represent 1,4-dehydrocubane.[14a] Interestingly, the singlet state of this diyl is calculated to be more stable than its triplet by over 10 kcal/mol, suggesting substantial through-bond interaction. At an extreme, one could envision this interaction proceeding to Grob fragmentation and formation of the diolefin **15**. The strained, bridgehead double bonds in **15** would be open to nucleophilic attack. Whether or not this could lead to reclosure to the cubane nucleus is moot. We would expect **15** to react readily with Diels–Alder dienes. However, when furan or 9,10-diphenylisobenzofuran is present during reaction of 1,4-diiodocubane with *n*-butyllithium, neither diene is incorporated. Thus, singlet 1,4-cubadiyl is the likely structure for the intermediate in the principal chemistry presented here.

Acknowledgment. The National Institutes of Health (GM-36436) and the Office of Naval Research provided the principal support for this work. We are grateful to Professor Borden for enlightening discussions about 1,4-dehydrocubane and thank both him and Professor Michl for prepublication access to their manuscripts.[14]

Registry No. 5, 124225-26-9; **6**, 124225-27-0; **7**, 124225-28-1; **8**, 124225-29-2; **9**, 124225-30-5; **10** (X = Br), 124225-31-6; **10** (X = Cl), 124225-32-7; **12**, 124225-33-8; **14**, 124225-34-9; 1,4-diiodocubane, 97229-08-8; 1,4-dibromocubane, 59346-70-2; 4-bromoiodocubane, 111873-47-3; 4-chloroiodocubane, 124225-25-8; 1,4-dicarbomethoxycubane, 29412-62-2; 4-chlorolithiocubane, 124225-35-0; bicubyl, 116503-50-5; 2-deuterio-4-bromoiodocubane, 124225-36-1; 2-dieuterio-4-*n*-butylcubyliodide, 124225-37-2; 3-deuterio-4-*n*-butylcubyliodide, 124225-38-3.

(14) (a) Hrovat, D. A.; Borden, W. T. *J. Am. Chem. Soc.* Second of three papers in this issue. (b) Hassenrück, K.; Radziszewski, J. G.; Balaji, V.; Murthy, G. S.; McKinley, A. J.; David, D. E.; Lynch, V. M.; Martin, H.-D.; Michl, J. *Ibid.* First of three papers in this issue.

A Practical and General Enantioselective Synthesis of Chiral Propa-1,2-dienyl and Propargyl Carbinols

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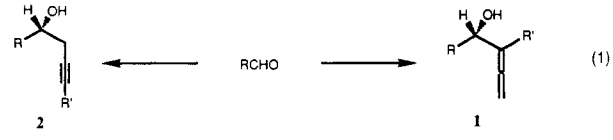
Received September 5, 1989

We report here a new and effective method for the enantioselective addition of propa-1,2-dienyl and propargyl groups to aldehydes to form chiral alcohols as shown in eq 1. The method

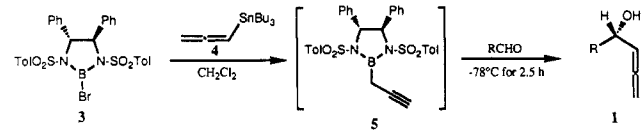


(1)

R = Aryl, alkyl, cycloalkyl; R' = H or alkyl

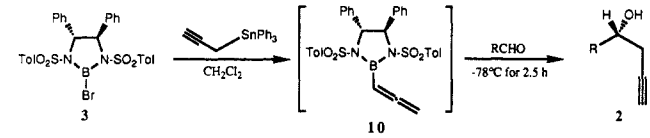
is successful with a wide variety of aldehydes and affords products of high enantiomeric purity. The absolute configuration of the reaction product in each case is predictable from the absolute configuration of the reagent and a well-defined model of the transition state. Further, either the *R* and *S* form of the alcohols **1** and **2** may be synthesized since the required reagents are readily accessible from the available enantiomers of 1,2-diphenyl-1,2-diaminoethane (stilbenediamine, stien).[1] Previous publications from this laboratory have described the use of the stien controller group in a number of other useful enantiocontrolled processes, including Diels–Alder,[1] aldol,[1] carbonyl allylation,[2] and olefin dihydroxylation reactions.[3] All of these reactions are characterized by stereochemical predictability, high yield and enantioselectivity, and efficient recovery of the chiral controller group.

Table I



aldehyde	isolated yield, %	% ee of **1**	abs config
n-C_5H_{11}CHO	82	>99	*S*
$(CH_3)_2$CHCHO	74	>99	*S*
c-C_6H_{11}CHO	78	>99	*S*
$(CH_3)_3$CCHO	78	>99	*S*
PhCHO	72	>99	*R*
PhCH=CHCHO	74	>99	*S*

Table II



aldehyde	isolated yield, %	% ee of **2**	abs config
n-C_5H_{11}CHO	81	91	*S*
$(CH_3)_2$CHCHO	76	94	*R*
c-C_6H_{11}CHO	82	92	*R*
$(CH_3)_3$CCHO	74	98	*R*
PhCHO	76	96	*R*
PhCH=CHCHO	79	98	*R*

An enantiospecific route to the propadienyl carbinols **1**, R = H, was developed as follows. The (*R*,*R*)-bromoborane reagent **3** was prepared as described earlier[2] from the bis-*p*-toluenesulfonamide of (*R*,*R*)-1,2-diphenyl-1,2-diaminoethane and boron tribromide in dry CH_2Cl_2 at 20 °C and, after removal of volatile components under vacuum, was used in the same flask. Reaction of bromoborane **3** with 0.95 equiv of propadienyltri-*n*-butylstannane (**4**)[4] in CH_2Cl_2 at 0 °C for 4 h and 23 °C for 0.5 h produced the propargylborane derivative **5** which was used in situ for reaction with various aldehydes (0.9 equiv) at −78 °C for 2.5 h. The results obtained with a series of six aldehydes are summarized in Table I. In addition, parallel experiments were performed with the (*S*,*S*) enantiomer of **5** and the six aldehydes shown in Table I to give the enantiomeric series of propa-1,2-dienyl carbinols. The adducts of general formula **1** and their enantiomers were each converted to the (*R*)-(+)-α-methoxy-α-(trifluoromethyl) phenyl acetate (MTPA) esters[5] and analyzed by 500 MHz ^{1}H NMR spectroscopy, which allowed clear distinction between the two diastereomers. For each reaction shown in Table I (and the other enantiomeric series as well) only a single enantiomeric product could be detected, with enantioexcesses definitely greater than 99% in each case. Absolute configurations were determined by optical rotation for the previously known alcohols (**1**, R = C_6H_5, R = cyclohexyl and R = *n*-alkyl).[6] The reaction products **1** were isolated in the indicated yields with purity of 98–99%, the contaminant being the isomeric propargyl carbinol (1–2%).[7]

The extraordinary enantiospecificity of the carbonyl addition to form the propadiene carbinols **1** is unprecedented.[6] Because

(1) Corey, E. J.; Imwinkelried, R.; Pikul, S.; Xiang, Y. B. *J. Am. Chem. Soc.* **1989**, *111*, 5493.
(2) Corey, E. J.; Yu, C.-M.; Kim, S. S. *J. Am. Chem. Soc.* **1989**, *111*, 5495.
(3) Corey, E. J.; Jardine, P. D.-S.; Virgil, S.; Yuen, P. W.; Connell, R. D. *J. Am. Chem. Soc.* **1989**, *111*, 9243–9244.
(4) Propadienyltri-*n*-butylstannane (**4**) (colorless liquid) was prepared by reaction of ethereal propargyl magnesium bromide with tri-*n*-butylchlorostannane followed by heating the crude product at reflux in methanol for 30 min and was obtained in 78% yield after distillation at 92–95 °C (0.2 Torr). See: (a) Ueno, Y.; Okawara, M. *J. Am. Chem. Soc.* **1979**, *101*, 1893. (b) Boaretto, A.; Marton, D.; Tagliavini, G. *J. Organomet. Chem.* **1985**, *297*, 149.
(5) Dale, J. A.; Mosher, H. S. *J. Am. Chem. Soc.* **1973**, *95*, 512.
(6) Boldrini, G. P.; Lodi, L.; Tagliavini, E.; Tarasco, C.; Trombini, C.; Umani-Ronchi, A. *J. Org. Chem.* **1987**, *52*, 5447.
(7) The recovery of the chiral controller, the bis-*p*-toluenesulfonamide of 1,2-diphenyl-1,2-diaminoethane, was also excellent (>90%).

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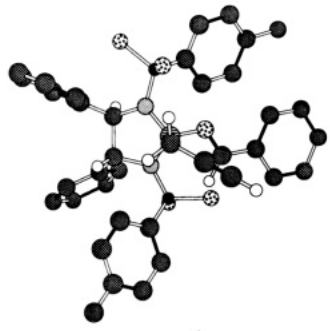
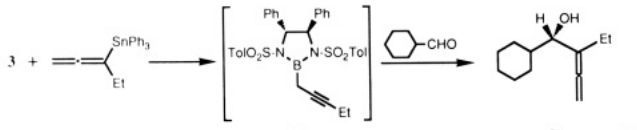
of this fact and also the many interesting transformations which can be foreseen for allenic alcohols of type **1**, for example, internal Diels–Alder reactions, Simmons–Smith methylenation, hydroboration, and other double bond addition reactions, this new methodology should prove valuable. The observed preference for absolute configuration **1** from the (*R*,*R*)-reagent **5** can readily be understood on the basis that assembly **6** is the most favorable arrangement for product formation; it also accords with previous observations on enantioselective carbonyl allylation.[2]



6

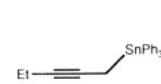
In order to demonstrate the extension of this carbonyl allenylation methodology to more alkylated systems, the stable, crystalline allenic tin reagent **7** was synthesized[8] and treated with bromoborane **3** (CH_2Cl_2, 0 °C, 5 h) to form reagent **8**. Reaction of **8** with cyclohexanecarboxaldehyde at −78 °C for 2.5 h afforded the adduct **9** in 78% isolated yield and 95% ee.[9] This result provides clear evidence for the broad generality of this new enantioselective allene synthesis.



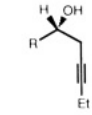
7 **8** **9** (2)

The scope of this approach has also been enlarged by the demonstration of its efficacy for the enantioselective propargylation of aldehydes, a process studied previously by H. Yamamoto using tartrate esters as controller groups.[10] 2-Propynyltriphenylstannane, mp 81–82.5 °C, readily prepared from propargylmagnesium bromide and triphenylchlorostannane in ether (71% yield),[11] upon treatment with bromoborane **3** in CH_2Cl_2 at 0 °C for 4 h and 23 °C for 10 min produced allenylborane **10** which reacted with a variety of aldehydes (Table II) to form propargyl carbinols **2**. The data in Table II allow the following conclusions: (1) excellent enantioselectivities are observed with the overall sense of chirality being that predicted by an assembly analogous to **6**, and (2) the process is effective for a variety of aldehydes in terms of isolated yield as well as enantioselectivity. In each case the chiral controller was easily separated from the propargylic alcohol **2** by precipitation from 3:1 ether–hexane at 0 °C for reuse,[7] and the pure alcohol was obtained simply by filtration of the soluble fraction through a short column of silica gel with use of 1:1 hexane–ether.

Enantioselective addition of the 2-pentynyl group to an aldehyde was selected for experimental study since this method would be ideal for the stereocontrolled synthesis of the third series of prostaglandins, e.g., PGE_3 and $PGF_{3\alpha}$.[12] The requisite organotin reagent 2-pentynyltriphenylstannane (**11**) was synthesized by



11



12 R: n-C_5H_{11}
13 R: (*E*)-$CH_3CH{=}CH$

reaction of the Grignard reagent from magnesium amalgam and 1-bromo-2-pentyne in ether with triphenylchlorostannane (84% yield of **11**, colorless liquid after filtration through silica gel deactivated with 2% Et_3N). Reaction of **11** with bromoborane **3** in CH_2Cl_2 (50 °C for 15 h) afforded the corresponding allenic borane which upon treatment with *n*-hexanal or crotonaldehyde at −78 °C for 2.5 h produced the (*S*)-carbinol **12** or **13** in 75–80% isolated yield and of 97–98% ee and >97% purity.[13] This highly successful result indicates a very practical solution to the long-standing problem of stereocontrolled synthesis of the PG_3 ω side chain.

In summary, this paper describes a new methodology for the enantioselective synthesis of alcohols of types **1** and **2** in a very efficient and practical way which promises to be widely useful.[14]

Supplementary Material Available: Detailed procedures are provided for the synthesis of **1** and **2** (R = n-C_5H_{11}), propadienyltri-*n*-butylstannane (**4**) and the triphenyl analogue, and 2-propynyltriphenylstannane, and key physical data (mp, IR, and ^1H NMR) are given for the chiral products listed in Tables I and II (5 pages). Ordering information is given on any current masthead page.

(8) The reagent **7** was prepared by the following sequence: (1) successive treatment of propargyl chloride with *n*-butyllithium in THF at −90 °C and triphenylchlorostannane to form 1-(triphenylstannyl)-3-chloro-1-propyne (91%); (2) reaction of this chloro compound with ethylmagnesium chloride and 1 equiv of CuBr in THF solution at −60 °C to form **7** (mp 75 °C, 87%). See: (a) Ruitenberg, K.; Westmijze, H.; Kleijn, H.; Vermeer, P. *J. Organomet. Chem.* **1984**, *277*, 227. (b) Ruitenberg, K.; Vermeer, P. *Tetrahedron Lett.* **1984**, *25*, 3019.

(9) Absolute configuration was assigned from the mechanistic model (assembly **6**).

(10) (a) Ikeda, N.; Arai, I.; Yamamoto, H. *J. Am. Chem. Soc.* **1986**, *108*, 483. (b) Haruta, R.; Ishiguro, M.; Ikeda, N.; Yamamoto, H. *J. Am. Chem. Soc.* **1982**, *104*, 7667.

(11) Le Quan, M.; Cadiot, P. *Bull. Soc. Chim. Fr.* **1965**, 45.

(12) For previous syntheses of PG_3's see: (a) Corey, E. J.; Shirahama, H.; Yamamoto, H.; Terashima, S.; Venkateswarlu, A.; Schaaf, T. K. *J. Am. Chem. Soc.* **1971**, *93*, 1490. (b) Corey, E. J.; Ohuchida, S.; Hahl, R. *J. Am. Chem. Soc.* **1984**, *106*, 3875.

(13) The main contaminant was the isomeric allene.

(14) This research was supported by the National Science Foundation and the National Institutes of Health.

Activation of Dioxygen by Bis(2,6-dicarboxylatopyridine)iron(II) for the Ketonization of Methylenic Carbons and the Dioxygenation of Acetylenes, Aryl Olefins, and Catechols: Reaction Mimics for Dioxygenase Proteins

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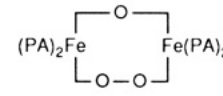
Received October 12, 1989

A recent study[1] has described the catalytic activation of excess hydrogen peroxide by bis(picolinato)iron(II) [$(Fe(PA)_2$] and (2,6-dicarboxylatopyridine)iron(II) [Fe(DPA)] for the efficient, selective ketonization of methylenic carbons and the dioxygenation of acetylenes and aryl olefins [the reactive intermediates have been postulated to be



and (DPA)FeOOFe(DPA)].[2] In contrast, the one-to-one combination of $Fe(PA)_2$ and HOOH results in Fenton chemistry with $(PA)_2Fe(OH)$ and $^{\bullet}OH$ the primary products.[3] Here we report

(1) Sheu, C.; Richert, S. A.; Cofré, P.; Ross, B., Jr.; Sobkowiak, A.; Sawyer, D. T.; Kanofsky, J. R. *J. Am. Chem. Soc.* Accepted for publication.

(2) Cofré, P.; Richert, S. A.; Sawyer, D. T. Submitted to *Inorg. Chem.*

0002-7863/90/1512-879$02.50/0