = 6.6 Hz, 2 H), 4.87 (t, J = 6.6 Hz, 2 H), 7.36 (t, J = 7.2 Hz, 1 H), 7.50 (t, J = 7.2 Hz, 1 H), 7.64 (d, J = 8.3 Hz, 1 H), 8.03 (t, J = 8.3 Hz, 1 H); ^{13}C NMR δ 14.1, 22.6, 23.5, 29.0, 29.2, 29.3, 29.5, 29.6, 31.9, 41.7, 42.2, 43.1, 109.7, 119.8, 123.9, 127.3, 133.1, 145.8, 207.7.

1-(Benzotriazol-1-yl)nonadecan-3-one (18c) was isolated as a white solid by column chromatography in the preparation of vinyl ketone **16c**, yield 5%: mp 90–91 °C; ^{1}H NMR δ 0.89 (t, J = 6.6 Hz, 3 H), 1.16–1.38 (m, 25 H), 1.48–1.62 (m, 2 H),

2.43 (t, J = 7.4 Hz, 2 H), 3.24 (t, J = 6.5 Hz, 2 H), 4.87 (t, J = 6.5 Hz, 2 H), 7.36 (t, J = 7.2 Hz, 1 H), 7.50 (t, J = 7.2 Hz, 1 H), 7.65 (d, J = 8.3 Hz, 1 H), 8.03 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 14.1, 22.6, 23.5, 29.0, 29.2, 29.3, 29.4, 29.5, 29.6, 29.7, 31.9, 41.7, 42.2, 43.1, 109.7, 119.8, 123.8, 127.3, 132.8, 145.8, 207.7.

Preparation of Benzotriazole Derivatives 19. Representative Procedure for Ethyl 4-(Benzotriazol-1-yl)-4-ethoxy-5-hexenoate (19a). *N*-(α-Ethoxyallyl)benzotriazole (**2**, 2.5 g, 12 mmol) was stirred with butyllithium (7.5 mL, 2 M, 12.5 mmol) in THF (60 mL) at −78 °C for 5 min to give a deep green solution (**14**) to which was added the α,β-unsaturated ester (ethyl acrylate for **19a**, 12.3 mmol) and the mixture stirred for 4 h at −78 °C. The mixture was quenched with water (30 mL) at −78 °C and extracted with ether (2 × 40 mL) at 20 °C. The extract was washed with H_2O (30 mL) and dried ($MgSO_4$) and the solvent removed to give an oily residue which was purified by column chromatography (silica gel, AcOEt/hexane, 1:5), yield 70%: ^{1}H NMR δ 1.09 (t, J = 7.0 Hz, 3 H), 1.27 (t, J = 7.1 Hz, 3 H), 2.46 (t, J = 7.0 Hz, 2 H), 2.85−3.15 (m, 3 H), 3.35 (quintet, J = 7.0 Hz, 1 H), 4.15 (q, J = 7.1 Hz, 2 H), 5.52 (d, J = 10.9 Hz, 1 H), 5.56 (d, J =16.6 Hz, 1 H), 6.23 (dd, J = 17.4, 10.9 Hz, 1 H), 7.37 (t, J = 7.1 Hz, 1 H), 7.45 (t, J = 7.1 Hz, 1 H), 7.80 (d, J = 8.2 Hz, 1 H), 8.07 (d, J = 8.2 Hz, 1 H); ^{13}C NMR δ 14.0, 14.6, 28.4, 31.0, 58.1, 60.5, 93.5, 112.7, 118.3, 119.7, 124.0, 127.1, 132.0, 135.6, 146.5, 172.4.

Ethyl 4-(Benzotriazol-1-yl)-4-ethoxy-3-methyl-5-hexenoate (19b) was prepared from ethyl crotonate as an oily mixture of two diastereomers (55:45) in a total yield of 65% and purified by column chromatography (silica gel, AcOEt/hexane, 1:5): ^{1}H NMR δ 0.74 (d, J = 6.9 Hz, 1.65 H), 1.03−1.12 (m, 3 H), 1.16−1.20 (m, 2.7 H), 1.32 (t, J = 7.0 Hz, 1.65 H), 2.07 (dd, J = 15.7, 10.4 Hz, 0.45 H), 2.15 (dd, J = 15.7, 7.9 Hz, 0.55 H), 2.40 (dd, J = 15.7, 3.2 Hz, 0.55 H), 2.76−2.91 (m, 1 H), 2.95−3.08 (m, 0.45 H), 3.19−3.30 (m, 0.45 H), 3.35−3.54 (m, 1.55 H), 4.05 (q, J = 7.1 Hz, 0.9 H), 4.10 (q, J = 7.1 Hz, 1.1 H), 5.57−5.78 (m, 2 H), 6.67 (dd, J = 17.5, 11.1 Hz, 0.45 H), 6.91 (dd, J = 17.5, 11.1 Hz, 0.55 H), 7.35−7.45 (m, 1 H), 7.51 (q, J = 7.0 Hz, 1 H), 7.91 (d, J = 8.51 Hz, 0.45 H), 8.02 (d, J = 8.5 Hz, 0.55 H), 8.07−8.11 (m, 1 H); ^{13}C NMR δ 13.5, 13.7, 13.8, 14.1, 14.2, 14.7, 36.0, 36.2, 37.4, 38.1, 58.1, 58.5, 59.7, 59.8, 96.5, 97.0, 112.3, 112.5, 119.0, 119.3, 119.4, 123.6, 123.7, 126.9, 127.0, 130.0, 131.0, 131.3, 131.8, 146.1, 146.2, 171.0, 171.9.

Preparation of β-Propenoylcarboxylic Esters 22. Representative Procedure for Ethyl β-Propenoylpropionate (22a). *N*-(α-Ethoxyallyl)benzotriazole (**2**, 2.5 g, 12 mmol) was stirred with butyllithium (7.5 mL, 2 M, 12.5 mmol) in THF (60 mL) at −78 °C for 5 min to give a deep green solution (**14**) to which was added the α,β-unsaturated ester (ethyl acrylate for **22a**, 12.3 mmol) and the mixture stirred for 4 h at −78 °C. The mixture was quenched with water (30 mL) at −78 °C and extracted with ether (2 × 40 mL) at 20 °C. The extract was washed with NaOH (2 N, 2 × 30 mL) and dried ($MgSO_4$) and the solvent removed to give an oily residue which was stirred for 5 min (note: stirring for a longer period led to the formation of a β-benzotriazolyl-substituted alkyl ketone similar to **18** as a side product) with silica gel (30 g) in CH_2Cl_2 (60 mL) containing $H_2C_2O_4$ (0.4 g) and H_2O (0.5 mL). After the silica gel and $H_2C_2O_4$ were filtered off, the filtrate was washed with NaOH (2 N, 2 × 15 mL) and dried ($MgSO_4$) and the solvent removed to give an oil which was purified by distillation, yield 63%: bp 57−60 °C/2 mmHg; ^{1}H NMR δ 1.27 (t, J = 7.3 Hz, 3 H), 2.63 (t, J = 6.5 Hz, 2 H), 2.94 (t, J = 6.5 Hz, 2 H), 4.15 (q, J = 7.3 Hz, 2 H), 5.88 (d, J = 11.4 Hz, 1 H), 6.26 (d, J = 17.5 Hz, 1 H), 6.38 (dd, J = 17.5, 11.4 Hz, 1 H); ^{13}C NMR δ 13.9, 27.6, 33.9, 60.2, 128.1, 135.9, 172.3, 198.4.

Methyl β-Propenoylbutyrate (22b) was prepared as an oil from methyl crotonate in 70% overall yield and purified by distillation, bp 43−45 °C/0.3 mmHg: ^{1}H NMR δ 1.23 (d, J = 7.3 Hz, 3 H), 2.43 (dd, J = 16.5, 5.7 Hz, 1 H), 2.88 (dd, J = 16.8, 8.4 Hz, 1 H), 3.35−3.45 (m, 1 H), 3.72 (s, 3 H), 5.92 (d, J = 10.3 Hz, 1 H), 6.38 (d, J = 17.5 Hz, 1 H), 6.52 (dd, J = 17.5, 10.3 Hz, 1 H); ^{13}C NMR δ 16.9, 36.6, 39.4, 51.6, 128.6, 134.8, 172.6, 202.1.

Preparation of β-Propenoyl Ketones 21 and 24. Representative Procedure for Hept-1-ene-3,6-dione (24a). The deep green solution of anion **14** prepared as above was stirred with the α,β−unsaturated ketone (methyl vinyl ketone for **24a**, 13.5 mmol) for 4 h at −78 °C. The mixture was quenched with water (30 mL) at −78 °C and extracted with ether (2 × 40 mL) at ambient temperature. The extract was washed with NaOH (2 N, 2 × 30 mL) and dried ($MgSO_4$) and the solvent removed to give an oily residue which was stirred for 5 min with silica gel (30 g) in CH_2Cl_2 (60 mL) containing $H_2C_2O_4$ (0.4 g) and H_2O (0.5 mL). After the silica gel and $H_2C_2O_4$ were filtered off, the filtrate was washed with NaOH (2 N, 2 × 15 mL) and dried ($MgSO_4$) and the solvent removed to give an oil which was purified by column chromatography (silica gel, AcOEt/hexane, 1:5) to give **24a** in 62% overall yield: ^{1}H NMR δ 2.22 (s, 3 H), 2.78 (t, J = 6.7 Hz, 2 H), 2.89 (t, J = 6.7 Hz, 2 H), 5.87 (d, J = 10.1 Hz, 1 H), 6.27 (d, J = 17.7 Hz, 1 H), 6.38 (dd, J = 17.7, 10.1 Hz, 1 H); ^{13}C NMR δ 29.9, 33.0, 36.7, 128.2, 136.2, 198.8, 206.9.

4-Methyloct-1-ene-3,6-dione (24b) was prepared as an oil from hex-2-en-4-one and purified by column chromatography (silica gel, AcOEt/hexane, 1:5) to give an overall yield of 44%: ^{1}H NMR δ 1.06 (t, J = 7.3 Hz, 3 H), 1.12 (d, J = 7.4 Hz, 3 H), 2.40−2.51 (m, 3 H), 3.01 (dd, J = 17.6, 8.9 Hz, 1 H), 3.35−3.42 (m, 1 H), 5.84 (d, J = 10.2 Hz, 1 H), 6.31 (d, J = 17.5 Hz, 1 H), 6.46 (dd, J = 17.5, 10.2 Hz, 1 H); ^{13}C NMR δ 7.5, 16.8, 35.8, 38.3, 44.9, 128.2, 134.9, 202.7, 209.5.

β-Propenoylcyclohexanone (21) was prepared as an oil from 2-cyclohexenone and purified by column chromatography (silica gel, AcOEt/hexane, 1:5), overall yield 40%: ^{1}H NMR δ 1.70−1.90 (m, 2 H), 2.03−2.16 (m, 2 H), 2.32−2.45 (m, 3 H), 2.58 (dd, J = 14.4, 10.7 Hz, 1 H), 3.20−3.32 (m, 1 H), 5.89 (d, J = 10.2 Hz, 1 H), 6.32 (d, J = 17.6 Hz, 1 H), 6.46 (dd, J = 17.6, 10.2 Hz, 1 H); ^{13}C NMR δ 24.3, 27.1, 40.5, 42.0, 47.0, 128.9, 134.1, 199.8, 209.4.

Preparation of Benzotriazole Derivatives 26: Representative Procedure for *N*-[1-Ethoxy-1-(α-hydroxy-*p*-methylbenzyl)allyl]benzotriazole (26a). *N*-(α-Ethoxylallyl)-benzotriazole (**2**, 2.03 g, 10 mmol) was stirred with butyllithium (11 mmol) in THF (50 mL) at −78 °C for 5 min to give a green solution (**14**) to which was added the aldehyde (*p*-methylbenzaldehyde for **26a**, 1.20 g, 10.0 mmol) at −78 °C and the mixture stirred at this temperature for 4 h. The reaction was quenched with water (30 mL) and extracted with ether. The extract was dried ($MgSO_4$) and the solvent removed to give an oil which was purified by column chromatography (silica gel, hexane/AcOEt, 1:5) to give a solid mixture of two diastereoisomers in a ratio of 88:12 in 46% overall yield: mp 134−135 °C; ^{1}H NMR δ (signals of the minor isomer are not presented) 1.19 (t, J = 7.0 Hz, 3 H), 2.24 (s, 3 H), 3.18−3.30 (m, 1 H), 3.45 (d, J = 2.4 Hz, 1 H), 3.46−3.60 (m, 1 H), 5.54 (d, J = 2.4 Hz, 1 H, OH), 5.58 (d, J = 17.8 Hz, 1 H), 5.66 (d, J = 11.2 Hz, 1 H), 6.42 (dd, J = 17.8, 11.2 Hz, 1 H), 6.70 (d, J = 7.8 Hz, 2 H), 6.91 (d, J = 7.8 Hz, 2 H), 7.41 (t, J = 8.1 Hz, 1 H), 7.47 (t, J = 8.1 Hz, 1 H), 7.81 (d, J = 8.3 Hz, 1 H), 8.08 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 14.9, 21.1, 60.3, 77.4, 96.5, 112.6, 120.1, 124.2, 127.2, 127.7, 128.4, 130.8, 132.6, 133.3, 137.9, 146.2.

***N*-[1-Ethoxy-1-(α-hydroxy-*p*-chlorobenzyl)allyl]benzotriazole (26b)** was prepared as a solid mixture of two diastereomers (*ca.* 50:50 ratio) from *p*-chlorobenzaldehyde and isolated by column chromatography (silica gel, AcOEt/hexane, 1:5), yield 48%: mp 123−124 °C; ^{1}H NMR δ 1.07 (t, J = 7.0 Hz, 1.5 H), 1.19 (t, J = 7.0 Hz, 1.5 H), 3.17−3.31 (m, 1.5 H), 3.48−3.57 (m, 0.5 H), 3.59 (d, J = 2.7 Hz, 0.5 H), 3.82 (d, J = 4.1 Hz, 0.5 H), 5.28 (d, J = 17.4 Hz, 0.5 H), 5.55 (d, J = 2.7 Hz, 0.5 H, OH), 5.58 (d, J = 17.4 Hz, 0.5 H), 5.59 (d, J = 11.1 Hz, 0.5 H), 5.67 (d, J = 11.1 Hz, 0.5 H), 5.76 (d, J = 4.1 Hz, 0.5 Hz, OH), 6.36 (dd, J = 17.7, 11.1 Hz, 0.5 H), 6.58 (dd, J = 17.7, 11.1 Hz, 0.5 H), 6.77 (d, J = 8.7 Hz, 1 H), 7.08 (d, J = 8.7 Hz, 1 H), 7.18−7.22 (m, 2 H), 7.32−7.50 (m, 2 H), 7.75 (d, J = 8.3 Hz, 0.5 H), 7.80 (d, J = 8.3 Hz, 0.5 H), 8.06 (d, J = 8.3 Hz, 1 H), 8.09 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 14.7, 14.9, 59.4, 60.4, 76.5, 77.4, 96.2, 96.4, 112.4, 113.0, 119.9, 120.2, 120.6, 120.8, 124.3, 124.4, 127.6, 127.7, 127.8, 127.9, 128.0,

128.2, 128.5, 128.9, 129.6, 130.7, 131.4, 132.6, 133.0, 133.8, 134.1, 134.9, 135.7, 146.1.

***N*-[1-Ethoxy-1-(α-hydroxy-2-phenylethyl)allyl]benzotriazole (26c)** was prepared from 2-phenylacetaldehyde and isolated as a white solid by column chromatography (silica gel, AcOEt/hexane, 1:5), yield 48%: mp 130–131 °C; ^{1}H NMR δ 1.06 (t, J = 6.9 Hz, 3 H), 2.71 (dd, J = 14.4, 10.4 Hz, 1 H), 2.90–3.00 (m, 1 H), 3.09 (d, J = 14.5 Hz, 1 H), 3.35–3.46 (m, 1 H), 3.53–3.58 (m, 1 H), 5.07–5.17 (m, 1 H), 5.68 (d, J = 10.9 Hz, 1 H), 5.77 (d, J = 17.4 Hz, 1 H), 6.47 (dd, J = 17.4, 10.9 Hz, 1 H), 7.15–7.40 (m, 6 H), 7.45 (t, J = 7.0 Hz, 1 H), 7.78 (d, J = 8.3 Hz, 1 H), 8.03 (d, J = 8.3 Hz, 1 H); ^{13}C NMR δ 15.0, 36.5, 58.7, 74.3, 95.4, 113.1, 119.7, 119.8, 124.3, 126.4, 127.6, 128.3, 129.3, 132.6, 132.8, 138.8, 146.1.

Preparation of α-Hydroxyalkyl Vinyl Ketones 27. Representative Procedure for 1-Hydroxy-1-(*p*-methylphenyl)-3-buten-2-one (27a). *N*-(α-Ethoxyallyl)benzotriazole (**2**, 2.03 g, 10 mmol) was stirred with butyllithium (11 mmol) in THF (100 mL) at −78 °C for 3 h to give a green solution (**14**) to which was added the aldehyde (4-methylbenzaldehyde for **27a**, 1.20 g, 10.0 mmol) and the mixture was stirred at −78 °C 4 h. The reaction was quenched with water (30 mL) and extracted with ether. The extract was dried ($MgSO_4$) and the solvent removed to give an oily residue which was stirred for 2.5 h with silica gel (30 g) in CH_2Cl_2 (60 mL) containing $H_2C_2O_4$ (0.4 g) and H_2O (0.5 mL). After the silica gel and $H_2C_2O_4$ were filtered off, the filtrate was washed with NaOH (2 N, 2 × 15 mL) and dried ($MgSO_4$) and the solvent removed to give an oil which was purified by column chromatography (silica gel, Et_2O/petroleum ether, 1:6) to give an oil in an overall yield of 70%: ^{1}H NMR δ 2.34 (s, 3 H), 4.37 (d, J = 4.7 Hz, 1 H), 5.25 (d, J = 4.7 Hz, 1 H), 5.74 (dd, J = 6.0, 5.9 Hz, 1 H), 6.39 (d, J = 6.0 Hz, 2 H), 7.15–7.23 (m, 4 H); ^{13}C NMR δ 21.1, 78.5, 127.6, 129.7, 130.5, 130.9, 134.5, 138.6, 197.8.

1-(*p*-Chlorophenyl)-1-hydroxy-3-buten-2-one (27b) was prepared as an oil from *p*-chlorobenzaldehyde as described above and isolated by column chromatography (silica gel, Et_2O/petroleum ether, 1:6) in an overall yield of 43%: ^{1}H NMR δ 4.41 (d, J = 4.5 Hz, 1 H), 5.26 (d, J = 4.5 Hz, 1 H), 5.80 (dd, J = 8.1, 3.7 Hz, 1 H), 6.41 (d, J = 8.1 Hz, 1 H), 6.42 (d, J = 3.7 Hz, 1 H), 7.26 (d, J = 8.4 Hz, 2 H), 7.36 (d, J = 8.4 Hz, 2 H); ^{13}C NMR δ 77.9, 129.0, 129.2, 130.6, 131.2, 134.7, 136.1, 197.2.

2-Hydroxy-1-phenyl-4-penten-3-one (27c) was prepared as an oil from 2-phenylacetaldehyde and isolated by chromatography (silica gel, Et_2O/petroleum ether, 1:6) in 30% overall yield: ^{1}H NMR δ 2.82 (dd, J = 14.1, 7.0 Hz, 1 H), 3.06 (dd, J = 14.1, 4.7 Hz, 1 H), 3.64 (d, J = 6.0 Hz, 1 H), 4.55–4.63 (m, 1 H), 5.80 (d, J = 10.4 Hz, 1 H), 6.35 (d, J = 17.5 Hz, 1 H), 6.49 (dd, J = 17.5, 10.4 Hz, 1 H), 7.15–7.32 (m, 5 H); ^{13}C NMR δ 40.1, 75.6, 126.5, 128.1, 129.2, 130.0, 131.4, 136.2, 200.0.

1-Hydroxy-1-(*p*-methoxyphenyl)-3-buten-2-one (27d) was prepared as an oil from *p*-methoxybenzaldehyde and purified by column chromatography (silica gel, Et_2O/petroleum ether, 1:6), overall yield 61%: ^{1}H NMR δ 3.75 (s, 3 H), 4.44 (d, J = 4.3 Hz, 1 H), 5.21 (d, J = 3.3 Hz, 1 H), 5.70 (dd, J = 7.2, 4.8 Hz, 1 H), 6.36 (d, J = 7.2 Hz, 1 H), 6.37 (d, J = 4.8 Hz, 1 H), 6.87 (d, J = 6.6 Hz, 2 H), 7.20 (d, J = 6.6 Hz, 2 H); ^{13}C NMR δ 55.0, 77.4, 78.0, 114.2, 128.8, 129.5, 130.2, 130.8, 159.7, 197.7.

Preparation of [3-(Benzotriazol-1-yl)-3-ethoxyallyl]tributyltin (28). *N*-(α-Ethoxyallyl)benzotriazole (**2**, 2.03 g, 10 mmol) was stirred with butyllithium (11 mmol) in THF (100 mL) at −78 °C for 5 min to give a green solution (**14**) to which was added tributyltin chloride (3.25 g, 10 mmol) and the mixture stirred at −78 °C for 2 h and at 20 °C for 10 h. The reaction was quenched with water (30 mL) and extracted with ether (2 × 30 mL). The extract was dried ($MgSO_4$) and the solvent removed to give compound **28** as an oil in 85% yield. Subsequent purification was carried out by column chromatography (silica gel, Et_2O/hexane ether, 1:6): ^{1}H NMR δ 0.89 (t, J = 7.2 Hz, 9 H), 0.98 (t, J = 7.2 Hz, 3 H), 1.27–1.40 (m, 12 H), 1.53–1.62 (m, 6 H), 1.97 (d, J = 9.3 Hz, 2 H), 3.62 (q, J = 7.2 Hz, 2 H), 5.58 (t, J = 9.3 Hz, 1 H), 7.40 (t, J = 8.2 Hz, 1 H), 7.51 (t, J = 8.2 Hz, 1 H), 7.70 (d, J = 8.1 Hz, 1 H), 8.06 (d, J = 8.1 Hz, 1 H); ^{13}C NMR δ 7.4, 9.7, 13.6, 14.8, 27.3, 29.0, 65.9, 110.9, 111.4, 119.8, 124.0, 127.7, 132.4, 139.4, 145.5.

Reactions of Compound 28 with Butyllithium Followed by Heptyl Bromide or *p*-Chlorobenzaldehyde. [3-(Benzotriazol-1-yl)-3-ethoxyallyl]tributyltin (**28**, 1.95 g, 5.0 mmol) was stirred with butyllithium (5.5 mmol) in THF (50 mL) at −78 °C for 5 min to give a green solution. Heptyl bromide or *p*-chlorobenzaldehyde (5.0 mmol) was added at −78 °C and the mixture stirred at −78 °C for 2 h and then at 20 °C for 10 h. The reaction was quenched with water (30 mL) and extracted with ether (3 × 50 mL). The extract was washed with water (25 mL) and dried ($MgSO_4$) and the solvent removed to give an oil. The NMR spectra of the crude products were identical to those of **15a** (when heptyl bromide was used) or **26b** (when *p*-chlorobenzaldehyde was used).

JO9507698