Chiral Synthesis via Organoboranes. 9. Crystalline "Chelates" from Borinic and Boronic Esters. A Simple Procedure for Upgrading Borinates and Boronates to Materials Approaching 100% Optical Purity

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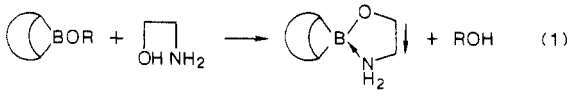
The synthesis of crystalline chelates from borinic and boronic esters was explored as a means of upgrading the optical purities of intermediates from asymmetric hydroboration. *B*-Methoxy-9-borabicyclo[3.3.1]nonane, methyl dicyclohexylborinate, and methyl diisopinocampheylborinate react with various amino alcohols to form the corresponding chelates. Steric factors play a major role in chelate formation. Crystallization of 2-pyrrolidinylmethyl isopinocampheyl-*exo*-norbornylborinate of 83% ee gives a product approaching 100% ee. Dimethyl cyclopentylboronate, dimethyl *exo*-norbornylboronate, and dimethyl siamylboronate, upon treatment with various amino diols, form the corresponding boronates. The formation of B←N bond is dependent both on steric and electronic factors. The corresponding boronates (2:1 derivatives) derived from these typical dimethyl boronates and tetrols were also prepared. The chelate derived from diethyl 3-tetrahydropyranylboronate of 83% ee and *N,N,N',N'*-tetrakis(2-hydroxyethyl)ethylenediamine, upon crystallization, yields a product with optical purities approaching 100% ee. Consequently, formation of crystalline chelates of asymmetric hydroboration products provides one possible route for upgrading such products of less than 100% ee to materials approaching 100% ee.

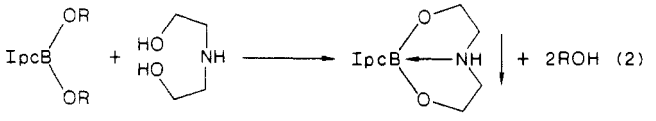
Amino alcohol–borinate derivatives have been widely used chelates to facilitate removal of borinates from reaction mixtures.[2,3] Thus, monoethanolamine provides a simple means for precipitating various borinic acids, such as 9-borabicyclo[3.3.1]borinate,[4-6] dicyclohexylborinate,[7] diarylborinates,[8] and diisopinocampheylborinates[9] from solutions. A typical example is shown in eq 1. Similarly,



(1)

8-hydroxyquinoline derivatives of diaryl- or arylalkylborinates have also been utilized for this purpose.[10]

Boronates are also known to form chelate compounds with diethanolamine[11,12] or diethanolamine *N*-oxide.[13] Diethanolamine also has been widely used to isolate boronates from reaction mixtures[14] (eq 2). Since these crystalline chelates are stable in air, they have also been used to store the borinates and boronates.



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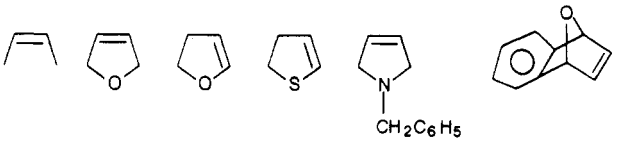
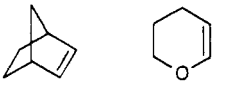
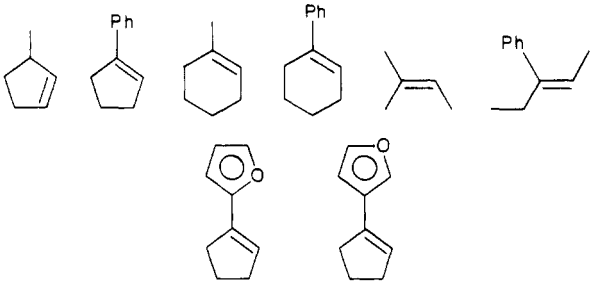
In a number of cases, hydroboration of olefins with diisopinocampheylborane, Ipc_2BH, provides boron intermediates, R^*BIpc_2, of 100% ee.[15-17] However, in other



cases, such as norbornene and 3,4-dihydropyran, the products exhibit only 83% ee.



Hydroboration of hindered olefins with monoisopinocampheylborane gives the monoalkyl derivative, R^*BHIpc. These commonly exist as crystalline dimers, so that simple crystallization serves to upgrade the optical purity to ~100% ee.[18,19]



Such crystallization has also served to upgrade the optical purities of the R_2BH reagents prepared by hydroboration of α-pinene,[20] Δ^3-carene,[21] and longifolene.[21]

The question arose as to how to achieve the upgrading of hydroboration products, Ipc_2BR^* and $IpcBHR^*$, that

(1) Postdoctoral research associate on Grant GM 10937-23 from the National Institutes of Health.
(2) Letsinger, R. L.; Skoog, I. K.; Remes, N. *J. Am. Chem. Soc.* **1954**, *76*, 4047.
(3) Letsinger, R. L.; Remes, N. *J. Am. Chem. Soc.* **1955**, *77*, 2489.
(4) Sinclair, J. A.; Molander, G. A.; Brown, H. C. *J. Am. Chem. Soc.* **1977**, *99*, 954.
(5) Brown, H. C.; Pai, G. G. *J. Org. Chem.* **1985**, *50*, 1384.
(6) Brown, H. C.; Molander, G. A.; Singh, S. M.; Racherla, U. S. *J. Org. Chem.* **1985**, *50*, 1577 and references cited therein.
(7) Campbell, J. B., Jr.; Brown, H. C. *J. Org. Chem.* **1980**, *45*, 549.
(8) Letsinger, R. L.; Skoog, I. K. *J. Am. Chem. Soc.* **1955**, *77*, 2491.
(9) Brown, H. C.; Jadhav, P. K.; Bhat, K. S. *J. Am. Chem. Soc.* **1985**, *107*, 2564.
(10) Douglass, J. E. *J. Org. Chem.* **1961**, *26*, 1312.
(11) Matteson, D. S.; Ray, R.; Rocks, R. R.; Tsai, D. J. *Organometallics* **1983**, *2*, 1536.
(12) Brown, H. C.; Vara Prasad, J. V. N. *J. Am. Chem. Soc.* **1986**, *108*, 2049.
(13) Kliegel, W. *Z. Chem.* **1970**, *10*, 437.
(14) Chandrasekharan, J.; Ramachandran, P. V.; Brown, H. C. *J. Org. Chem.* **1985**, *50*, 5446.
(15) Brown, H. C.; Desai, M. C.; Jadhav, P. K. *J. Org. Chem.* **1982**, *47*, 5065.
(16) Brown, H. C.; Jadhav, P. K. *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: New York, 1983; Vol. 2.
(17) Brown, H. C.; Vara Prasad, J. V. N.; Gupta, A. K., communicated.
(18) Brown, H. C.; Singaram, B. *J. Am. Chem. Soc.* **1984**, *106*, 1797.
(19) Brown, H. C.; Gupta, A. K.; Vara Prasad, J. V. N., unpublished results.
(20) Brown, H. C.; Singaram, B. *J. Org. Chem.* **1984**, *49*, 945.
(21) Jadhav, P. K.; Vara Prasad, J. V. N.; Brown, H. C. *J. Org. Chem.* **1985**, *50*, 3203.

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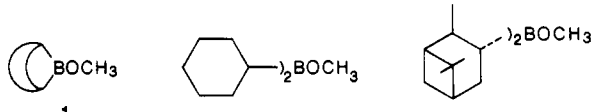
are not crystalline. These products are readily converted into borinates, IpcBR*OEt, and boronates, $R^*B(OEt)_2$, by treatment with acetaldehyde. Consequently, it appeared that the formation of crystalline chelates might provide a satisfactory route to achieve the upgrading of the optical purity of the R*-B< moiety. Accordingly, we undertook a systematic study of typical borinates and boronates with various amino alcohols.

While our model study was underway, Masamune and co-workers[22] used this strategy for isolating the cis and trans isomers of *B*-methoxy-2,5-dimethylborinanes and for resolving the optical isomers of *trans*-*B*-methoxy-2,5-dimethylborinane. In his beautiful study, advantage was taken of the high volatilities of the uncomplexed borinates to separate selectively the complexed isomers. Because of the low volatility of the isopinocampheyl derivatives, that process was not practical here. In this paper we report the study of the reaction of borinates and boronates with amino alcohols and the application of the results of this study to achieve upgrading of the *exo*-norbornyl and the pyranyl derivatives of 83% ee to materials approaching 100% ee.

Results and Discussion

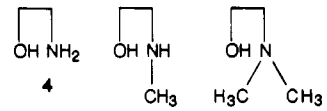
Representative borinates and boronates of different steric requirements were selected for study. The borinates selected were *B*-methoxy-9-borabicyclo[3.3.1]nonane (**1**), methyl dicyclohexylborinate (**2**) and methyl diisopinocampheylborinate (**3**). These borinates were prepared by



1 2 3

methanolysis of the corresponding dialkylboranes. The formation of the B←N bond in the ester (chelation) was followed by ^{11}B NMR.

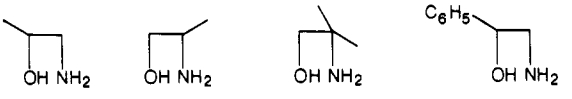
Reaction of Borinates with Amino Alcohols. Borinates **1**, **2**, and **3** react with monoethanolamine (**4**) to give white crystalline compounds. These form B←N (chelation) bonds, as evidenced by a shift in the ^{11}B NMR signal from around δ 52 to downfield (δ 9–15). Similarly, borinates **1** and **2** give chelates with 2-(methylamino)ethanol (**5**). However, borinates **3** form only the transesterification



4 5 6

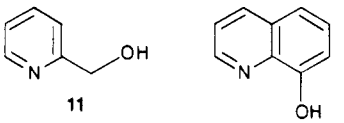
product, with no B←N bond formation observed. *N*,*N*-Dimethylethanolamine (**6**) gives a crystalline chelate, unstable in air, only with **1**. However, the borinates **2** and **3** give a viscous liquid, evidently a transesterification product, with no chelation indicated by the ^{11}B NMR signals at δ 51.5 and 55.3. This clearly establishes that, as the steric bulk around boron increases, the more bulky *N*-substituted ethanolamines resist chelation. (The Masamune study shows a valuable application of this phenomenon.[22])

Substitution on the carbons of the monoethanolamine does not affect formation of the B–N bond with these three typical borinates. Thus, 1-amino-2-propanol (**7**), 2-amino-1-propanol (**8**), 2-amino-2-methyl-1-propanol (**9**), and 2-amino-1-phenylethanol (**10**) form white crystalline



7 8 9 10

solids with all of these borinates. Even in cases where the nitrogen is part of the aromatic ring, i.e., pyridine, chelation is achieved with the boron of the above-mentioned borinates. Thus, 2-pyridylcarbinol (**11**) and 8-hydroxyquinoline (**12**) form chelates with these typical borinates included in this study.



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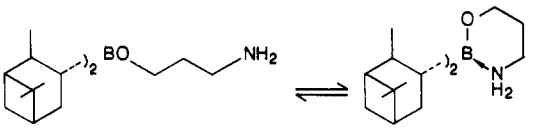
Borinates **1** and **2** react smoothly with 3-amino-1-propanol (**13**) to give crystalline derivatives. ^{11}B NMR indicates the formation of a B←N bond, even though chelation requires the formation of a six-membered ring. However, the more sterically hindered borinate **3** forms a gummy viscous liquid with the ^{11}B NMR signal at δ 36. Probably the greater steric difficulties associated with the formation of a six-membered ring and the bulky isopinocampheyl groups results in the formation of an equilibrium mixture of the simple ester and the chelate (eq 3).



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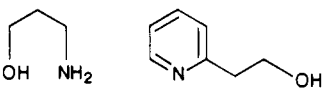
Similarly, 2-(β-hydroxyethyl)pyridine (**14**), upon treatment with these typical borinates **1**–**3** forms light brown solids, unstable in air. The ^{11}B NMR spectrum of the



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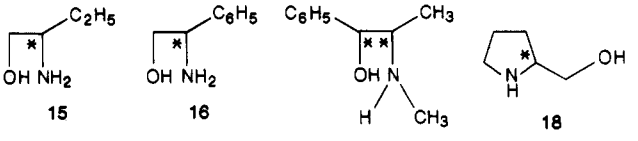
borinate derived from **1** and **2** showed the formation of the characteristic B–N bond of the chelate. However, the borinate derived from **3** shows the ^{11}B NMR signal at δ 54, indicating that the borinate is exclusively in the open chain form. These results are summarized in Table I.

The reaction of these three typical borinates with selected optically active amino alcohols was also examined. Borinates **1** and **2** form white crystalline chelates with (*R*)-(−)-2-amino-1-butanol (**15**), (*S*)-(−)-α-phenylglycinol (**16**), (1*S*,2*R*)-(+)-ephedrine (**17**), and (*S*)-(+)-pyrrolidinemethanol (**18**). Similarly, both optical isomers



15 16 17 18

of **3** prepared from (+)-α-pinene or (−)-α-pinene form crystalline adducts with a B←N bond upon treatment with (*R*)-(−)-**15** and (*S*)-(−)-**16**. However, (1*S*,2*R*)-(+)-**17** fails to form a chelate with either enantiomer of **3**, even though the reaction proceeds to give white crystalline solids. Of special interest is the observation that (*S*)-(+)-**18** forms a chelate, as indicated by the ^{11}B NMR signal at δ 24.7, only with **3** derived from (−)-α-pinene. However, **3** derived from (+)-α-pinene on treatment with the same amino alcohol (*S*)-(+)-**18** forms only a viscous liquid without

(22) Masamune, S.; Kim, B. M.; Peterson, J. S.; Sato, T.; Veenstra, S. J.; Imai, T. *J. Am. Chem. Soc.* **1985**, *107*, 4549.

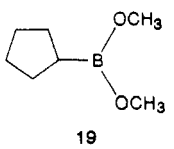
Table I. Physical and ^{11}B NMR Spectral Data of Chelates Derived from Borinates and Amino Alcohols

borinate	amino alcohol	yield, %	mp, °C	^{11}B NMR, δ ($CDCl_3$)
1	4	96	202–203	9.4
2	4	98	164–166	9.4
(−)-3[a]	4	81	124–126	16.1
1	5	85	164–168 dec	9.7
2	5	85	129–132	10.2
(−)-3	5	98		52.9
1	6	93	66	52.9
2	6	97		51.5
(−)-3	6	96		55.3
1	7	93	96–98	8.8
2	7	91	136–138	8.4
(−)-3	7	78	98	12
1	8	92	128	9
2	8	94	125	10.1
(−)-3	8	84	94–96	17.1
1	9	97	135	9.5
2	9	95	120	10.6
(−)-3	9	87	86	29.9
1	10	98	126 dec	9.6
2	10	91	156–160 dec	13.4
(−)-3	10	87	88–92 dec	13.4
1	11	78	158 dec	13.4
2	11	82	105–107	14.5
(−)-3	11	68	121 dec	14.8
1	12	96	188	14
2	12	92	126–130	14.8
(−)-3	12	90	71	17
1	13	89	169–170	4.2
2	13	93	122–124	4.9
(−)-3	13	98		36
1	14	93	62	34.3
2	14	96	58–60	9.6
(−)-3	14	93	54	54
1	(*R*)-(−)-15	95	156	8.4
2	(*R*)-(−)-15	88	148–150	9.6
(−)-3	(*R*)-(−)-15	87	84–86	14.2
(+)-3[b]	(*R*)-(−)-15	85	94–96	14.9
1	(*S*)-(−)-16	81	132 dec	9.5
2	(*S*)-(−)-16	84	124–128	11.6
(−)-3	(*S*)-(−)-16	79	89–93	23.2
(+)-3	(*S*)-(−)-16	83	101–103	23.7
1	(1*S*,2*R*)-(+)-17	82	111–113	10.4
2	(1*S*,2*R*)-(+)-17	89	99–102	9.5
(−)-3	(1*S*,2*R*)-(+)-17	87	68	54.2
(+)-3	(1*S*,2*R*)-(+)-17	84	87–89	39.1 (broad)
1	(2*S*)-(+)-18	86	184–186 dec	9.2
2	(2*S*)-(+)-18	75	104–105	10.1
(−)-3	(2*S*)-(+)-18	96		56.6
(+)-3	(2*S*)-(+)-18	98	82–84	24.7

[a] Derived from (+)-α-pinene, >99% ee. [b] Derived from (−)-α-pinene, > 99% ee.

chelation (^{11}B NMR signal at δ 56.6). Similarly, (*R*)-(−)-**18** forms a crystalline chelate only with **3** derived from (+)-α-pinene but a viscous liquid without any B–N bond with **3** derived from (−)-α-pinene. The results are shown in Table I.

Reaction of Boronates with Amino Diols. The three representative boronates selected for study are methyl cyclopentylboronate (**19**), *exo*-norbornylboronate (**20**), and methyl (3-methyl-2-butyl)boronate (**21**). The boronates



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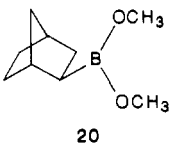

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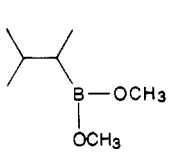

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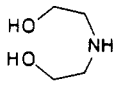
were prepared from the corresponding olefins via hydroboration with dibromoborane–methyl sulfide, followed by hydrolysis and esterification with methanol.[23] The amino diols examined are diethanolamine (**22**), *N*-methyldiethanolamine (**23**), *N*-phenyldiethanolamine (**24**), 2-amino-2-methyl-1,3-propanediol (**25**), and (1*R*,2*S*)-(+)-2-amino-1-phenyl-1,3-propanediol (**26**).



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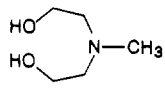

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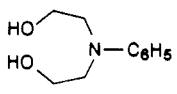

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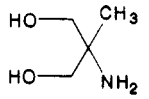

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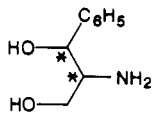

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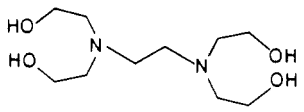
We also included *N*,*N*,*N'N'*-tetrakis(2-hydroxyethyl)-ethylenediamine (**27**) in our study since we hoped that the



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formation of a derivative containing two optically active boronic esters within a single molecule would produce diastereomers capable of purification by resolution.

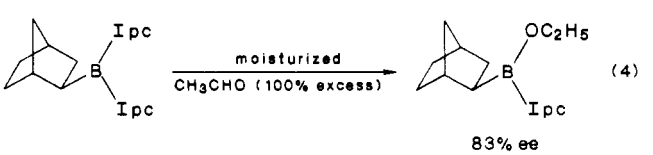
These boronates, **19**–**21**, upon treatment with **22**, form crystalline solids, the ^{11}B NMR spectra indicating the formation of B←N bonds. Similarly, **23** with these boronates gives chelate compounds. However, amino diol **24** gives only gummy substances with the ^{11}B NMR spectrum showing the absence of any B←N bond. This may be due to the electron-withdrawing effect of the phenyl ring, reducing the ability of the nitrogen atom to donate an electron pair to boron.

Amino diols **25** and (1*R*,2*S*)-(+)-**26** form white crystalline cyclic boronates with the above typical boronates. However, the ^{11}B NMR spectrum shows the absence of chelation. This may be attributed to the fact that the formation of a B←N bond requires the formation of a sterically encumbered 2.2.1 system. Surprisingly, these crystalline solids are stable in air.

Compound **27** forms 1:2 adducts with these three typical boronates. The products are stable in air. Moreover, the ^{11}B NMR spectrum showed the presence of B←N bonds. The results are shown in Table II.

Successful Upgrading of the Two Test Cases. Originally we had hoped that the presence of two optically active groups in the borinate would make it possible to purify a chelate from an inactive amino alcohol. Accordingly, we prepared the chelate from Ipc-*exo*-NbBOEt and ethanolamine. But recrystallization failed to improve the optical purity of the product. We then tested prolinol. Here we were successful.

Norbornene, upon hydroboration with diisopinocampheylborane, produces a product with asymmetric induction of 83% ee.[15] The trialkylborane, *exo*-norbornyldiisopinocampheylborane, upon treatment with moisturized acetaldehyde, eliminates one α-pinene group



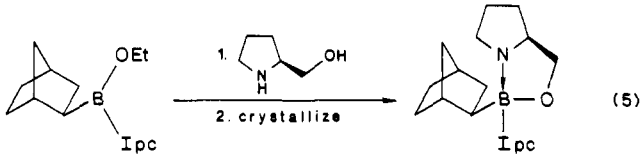
(4)

(23) Brown, H. C.; Bhat, N. G.; Somayaji, V. *Organometallics* **1983**, 2, 1311.

Table II. Physical and ^{11}B NMR Spectral Data of Chelates Derived from Boronates and Amino Diols

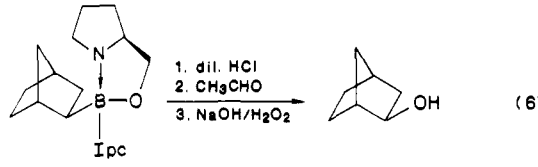
boronate	amino diols	yield, %	mp, °C	^{11}B NMR, δ ($CDCl_3$)
19	22	93	208–209	14.2
20	22	96	212–213 dec	12.6
21	22	93	150–152	14.4
19	23	89		13.9
20	23	93	95–96	14.2
21	23	88	44	13.7
19	24	97		32.8
20	24	99		31.2
21	24	98		31.6
19	25	92	82–85	31.6
20	25	94	68–71	30.7
21	25	83	60–61	31.9
19	26	95	100–103	31.6
20	26	93	96–98	32.2
21	26	84	60–61	31.9
19	27	98	198–199	17.5
20	27	96	212–213 dec	11.2
21	27	82	186–187	1.7

cleanly, even though excess acetaldehyde is present in the reaction mixture (eq 4). Treatment of the borinate [derived from (+)-α-pinene] with (*S*)-(+)-**18** gives only the transesterification product. The ^{11}B NMR spectrum indicates the absence of any chelation and all of our attempts to crystallize the corresponding borinate failed. However, treatment of the borinate derived from (−)-α-pinene with (*S*)-(+)-**18** forms chelate. This chelate could be crystallized in pentane/methanol (1:1) at −78 °C (eq 5). The crys-



83% ee 100% ee (5)

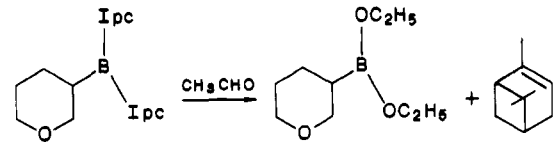
talline chelate thus obtained following a single recrystallization was treated with dilute hydrochloric acid, followed by acetaldehyde, and then oxidized by alkaline hydrogen peroxide. There was obtained *exo*-norborneol, $[\alpha]^{23}_D$ +5.17° (c 7.5, absolute ethanol), [lit.[15] $[\alpha]^{23}_D$ −4.2 (c 7.5, EtOH)] in essentially 100% ee (eq 6). The *exo*-norbornyl



(6)

boronate of high enantiomeric purity was also prepared and isolated in the usual manner.[24] With such a boronate of high optical purity now available, one can utilize this product to form various enantiomerically pure *exo*-norbornyl compounds using the known methods of boron chemistry.[25,26]

3,4-Dihydropyran, upon hydroboration with diisopinocampheylborane, followed by oxidation, yields 3-hydroxytetrahydropyran in 83% ee.[16] (3-Tetrahydropyranyl)isopinocampheylborane, upon treatment with acetaldehyde, provides the corresponding boronate (eq 7).



(7)

The boronate thus obtained, upon treatment with **27**, forms a crystalline 2:1 adduct; a single crystallization of the adduct from ether was sufficient to upgrade it to 100% ee. The crystalline adduct, upon treatment with dilute hydrochloric acid, followed by alkaline hydrogen peroxide oxidation, gives 3-hydroxytetrahydropyran. The ^{19}F NMR of the corresponding Mosher ester[27] established the alcohol to be of 100% ee. The optically pure boronate (~100% ee), a synthetically versatile intermediate, was also isolated.

Conclusion

This study demonstrates the influence of electronic and steric factors in forming B–N bonds in esters of representative borinic and boronic acids with selected amino alcohols. This study also demonstrates the potentiality of these chelates for upgrading the optical purities of borinates and boronates. Perhaps the most convincing demonstration of the practicality of this approach is the preparation of optically pure *trans*-2,5-dimethylborolane, recently described by Masamune and his co-workers.[22]

Experimental Section

The reaction flasks and other glass equipment were stored in an oven at 150 °C overnight and assembled in a stream of dry nitrogen. Gas syringes were assembled and fitted with needles while hot and cooled in a stream of dry nitrogen gas. Special techniques used in handling air-sensitive materials are described in detail elsewhere.[28]

Spectra. ^{11}B NMR spectra were recorded on a Varian FT-80A instrument. The chemical shifts are in δ relative to BF_3·OEt_2. ^1H NMR (60 MHz) and ^{19}F NMR (200 MHz) spectra were recorded on Varian T-60 and Varian FT-200 instruments, respectively. Mass spectra were recorded on Feningan GC/mass spectrometers. Optical rotations were measured on a Rudolph polarimeter Autopol III.

Materials. Borane–methyl sulfide, 9-borabicyclo[3.3.1]nonane, and dibromoborane, purchased from Aldrich Chemical Company, were estimated according to standard procedures. Dicyclohexylborane[29] and diisopinocampheylborane[20] (>99% ee) were prepared according to the literature procedures. Methyl cyclopentylboronate, methyl *exo*-norbornylboronate, and methyl (3-methyl-2-butyl)boronate were prepared according to the literature procedures.[23] All of the amino alcohols mentioned in this study were purchased from Aldrich Chemical Company and were used as such without further purification.

General Procedure for the Preparation of Chelate Borinates. In a 25-mL round-bottomed flask equipped with a septum inlet, magnetic stirring bar, and connecting tube leading to a mercury bubbler was placed 5 mmol of the borinate taken in 10 mL of pentane/ether. To it was added 5 mmol of amino alcohol dropwise, and the reaction mixture was stirred for 0.5 h. Then all of the volatiles were pumped off, 10 mL of solvent was added, and the reaction mixture was stirred for 0.5 h. The solid obtained was filtered and freed from the solvent.

General Procedure for the Preparation of 8-Hydroxyquinoline Derivatives. In the usual setup, 5 mmol of borinate was taken in 5 mL of methanol. To it was added 5 mmol of 8-hydroxyquinoline, and the reaction mixture stirred for 0.5 h.

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It was diluted with 10 mL of water. The yellow fluorescent solids thus obtained were filtered and washed with pentane. The solid was dried.

General Procedure for the Preparation of Chelate Boronates. In the usual experimental setup was placed 5 mmol of boronate in ether. To it was added 1.66 mL of amino diol (5 mmol, 3 M solution in isopropyl alcohol), and the reaction mixture was stirred for 1 h. The solid obtained was filtered and washed with 5 mL of pentane. The solid was freed from solvent under vacuum.

Upgrading the Optical Purity of Ethyl *exo*-Norbornylisopinocampheylborinate. Preparation of Borinate. Norbornen (25 mmol) was hydroborated with diisopinocampheylborane (25 mmol, derived from (−)-α-pinene, >99% ee) at −25 °C according to the literature procedure.[15] The trialkylborane obtained was treated with 5 mL of water, followed by 2.8 mL (50 mmol) of acetaldehyde. The reaction mixture was stirred overnight and excess acetaldehyde pumped off under reduced pressure. The borinate (^{11}B NMR δ 52) thus obtained was dried over anhydrous $MgSO_4$ and filtered.

(i) Via Monoethanolamine Adduct. From the ethyl borinate (20 mmol, 5.8 g), the monoethanolamine adduct was prepared as described in the general procedure for the preparation of chelate borinates. The adduct, recrystallized from ether, was treated with dilute hydrochloric acid (3 M, 10 mL) to remove the ethanolamine. Oxidation of the boronic acid by alkaline hydrogen peroxide gave *exo*-norborneol, which was then further purified by preparative GC to obtain GC-pure material: $[\alpha]^{23}_D$ +4.158° (*c* 7.5, absolute EtOH), 83.6% ee. [lit.[15] $[\alpha]^{23}_D$ −4.2° (*c* 7.5, EtOH)].

(ii) Via Pyrrolidine-2-methanol. To the borinate (20 mmol, 5.8 g) taken in 10 mL of ether was added 1.8 g (18 mmol) of (*S*)-(+)-2-pyrrolidinemethanol, and the reaction mixture was stirred for 0.5 h. The volatiles were pumped off, 10 mL of ether was added, and the reaction mixture was stirred for 0.5 h. The same operation was repeated once more. The ^{11}B NMR spectrum showed a signal at δ 26. The chelate thus obtained was taken in 20 mL of pentane and cooled to −78 °C. To it was added 10 mL of methanol, and the reaction mixture was stirred for 5 min. The reaction mixture was kept at −78 °C for 4 h. The crystals obtained were freed from solvent and washed with 2 × 5 mL of methanol at −78 °C. The solid was dried under vacuum at 25 °C (6.2 g, 90% yield, mp 78–80 °C).

Isolation of Methyl *exo*-2-Norbornylborinate. The chelate (5.2 g, 15 mmol) thus obtained was taken in 15 mL of ether and treated with 10 mL (3 M) of dilute hydrochloric acid. The reaction mixture was stirred at 25 °C for 0.5 h. The ether layer was separated and dried over anhydrous $MgSO_4$. To it was added 1.7 mL (30 mmol) of acetaldehyde, and the solution was stirred overnight. Excess acetaldehyde was removed and the reaction mixture was extracted with 2 × 5 mL (3 M) of sodium hydroxide. The alkaline solution was neutralized with 6 mL of 6 N hydrochloric acid and the boronic acid extracted into 3 × 15 mL of ether. The boronic acid was reesterified with methanol according to the standard procedure[16] to give the methylborinate: bp 46 °C/1 mm; $[\alpha]^{23}_D$ −26.47° (*c* 7, methanol).

The borinate, 10 mmol, thus obtained was oxidized with 3 M sodium hydroxide and 30% hydrogen peroxide in the usual manner. The alcohol was extracted with ether. The solvent was removed. The product was purified by preparative GC to afford GC pure material: mp 125–126 °C; $[\alpha]^{23}_D$ +5.17° (*c* 7.5, absolute ethanol), ~100% ee; [lit.[15] $[\alpha]^{23}_D$ −4.2° (*c* 7.5, EtOH)], 83% ee.

Upgrading the Optical Purity of Ethyl Tetrahydro-2*H*-3-pyranylborinate. 3,4-Dihydropyran (25 mmol) was hydroborated with diisopinocampheylborane [25 mmol, derived from (+)-α-pinene], as described in the literature.[12] The trialkylborane (^{11}B NMR δ 87) thus obtained was treated with 5.6 mL (100 mmol) of acetaldehyde and was stirred at 25 °C for 6 h. Excess acetaldehyde and liberated α-pinene were pumped off under reduced pressure.

The ethyl tetrahydro-2*H*-3-pyranylborinate (^{11}B NMR δ 29.7) thus obtained was placed in 25 mL of ether. To it was added 2.95 g of (25 mmol) *N*,*N*,*N*′,*N*′-tetrakis(hydroxyethyl)ethylenediamine in 15 mL of isopropyl alcohol, and the reaction mixture was stirred at room temperature for 1 h. A white crystalline solid separated. It was filtered to obtain 5.5 g of chelate (^{11}B NMR δ 37.2, mp 81 °C). The solid was suspended in 17 mL of ether, to it was added 5 mL of 6 N hydrochloric acid, and the mixture was stirred at room temperature for 0.5 h. The ether layer was separated, and the aqueous layer was saturated with sodium chloride and then extracted with 3 × 10 mL of ether. The combined ether extracts were oxidized with 3 N sodium hydroxide and 30% hydrogen peroxide in the usual manner. The alcohol was distilled: bp 90 °C/20 mm. It was subjected to preparative GC to obtain GC-pure material: $[\alpha]^{23}_D$ +11.9° (neat). The corresponding Mosher ester was prepared as described in the literature.[20] The ^{19}F NMR spectrum showed the alcohol to be ~100% ee.

Isolation of Methyl 3-Tetrahydropyranylborinate. The crystalline chelate, 5.5 g, obtained as described above, was suspended in 17 mL of ether, to it was added 5 mL of 6 N hydrochloric acid, and the mixture was stirred at 25 °C. The aqueous layer was extracted with ether and the combined ether layer dried. The ether was evaporated. The boronic acid obtained was esterified as described in the literature:[23] $[\alpha]^{23}_D$ −20.45° (*c* 5.9, MeOH).

The percentage of yield, ^{11}B NMR spectra, and melting points are described in Tables I and II. The ^{1}H NMR spectra are in agreement with the structures.

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