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Resolution of α-hydroxystannanes via norephedrine carbamates

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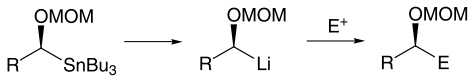
Abstract—Norephedrine carbamate derivatives of α-hydroxystannanes can be readily prepared and the resulting diastereomers are separable by column chromatography. Removal of the carbamate moiety by reduction provides enantiomerically-enriched α-hydroxystannanes.

1. Introduction

α-Alkoxyorganostannanes are useful reagents for organic synthesis.[1–3] For example, they can be converted to the corresponding α-alkoxyorganolithiums which, in turn, can be trapped with a variety of electrophiles. Transmetalation to organocopper reagents[4] as well as Pd/Cu catalyzed couplings[5] can also be performed. In most cases, these transformations occur with complete retention of configuration (Scheme 1). Thus access to α-alkoxystannanes of high enantiomeric purity and known absolute configuration would allow for the preparation of chiral secondary alcohol derivatives.



Scheme 1.

It has previously been reported that enantiomerically enriched α-hydroxystannanes (which are readily converted to α-alkoxystannanes) can be prepared by chromatographic separation of diastereomeric Mosher esters[1b] or menthyloxymethyl acetals.[6] These methods are workable but are limited by the high expense or lack of commercial availability of derivatizing agents used as well as marginal chromatographic separations. Enantiomerically enriched α-alkoxystannanes have also been prepared by enzymatic kinetic resolution,[7] diastereoselective cleavage of chiral stannyl acetals,[8] asymmetric additions of stannyl nucleophiles to aldehydes,[9] and asymmetric reductions of acylstannanes.[10,11] Currently, the asymmetric reduction route is probably the most attractive (at least on paper) since high selectivities can be obtained for a wide variety of substrates. However, the oxidatively unstable acylstannanes are not particularly easy to handle and, more importantly, we[12] and others[1,6b] have observed that reproducibly high selectivities are difficult to achieve, particularly on larger scales. Thus practical routes to enantiomerically enriched α-alkoxystannanes are still required.

2. Results and discussions

We decided to investigate the chromatographic separation of diastereomeric hydroxystannane derivatives for a variety of reasons: (1) as long as some separation could be achieved, high levels of purity should be accessible at the expense of yield; (2) the oily nature of tributylstannyl derivatives renders fractional crystallization next to impossible; (3) both enantiomers of chiral derivatizing agents are often available so the 'correct' isomer can be chosen such that the desired diastereomer will have the higher R_f (and thus be easier to purify). In addition, the non-crystalline nature of tributylstannyl compounds makes it very difficult to enhance the enantiomeric purity of materials with unsatisfactory enantiomeric purity prepared by asymmetric synthesis.

The conversion of α-hydroxystannanes into ester or acetal derivatives is well known but there are few examples of other derivatives.[13] While studying the effects of different protecting groups on the chemistry of α-alkoxytrimethylstannanes, we found that carbamate derivatives could be readily prepared by conversion of hydroxystannanes into mixed carbonates with *p*-nitrophenyl chloroformate followed by treatment with amines (Scheme 2).[14] The use of a 2-phase acetonitrile–hexanes solvent system was critical for obtaining high yields.

Since many chiral amines are commercially available, it seemed that it would be a straightforward matter to screen

Keywords: resolution; α-alkoxystannanes; carbamates.

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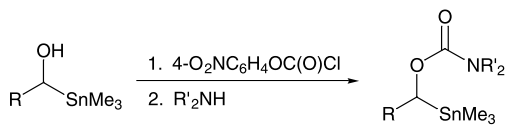
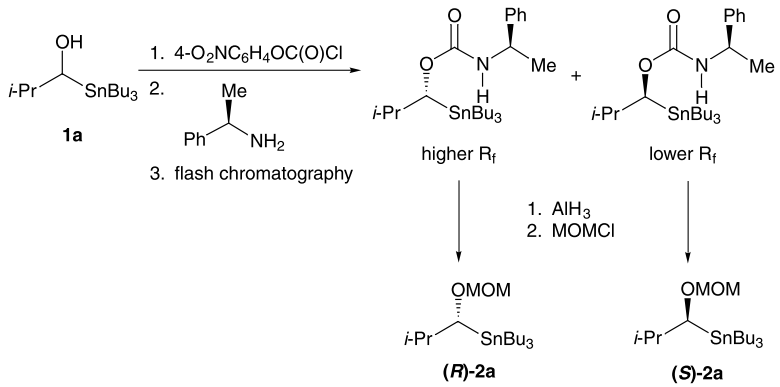


Scheme 2.



Scheme 3.

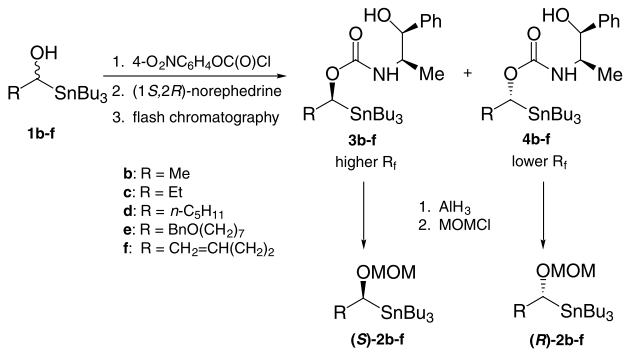
various amines for their ability to form diastereomeric derivatives which could be separated by silica gel chromatography. Initial results using simple amines such as α-methylbenzylamine and 1-(1-naphthyl)ethylamine were encouraging but not brilliantly successful. For example, the carbamates derived from (*R*)-α-methylbenzylamine and hydroxystannane **1a** could be separated by flash chromatography (hexanes/CH_2Cl_2, 1:1) but the yield of pure (>98:2 dr) material was only about 20% with many mixed fractions (Scheme 3): 5 g of mixture provided 0.5 g of each diastereomer of >98:2 dr and re-chromatography of the remaining mixed fractions was necessary to obtain more material. In other words, the separation efficiency left a lot to be desired.

Nonetheless, the carbamates so obtained could be readily converted back to α-hydroxystannane **1a** by reduction with AlH_3[15] and derivatized to the synthetically useful MOM ethers (*R*)-**2a** and (*S*)-**2a** in gram quantities and high (~80–95% from carbamates) overall yields.

With the methodology to carry out the functional group interconversions in hand, we searched for amines that might give better separations. We reasoned that an amine which possessed another functional group such as an alcohol group which could participate in hydrogen bonding might produce carbamates that would show some conformational biases. The diastereomers might then be more likely to show different chromatographic mobilities. Various β-amino alcohols derived from α-amino acids (e.g. phenylglycinol) as well as other commercially available amino alcohols were surveyed. Most promising results were obtained using norephedrine.[16] Norephedrine is particularly appealing as both enantiomers are readily available with good (≥99.9:0.1 er) enantiomeric purity.[17] This is important in a resolution scheme since the enantiomeric purity of the final products is limited by the enantiomeric purity of the chiral reagent used.

When a series of α-hydroxystannanes were transformed into diastereomeric mixtures of *N*-(1*S*,2*R*)-norephedrine carbamates, separation of diastereomers was evident by thin layer chromatography even after only a single elution (compared with three elutions required with α-methylbenzylamine-derived carbamates.) Solvent mixtures using CH_2Cl_2 gave best separations. In most cases, a single pass through a flash chromatography column was sufficient to yield reasonable amounts of diastereomerically enriched compounds (Table 1). The less polar (higher R_f) diastereomer was usually isolated since larger amounts of more nearly pure material could be obtained; in the case of **3/4f**, the fractions containing the more polar diastereomer seemed less contaminated with the other diastereomer. The isolated diastereomer was reduced to the parent α-hydroxystannane,

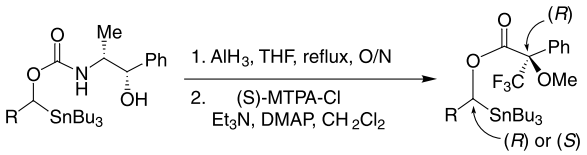
Table 1. Preparation of enantiomerically-enriched α-alkoxystannanes **2** via separation of diastereomeric carbamates **3/4**



R	Yield of **3/4**[a]	**2**		
		Yield[b]	$[\alpha]_D$[c]	er[d] (configuration)
Me	79 (**3b**)	73 (**2b**)	+23.8	95:5 (*S*)
Et	69 (**3c**)	60 (**2c**)	+32.1	97:3 (*S*)
nC_5H_{11}	55 (**3d**)	96 (**2d**)	+28.7	98:2 (*S*)
$BnO(CH_2)_7$	53 (**3e**)	77 (**2e**)	+22.4	98:2 (*S*)
$H_2C{=}CH(CH_2)_2$	61 (**4f**)	66 (**2f**)	−32.5	96:4 (*R*)

[a] Yield of isolated diastereomer after flash chromatography based on 50% content of that diastereomer in the original 1:1 mixture. The less polar diastereomer (**3**) was isolated in most cases.
[b] Isolated yields of MOM ethers from carbamates **3/4**.
[c] Optical rotations measured in $CHCl_3$, c=1.0.
[d] Determined by HPLC measurements on MTPA esters (Table 2). Absolute configurations were assigned by comparison of rotations with previously reported values.

Table 2. Analysis of MTPA esters of α-hydroxystannanes by HPLC



Entry	R	R_t (min)[a]	dr
1	Me	9.01/11.30	95:5
2	Et	8.25/10.50	97:3
3	nC_5H_{11}	7.78/8.98	98:2
4	$BnO(CH_2)_7$	12.39/13.54	98:2
5	$H_2C{=}CH(CH_2)_2$	9.58/11.85	96:4

A 4.6 mm×150 mm 5 μm silica column was used eluting with 20% CH_2Cl_2 in hexanes at 1.0 mL/min.

[a] Retention times of the two diastereomers. In each case, the (*R*,*R*) diastereomer eluted first followed by the (*S*,*R*)-diastereomer.

and a small sample was converted to MTPA esters[18] for analysis while the remainder was converted to a MOM ether.

Analysis of the derived MTPA esters showed that hydroxystannanes of >95:5 er were obtained in each case. The absolute configurations of the hydroxystannanes were assigned by comparison with data previously reported where available. In all the cases examined the configuration of the hydroxystannane derived from the less polar diastereomer using (1*S*,2*R*)-norephedrine had *S* configuration. The MTPA esters prepared also showed a consistent trend: esters prepared from (*R*)-hydroxystannanes and (*S*)-MTPA-Cl always eluted first on silica gel (Table 2). Thus it seems that for simple α-hydroxystannanes, relative mobilities of diastereomeric derivatives are quite predictable. Practically, this means that if an (*S*)-hydroxystannane is required, use of (1*S*,2*R*)-norephedrine will give the desired diastereomer as the higher R_f component; if an (*R*)-hydroxystannane is desired, (1*R*,2*S*)-norephedrine may be used so that the desired diastereomer has the higher R_f.

Since hydroxystannanes of >98:2 er could be obtained, it is unlikely that any appreciable racemization occurs during cleavage of the carbamates. In fact, the enantiomeric purities of the hydroxystannanes were consistent with expectations based on the amounts of minor diastereomeric carbamates present in the pooled column fractions (as estimated by TLC).

All of the hydroxystannanes examined showed separation of diastereomers by TLC. However, in the case of stannane **1a** which has a branched isopropyl group and the *tert*-butyl analogue, good separation could not be achieved by flash chromatography. Thus it seems that branching in the alkyl side chain reduces the mobility difference between the diastereomeric carbamates. This can be rationalized (in hindsight) by suggesting that branching makes the alkyl group more similar to a Bu_3Sn group. However, it should be noted that α-hydroxystannanes with *n*-alkyl groups of various lengths (e.g. **1b**–**1d**) as well as those with functionalized groups (e.g. **1e**, **1f**) all gave diastereomers which were readily separated.

3. Conclusions

In summary, we have shown that racemic α-hydroxystannanes can be transformed into norephedrine carbamates. These carbamates are readily separable by flash chromatography and the individual diastereomers can be reduced with AlH_3 to enantiomerically enriched α-hydroxystannanes. The procedures are operationally simple and can be easily carried out on multigram scales. This protocol for obtaining enantiomerically enriched α-hydroxystannanes compares favorably with existing methods.

4. Experimental

4.1. General

All reactions were carried out under argon using flame-dried glassware. NMR data were recorded on a 300 MHz instrument in $CDCl_3$ unless otherwise noted. THF was distilled from Na/benzophenone. Hexanes, acetonitrile, diisopropylamine, and pyridine were distilled from CaH_2. Reagents were purchased from Aldrich Chemical Co. and used without further purification. Silica gel 60 (40–63 μm) from EM Science was used for flash chromatography.

4.2. General procedure for formation of diastereomeric carbamates (3/4)

(a) *Preparation of p-nitrophenyl carbonates*. To a solution of LDA (3.72 mmol) in THF (20 mL) at 0°C under Ar was added Bu_3SnH (1.0 mL, 3.72 mmol). The reaction was stirred for 15 min at 0°C, then cooled to −78°C. The aldehyde (3.72 mmol) was added neat via syringe, and the reaction was stirred for 45 min at −78°C. The reaction was quenched at −78°C with a saturated aqueous solution of NH_4Cl and allowed to warm to room temperature. Standard aqueous workup with ether and brine provided the crude α-hydroxystannane which was dried in vacuo.[1a]

The crude hydroxystannane was dissolved in 20 mL of 1:1 hexane/CH_3CN and cooled to 0°C. *p*-Nitrophenyl chloroformate (1.13 g, 5.6 mmol) was added to the solution, followed by pyridine (0.90 mL, 11.2 mmol), and the solution stirred for 45 min at rt under Ar. The reaction was quenched by the addition of 15 mL of water, and diluted with 20 mL of acetonitrile and 100 mL of hexanes. The hexanes layer was washed with acetonitrile (2×20 mL), water (20 mL), and brine (20 mL), dried with sodium sulfate, and concentrated under reduced pressure to yield the mixed carbonate as a clear yellowish oil which was used without further purification.

(b) *Preparation of carbamates*. To the crude carbonate in 1:1 hexanes/acetonitrile (20 mL) at 0°C, was added (1*S*,2*R*)-(+)-norephedrine (0.731 g, 4.84 mmol) followed by diisopropylethylamine (1.94 mL, 11.16 mmol). The reaction was allowed to warm to rt overnight. It was quenched by the addition of 15 mL of water, and diluted with 100 mL of hexanes. The hexanes layer was washed with acetonitrile (20 mL), water (20 mL), and brine (2×20 mL), dried with sodium sulfate, and concentrated under reduced pressure to yield a clear yellow oil.

4.3. Purification of diastereomeric carbamates

Polar impurities were removed by filtration through silica gel, using 20% ethyl acetate in hexanes. The crude carbamates (typically obtained in 25–35% overall yield based on starting aldehydes) were then separated using flash chromatography (100 g silica/g crude material, 0.1–0.4% MeOH/CH_2Cl_2). For **3/4b** (R=Me), 0.4%; **3/4c** (R=Et) and **3/4d** (R=*n*-C_5H_{11}), 0.2%; **3/4e** (R=$BnO(CH_2)_7$), 0.3%; and for **3/4f** (R=$H_2C{=}CH(CH_2)_2$), 0.1% MeOH/CH_2Cl_2 was used.

4.3.1. *N*-[(1*S*,2*R*)-1-Hydroxy-1-phenyl-2-propyl] *O*-(*S*)-1-tributylstannylethyl carbamate (3b). $[\alpha]_D$=+50.7 (*c*=1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (5H, m), 4.85–4.68 (3H, m), 4.01 (1H, br s), 3.13 (1H, br s), 1.78–1.21 (12H, m), 1.49 (3H, d, *J*=7.6 Hz), 0.95 (3H, d, *J*=6.9 Hz), 0.91–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 157.6, 140.7, 128.1, 127.5, 126.2, 72.3, 67.3, 52.2, 29.1, 27.4, 20.3, 14.6, 13.7, 9.2; IR (neat) 3435, 1700, 1049 cm^{-1}; MS (ESI) *m*/*z* 536 (M−H+Na, 10), 456 (100), 220 (23). Anal. calcd for $C_{24}H_{43}NO_3Sn$: C, 56.27; H, 8.46; N, 2.73. Found: C, 56.43; H, 8.43; N, 2.86.

4.3.2. *N*-[(1*S*,2*R*)-1-Hydroxy-1-phenyl-2-propyl] *O*-(*S*)-1-tributylstannylpropyl carbamate (3c). $[\alpha]_D$=+48.7 (*c*=1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (5H, m), 4.85 (1H, d, *J*=3.0 Hz), 4.73 (1H, m), 4.66 (1H, dd, *J*=8.1, 6.3 Hz), 4.01 (1H, br s), 3.11 (1H, br s), 1.84 (2H, m), 1.60–1.22 (12H, m), 0.95 (3H, d, *J*=6.9 Hz), 0.93 (3H, t, *J*=7.3 Hz), 0.91–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 157.6, 140.7, 128.2, 127.5, 126.3, 77.2, 73.9, 52.3, 29.1, 27.8, 27.7, 14.7, 13.7, 12.1, 9.5; IR (neat) 3435, 1664, 1045 cm^{-1}; MS (ESI) *m*/*z* 550 (M−H+Na, 87), 470 (100), 293 (40), 219 (34), 159 (96). Anal. calcd for $C_{25}H_{45}NO_3Sn$: C, 57.05; H, 8.62; N, 2.66. Found: C, 57.14; H, 8.51; N, 2.75.

4.3.3. *N*-[(1*S*,2*R*)-1-Hydroxy-1-phenyl-2-propyl] *O*-(*S*)-1-tributylstannylhexyl carbamate (3d). $[\alpha]_D$=+49.2 (*c*=1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (5H, m), 4.83 (1H, br s), 4.72 (2H, m), 4.01 (1H, br s), 3.19 (1H, br s), 2.00–1.2 (20H, m), 0.97 (3H, d, *J*=6.9 Hz), 0.90–0.82 (18H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 157.6, 140.7, 128.1, 127.5, 126.3, 76.8, 72.3, 52.2, 34.5, 31.6, 29.1, 27.5, 22.6, 14.8, 14.1, 13.7, 11.6, 9.5; IR (neat) 3436, 1682, 1072 cm^{-1}; MS (ESI) *m*/*z* 592 (M−H+Na, 98), 464 (60), 218 (100), 178 (57). Anal. calcd for $C_{28}H_{51}NO_3Sn$: C, 59.16; H, 9.04; N, 2.46. Found: C, 59.31; H, 8.93; N, 2.42.

4.3.4. *N*-[(1*S*,2*R*)-1-Hydroxy-1-phenyl-2-propyl] *O*-(*S*)-8-benzyloxy-1-tributylstannyloctyl carbamate (3e). $[\alpha]_D$=+39.8 (*c*=1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (10H, m), 4.83 (1H, d, *J*=3.0 Hz), 4.73 (2H, m), 4.47 (2H, s), 4.01 (1H, br s), 3.43 (2H, t, *J*=6.5 Hz), 1.97–1.20 (24H, m), 0.96 (3H, d, *J*=6.9 Hz), 0.91–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 157.6, 140.9, 138.5, 128.3, 128.1, 127.6, 127.4, 126.2, 77.2, 72.8, 72.1, 70.4, 52.2, 34.5, 29.7, 29.4, 29.2, 29.1, 29.0, 27.5 (^3J=56 Hz), 26.1, 14.6, 13.7, 9.5 (^1J=320 Hz); IR (neat) 3436, 1694, 1073 cm^{-1}; MS (ESI) *m*/*z* 726 (M−H+Na, 100), 218 (21), 179 (23). Anal. calcd for $C_{37}H_{61}NO_4Sn$: C, 63.25; H, 8.75; N, 1.99. Found: C, 63.44; H, 8.54; N, 1.91.

4.3.5. *N*-[(1*S*,2*R*)-1-Hydroxy-1-phenyl-2-propyl] *O*-(*R*)-1-tributylstannyl-4-pentenyl carbamate (4f). $[\alpha]_D$=+13.3 (*c*=1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (5H, m), 5.79 (1H, m), 4.98 (2H, m), 4.83 (1H, br s), 4.76 (1H, m), 4.67 (1H, m), 4.01 (1H, br s), 3.13 (1H, br s), 2.20–1.68 (4H, m), 1.56–1.22 (12H, m), 0.97 (3H, d, *J*=6.9 Hz), 0.90–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 157.6, 140.6, 138.0, 128.1, 127.5, 126.3, 114.8, 77.2, 71.4, 52.2, 33.9, 31.9, 29.1 (^2J=19 Hz), 27.5 (^3J=56 Hz), 14.8, 13.7, 9.6 (^1J=323, 308 Hz); IR (neat) 3435, 1679, 1044, 999 cm^{-1}; MS (ESI) *m*/*z* 576 (M−H+Na, 100), 464 (43). Anal. calcd for $C_{27}H_{47}NO_3Sn$: C, 58.71; H, 8.58; N, 2.54. Found: C, 58.60; H, 8.43; N, 2.54.

4.4. Cleavage of carbamates

To the diastereomerically-enriched carbamate (0.14 mmol) in THF (2 mL) was added AlH_3 (0.4 M in THF, 1.80 mL, 0.72 mmol), and the reaction mixture was stirred overnight at a gentle reflux.[15] The solution was cooled to 0°C and quenched by the addition of solid $Na_2SO_4{\cdot}10H_2O$. The mixture was stirred for 20 min at room temperature, and then solids were filtered off through a pad of Celite, and concentrated under reduced pressure (room temperature water bath) to yield the crude hydroxystannane. A small sample was treated with (*S*)-MTPA-Cl (Et_3N, cat. DMAP, CH_2Cl_2) for analysis of enantiomeric purity while the remainder was converted to its MOM ether using standard conditions (1.5 equiv. MOM-Cl, 2 equiv. *i*Pr_2NEt, CH_2Cl_2, 0°C to rt). Yields and enantiomeric purities are listed in Table 1.

4.4.1. (*S*)-1-Methoxymethoxy-1-tributylstannylethane (*S*)-2b. $[\alpha]_D$=+23.8 (*c*=1.0, $CHCl_3$), lit:[10] $[\alpha]_D$=−32.1 (*c*=1.0, $CHCl_3$) for (*R*)-**2b** with 95:5 er; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.58 (2H, ABq, J_{AB}=6.5 Hz, $\Delta\nu$=35.6 Hz), 4.05 (1H, q, *J*=7.5 Hz), 3.32 (3H, s), 1.47 (3H, d, *J*=7.5 Hz), 1.53–1.22 (12H, m), 0.90–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 95.6, 67.8, 55.2, 29.2, 27.5, 20.4, 13.7, 8.6.

4.4.2. (*S*)-1-Methoxymethoxy-1-tributylstannylpropane (*S*)-2c. $[\alpha]_D$=+32.1 (*c*=1.0, $CHCl_3$), lit:[10] $[\alpha]_D$=−34.5 (*c*=1.0, $CHCl_3$) for (*R*)-**2c** with 98:2 er; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.56 (2H, ABq, J_{AB}=6.5 Hz, $\Delta\nu$=19.1 Hz), 3.97 (1H, t, *J*=6.6 Hz), 3.33 (3H, s), 1.82 (2H, dq, *J*=7.4, 7.1 Hz), 1.53–1.22 (12H, m), 0.94 (3H, t, *J*=7.4 Hz), 0.90–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 96.3, 75.5, 55.4, 29.2, 27.9, 27.5, 13.7, 12.4, 9.1.

4.4.3. (*S*)-1-Methoxymethoxy-1-tributylstannylhexane (*S*)-2d. $[\alpha]_D$=+28.7 (*c*=1.0, $CHCl_3$), lit:[10] $[\alpha]_D$=−31.8 (*c*=1.0, $CHCl_3$) for (*R*)-**2d** with 95:5 er; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.55 (2H, ABq, J_{AB}=6.5 Hz, $\Delta\nu$=17.3 Hz), 4.03 (1H, t, *J*=6.6 Hz), 3.33 (3H, s), 1.77 (2H, dt, *J*=6.1, 7.1 Hz), 1.55–1.21 (18H, m), 0.90–0.83 (18H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 96.3, 74.0, 55.4, 35.1, 31.9, 29.2 (^2J=20 Hz), 27.9, 27.6 (^3J=54 Hz), 22.7, 14.1, 13.7, 9.1 (^1J=303, 290 Hz).

4.4.4. (*S*)-8-Benzyloxy-1-methoxymethoxy-1-tributylstannyl-octane (*S*)-2e. $[\alpha]_D$=+22.4 (*c*=1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 (5H, m), 4.55 (2H, ABq,

J_{AB}=6.5 Hz, $\Delta\nu$=16.7 Hz), 4.48 (2H, s), 4.03 (1H, t, J=6.6 Hz), 3.44 (2H, t, J=6.5 Hz), 3.32 (3H, s), 1.77 (2H, m), 1.63–1.22 (22H, m), 0.90–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 138.7, 128.3, 127.6, 127.4, 96.3, 74.0, 72.8, 70.5, 55.4, 35.1, 29.8, 29.6, 29.5, 29.2, 27.9, 27.5 (^3J=54 Hz), 26.2, 13.7, 9.2 (^1J=303, 290 Hz); IR (neat) 1145, 1099 cm^{-1}; MS (ESI) *m/z* 593 (M−H+Na, 100), 375 (55), 317 (59). Anal. calcd for $C_{29}H_{54}O_3Sn$: C, 61.17; H, 9.56. Found: C, 61.13; H, 9.45.

4.4.5. (*R*)-1-Methoxymethoxy-1-tributylstannyl-4-pentene (*R*)-2f. $[\alpha]_D$=−32.5 (c=1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.82 (1H, ddt, J=6.7, 6.8, 10.3 Hz), 5.00 (1H, dd, J=18.5, 1.4 Hz), 4.94 (1H, dd, J=10.3, 1.4 Hz), 4.55 (2H, ABq, J_{AB}=6.5 Hz, $\Delta\nu$=13.3 Hz), 4.04 (1H, dd, J=7.9, 5.4 Hz), 3.33 (3H, s), 2.12 (2H, m), 1.87 (2H, m), 1.53–1.22 (12H, m), 0.90–0.83 (15H, m); ^{13}C NMR (300 MHz, $CDCl_3$) δ 138.6, 114.6, 96.5, 73.3, 55.5, 34.6, 32.2, 29.2 (^2J=20 Hz), 27.5 (^3J=54 Hz), 13.7, 7.1 (^1J=304, 291 Hz); IR (neat) 1146, 1097 cm^{-1}; MS (ESI) *m/z* 443 (M−H+Na, 100). Anal. calcd for $C_{19}H_{40}O_2Sn$: C, 54.43; H, 9.62. Found: C, 54.31; H, 9.85.

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