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Boron-Mediated Aldol Reaction of Carboxylic Esters: Complementary Anti- and Syn-Selective Asymmetric Aldol Reactions

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The boron-mediated aldol reaction of carboxylic esters is described in detail. Contrary to the general belief that carboxylic esters are inert under the condition of the boron enolate formation, propionate esters are enolized with certain combinations of a boron triflate and an amine. More importantly, the stereochemical course of the aldol reaction can be controlled by the judicious selection of the enolization reagents. Treatment of propionate esters with *c*-Hex_2BOTf and triethylamine produces *anti*-aldol products, and that with Bu_2BOTf and diisopropylethylamine gives *syn*-aldol products selectively after reaction with aldehydes. Complementary anti- and syn-selective asymmetric aldol reactions with structurally related, readily available chiral norephedrine-derived propionate esters are developed.

Introduction

Since around 1980, numerous efforts have been devoted to the development of efficient procedures for the construction of β-hydroxycarbonyl compounds in a stereodefined fashion, and undoubtedly, the boron-mediated aldol reaction has been one of the most useful and practical variants of the modern aldol methodology.[1] Earlier efforts resulted in the development of highly efficient and practical boron-mediated asymmetric aldol reactions with chiral ketones,[2] chiral acyloxazolidinones,[3] achiral thioesters with an external chiral boron triflate,[4] and others.[5] Carboxylic esters, another major family of carbonyl compounds, have long been assumed to be inactive under the enolization conditions,[6] and the boron-mediated aldol reaction of carboxylic esters is relatively unexplored. Only a few recorded examples are available. Corey reported[7] asymmetric aldol reactions of propionate esters with aldehydes, using a chiral bis-sulfonamide derivative of boron bromide and an amine for enolization, and Brown[8] developed dicyclohexylboron iodide for the aldol reaction of esters and amides. Recently, we have found that carboxylic esters, in fact, are as good a substrate as other carbonyl compounds for the boron-mediated aldol reaction[9] and, more importantly, devised complementary anti-[10] and syn-selective[11] asymmetric aldol reactions of chiral carboxylic esters. Herein we describe in detail our findings on the boron-mediated aldol reaction of propionate esters.

Results and Discussion

Enolization of Propionate Esters with Boron Triflate and Amine. At the very early stage of the boron aldol history, it was documented that enolization of methyl propionate failed with a combination of a boron triflate and an amine as enolization reagents.[6] Contrary to this reported inertness, treatment of benzyl propionate with certain pairs of a dialkylboron triflate (1.3 equiv) and an amine (1.5 equiv) provided the corresponding aldol product in high yield (Table 1). However, the reaction was extremely sensitive to the choice of enolization reagents. As shown in Table 1, the steric size of amine was very important for the success of the enolization. A very large or a very small amine, such as triisopropylamine or 1-methylpyrrolidine, was ineffective

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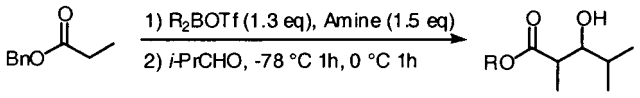
TABLE 1. Boron Aldol Reaction of Benzyl Propionate



	yield (%) (syn:anti) with trilate			
amine	Et_2BOTf	Bu_2BOTf	*c*-Pen_2BOTf	*c*-Hex_2BOTf
i-Pr_3N	0	0	0	0
i-Pr_2NEt	96 (92:8)	97 (95:5)	97 (95:5)	84 (90:10)
c-Hex_2NMe	93 (95:5)	95 (95:5)	96 (92:8)	
c-HexNEt_2		78 (94:6)		88 (98: 2)
Bu_3N	0	<10		
Et_3N	0	<10	94 (22:78)	92 (10:90)
$(CH_2)_4$NMe	0	0	0	0

for enolization. The failure of enolization with a very small amine is presumably due to formation of a very tight boron triflate−amine complex, and that with a very large amine (*i*-Pr_3N) is due to steric hindrance.

It is interesting to note that the combination of a smaller boron triflate (Et_2BOTf, Bu_2BOTf) and a smaller amine (Et_3N, Bu_3N) led to the failure of enolization of the ester. The fact that the same combination of reagents (Bu_2BOTf and Et_3N) effects the enolization of ketones, acylimides, thioesters, or methyl acetate implies that the inactivity toward propionate esters should be attributed to the insufficient basicity of the amine to deprotonate an α-proton of the propionate from a propionate−boron triflate complex, or in other words, the unfavorable formation of a propionate−boron triflate complex against an amine−boron triflate complex.

Diastereoselectivity (Syn−Anti Selectivity) of the Boron-Mediated Aldol Reaction of Propionate Esters. The boron-mediated aldol reaction of propionate esters was investigated. With use of two sets of enolization reagents, Bu_2BOTf-*i*-Pr_2EtN and *c*-Hex_2BOTf-Et_3N, a series of propionate esters was subjected to the aldol reaction (Table 2). Adequate reactivity was observed with all the combinations, and more importantly, with *c*-Hex_2-BOTf-Et_3N more anti-isomer was produced than from the reactions with Bu_2BOTf-*i*-Pr_2EtN (compare entries 2 and 8, 3 and 9, and 4 and 12). The diastereoselectivity of the *c*-Hex_2BOTf-Et_3N reaction was sensitive to the alcohol residue of the ester as well as the reaction temperature; the bulkier the ester, the more anti-isomer was produced (entries 6, 8, 10, 12, and 14),[12] and at higher temperature the syn-isomers became predominant (entries 5, 7, and 11). Formation of the anti-isomer should be attributed to the kinetic formation of *E*-enolate,[13] because isomerization of the enolate was observed under the enolization conditions (Table 3, entries 4 and 5). Thus, the aldol reaction at −95 °C afforded the *anti*-aldol product (>97:3), which implies the intermediate enolate consisted of >97% *E*-enolate. When the enolate solution was warmed to 0 °C before addition of aldehyde, the *syn*-aldol product was obtained as a major product (anti:syn = 33:67 for 30 min and 10:90 for 1 h). These results clearly indicate isomerization of the *E*-enolate to the *Z*-enolate under the enolization conditions. This facile isomerization is particularly noteworthy in comparison with an enolate of propiophenone.[14] Although the isomer ratio of the aldol products was altered depending on the reaction temperature (anti:syn = 5:95 at 0 °C and 27:73 at −78 °C), it did not change with warming of the enolate mixture (Table 3, entries 6−10). The geometry of the enolate of propiophenone was determined at the enolization stage and the configuration did not change under the enolization conditions.[15]

The Anti-Selective Asymmetric Aldol Reaction. The results in Tables 1 and 2 demonstrate the possibility of control of the stereochemical course of the aldol reaction by the judicious choice of enolization conditions. Thus, the combination of Bu_2BOTf-*i*-Pr_2EtN leads to the predominant formation of the *syn*-aldol products, while the enolization of a bulkier ester with *c*-Hex_2BOTf-Et_3N at lower temperature affords the corresponding *anti*-aldol products selectively (Scheme 1).

In designing aldol reagents in recent years, significant emphasis has been placed on the development of highly selective and practical asymmetric aldol methodologies.[16] Several efficient and practical reagents have been designed for the *syn*-propionate aldol reaction and resulted in widespread use as a tool in the total synthesis of natural products. However, the development of *anti*-propionate aldol reagents has not been very successful, despite the large amount of work in this field. The existing methods present problems in terms of the availability of the reagent, the generality of reactions, or the conditions required for the reaction. As a result of these difficulties, the *anti*-aldol reaction was often avoided in synthesis.

On the basis of the findings described above, chiral propionate esters were tested for the asymmetric aldol reaction. Among them, **1f** (derived from norephedrine) and **1c** (derived from ephedrine or norephedrine) exhibited excellent diastereo- and diastereofacial selectivities for the anti- and syn-selective aldol reactions, respectively. Both esters are readily accessible from commercial materials with use of reactions applicable to a large-scale preparation (Scheme 2). Thus, norephedrine was quantitatively converted to the sulfonamide (**2b**) with mesitylenesulfonyl chloride in the presence of triethylamine[17] and selective *N*-alkylation was achieved with benzyl bromide and K_2CO_3 to afford **3f** in 95% yield.[18] Simple acylation (∼100%) completed the synthesis of **1f**. The overall yield exceeded 95% and all the intermediates

(12) These observations could be rationalized on the basis of conformations similar to those proposed earlier for the enolization of ketones. See refs 1a and 6a.

(13) In this paper the *Z* and *E* stereochemical descriptors of enol borinates are defined on the assignment of the highest priority designation to the OBR_2 group.

(14) Earlier studies on the stereochemistry of enol boration, see: (a) Brown, H. C.; Ganessan, K.; Dhar, R. K. *J. Org. Chem.* **1992**, *57*, 3767. (b) Brown, H. C.; Ganessan, K.; Dhar, R. K. *J. Org. Chem.* **1993**, *58*, 147. (c) Ganessan, K.; Brown, H. C. *J. Org. Chem.* **1993**, *58*, 7162.

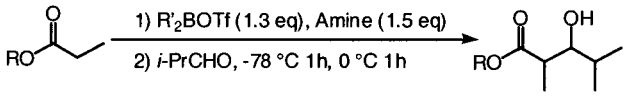
(15) This difference in propionate ester and propiophenone could be explained as a degree of contribution of the carbon-bound boron enolate, which facilitates the isomerization of the enolate. See: Abiko, A.; Inoue, T.; Masamune, S. *J. Am. Chem. Soc.* In press.

(16) Recent examples of asymmetric aldol reagents; see: Kurosu, M.; Lorca, M. *J. Org. Chem.* **2001**, *66*, 1205. Vicario, J. L.; Badia, D.; Dominguez, E.; Rodriguez, M.; Carrillo, L. *J. Org. Chem.* **2000**, *65*, 3754 and references therein.

(17) Under the Shotten−Baumann conditions in aqueous THF ($MesSO_2Cl$, $NaHCO_3$), the sulfonamide was precipitated from the aqueous solution as a hydrate. Thus, the reaction in an organic solvent is more convenient.

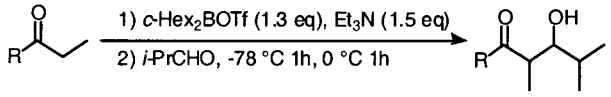
(18) This alkylation could be achieved under various conditions; BnCl, Bu_4NI, and K_2CO_3 in CH_3CN, which is less expensive but takes longer reaction time, or *t*-BuOK, BnBr, and DMF, which is convenient for a small-scale preparation.

TABLE 2. Boron Aldol Reaction of Propionate Esters



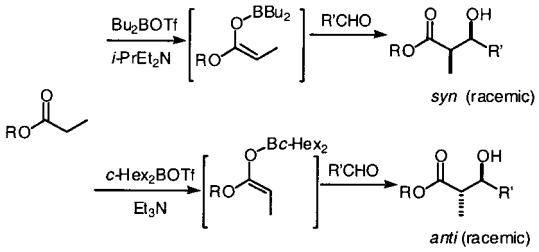
entry	propionate ester	enolization reagents	enolization conditions	yield (%)	syn:anti
1	EtCOOMe	Bu_2BOTf-*i*-Pr_2EtN	−78 °C, 1 h	85	>97:3
2	EtCOOEt		−78 °C, 1 h	81	95:5
3	EtCOOCH$_2$*c*-Hex		−78 °C, 1 h	89	80:20
4	EtCOO*i*-Pr		−78 °C, 1 h	65	75:25
5	EtCOOMe	*c*-Hex_2BOTf-Et_3N	0 °C, 30 min	64	>97:3
6	EtCOOMe		−78 °C, 1 h	84	>97:3
7	EtCOOEt		0 °C, 30 min	77	70:30
8	EtCOOEt		−78 °C, 1 h	86	60:40
9	EtCOOEt		−95 °C, 1 h	75	7:93
10	EtCOOCH$_2$*c*-Hex		−78 °C, 1 h	92	30:70
11	EtCOO*i*-Pr		0 °C, 30 min	90	96:4
12	EtCOO*i*-Pr		−78 °C, 1 h	63	30:70
13	EtCOO*i*-Pr		−95 °C, 1 h	86	18:82
14	EtCOO*t*-Bu		−78 °C, 1 h	69	3:>97

TABLE 3. Isomerization of the Boron Enolate



entry	R	enolization conditions	yield (%)	syn:anti
1	BnO	0 °C, 30 min	94	90:10
2		−78 °C, 30 min	92	10:90
3		−95 °C, 1 h	80	3:>97
4		−95 °C 1 h, 0 °C 30 min	84	67:33
5		−95 °C 1 h, 0 °C 2 h	90	90:10
6	Ph	0 °C, 30 min	97	95: 5
7		−78 °C, 30 min	92	73:27
8		−78 °C, 30 min, 0 °C 30 min	92	75:25
9		−95 °C 1 h,	84	67:33
10		−95 °C 1 h, 0 °C 30 min	92	74:26

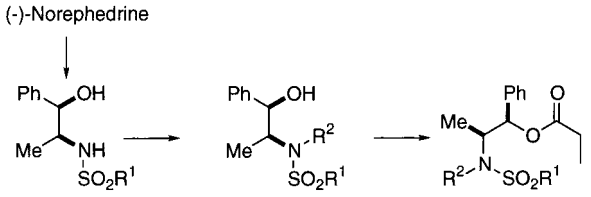
SCHEME 1. Stereoselective Aldol Reaction



could be purified by recrystallization if necessary. **1c** and related esters were synthesized similarly.

From the careful survey of the enolization conditions, the optimum conditions were established as in Table 4, entry 9. With 1 equiv of *c*-Hex_2BOTf, the maximun yield of the aldol products was 78% after 2 h of enolization (Table 4, entries 1−3). Longer treatment did not improve the yield (entry 4). With 2 equiv of the boron triflate, the propionate was quantitatively enolized within 2 h (entries 7−9). A change in the number of equivalents of the boron triflate (1−2 equiv) did not affect the selectivity of the reaction (entries 3, 5, 6, and 9), thus eliminating a Lewis acid-catalyzed pathway for the formation of the *anti*-aldol products. It should be added that again the Bu_2BOTf-Et_3N combination was inert for the enolization of **1f** (entry 10), and the syn-isomer (syn:anti = 87:13) of high ds was obtained with Bu_2BOTf-*i*-Pr_2EtN (entry 11). The

SCHEME 2. Synthesis of 1f and Related Esters



2a: R^1 = Tol
2b: R^1 = Mes[a]
2c: R^1 = OHA[b]
2d: R^1 = TIP[c]

3a: R^1 = Tol; R^2 = Me
3b: R^1 = Mes; R^2 = Me
3c: R^1 = OHA; R^2 = Me
3d: R^1 = TIP; R^2 = Me
3e: R^1 = Tol; R^2 = Bn
3f: R^1 = Mes; R^2 =B n
3g: R^1 = OHA; R^2 = Bn
3h: R^1 = TIP; R^2 = Bn

1a: R^1 = Tol; R^2 = Me
1b: R^1 = Mes; R^2 = Me
1c: R^1 = OHA; R^2 = Me
1d: R^1 = TIP; R^2 = Me
1e: R^1 = Tol; R^2 = Bn
1f: R^1 = Mes; R^2 =B n
1g: R^1 = OHA; R^2 = Bn
1h: R^1 = TIP; R^2 = Bn

a) Mes = 2,4,6-trimethylphenyl;
b) OHA =1,2,3,4,6,7,8,9-octahydroanthracenyl;
c) TIP=2,4,6-triisopropylphenyl

E-enolate of **1f** isomerized to a mixture of *E*- and *Z*-enolate at 0 °C (entry 13).

The incomplete enolization with 1 equiv of the boron triflate should be attributed to deactivation (or decomposition) of *c*-Hex_2BOTf. When *c*-Hex_2BOTf was pretreated with Et_3N (before addition of ester), the yield of the aldol reaction decreased dramatically: −78 °C, 2 h, 65%; −78 °C, 4 h, 46%; RT, 15 min, 49%; RT, 30 min, 39%; RT, 2 h, 8%. And even with 2 equiv of *c*-Hex_2BOTf, pretreatment for 2 h at −78 °C lowered the yield to 75%. From the variable-temperature NMR experiments, it was confirmed that *c*-Hex_2BOTf reversibly formed a complex with triethylamine (Figure 1). Two sets of broad peaks of triethylamine, assigned as a complexed and an uncomplexed ones, appeared at low temperature, which coalesced in a well-resolved single set of peaks above ∼270 K. The same two sets of broad peaks were revived by cooling the mixture again. The *c*-Hex_2BOTf-Et_3N complex was, however, not stable for long periods of time. ^{1}H and ^{11}B NMR showed that the initially formed complex almost disappeared after 2 h at room temperature. ^{11}B NMR: after 5 min, 55.8 ppm;[19] after 2 h, 51.2, 0.7 ppm. ^{1}H NMR: after 5 min, 1.02 (9H, t, J = 7 Hz),

TABLE 4. Asymmetric Aldol Reaction of 1f

entry	R_2BOTf (equiv)	amine (equiv)	enolization conditions	yield (%)	anti:syn (ds)
1	*c*-Hex_2BOTf (1)	Et_3N (1.5)	−78 °C, 0.5 h	27	>98:2 (98:2)
2	*c*-Hex_2BOTf (1)	Et_3N (1.5)	−78 °C, 1 h	59	>98:2 (97:3)
3	*c*-Hex_2BOTf (1)	Et_3N (1.5)	−78 °C, 2 h	78	>98:2 (97:3)
4	*c*-Hex_2BOTf (1)	Et_3N (1.5)	−78 °C, 4 h	77	>98:2 (96:4)
5	*c*-Hex_2BOTf (1.3)	Et_3N (1.6)	−78 °C, 2 h	88	>98:2 (97:3)
6	*c*-Hex_2BOTf (1.7)	Et_3N (2.1)	−78 °C, 2 h	92	>98:2 (98:2)
7	*c*-Hex_2BOTf (2)	Et_3N (2.4)	−78 °C, 0.5 h	91	>98:2 (96:4)
8	*c*-Hex_2BOTf (2)	Et_3N (2.4)	−78 °C, 1 h	93	>98:2 (97:3)
9	*c*-Hex_2BOTf (2)	Et_3N (2.4)	−78 °C, 2 h	98	>98:2 (98:2)
10	Bu_2BOTf (2)	Et_3N (2.4)	−78 °C, 2 h	<3	
11	Bu_2BOTf (2)	*i*-Pr_2EtN (2.4)	−78 °C, 2 h	80	13:87 (97:3)[a]
12	*c*-Hex_2BOTf (2)	*i*-Pr_2EtN (2.4)	−78 °C, 2 h	70	>98:2 (98:2)
13	*c*-Hex_2BOTf (2)	Et_3N (2.4)	−78 °C, 2 h; 0 °C, 1 h	97	68:32 (94:6)

[a] Ds for syn-isomers.

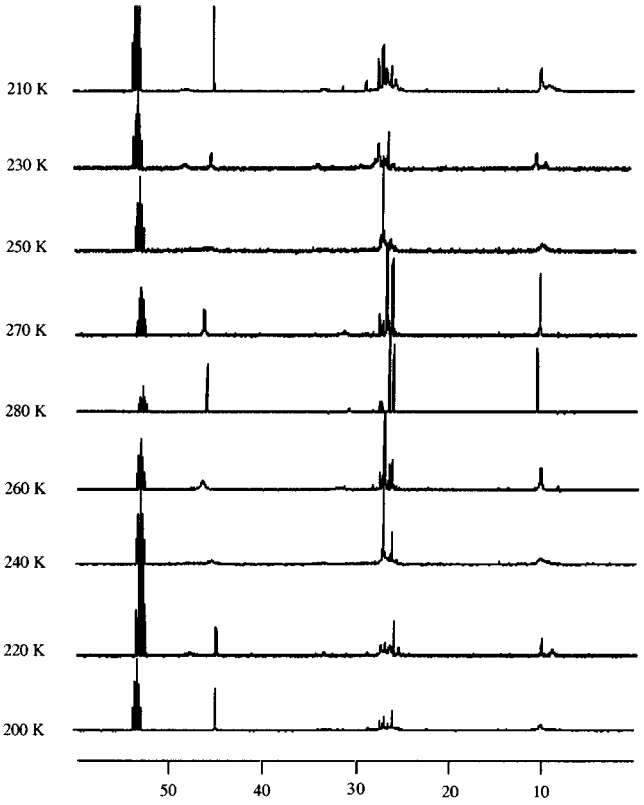


FIGURE 1. Variable-temperature ^{13}C NMR of the *c*-Hex_2-$BOTf$-Et_3N mixture.

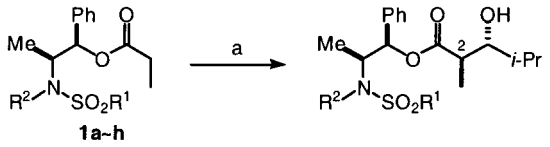
2.58 (6H, q, J = 7 Hz); after 2 h, 1.18 (9H, t, J = 7 Hz), 2.87 (6H, q, J = 7 Hz).

Propionate esters (**1a**−**h**) derived from the structurally related chiral alcohols were examined under the optimal anti-selective aldol conditions (Table 5). As expected, in all cases the anti-isomers were obtained with excellent selectivities, although the diastereofacial selectivity of the anti-products fluctuated significantly depending on the substituents. Thus, **1f** was established as the reagent for the anti-selective aldol reaction.

The anti-selective asymmetric aldol reaction of **1f** proceeded with excellent diastereo- (>98:2) and diastereofacial (>95:5) selectivities with all of the aldehydes examined, including aliphatic aldehydes of various steric bulkiness and aromatic and α,β-unsaturated aldehydes (Table 6). This wide applicability definitely secures the practical merit of this procedure. The absolute stereochemistry of the purified aldol products was determined

(19) Cf.: Naula, C. K.; Nöth, H. *Inorg. Chem.* **1985**, *24*, 2532.

TABLE 5. Anti-Selective Asymmetric Aldol Reaction of 1

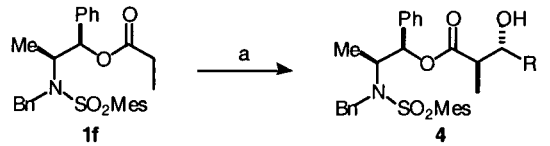


1a~h

entry	compd[b]	anti:syn	ds
1	**1a** (R^1 = Tol; R^2 = Me)	91:9	98:2
2	**1b** (R^1 = Mes; R^2 = Me)	>98:2	94:6
3	**1c** (R^1 = OHA; R^2 = Me)	>98:2	89:11
4	**1d** (R^1 = TIP; R^2 = Me)	>98:2	90:10
5	**1e** (R^1 = Tol; R^2 = Bn)	>98:2	87:13
6	**1f** (R^1 = Mes; R^2 = Bn)	>98:2	98:2
7	**1g** (R^1 = OHA; R^2 = Bn)	>98:2	88:12
8	**1h** (R^1 = TIP; R^2 = Bn)	>98:2	89:11

[a] *c*-Hex_2BOTf (2.0 equiv), Et_3N (2.4 equiv), −78 °C for 2 h; then *i*-PrCHO, −78 °C for 1 h, 0 °C for 1 h. [b] Mes = 2,4,6-trimethylphenyl; OHA = 1,2,3,4,6,7,8,9-octahydroanthracenyl; TIP = 2,4,6-triisopropylphenyl.

TABLE 6. Anti-Selective Asymmetric Aldol Reaction of 1f

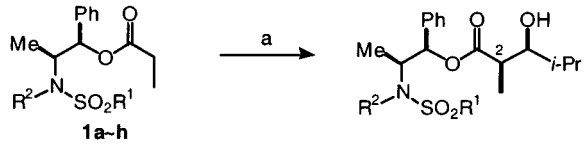


1f **4**

entry	RCHO	product	yield	ds for anti[b]
1	MeCHO	4a	92 (%)	97:3
2	EtCHO	4b	90	96:4
3	*n*-PrCHO	4c	95	95:5
4	*i*-PrCHO	4d	95	98:2
5	*c*-HexCHO	4e	91	95:5
6	*t*-BuCHO	4f	96	>99:1
7	PhCHO	4g	93	95:5
8	(*E*)-CH_3CH=$CHCHO$	4h	96	98:2
9	CH_2=$C(CH_3)CHO$	4i	97	96:4
10	$BnOCH_2CH_2CHO$	4j	94	95:5
11	$BnOCH_2C(CH_3)_2CHO$	4k	98	96:4

[a] *c*-Hex_2BOTf (2.0 equiv), Et_3N (2.4 equiv), −78 °C for 2 h; then RCHO, −78 °C for 1 h, 0 °C for 1 h. [b] Anti:syn = >98:2.

TABLE 7. Syn-Selective Asymmetric Aldol Reaction of 1

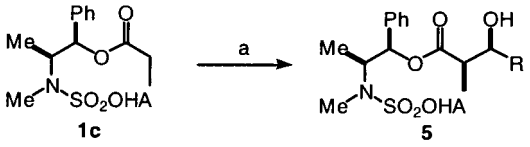


1a–h

entry	compd	syn:anti	ds
1	**1a** (R^1 = Tol; R^2 = Me)	93:7	90:10
2	**1b** (R^1 = Mes; R^2 = Me)	91:9	92:8
3	**1c** (R^1 = OHA; R^2 = Me)	95:5	94:6
4	**1d** (R^1 = TIP; R^2 = Me)	93:7	92:8
5	**1e** (R^1 = Tol; R^2 = Bn)	89:11	94:6
6	**1f** (R^1 = Mes; R^2 = Bn)	87:13	96:4
7	**1g** (R^1 = OHA; R^2 = Bn)	92:8	88:12
8	**1h** (R^1 = TIP; R^2 = Bn)	90:10	90:10

[a] Bu_2BOTf (2.0 equiv), Et_3N (2.4 equiv), −78 °C for 2 h; then *i*-PrCHO, −78 °C for 1 h, 0 °C for 1 h.

TABLE 8. Syn-Selective Asymmetric Aldol Reaction of 1c



1c **5**

entry	RCHO	product	yield (%)	ds for syn[b]
1	EtCHO	**5a**	95	97:3
2	*n*-PrCHO	**5b**	93	>97:3
3	*i*-PrCHO	**5c**	98	97:3
4	*t*-BuCHO	**5d**	97	97:3
5	PhCHO	**5e**	97	95:5
6	(*E*)-CH_3CH=$CHCHO$	**5f**	98	>97:3

[a] Bu_2BOTf (2.0 equiv), Et_3N (2.4 equiv), −78 °C for 2 h; then RCHO, −78 °C for 1 h, 0 °C for 1 h. [b] Syn:anti= >95:5.

after conversion to the corresponding alcohol or carboxylic esters.

The Syn-Selective Asymmetric Aldol Reaction. With use of a series of propionates (**1a**−**h**), the syn-selective asymmetric aldol reaction was examined under the conditions defined above: Bu_2BOTf (2.0 equiv), *i*-Pr_2-EtN (2.4 equiv) in CH_2Cl_2 at −78 °C 2 h, followed by the reaction with isobutyraldehyde (−78 °C 1 h, 0 °C 1 h) (Table 7).[20] As expected, in all cases the syn-isomer was obtained as the major product. Contrary to the *anti*-aldol reactions, the R^2 = Me series provided product with a higher syn:anti selectivity than those with a benzyl substituent. Although the selectivity fluctuated significantly depending on the substituents of the sulfonamide (R^1), **1c** exhibited excellent selectivity in both diastereo- and diastereofacial manner (Table 7). Again, **1c** exhibited excellent selectivities with a wide range of aldehydes (Table 8) and will be an alternate of the existing syn-selective aldol reactions.[11]

It should be added that the stereochemistry of the major product of the *anti*- and *syn*-aldol reaction of **1f**, **1c**, and related esters is a result of opposite diastereofacial selection of the intermediate enolates. This implies that the conformations of the transition states leading to *anti*-aldol from *E*-enolate and *syn*-aldol from *Z*-enolate are totally different.

In summary, the boron-mediated aldol reaction of carboxylic esters is shown to be particularly interesting and useful that the stereochemistry of the intermediate enolate can be controlled by the judicious choice of the enolization conditions. We have devised complementary anti- and syn-selelctive asymmetric aldol reactions of chirl propionate esters. Notably, the anti-selective aldol reaction with reagent **1f** represents the most reliable and practical method for the direct construction of the *anti*-3-hydroxy-2-methylcarbonyl system,[21] which has challenged synthetic chemists in the aldol field for many years.

Experimental Section

Preparation of a Stock Solution of Dicyclohexylboron Triflate in Hexane.[22] An oven-dried 250-mL round-bottom flask capped with a rubber septum was charged with cyclohexene (35 mL, 0.33 mol) and dry diethyl ether (100 mL), and kept at 0 °C under nitrogen. Borane−dimethyl sulfide complex (16.6 mL, 0.16 mol) was added dropwise during 30 min with stirring, and then the whole reaction mixture was stirred for 3 h at 0 °C, when the solid was settled without stirring. The supernatant organic solution was removed as much as possible by syringe, and the residual solid was dried under vacuum to give dicyclohexylborane (27.2−30.0 g), which was used for the preparation of the triflate without purification.

The solid was suspended in 100 mL of dry *n*-hexane and trifluoromethanesulfonic acid (25.0 g, 0.16 mol) was added dropwise via syringe during 30 min with constant stirring, during which time vigorous gas evolution occurred and the solid gradually disappeared. Stirring continued at room temperature for 1 h and the reaction was left for 1−2 h without stirring. Two layers appeared and the top layer was transferred into a dry 200-mL round-bottom storage flask with a stopcock-equipped septum inlet and a magnetic stirring bar, which had been weighed and graduated.

Determination of the Concentration of the *c*-Hex_2BOTf Solution. (a) By weight: Solid *c*-Hex_2BOTf was obtained by removing the solvent with a water aspirator, and a stock solution in *n*-hexane (1.0 M) was prepared. Alternatively, crystalline *c*-Hex_2BOTf may also be obtained by cooling a hexane solution below −20 °C overnight, followed by removal of the solvent with a syringe (yield 70−80%).

(b) By ^{13}C NMR: An aliquot of the stock solution was taken into a dry NMR sample tube and $CDCl_3$ (0.1 mL) was added for locking. ^{13}C NMR was measured with a delay time (d1) of 60 s. Integration of the peaks at 14.0 ppm (CH_3- of hexane) (=[H]) and summing of the integration of peaks at 27.0 (2C), 26.7 (1C), and 26.5 (2C) ppm (=[B]) gave the molar ratio of hexane and *c*-Hex_2BOTf: [hexane]:[*c*-Hex_2BOTf] = ([H]/2):([B]/10). Then the concentration was calculated according to the following equations.

$$W = \text{w/w (\%)} = \{([c\text{-Hex}_2\text{BOTf}] \times 326)/([c\text{-Hex}_2\text{BOTf}] \times 326) + ([\text{hexane}] \times 86)\} \times 100$$

$$N\ (\text{mol/L}) = \{(d \times W)/326\} \times 100$$

where d (density of a ~1 M solution) ~ 0.75

(20) At higher temperature, the reaction proceeded less cleanly with a significant amount of side products.

(21) Some application to the natural product syntheses has been reported. (a) Yoshimitsu, T.; Song, J. J.; Wang, G.-Q.; Masamune, S. *J. Org. Chem.* **1997**, *62*, 8978. (b) Yokokawa, F.; Fujiwara, H.; Shioiri, T. *Tetrahedron* **2000**, *56*, 1759. (c) Andrus, M. B.; Turner, T. M.; Sauna, Z. E.; Ambudkar, S. V. *J. Org. Chem.* **2000**, *65*, 4973. (d) Kogen, H.; Kiho, T.; Nakayama, M.; Furukawa, Y.; Kinoshita, T.; Inukai, M. *J. Am. Chem. Soc.* **2000**, *122*, 10214.

(22) Slight modification of the reported procedure. See: (a) Brown, H. C.; Kramer, G. W.; Levy, A. B.; Midland, M. M. *Organic Synthesis via Boranes*; Wiley-Interscience: New York, 1975; pp 28 and 29. (b) Reference 14b.

(c) By the standard reaction: The concentration of a *c*-Hex_2BOTf solution can be estimated by the standard reaction. For example, benzyl acetate (2.0 mmol) was treated with a *c*-Hex_2BOTf solution (1.0 mL) and Et_3N (0.16 mL, 1.15 mmol) in CH_2Cl_2 (10 mL) at −78 °C for 2 h, followed by *i*-PrCHO (0.135 mL) at −78 °C for 1 h. The reaction was allowed to warm to room temperature for 1 h, then quenched with pH 7.0 buffer solution and MeOH (1:1, 10 mL). Oxidative workup with 30% H_2O_2 solution gave a crude reaction mixture and the conversion was determined by ^{1}H NMR to give the concentration of the *c*-Hex_2BOTf solution used.

Errors in these methods were less than 10%.

Synthesis of Chiral Propionate Reagents 1f and 1c. 2-(*N*-Mesitylenesulfonyl)amino-1-phenyl-1-propanol (2b): To a stirred solution of recrystallized norephedrine (30.2 g, 0.20 mol) and triethylamine (33.4 mL, 0.24 mol) in methylene chloride (400 mL) was added mesitylenesulfonyl chloride (43.8 g, 0.20 mol) at 0 °C. The reaction mixture was stirred at 0 °C to room temperature for 2 h and diluted with diethyl ether (600 mL). The mixture was washed successively with 100 mL each of water, 1 M HCl, water, saturated sodium hydrogencarbonate solution, and brine and dried over anhydrous sodium sulfate. The filtered organic solution was concentrated to give an oily residue, which was dissolved in methylene chloride (50 mL). Hexane (100 mL) was added to the solution in portions with swirling to cause crystallization. An additional hexane (300 mL) was added and the crystalline **2b** (60.8 g) was isolated by filtration. Concentration of the mother liquor afforded the second crop of **2b** (6.0 g, total yield ∼100%).

(1*R*,2*S*)-**2b**: mp 121−122 °C; $[\alpha]^{23}_D$ −12.4 (*c* 2.12, $CHCl_3$). (1*S*,2*R*)-**2b**: mp 120.5−121.5 °C; $[\alpha]^{23}_D$ 12.8 (*c* 2.12, $CHCl_3$). ^{1}H NMR ($CDCl_3$) (concentration dependent; 10 mg/0.5 mL) δ 0.87 (3H, d, J = 6.8 Hz), 2.30 (3H, s), 2.52 (1H, −O*H*), 2.66 (6H, s), 3.53 (1H, m), 4.76 (1H, br, −N*H*), 4.82 (1H, d, J = 8.8 Hz), 6.96 (2H, s), 7.20−7.36 (5H, m); ^{1}H NMR ($CDCl_3$) (100 mg/0.5 mL) δ 0.88 (3H, d, J = 6.8 Hz), 2.32 (3H, s), 2.68 (6H, s), 3.08 (1H, −O*H*), 3.51 (1H, m), 4.81 (1H, br, −N*H*), 5.23 (1H, br), 6.98 (2H, s), 7.20−7.36 (5H, m);^{13}C NMR ($CDCl_3$) δ 14.3, 20.9, 22.9, 54.6, 75.6, 125.9, 127.5, 128.3, 132.0, 134.2, 138.9, 140.5, 142.2; FAB-MS (*m*-NBA) 334 (MH^+); HR-MS, found 334.1487, calcd for $C_{18}H_{24}NO_3S$ 334.1477. Anal. Calcd for $C_{18}H_{23}NO_3S$: C, 64.84; H, 6.95; N, 4.20. Found: C, 64.94; H, 6.98; N, 4.17.

2-(*N*-Benzyl-*N*-mesitylenesulfonyl)amino-1-phenyl-1-propanol (3f). Procedure A, with K_2CO_3 and BnCl−Bu_4NI (suitable for a large-scale preparation). A mixture of **2b** (16.7 g, 0.05 mol), benzyl chloride (6.90 mL, 0.06 mol), tetrabutylammonium iodide (200 mg), and potassium carbonate (8.4 g, 0.06 mol) in acetonitrile (100 mL) was heated under reflux for 17 h. The cooled mixture was filtered and the salt was washed with diethyl ether. The combined organic layers were concentrated and the residue was crystallized from methylene chloride (25 mL) and hexane (100 mL) to give **3f** (17.0 g, 80%). An additional 3.2 g (15%) of **3f** was isolated by chromatography of the mother liquor on silica gel (100 g) with 10% ethyl acetate in hexane.

Procedure B, with K_2CO_3, BnBr (faster reaction). A mixture of **2b** (3.3 g, 10 mmol), benzyl bromide (1.43 mL, 12 mmol), and K_2CO_3 (2.09 g, 15 mmol) in acetonitrile (40 mL) was heated under reflux for 7 h. The cooled mixture was filtered and the salt was washed with diethyl ether. Organic layers were combined, concentrated, and purified by flash chromatography to afford **3f** (4.0 g, 95%) and *N*,*O*-dibenzyl compound (0.25 g, 5%).

Procedure C, with *t*-BuOK as a Base (convenient for a small-scale preparation). This procedure was used for the preparation of the R^2 = Me series from norephedrine with MeI in place of benzyl bromide.

To a stirred solution of **2b** (11 g, 33 mmol) in DMF (150 mL) was added *t*-BuOK (3.70 g, 33 mmol) at room temperature. After 15 min, benzyl bromide (3.93 mL, 33 mmol) was added. The mixture was stirred at room temperature for 3 h and poured into water (500 mL). Extractive workup and chromatography afforded **3f** (13.3 g, 95%).

(1*R*,2*S*)-**3f**: mp 123−124 °C; $[\alpha]^{23}_D$ −6.31 (*c* 2.06, $CHCl_3$). (1*S*,2*R*)-**3f**: mp 123−124 °C, $[\alpha]^{23}_D$ 6.43 (*c* 2.05, $CHCl_3$). ^{1}H NMR ($CDCl_3$) (concentration dependent; 9 mg/0.5 mL) δ 1.03 (3H, d, J = 7.0 Hz), 2.14 (1H, −O*H*), 2.29 (3H, s), 2.65 (6H, s), 3.82 (1H, dq, J = 1.9 and 7.0 Hz), 4.54 (1H, A of ABq, J_{AB} = 16.1 Hz), 4.77 (1H, B of ABq, J_{AB} = 16.1 Hz), 5.00 (1H, br s), 6.93 (2H, s), 7.04−7.08 (2H, m), 7.10−7.36 (8H, m); ^{1}H NMR ($CDCl_3$) (109 mg/0.5 mL) 1.02 (3H, d, J = 7.0 Hz), 2.27 (3H, s), 2.34 (1H, −O*H*), 2.62 (6H, s), 3.82 (1H, dq, J = 1.9 and 7.0 Hz), 4.56 (1H, A of ABq, J_{AB} = 16.1 Hz), 4.75 (1H, B of ABq, J_{AB} = 16.1 Hz), 4.96 (1H, br s), 6.91 (2H, s), 7.04−7.08 (2H, m), 7.10−7.36 (8H, m); ^{13}C NMR ($CDCl_3$) δ 10.1, 20.8, 22.9, 48.9, 59.5, 76.5, 125.4, 127.1, 127.2, 127.6, 128.0, 128.4, 132.0, 133.4, 138.6, 140.0, 142.2, 142.5; FAB-MS (*m*-NBA), 424 (MH^+); HR-MS, found 424.1951, calcd for $C_{25}H_{30}NO_3S$ 424.1946. Anal. Calcd for $C_{25}H_{29}NO_3S$: C, 70.89; H, 6.90; N, 3.31. Found: C, 70.91; H, 6.95; N, 3.32.

2-(*N*-Methyl-*N*-(2,3,4,5,7,8,9,10-octahydroanthracenesulfonyl))amino-1-phenyl-1-propanol (3c) (ephedrine as a starting material). To a solution of ephedrine (5.8 g, 35 mmol) in CH_2Cl_2 (100 mL) at 0 °C was added triethylamine (7.0 mL, 50 mmol). After 5 min, octahydroanthracenesulfonyl chloride[23] (11 g, 38.7 mmol) was added, and the solution was allowed to warm to room temperature for 1 h. The reaction was quenched with water and the mixture was washed with 1 M HCl, water, and brine. The organic layer was dried over anhydrous $MgSO_4$ and the solvent was removed. The residue was recrystallized from diethyl ether and hexane to give **3c** as colorless crystals, (13.8 g, 95%). (1*S*,2*R*)-**3c**: mp 122−123 °C; $[\alpha]^{21}_D$ −10.62 (*c* 1.32, $CHCl_3$). (1*R*,2*S*)-**3c**: mp 121−122 °C; $[\alpha]^{21}_D$ 10.16 (*c* 3.7, $CHCl_3$). ^{1}H NMR ($CDCl_3$) δ 1.13 (3H, d, J = 6.9 Hz), 1.70 (8H, br), 2.10 (1H, br), 2.75 (4H, br), 2.88 (3H, s), 3.08 (4H, m), 3.94 (1H, dq, J = 3.0 and 6.9 Hz), 6.99 (1H, s), 7.16 (2H, d, J = 7.5 Hz), 7.22−7.27 (3H, m); ^{13}C NMR ($CDCl_3$) δ 10.1, 21.9, 23.2, 27.6, 29.1, 30.3, 57.0, 125.6, 127.5, 128.3, 135.1, 135.6, 136.1, 137.6, 142.2; FAB-MS (*m*-NBA), 414 (MH^+); HR-MS, found 414.2093, calcd for $C_{24}H_{32}NO_3S$ 414.2105. Anal. Calcd for $C_{24}H_{31}NO_3S$: C, 69.70; H, 7.55; N, 3.39. Found: C, 69.81; H, 7.45; N, 3.32.

2-(*N*-Benzyl-*N*-mesitylenesulfonyl)amino-1-phenyl-1-propyl Propionate (1f). Propionyl chloride (3.8 mL, 42.5 mmol) was added dropwise at 0 °C to a solution of **3f** (15.0 g, 35.4 mmol) and pyridine (3.7 mL, 46.0 mmol) in methylene chloride (200 mL). The reaction was stirred at room temperature for 13 h and diluted with diethyl ether (300 mL). The mixture was washed successively with 100 mL each of water, 1 M HCl, water, saturated sodium hydrogencarbonate solution, and brine, and dried with anhydrous sodium sulfate. The filtered organic solution was concentrated to give a crystalline residue, which was triturated with hexane to give **1f** (16.8 g, ∼100%). (1*R*,2*S*)- and (1*S*,2*R*)-**1f** exist as polymorphic forms. Recrystallization from hot ethyl acetate (4 mL/g of **1f**) and hexane (ethyl acetate:hexane = 1:2) afforded higher melting crystals. (1*R*,2*S*)-**1f**: mp 124, 147−148 °C; $[\alpha]^{23}_D$ 11.1 (*c* 2.24, $CHCl_3$). (1*S*,2*R*)-**1f**: mp 124, 147−148 °C; $[\alpha]^{23}_D$ −11.2 (*c* 2.38, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 1.01 (3H, t, J = 7.4 Hz), 1.12 (3H, d, J = 7.0 Hz), 2.14 (2H, m), 2.27 (3H, s), 2.51 (6H, s), 4.04 (1H, dq, J = 4.0 and 7.0 Hz), 4.60 (1H, A of ABq, J_{AB} = 16.6 Hz), 4.72 (1H, B of ABq, J_{AB} = 16.6 Hz), 5.84 (1H, d, J = 3.9 Hz), 6.87 (2H, s), 6.88−6.96 (2H, m), 7.13−7.35 (8H, m); ^{13}C NMR ($CDCl_3$) δ 8.5, 12.3, 20.6, 22.7, 27.1, 47.9, 56.5, 77.7, 125.6, 126.8, 127.1, 127.5, 128.1 (2C), 131.9, 133.2, 138.4, 138.5, 139.8, 142.3, 172.2; FAB-MS (*m*-NBA), 480 (MH^+); HR-MS, found 480.2208, calcd for $C_{28}H_{34}NO_4S$ 480.2209. Anal. Calcd for $C_{28}H_{33}NO_4S$: C, 70.12; H, 6.93; N, 2.92. Found: C, 70.40; H, 6.97; N, 2.90.

(23) 1,2,3,4,6,7,8,9-Ocatahydroanthracenesulfonyl chloride was prepared from 1,2,3,4,6,7,8,9-octahydroanthracene by the literature method. Schröter, G. *Chem. Ber.* **1924**, *57*, 2003.

2-(*N*-Methyl-*N*-(2,3,4,5,7,8,9,10-octahydroanthracenesulfonyl)amino)-1-phenyl-1-propyl Propionate. (1*S*,2*R*)-**1c**: glass; $[\alpha]^{21}_D$ 9.5 (c 1.67, $CHCl_3$). (1*R*,2*S*)-**1c**: $[\alpha]^{20}_D$ −10.3 (*c* 2.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 1.14 (3H, t, J = 7.5 Hz), 1.26 (3H, d, J = 6.9 Hz), 1.68 (8H, m), 2.37 (2H, q, J = 7.5 Hz), 2.73 (4H, m), 2.77 (3H, s), 3.00 (4H, m), 4.03 (1H, dq, J = 4.5 and 6.9 Hz), 5.68 (1H, d, J = 4.5 Hz), 6.98 (3H, m), 7.20 (3H, m); ^{13}C NMR ($CDCl_3$) δ 9.0, 11.8, 21.8, 23.2, 27.6, 27.8, 28.4, 31.3, 55.3, 77.7, 126.0, 127.9, 128.3, 135.1, 135.2, 136.2, 137.7, 138.2, 172.8; FAB-MS (*m*-NBA), 470 (MH^+); HR-MS, found 470.2365, calcd for $C_{27}H_{36}NO_4S$ 470.2366. Anal. Calcd for $C_{27}H_{35}NO_4S$: C, 69.05; H, 7.51; N, 2.98. Found: C, 68.91; H, 7.71; N, 2.80.

Typical Procedure for the Anti-Selective Aldol Reaction. Into an oven-dried 500-mL round-bottom flask was placed (1*R*,2*S*)-**1f** (4.80 g, 10 mmol) and methylene chloride (50 mL) under nitrogen. To this solution was added triethylamine (3.40 mL, 24 mmol) via syringe. The solution was cooled to −78 °C and a solution of dicyclohexylboron triflate (1.0 M in hexane, 22 mL, 22 mmol) was added dropwise over 20 min. The resulting solution was stirred at −78 °C for 2 h. Isobutyraldehyde (1.08 mL, 12 mmol) was added dropwise to the enolate solution. The reaction mixture was stirred for 1 h at −78 °C and was allowed to warm to room temperature over 1 h, then quenched by addition of pH 7 buffer solution (40 mL). The mixture was diluted with MeOH (200 mL) and 30% hydrogen peroxide (20 mL) was added carefully. The whole mixture was stirred vigorously overnight and then was concentrated. The residue was partitioned between water (100 mL) and methylene chloride (200 mL). The aqueous layer was extracted with methylene chloride (150 mL × 2). The combined organic extracts were washed with water (100 mL × 3) and dried with anhydrous sodium sulfate. The filtered organic layer was concentrated and the residue was crystallized from hexane (150 mL) to afford (+)-**4d** (4.4 g). After concentration, the residue was distilled with mesitylene (50 mL) at ∼60 °C at 0.1 mmHg to remove cyclohexanol. The residue was separated by chromatography over silica gel (30 g) with hexane and ethyl acetate (5:1) to give additional (+)-**4d** (0.6 g): mp 142−142.5 °C; $[\alpha]^{23}_D$ 19.7 (*c* 2.05, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 0.90 (3H, d, J = 6.7 Hz), 0.95 (3H, d, J = 6.8 Hz), 1.10 (3H, d, J = 7.2 Hz), 1.17 (3H, d, J = 7.0 Hz), 1.73, (1H, m), 2.28 (3H, s), 2.37 (1H, br s, −O*H*), 2.49 (6H, s), 2.62 (1H, dq, J = 7.1 and 7.2 Hz), 3.41 (1H, br), 4.11 (1H, dq, J = 4.4 and 7.0 Hz), 4.55 (1H, A of ABq, J_{AB} = 16.5 Hz), 4.79 (1H, B of ABq, J_{AB}= 16.5 Hz), 5.82 (1H, d, J = 4.4 Hz), 6.82−6.86 (2H, m), 6.87 (2H, s), 7.12−7.33 (8H, m); ^{13}C NMR ($CDCl_3$) δ 13.4, 14.2, 15.5, 19.8, 20.7, 22.8, 30.0, 42.9, 48.1, 56.7, 77.6, 78.1, 125.8, 127.0, 127.6, 127.8, 128.2, 128.3, 132.0, 133.3, 138.1, 138.5, 140.1, 142.4, 174.9; FAB-MS (*m*-NBA), 552 (MH^+); HR-MS, found 552.2785, calcd for $C_{32}H_{42}NO_5S$ 552.2784. Anal. Calcd for $C_{32}H_{41}NO_5S$: C, 69.66; H, 7.49; N, 2.54. Found: C, 69.84; H, 7.62; N, 2.53.

Typical Procedure for the Syn-Selective Aldol Reaction. To a stirred solution of the ester (1*R*,2*S*)-**1c** (188 mg, 0.4 mmol) in CH_2Cl_2 (4 mL) at −78 °C was added *n*-Bu_2BOTf (1 M in CH_2Cl_2, 0.80 mL, 0.8 mmol), then *i*-Pr_2EtN (0.21 mL, 1.2 mmol). The mixture was stirred for 2 h, then isobutyraldehyde (54 μL, 0.6 mmol) was added. The reaction was stirred at −78 °C for 1 h, then at 0 °C for 1 h. The mixture was quenched by addition of pH 7 buffer and MeOH (1:1, 3 mL), and diluted with MeOH to make a homogeneous solution. After careful addition of 30% H_2O_2 (1.5 mL), the mixture was stirred at room temperature for 14 h and then concentrated. The residue was partitioned between water and CH_2Cl_2 and the aqueous layer was extracted with CH_2Cl_2. The combined organic layers were washed with water and brine. The organic layer was dried over anhydrous $MgSO_4$ and the solvent was removed. The residue was separated by chromatography over silica gel to afford pure *syn*-aldol product **5c** in 98% yield. **5c** viscous oil: $[\alpha]^{20}_D$ −8.50 (*c* 2.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ 0.88 (3H, d, J = 6.7 Hz), 0.99 (3H, d, J = 6.7 Hz), 1.18 (3H, d, J = 7.0 Hz), 1.29 (3H, d, J = 7.0 Hz), 1.69 (9H, m), 2.73 (3H, s), 2.71 (5H, m, overlap), 3.00 (4H, m), 3.64 (1H, dd, J = 3.7 and 7.9 Hz), 4.19 (1H, dq, J = 2.4 and 6.8 Hz), 5.70 (1H, d, J = 2.4 Hz), 7.00 (1H, s), 7.02 (2H, m), 7.22 (3H, m); ^{13}C NMR ($CDCl_3$) δ 10.1, 12.2, 18.8, 19.2, 22.0, 23.4, 27.8, 28.7, 30.5, 30.7, 42.4, 55.5, 76.7, 78.4, 126.2, 128.2, 128.5, 135.2, 135.5, 136.4, 137.8, 137.9, 175.1; FAB-MS (*m*-NBA), 542 (MH^+); HR-MS (EI, M^+), found 541.2861, calcd for $C_{31}H_{43}NO_5S$ 541.2862.

Determination of the Stereoselectivity of the Aldol Reaction of 1 and Isobutyradehyde (Tables 5 and 8). The isomer ratio was determined by chiral HPLC analysis (Daicel, Chiracel OD) of the dibenzoate derivative of the diol, which was obtained by $LiAlH_4$ reduction of the crude mixture of the aldol products. The major isomer of the aldol product was characterized by ^{1}H and ^{13}C NMR of the mixture. See Supporting Information.

Removal of the Chiral Auxiliary and Determination of the Absolute Stereochemistry of the Aldol Product. (2*S*,3*R*)-2,4-Dimethyl-1,3-pentanediol: To a stirred solution of (+)-**4d** (5.51 g, 10 mmol) in THF (100 mL) was added lithium aluminum hydride (0.38 g, 10 mmol) at 0 °C. The reaction mixture was stirred at room temperature for 1 h and was quenched by the careful addition of sodium sulfate decahydrate (5 g). The mixture was stirred vigorously for 30 min and filtered. The filtrate was concentrated and triturated with hexane (100 mL). The auxiliary alcohol **3f** (3.60 g) was recovered by filtration. The residue was separated by chromatography over silica gel (80 g) with hexane and ethyl acetate (3:1 to 1:1) to afford **3f** (0.60 g) and (2*S*,3*R*)-2,4-dimethyl-1,3-pentanediol (1.32 g, ∼100%), $[\alpha]^{23}_D$ 19.6 (*c* 0.57, $CHCl_3$).[24]

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Supporting Information Available: Characterization data of the chiral esters (**1a**,**b**,**d**,**e**,**g**,**h**), synthetic intermediates (**2a**,**c**,**d**, **3a**,**b**,**d**,**e**,**g**,**h**), and aldol products (**4**, **5**), and spectroscopic data of the aldol products of **1** and isobytyraldehyde. This material is available free of charge via the Internet at http://pubs.acs.org.

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(24) Similarly, the absolute stereochemistry of the aldol products was determined by comparison of the optical rotation data of the corresponding diols with the reported value, see: Masamune, S.; Sato, T.; Kim, B.-M.; Wollmann, T. S. *J. Am. Chem. Soc.* **1986**, *108*, 827.