Synthesis of Enantiopure Homoallylic Alcohols and Ethers by Diastereoselective Allylation of Aldehydes

Lutz F. Tietze,* Kai Schiemann, Christoph Wegner and Christian Wulff

Abstract: Enantiopure homoallylic alcohols **5**, which are important building blocks in organic synthesis, are obtained with an *ee* of greater than 99% and a yield of 75–95% by cleavage of the secondary homoallylic ethers **4** using sodium in liquid ammonia. The ethers **4** are formed with excellent diastereoselectivity and in 52–89% yield by treatment of the aldehydes **1** with the trimethylsilyl ether of *N*-trifluoroacetylnorpseudoephedrine (**2**) in the presence of a catalytic amount of TMS triflate or TMS borontriflate, followed by addition of allylsilane **3**. Nearly all achiral aliphatic aldehydes employed gave a diastereoselectivity of over 99:1. With the chiral aldehydes **24**, the difference between matched and mismatched pairs was low; this reveals that there is strong reagent control.

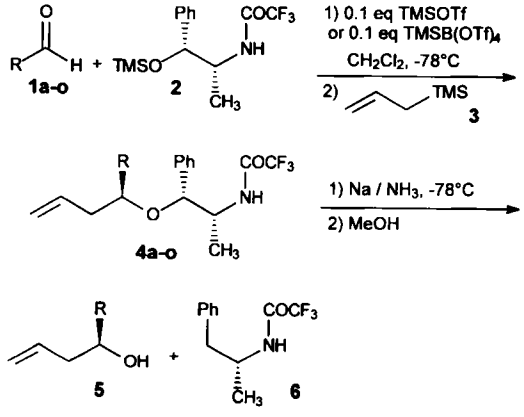
Keywords
allylations · allylsilanes · double stereodifferentiation · ephedrine · homoallylic alcohols

Introduction

Homoallylic alcohols and ethers are important building blocks in organic synthesis. They can readily be obtained by the reaction of aldehydes or acetals with allylmetal compounds.[1] Moreover, several methods have been developed for the formation of these compounds in an enantioenriched or enantiopure form, using equimolar amounts of chiral allyl reagents, such as allylboron[2] and allyltitanium[3] compounds, or chiral acetals.[4] Recently, catalytic methods have also been published.[5] We have shown that aliphatic aldehydes can be transformed highly efficiently into the corresponding enantiomerically and diastereomerically pure homoallylic ethers and the corresponding enantiopure homoallylic alcohols in a domino-type reaction[6] by treatment with the trimethylsilyl ether of *N*-trifluoroacetylnorpseudoephedrine and allylsilane in the presence of catalytic amounts of trimethylsilyl trifluoromethanesulfonate (TMSOTf) (Scheme 1).[7] This procedure gave an asymmetric induction of greater than 99:1 for nearly all examples, making it the most selective reported to date for obtaining homoallylic ethers. The ethers can then be readily transformed into the enantiopure homoallylic alcohols by treatment with Na/NH_3. Recently, we have shown that ketones can also be allylated by this method.[8] In this paper we describe the details of the reaction with achiral aldehydes and the use of chiral aldehydes.

Results and Discussion

Allylation of achiral aliphatic and aromatic aldehydes: Allylation was performed by treating two equivalents of the aldehydes **1a–o** with one equivalent of the trimethylsilyl ether of (1*R*,2*R*)-*N*-trifluoroacetylnorpseudoephedrine (**2**) in the presence of a catalytic amount of trimethylsilyl triflate (Me_3SiOTf, 0.2 equiv) at −78 °C for 1 h. Subsequently, two equivalents of allyltrimethylsilane (**3**) were added and stirring was continued for a few hours. The best results were obtained with aliphatic aldehydes. Thus, the homoallylic ethers **4a–j** were obtained from aldehydes **1a–j** in 52–81% isolated yields and with excellent diastereoselectivities of >99:1 (Table 1). Usually conversion to the ethers **4** was complete within minutes after addition of the allylsilane **3**, and longer reaction times did not normally improve the yield.



Scheme 1. Allylation of aldehydes **1**.

For the transformation, $Me_3SiB(OTf)_4$[9] can also be used instead of TMSOTf. Owing to its higher reactivity the reaction time is even shorter, but there is no improvement in yield and a greater number of by-products are often formed (Scheme 2). The reaction using TMSOTf proceeds quite cleanly; only small amounts of the desilylated auxiliary **2** and the acetal **8** are formed. At higher temperatures the oxazolidine **7** may also

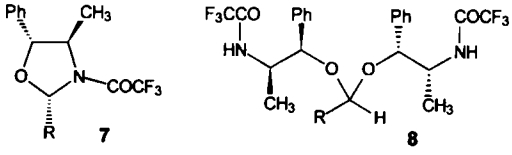
[*] Prof. Dr. Dr. h. c. L. F. Tietze, Dr. K. Schiemann, Dipl.-Chem. C. Wegner, Dipl.-Chem. C. Wulff
Institut für Organische Chemie der Georg-August-Universität Göttingen
Tammannstraße 2, D-37077 Göttingen (Germany)
Fax: Int. code +(551)399-476

0947-6539/96/0209-1164 $ 15.00+.25/0

Table 1. Synthesis of homoallylic ethers **4a–o** from aldehydes **1a–o**.

1	R	Yield 4 [%] [a]	Ratio [b]	$[\alpha]_D^{20}$ [c]	Yield 5 [%]
a	$-CH_3$	52 (66)	>99:1	+1.5	95 [d]
b	$-CH_2CH_3$	73	>99:1	+9.6	94 [d]
c	$-(CH_2)_4CH_3$	71	>99:1	−5.3 [i]	85 [e]
d	$-(CH_2)_5CH_3$	81	>99:1	−4.2 [j]	87 [e]
e	$-(CH_2)_7CH_3$ [f]	68	>98:2 [g]	+7.4	92
f	$-CH(CH_2CH_3)_2$	71	>99:1	−9.7 [i]	88
g	$-C(CH_3)_3$	55 (80)	>99:1	+38.5	82
h	$-C_6H_{11}$	49 (79)	98:2 [h]	−5.3	90
i	$-(CH_2)_2CH=CH_2$ [f]	58	>99:1 [g]	+7.8	
j	$-(CH_2)_4COOCH_3$ [f]	62	>99:1	+5.1	
k	$-CH=CH-C_6H_5$	61	87:13	−133.5	
l	$-CH=CH-(CH_2)_2CH_3$	73	87:13	−40.5	
m	$-C_6H_5$	73	82:18	−108.0	
n	$-p-C_6H_5OCH_3$	80	98:2	−125.4	75
o	$-m-C_6H_5Br$	89	91:9	−101.2	

[a] The yields in parentheses are based on conversion. [b] Ratio of diastereomers determined by GC. [c] $c = 1$ in $CHCl_3$. [d] After transformation into the corresponding Mosher ester. [e] After transformation into the corresponding acetate. [f] The reaction was performed with the (1*S*,2*S*)-norpseudoephedrine derivative *ent*-**2**. [g] Determined by HPLC. [h] The reaction mixture solidifies to form a jelly at −78 °C; it therefore had to be performed at elevated temperature. [i] $c = 0.7$. [j] $c = 0.5$.



Scheme 2. By-products in the allylation of aldehydes **1**.

be found. However, formation is completely suppressed at −100 °C.

Sterically hindered aldehydes, such as the *tert*-butylcarbaldehyde (**1g**), can also be allylated, but the reaction does not always go to completion, even after a prolonged reaction time. However, an excellent selectivity is obtained. Thus, reaction of **1g**, **2** and **3** in the presence of TMSOTf for 24 h at −78 °C gave 55% yield of **4g** with >99:1 diastereoselectivity; the starting material **2** (31% yield) could be recovered.

The norpseudoephedrine derivative **2** seems to be the best auxiliary. Astonishingly, similar norephedrine or ephedrine derivatives gave much lower selectivities. Thus, reaction of the trimethylsilyl ether of (1*S*,2*R*)-*N*-trifluoroacetylnorephedrine afforded the corresponding homoallylic ethers in 25–63% yield and with diastereomeric ratios of between 76:24 and 89:11; the trimethylsilyl ether of (1*S*,2*R*)-*N*-trifluoroacetylephedrine gave yields of 32–34% and selectivities of between 78:22 and 81:19. The selectivity of the allylation was determined to a high degree of accuracy by GC analysis, on a 50 m capillary column, of the crude reaction mixture after filtration over silica.

The transformation of the diastereomerically pure homoallylic ethers **4** into the corresponding enantiopure homoallylic alcohols was achieved by reductive cleavage of the benzyl moiety with four equivalents of sodium in liquid ammonia at −78 °C. In addition to the alcohols **5**, the enantiopure amphetamine **6** was obtained, which could be separated by column chromatography. Reaction of **4a** under these conditions afforded **5a** in 95% isolated yield. The enantiopurities of the homoallylic alcohols **5a** and **5b** were determined by transforming them into the corresponding Mosher esters (Table 1). GC analysis gave a *de* of >99%. It can therefore be concluded that no racemisation took place during deprotection. The transformation in situ of the homoallylic alcohols into the corresponding acetates in quantitative yields was also shown to be possible with the examples of **5c** and **5d** (Table 1).

The absolute configuration of the homoallylic ether **4a** was determined by X-ray crystallographic analysis. In addition, the optical rotation of the homoallylic alcohol **5g** was in agreement with published values.[10] From this data it can be deduced that allylation of the aldehydes **1** using the (*R*,*R*)-norpseudoephedrine derivative **2** occurs from the *Si* face. Conversely, the aldehydes allylated at the *Re* face are obtained with the (*S*,*S*)-norpseudoephedrine derivative *ent*-**2**.

Aromatic aldehydes and α,β-unsaturated aldehydes can also be transformed into the corresponding homoallylic ethers. However, the selectivity is significantly lower. Thus, reaction of *p*-methoxybenzaldehyde (**1n**) led to the homoallylic ether **4n** in 80% yield and with a diastereoselectivity of 98:2. The diastereoselectivity of the formation of the homoallylic ethers **4o** and **4m** from *m*-bromobenzaldehyde (**1o**) and benzaldehyde (**1m**), respectively, was even lower (91:9 and 82:18, respectively; Table 1). Similar results were obtained with α,β-unsaturated aldehydes, such as **1k** and **1l** (diastereoselectivities of 87:13 for **4k** and **4l**). Interestingly, aldehydes bearing nonconjugated phenyl groups or double bonds were allylated with excellent diastereoselectivities.

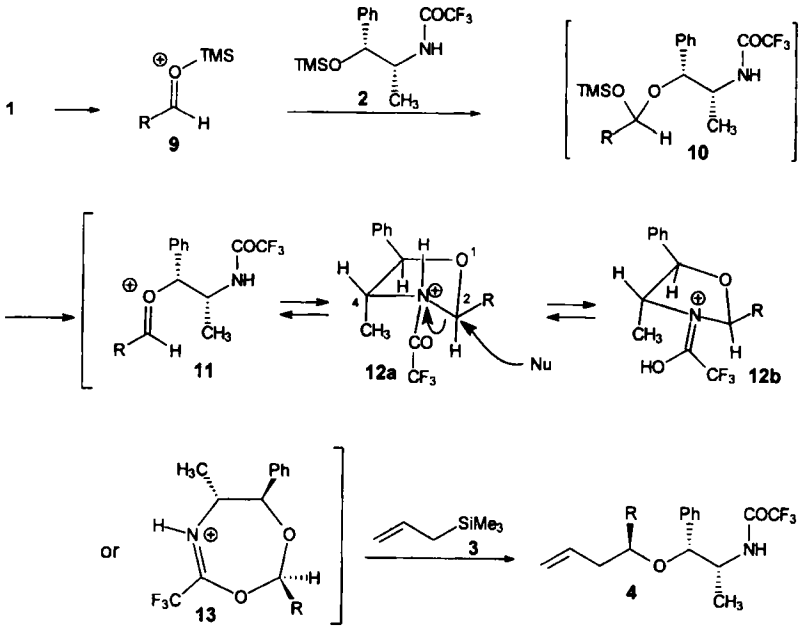
Structure elucidation of the homoallylic ethers and homoallylic alcohols: The ^1H NMR spectra of the homoallylic ethers **4** and homoallylic alcohols **5** could readily be assigned. This is illustrated with the examples of **4a** and **5a**. The hydrogens in the vinyl groups of **4a** resonate at $\delta = 4.98–5.10$ and 5.63–5.85 as multiplets. A sextet is observed for the hydrogen at the newly formed stereogenic centre at $\delta = 3.48$ with $J = 6$ Hz, whereas 1′-H resonates at $\delta = 4.43$ as a doublet with $J = 3.5$ Hz and 2′-H at $\delta = 4.02–4.20$ as a multiplet. The signals for the phenyl group are at $\delta = 7.20–7.40$, and that for the NH group is at $\delta = 6.63$ as a doublet with $J = 7.5$ Hz. The two diastereotopic protons at C-3 resonate at $\delta = 2.23$ as a multiplet. In the ^1H NMR spectrum of the Mosher ester of **5a** the signals for the ephedrine moiety are missing, and 1-H resonates at $\delta = 5.64–5.88$ as a multiplet.

As expected, the absolute configuration of the newly formed stereogenic centres in the homoallylic ethers could not be determined by NMR spectroscopy. For this purpose an X-ray crystallographic analysis was carried out on the homoallylic ether **4a**.

Mechanistic considerations for the allylation of aldehydes: The excellent diastereoselectivity in the allylation of the aldehydes **1** and **24** (see below) using **2** or *ent*-**2** is somewhat surprising, since the stereocontrol, which is nearly 100%, takes place in an acyclic system and chelation does not occur. We assume that in the first step an oxonium ion **9** is formed by reaction of **1** with TMS triflate or TMS borontriflate, which gives the mixed acetal **10** on reaction with the trimethylsilyl ether **2** (Scheme 3).[11] The oxazolidinium ion **12a** is formed, presumably in a kinetically controlled reaction, either via a second oxonium ion **11** or by direct substitution. Compound **12a** might be undergoing proton transfer to give **12b**, but this assumption is not essential to explain the outcome of the reaction. The dioxazepane derivative **13** cannot be excluded as an alternative intermediate to **12a**, which could be formed by nucleophilic attack of the oxygen in the amide group at the oxonium ion in **11** or at the acetal in **10**; however, so far we have no evidence for the existence of **13**.

The final irreversible step in the proposed mechanism via **12a** is the opening of its oxazolidine ring in an S_N2-type attack of the allylsilane to give the ether **4** with inversion of the configura-

  0947-6539/96/0209-1165 $ 15.00+.25/0



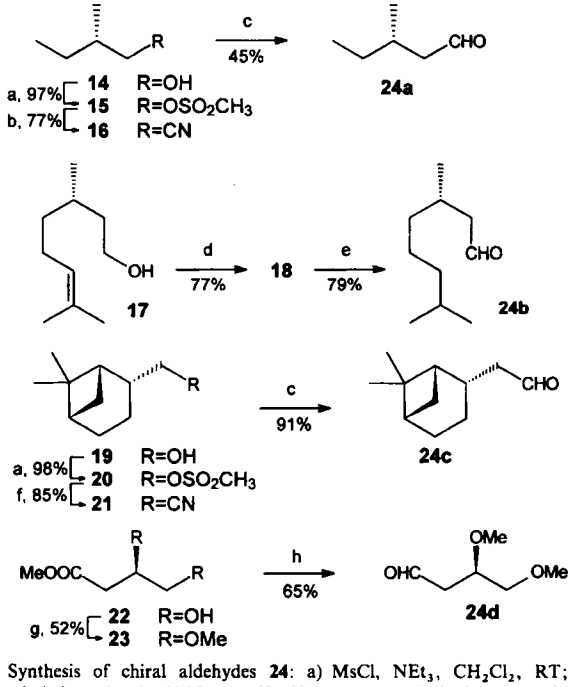
Scheme 3. Proposed mechanism of allylation of aldehydes 1.

tion.[12] This is in agreement with the observed absolute configuration of the newly formed stereogenic centre. Direct attack of the allylsilane at the mixed acetal **10**, though possible, would not explain the observed stereoselectivity. In addition, the formation of the by-product **7** is a good indication for the intermediacy of **12a** or **12b**.

The better selectivity obtained with the norpseudoephedrine derivative **2** compared to the norephedrine and ephedrine auxiliaries can be explained in the following way: In the proposed intermediate **12**, obtained from **2**, the methyl group at C-4 and the alkyl group at C-2 are in an *anti* orientation, which is the most stable arrangement; the other diastereomer, with an α-oriented alkyl group at C-2, should be highly disfavoured owing to 1,3-diaxial repulsion. In the norephedrine and ephedrine derivatives, the methyl group at C-4 is β-oriented, and a preference for one diastereomer therefore does not exist. This again is a good indication for the existence of the intermediate **12**. However, surprisingly, reaction of **7** in the presence of a strong acid, such as trifluoromethanesulfonic acid, and allylsilane does not lead to the homoallylic ethers **4**. We assume that under these conditions protonation does not take place at the nitrogen or oxygen in the trifluoroacetamide group, but at the ring oxygen; the opening of the N,O-acetal moiety is thus blocked.

The lower selectivity observed for the allylation of α,β-unsaturated or aromatic aldehydes can be explained by stabilisation of the oxonium ion **11**, which in its most stable conformation should also allow an attack at the *Si* face, although the stereocontrol would be much less pronounced. However, this model does not agree with the experimental observation that the reaction of *p*-methoxybenzaldehyde shows a higher diastereoselectivity than that of benzaldehyde itself, since the formation of an oxonium ion **11** should be more favoured in the former.

Allylation of chiral aldehydes: A major problem in the stereoselective allylation of chiral aldehydes is the formation of matched and mismatched pairs.[13] Usually only one of the two possible diastereomers can be obtained with high selectivity. It was therefore of great interest to determine the degree of reagent and substrate control in the newly developed method of allylation. For this purpose, the four enantiopure aldehydes **24a–d**, containing a stereogenic centre in the β-position, were synthesised (Scheme 4). Compounds **24a–d** and the commercially available aldehyde **24e** were then treated with **2** and **3** in the presence of TMS borontriflate (Scheme 5). Aldehydes with a stereogenic centre and a hydrogen atom in the α-position could not be used, since they racemise under the reaction conditions. The aldehyde **24a**[14] was obtained from the commercially available (*S*)-2-methylbutanol (**14**) in an overall yield of 34% by formation of the methanesulfonate, followed by nucleophilic substitution with cyanide and reduction with DIBAH (diisobutylaluminium hydride). For the synthesis of **24b**, (*S*)-citronellol was hydrogenated and oxidised. This procedure was chosen rather than the hydrogenation of natural citronellal,[15] since citronellol can be purchased with a higher enantiopurity. Homomyrtanal **24c**, containing three stereogenic centres, was prepared in 75% overall yield by a similiar procedure to that described for **24a**. Finally, the aldehyde **24d**, containing a methoxy group at the stereogenic centre in the 3-position, was obtained from methyl (*R*)-3,4-dihydroxybutanoate (**22**) in 34% overall yield by bismethylation of the hydroxyl groups, reduction and oxidation. The methylation of **22** was plagued by side reactions. Hoffmann et al. have shown that an excess of diazomethane in the presence of silica can be used;[16] the silica must be base-deacti-

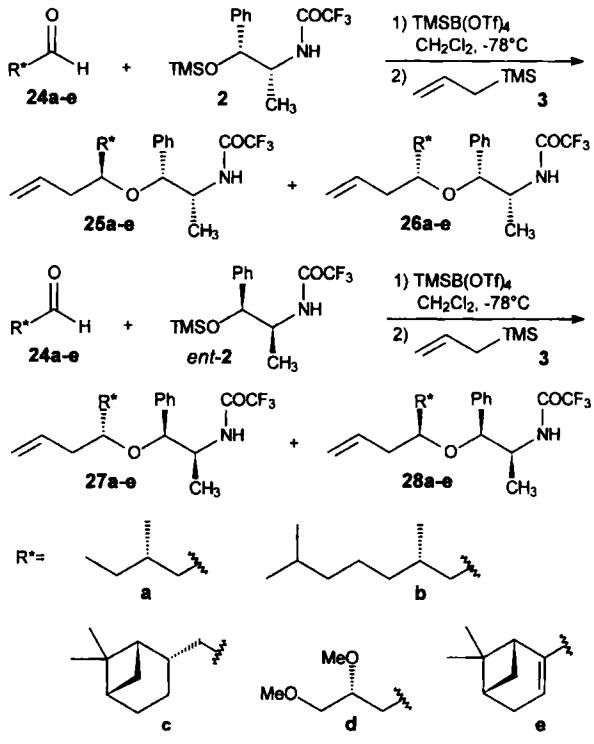


Scheme 4. Synthesis of chiral aldehydes **24**: a) MsCl, NEt_3, CH_2Cl_2, RT; b) NaCN, triethylene glycol, 150 °C; c) DIBAH, pentane, −78 °C; d) H_2, Pd/C; e) DMSO, $(COCl)_2$, NEt_3; f) NaCN, DMSO, 100 °C; g) $Me_3O^+BF_4^-$, proton sponge, RT; h) 1. $LiAl_4$, Et_2O, 2. $(COCl)_2$, DMSO, NEt_3.

vated to avoid a fast decomposition of the diazomethane resulting in low yields. We developed an alternative, less dangerous and toxic procedure, involving the methylation of **22** with trimethyloxonium tetrafluoroborate in the presence of 1,8-bis(dimethylamino)naphthalene in dichloromethane at room temperature, which afforded the dimethyl ether **23** in 52% yield.

0947-6539/96/0209-1166 $ 15.00+.25/0 Chem. Eur. J. 1996, 2, No. 9

For the examination of the double asymmetric stereodifferentiation, the enantiomerically pure aldehydes **24a–e** were first allylated in the presence of (*R,R*)-norpseudoephedrine **2** to give the homoallylic ethers **25a–e** and **26a–e** and then in the presence of the (*S,S*) derivative *ent*-**2** to give the homoallylic ethers **27a–e** and **28a–e** (Scheme 5). The diastereoselectivity of the



Scheme 5. Allylation of the chiral aldehydes **24**.

reaction of the matched pairs, **24a–d** and **2**, ranged from over 99:1 to 97:3 (Table 2). Astonishingly, the mismatched pairs, **24a–d** and *ent*-**2**, also reacted with good selectivities of 96:4 to 89:11; the lowest value was found for the allylation of **24d**. This clearly shows that there is strong reagent control with the norpseudoephedrine moiety, even stronger than the best result previously reported for **24d**—though only slightly (89:11 versus 87:13[116]). As expected, the reaction of the α,β-unsaturated aldehyde **24e** showed lower selectivities of 92:8 for the matched pair (*ent*-**2**) and 88:12 for the mismatched pair (**2**).

Table 2. Synthesis of the homoallylic ethers **25a–e/26a–e** and **27a–e/28a–e** from the chiral aldehydes **24a–e**.

Aldehyde	Reagent	Product	Ratio [a]	$[\alpha]_D^{20}$ [b]	Yield/% [c]
24a	**2**	**25a/26a**	99:1	+18.8	65 (88)
24a	*ent*-**2**	**27a/28a**	93:7	+1.6	71 (86)
24b	**2**	**25b/26b**	97:3	+13.0	48 (84)
24b	*ent*-**2**	**27b/28b**	92:8	+6.0	54 (82)
24c	**2**	**25c/26c**	98:2	−20.0	50 (94)
24c	*ent*-**2**	**27c/28c**	96:4	−14.0	49 (79)
24d	**2**	**25d/26d**	>99:1	−31.0	55 (83)
24d	*ent*-**2**	**27d/28d**	89:11	+18.2	35 (53) [d]
24e	**2**	**25e/26e**	88:12	−53.0	96
24e	*ent*-**2**	**27e/28e**	92:8	+24.8	95

[a] Determination by GC. [b] $c = 0.5$ in $CHCl_3$. [c] Yields in parentheses take into account nonconverted starting material. [d] A by-product was formed in 21% yield.

It should be mentioned that β-alkoxy aldehydes can undergo elimination under the reaction conditions used. Thus, in the allylation of **24d** using *ent*-**2** to give the homoallylic ether **27d**, 4-methoxy-2-butenal was formed in situ and subsequently allylated to form the corresponding homoallylic ether as a by-product in 21% yield. However, the amount of elimination product depends on the reaction conditions used, and especially on the catalyst. When a a new batch of TMS borontriflate was used in the allylation of **24d** with **2**, formation of the unsaturated aldehyde was not observed.

Conclusion

The allylation of aldehydes with the norpseudoephedrine derivatives **2** or *ent*-**2** and allylsilane is a very powerful method—the most selective reported to date—for the synthesis of enantiopure homoallylic ethers and alcohols: for nearly all aliphatic aldehydes the diastereoselectivity was over 99:1. Another remarkable feature of our method is the strong reagent control, which allows both possible diastereomers to be synthesised from chiral aldehydes with a stereogenic centre at C-3 with excellent to good selectivities, even in the cases of mismatched pairs. However, for the allylation of aromatic and α,β-unsaturated aldehydes other methods may give better results. The high stereoselectivity is explained in terms of the formation of an oxazolidinium intermediate, which undergoes ring opening in an S_N2-type attack by allylsilane with inversion of configuration.

Experimental Section

General Aspects: All reactions were performed in oven-dried glassware under an atmosphere of nitrogen unless otherwise stated. Melting points were determined on a Mettler FP61 and are uncorrected. Optical rotations were measured on a Perkin-Elmer 241 digital polarimeter in a 1 dm cell. IR spectra were recorded on a Bruker IFS 25 FT-IR instrument, and ^1H and ^{13}C NMR spectra with a Bruker AM-300 and a Varian VXR-200. Chemical shifts were reported on the δ scale relative to $CDCl_3$ as internal standard. Mass spectra were measured at 70 eV with a Varian MAT311A. GC analysis was carried out with hydrogen as carrier gas on a DB1701 column (J & W Scientific, 0.25 mm × 50 m). HPLC analysis was carried out on Nucleosil 5C18 (250 mm, 5 μm). TLC chromatography was performed on precoated silica gel SILG/UV_{254} plates (Macherey, Nagel & Co.), and silica gel 32–63 (0.032–0.064 mm) (Macherey, Nagel & Co.) was used for column chromatography. Microanalyses were carried out by the Mikroanalytisches Labor des Instituts für Organische Chemie der Universität Göttingen.

(1*R*,2*R*)- and (1*S*,2*S*)-2-(trifluoroacetylamido)-1-trimethylsiloxy-1-phenylpropane (**2** and *ent*-**2**, respectively): To a solution of triethylamine (4.15 g, 5.72 mL, 41.0 mmol, 1.10 equiv) and (1*R*,2*R*)- or (1*S*,2*S*)-norpseudoephedrine hydrochloride (7.00 g, 37.3 mmol), respectively, in MeOH (25 mL) was added at 0 °C with stirring ethyl trifluoroacetate (6.37 g, 5.33 mL, 44.8 mmol, 1.20 equiv), and stirring was continued for 18 h at room temperature. After removal of the solvent in vacuo the residue was dissolved in CH_2Cl_2 (150 mL), and chlorotrimethylsilane (4.87 g, 44.8 mmol, 1.20 equiv) and triethylamine (9.44 g, 93.3 mmol, 1.10 equiv) were added at 0 °C. The mixture was stirred for 4 h at room temperature. Washing with ice water (50 mL), drying over Na_2SO_4, and removal of the solvent at 50 °C/20 mbar provided crude **2** and *ent*-**2**, respectively, which were distilled at 0.05 mbar to give 11.5 g (35.9 mmol, 97%) of a colourless solid. B.p. 110 °C (0.05 mbar); **2**: $[\alpha]_D^{20} = -15.3$ ($c = 1$, MeOH); *ent*-**2**: +15.3 ($c = 1$, MeOH); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 0.08$ (s, 9H), 1.27 (d, $J = 7.0$ Hz, 3H), 4.04–4.24 (m, 1H), 4.72 (d, $J = 3.5$ Hz, 1H), 6.52 (d, $J = 8.0$ Hz, 1H), 7.20–7.39 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = -0.09$, 17.69, 52.27, 76.08, 115.86 (q, $^1J_{CF} = 288$ Hz), 125.81, 127.92, 128.34, 141.02, 156.51 (q, $^2J_{CF} = 36$ Hz). IR (KBr): $\tilde{\nu} = 3430\ cm^{-1}$, 3074, 2962, 1732, 1564, 1254, 1178, 874, 754, 700; MS (70 eV, EI): *m/z* (%): 319 (0.5) [M^+], 304 (2) [$M^+ - CH_3$], 179 (100) [$C_{10}H_{17}OSi^+$], 73 (82) [$C_3H_9Si^+$]; $C_{14}H_{20}F_3NO_2Si$ (319.4): calcd C 52.65, H 6.31; **2**: found C 52.74, H 6.21; *ent*-**2**: found C 52.75, H 6.22.

General procedure 1—preparation of homoallylethers: TMSOTf (0.2 mmol) was added at −78 °C with stirring to a solution of aldehyde **1a–o** (2 mmol) or **24a–e** (2 mmol) and **2** or *ent*-**2** (1 mmol) in CH_2Cl_2 (4 mL). Stirring was continued for 1 h at −78 °C. Cooled allylsilane (2 mmol) was then added and the solution stirred for

48 h. After the reaction had been quenched with triethylamine (160 μL), the mixture was poured into water (10 mL) and the aqueous phase extracted with CH_2Cl_2 (2 × 10 mL). The combined organic phases were dried over Na_2SO_4 and concentrated in vacuo. Purification of the residue by column chromatography on silica gel gave the homoallylethers **4a–o**, **25a–e** and **27a–e**, respectively. In an identical procedure a 0.4 M TMS borontriflate solution (250 μL) in CH_2Cl_2 instead of TMSOTf, was used. Recent results indicate that the use of TMSOTf for the reaction is preferable. However, the TMSOTf should be free of TfOH.

(4*R*,1′*R*,2′*R*)-4-(2′-Trifluoroacetamido-1′-phenylpropoxy)pent-1-ene (4a): According to general procedure 1, reaction of aldehyde **1a** (176 mg, 230 μL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4a** (328 mg, 1.04 mmol, 52%) as colourless needles; 134 mg of **2** were recovered (0.420 mmol, 21%). M.p. 60.2 °C; $[\alpha]_D^{20} = +1.5$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 1.14$ (d, $J = 7$ Hz, 3H), 1.29 (d, $J = 7.0$ Hz, 3H), 2.13–2.34 (m, 2H), 3.48 (sext, $J = 6$ Hz, 1H), 4.02–4.20 (m, 1H), 4.43 (d, $J = 3.5$ Hz, 1H), 4.98–5.10 (m, 2H), 5.63–5.85 (m, 1H), 6.63 (d, $J = 7.5$ Hz, 1H), 7.20–7.40 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.67$, 18.37, 41.89, 51.64, 72.10, 79.38, 115.8 (q, $^1J_{CF} = 286$ Hz), 117.2, 126.8, 128.3, 128.5, 134.7, 138.8, 156.4 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3412$ cm^{-1}, 3304, 3112, 3084, 3032, 2976, 2928, 2886, 1724, 1702, 1568, 1214, 1186, 1162, 1084, 912, 762, 724, 702; MS (70 eV, EI): *m/z* (%): 230 (36), 175 (40), 160 (2), 131 (58), 117 (42), 107 (100), 69 (93), 41 (54); $C_{16}H_{20}F_3NO_2$ (315.3): calcd C 60.94, H 6.39; found C 60.85, H 6.31.

(4*R*,1′*R*,2′*R*)-4-(2′-Trifluoroacetamido-1′-phenylpropoxy)hex-1-ene (4b): According to general procedure 1, reaction of aldehyde **1b** (232 mg, 0.290 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4b** (480 mg, 1.46 mmol, 73%) as colourless needles. M.p. 70.6 °C; $[\alpha]_D^{20} = +9.6$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.82$ (t, $J = 7.0$ Hz, 3H), 1.21 (d, $J = 7.0$ Hz, 3H), 1.42–1.58 (m, 2H), 2.13 (t, $J = 6.0$ Hz, 2H), 3.28 (quint, $J = 5.5$ Hz, 1H), 3.95–4.13 (m, 1H), 4.36 (d, $J = 3.5$ Hz, 1H), 4.89–5.01 (m, 2H), 5.54–5.76 (m, 1H), 6.59 (d, $J = 7.5$ Hz, 1H), 7.14–7.32 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 8.565$, 17.63, 24.45, 38.12, 51.63, 77.00, 79.71, 115.8 (q, $^1J_{CF} = 286$ Hz), 117.0, 126.9, 128.2, 128.4, 134.9, 138.8, 156.4 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3430$ cm^{-1}, 3300, 3110, 3080, 3030, 2966, 2930, 2880, 1722, 1700, 1566, 1210, 1184, 1164, 1090, 1062, 914, 760, 722, 702; MS (70 eV, EI): *m/z* (%): 230 (51), 160 (12), 131 (38), 117 (58), 107 (100), 83 (36), 41 (36); $C_{17}H_{22}F_3NO_2$ (329.4): calcd C 61.99, H 6.73; found C 62.17, H 6.79.

(4*R*,1′*R*,2′*R*)-4-(2′-Trifluoroacetamido-1′-phenylpropyl)non-1-ene (4c): According to general procedure 1, reaction of aldehyde **1c** (401 mg, 0.490 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4c** (527 mg, 1.42 mmol, 71%) as colourless needles. M.p. 60.0 °C; $[\alpha]_D^{20} = -5.3$ ($c = 0.7$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.89$ (t, $J = 6.5$ Hz, 3H), 1.18–1.40 (m, 6H), 1.28 (d, $J = 7.0$ Hz, 3H), 1.41–1.62 (m, 2H), 2.20 (dd, $J_1 = 7.0$ Hz, $J_2 = 6.0$ Hz, 2H), 3.38 (quint, $J = 6.0$ Hz, 1H), 4.04–4.20 (m, 1H), 4.43 (d, $J = 3.5$ Hz, 1H), 5.02 (d, $J = 16$ Hz, 1H), 5.04 (d, $J = 10$ Hz, 1H), 5.59–5.83 (m, 1H), 6.64 (d, $J = 7.5$ Hz, 1H), 7.20–7.42 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 13.96$, 17.58, 22.54, 24.20, 32.01, 32.06, 38.76, 51.61, 76.49, 79.87, 115.9 (q, $^1J_{CF} = 287$ Hz), 116.9, 126.8, 128.2, 128.4, 134.9, 138.9, 156.5 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3426$ cm^{-1}, 3312, 3106, 3080, 3034, 2956, 2934, 2870, 1720, 1700, 1564, 1208, 1182, 1170, 1076, 1058, 910, 764, 726, 702; MS (70 eV, EI): *m/z* (%): 230 (89), 160 (10), 131 (35), 117 (73), 107 (100), 83 (32), 69 (51), 41 (20); $C_{20}H_{28}F_3NO_2$ (371.4): calcd C 64.67, H 7.59; found C 64.73, H 7.53.

(4*R*,1′*R*,2′*R*)-4-(2′-Trifluoroacetamido-1′-phenylpropyl)dec-1-ene (4d): According to general procedure 1, reaction of aldehyde **1d** (457 mg, 0.560 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4d** (625 mg, 1.62 mmol, 81%) as colourless needles. M.p. 34.3 °C; $[\alpha]_D^{20} = -4.2$ ($c = 0.5$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.90$ (t, $J = 6.5$ Hz, 3H), 1.20–1.41 (m, 8H), 1.28 (d, $J = 7.0$ Hz, 3H), 1.46–1.62 (m, 2H), 2.21 (dd, $J_1 = 7.0$ Hz, $J_2 = 6.0$ Hz, 2H), 3.40 (quint, $J = 6.0$ Hz, 1H), 4.04–4.22 (m, 1H), 4.45 (d, $J = 3.5$ Hz, 1H), 5.05 (d, $J = 16$ Hz, 1H), 5.06 (d, $J = 10$ Hz, 1H), 5.63–5.86 (m, 1H), 6.67 (d, $J = 7.5$ Hz, 1H), 7.24–7.42 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 14.08$, 17.63, 22.63, 24.56, 29.57, 31.80, 32.19, 38.84, 51.68, 76.57, 79.97, 115.9 (q, $^1J_{CF} = 287$ Hz), 117.0, 127.0, 128.3, 128.5, 134.9, 139.0, 156.5 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3312$ cm^{-1}, 3080, 3036, 2956, 2852, 1720, 1698, 1564, 1208, 1178, 1164, 1068, 902, 754, 700; MS (70 eV, EI): *m/z* (%): 230 (83), 160 (22), 131 (31), 117 (62), 107 (100), 97 (14), 83 (35), 69 (21), 41 (22); $C_{21}H_{30}F_3NO_2$ (385.5): calcd C 65.43, H 7.84; found C 65.59, H 7.75.

(4*S*,1′*S*,2′*S*)-4-(2′-Trifluoroacetamido-1′-phenylpropoxy)dodec-1-ene (*ent*-4e): According to general procedure 1, reaction of aldehyde **1e** (568 mg, 0.680 mL, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **4e** (562 mg, 1.36 mmol, 68%) as colourless needles. M.p. 30.8 °C; $[\alpha]_D^{20} = -7.4$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.90$ (t, $J = 6.5$ Hz, 3H), 1.15–1.40 (m, 15H), 1.44–1.61 (m, 2H), 2.19 (t, $J = 6.0$ Hz, 2H), 3.48 (quint, $J = 6.0$ Hz, 1H), 4.11 (m_c, 1H), 4.42 (d, $J = 4.0$ Hz, 1H), 4.94–5.08 (m, 2H), 5.71 (m_c, 1H), 6.62 (d, $J = 7.5$ Hz, 1H), 7.20–7.41 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 14.12$, 17.66, 22.70, 24.65, 29.29, 29.56, 29.91, 31.90, 32.23, 38.86, 51.70, 76.61, 80.00, 115.9 (q, $^1J_{CF} = 285$ Hz), 117.1, 127.0, 128.3, 128.5, 134.9, 139.0, 156.5 (q, $^2J_{CF} = 35$ Hz); IR (film): $\tilde{\nu} = 3428$ cm^{-1}, 3312, 3078, 3032, 2930, 2858, 1706, 1558, 1456, 1208, 1178, 1166, 914, 760, 726, 702; MS (70 eV, EI): *m/z* (%): 304 (2), 258 (16), 230 (76), 179 (100), 117 (19), 107 (56), 73 (66); $C_{23}H_{34}F_3NO_2$ (413.5): calcd C 66.80, H 8.29; found C 66.68, H 8.09.

(4*S*,1′*R*,2′*R*)-5-Ethyl-4-(2′-trifluoroacetamido-1′-phenylpropoxy)hept-1-ene (4f): According to general procedure 1, reaction of aldehyde **1f** (401 mg, 0.490 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4f** (530 mg, 1.42 mmol, 71%) as colourless needles. M.p. 75.8 °C; $[\alpha]_D^{20} = -9.7$ ($c = 0.7$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.79$ (t, $J = 7.0$ Hz, 3H), 0.96 (t, $J = 7.0$ Hz, 3H), 1.04–1.70 (m, 5H), 1.26 (d, $J = 7.0$ Hz, 3H), 2.11 (t, $J = 6.0$ Hz, 2H), 3.40 (td, $J_1 = 6.0$ Hz, $J_2 = 3.0$ Hz, 1H), 4.02–4.20 (m, 1H), 4.41 (d, $J = 3.5$ Hz, 1H), 4.98 (d, $J = 16$ Hz, 1H), 5.00 (d, $J = 11$ Hz, 1H), 5.54–5.76 (m, 1H), 6.68 (d, $J = 7.5$ Hz, 1H), 7.20–7.39 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 12.38$, 12.58, 17.62, 21.95, 22.65, 34.97, 42.86, 51.56, 78.01, 79.81, 115.9 (q, $^1J_{CF} = 287$ Hz), 116.6, 127.2, 128.3, 128.4, 136.2, 138.7, 156.4 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3428$ cm^{-1}, 3318, 3088, 3032, 2964, 2934, 2878, 1720, 1700, 1562, 1210, 1184, 1164, 1080, 910, 764, 726, 702; MS (70 eV, EI): *m/z* (%): 230 (83), 160 (6), 131 (37), 117 (90), 107 (87), 83 (80), 69 (100), 41 (52); $C_{20}H_{28}F_3NO_2$ (371.4): calcd C 64.67, H 7.60; found C 64.69, H 7.71.

(4*S*,1′*R*,2′*R*)-5,5-Dimethyl-4-(2′-trifluoroacetamido-1′-phenylpropoxy)hex-1-ene (4g): According to general procedure 1, reaction of aldehyde **1g** (345 mg, 0.430 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4g** (393 mg, 1.10 mmol, 55%) as colourless needles; 198 mg of **2** were recovered (0.620 mmol, 31%). M.p. 57.0 °C; $[\alpha]_D^{20} = +38.5$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.98$ (s, 9H), 1.23 (d, $J = 7.0$ Hz, 3H), 1.95–2.32 (m, 2H), 3.22 (t, $J = 6.0$ Hz, 1H), 4.11–4.31 (m, 1H), 4.47 (d, $J = 3.5$ Hz, 1H), 4.67–4.83 (m, 2H), 5.54–5.67 (m, 1H), 6.49 (d, $J = 7.5$ Hz, 1H), 7.19–7.39 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 16.81$, 26.81, 36.04, 36.58, 50.95, 82.36, 87.43, 115.8, 115.8 (q, $^1J_{CF} = 286$ Hz), 127.4, 128.1, 128.3, 136.9, 139.3, 156.4 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3400$ cm^{-1}, 3310, 3104, 3070, 3030, 2958, 2912, 2878, 1720, 1702, 1564, 1208, 1182, 1164, 1090, 1078, 914, 766, 724, 704; MS (70 eV, EI): *m/z* (%): 316 (1), 230 (100), 217 (14), 131 (29), 117 (50), 111 (38), 107 (27), 69 (53), 41 (32). $C_{17}H_{22}F_3NO_2$ (357.4): calcd C 63.85, H 7.33; found C 63.99, H 7.30.

(4*S*,1′*R*,2′*R*)-4-Cyclohexyl-(2′-trifluoroacetamido-1′-phenylpropoxy)but-1-ene (4h): According to general procedure 1, reaction of aldehyde **1h** (449 mg, 0.480 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4g** (375 mg, 0.98 mmol, 49%) as colourless needles, 243 mg of **2** were recovered (0.760 mmol, 38%). M.p. 73.2 °C; $[\alpha]_D^{20} = -5.3$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.93$–1.36 (m, 6H), 1.29 (d, $J = 7.0$ Hz, 3H), 1.51–1.87 (m, 5H), 2.12 (dd, $J_1 = 7.0$ Hz, $J_2 = 6.0$ Hz, 2H), 3.40 (td, $J_1 = 6.0$ Hz, $J_2 = 3.5$ Hz, 1H), 4.04–4.22 (m, 1H), 4.45 (d, $J = 3.5$ Hz, 1H), 4.98 (d, $J = 16$ Hz, 1H), 5.00 (d, $J = 10$ Hz, 1H), 5.60–5.80 (m, 1H), 6.68 (d, $J = 7.5$ Hz, 1H), 7.24–7.42 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.55$, 26.39, 26.49, 26.65, 27.97, 28.71, 35.48, 39.82, 51.60, 80.37, 81.14, 115.9 (q, $^1J_{CF} = 287$ Hz), 116.6, 127.2, 128.2, 128.3, 135.7, 138.9, 156.5 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3332$ cm^{-1}, 3070, 3032, 2928, 2856, 1692, 1640, 1554, 1184, 1062, 910, 762, 702; MS (70 eV, EI): *m/z* (%): 230 (100), 160 (4), 131 (18), 117 (73), 107 (41), 95 (51), 69 (12), 41 (20); $C_{21}H_{28}F_3NO_2$ (383.5): calcd C 65.77, H 7.36; found C 65.97, H 7.32.

(4*S*,1′*S*,2′*S*)-4-(2′-Trifluoroacetamido-1′-phenylpropoxy)octa-1,7-diene (*ent*-4i): According to general procedure 1, reaction of aldehyde **1i** (336 mg, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **4i** (460 mg, 1.16 mmol, 58%) as a colourless oil. $[\alpha]_D^{20} = +7.8$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 1.28$ (d, $J = 6.0$ Hz, 3H), 1.64 (m_c, 2H), 2.02–2.17 (m, 2H), 2.21 (t, $J = 6.0$ Hz, 2H), 3.43 (quint, $J = 6.0$ Hz, 1H), 4.13 (m_c, 1H), 4.44 (d, $J = 4.0$ Hz, 1H), 4.91–5.11 (m, 4H), 5.59–5.91 (m, 2H), 6.62 (d, $J = 7.5$ Hz, 1H), 7.19–7.45 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.56$, 28.84, 31.42, 38.69, 51.54, 76.20, 80.05, 115.8 (q, $^1J_{CF} = 285$ Hz), 114.8, 117.2, 126.9, 128.3, 128.4, 134.5, 138.1, 138.8, 156.4 (q, $^2J_{CF} = 35$ Hz); IR (film): $\tilde{\nu} = 3314$ cm^{-1}, 3106, 3088, 3034, 2968, 2944, 2878, 1726, 1704, 1564, 1458, 1208, 1184, 1160, 1086, 910, 760, 726, 702; MS (70 eV, EI): *m/z* (%): 230 (86), 215 (22), 141 (52), 117 (25), 107 (100), 77 (25), 67 (19); $C_{19}H_{24}F_3NO_2$ (355.4): calcd C 64.21, H 6.81; found C 64.01, H 6.76.

(6*S*,1′*S*,2′*S*)-Methyl-(2′-trifluoroacetamido-1′-phenylpropoxy)non-8-enoate (*ent*-4j): According to general procedure 1, reaction of aldehyde **1j** (576 mg, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **4j** (516 mg, 1.24 mmol, 62%) as colourless needles. M.p. 56.3 °C; $[\alpha]_D^{20} = +5.1$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 1.26$ (d, $J = 6.0$ Hz, 3H), 1.26–1.72 (m, 6H), 2.17 (t, $J = 6.5$ Hz, 2H), 2.34 (t, $J = 7.5$ Hz, 2H), 3.38 (quint, $J = 5.5$ Hz, 1H), 3.68 (s, 3H), 4.13 (m_c, 1H), 4.43 (d, $J = 4.0$ Hz, 1H), 4.91–5.09 (m, 2H), 5.68 (m_c, 1H), 6.68 (d, $J = 7.5$ Hz, 1H), 7.17–7.43 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.50$, 23.84, 24.98, 31.71, 33.77, 38.72, 51.49, 76.13, 80.10, 115.8 (q, $^1J_{CF} = 285$ Hz), 117.2, 126.9, 128.3, 128.4, 134.6, 138.8, 156.4 (q, $^2J_{CF} = 35$ Hz), 174.0; IR (film): $\tilde{\nu} = 3318$ cm^{-1}, 3088, 3072, 3034, 2938, 2868, 1740, 1704, 1558, 1456, 1366, 1308, 1270, 1212, 1172, 1166, 1112, 1086, 1062, 918, 756, 726, 702; MS (70 eV, EI): *m/z* (%): 269 (38), 239 (20), 230 (17), 199 (100), 117 (7), 107 (13), 95 (7); $C_{21}H_{28}F_3NO_4$ (415.5): calcd C 60.71, H 6.79; found C 61.00, H 6.95.

0947-6539/96/0209-1168 $ 15.00+.25/0 Chem. Eur. J. 1996, 2, No. 9

(4*RS*,1′*R*,2′*R*)-6-Phenyl-4-(2′-trifluoroacetamido-1′-phenylpropoxy)hexa-1,5-diene (4k): According to general procedure 1, reaction of aldehyde **1k** (529 mg, 500 μL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4k** (492 mg, 1.22 mmol, 61%) as colourless needles. Mp. 94.0 °C; $[\alpha]_D^{20} = -133.5$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 1.29$ (d, $J = 7.0$ Hz, 3H), 2.34–2.60 (m, 2H), 3.87 (dt, $J_1 = 8.5$ Hz, $J_2 = 6.5$ Hz, 1H), 4.07–4.26 (m, 1H), 4.50 (d, $J = 3.5$ Hz, 1H), 5.13 (d, $J = 16$ Hz, 1H), 5.14 (d, $J = 12$ Hz, 1H), 5.72–5.96 (m, 1H), 6.05 (dd, $J_1 = 16$ Hz, $J_2 = 8.5$ Hz, 1H), 6.39 (d, $J = 16$ Hz, 1H), 6.64 (d, $J = 7.5$ Hz, 1H), 7.24–7.46 (m, 10H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.80$, 40.58, 51.47, 77.22, 78.92, 115.8 (q, $^1J_{CF} = 286$ Hz), 117.6, 126.6, 126.9, 128.3, 128.4, 128.6, 128.7, 129.1, 134.0, 134.2, 136.0, 138.3, 156.4 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3426$ cm^{-1}, 3323, 3084, 3066, 3030, 2980, 2928, 2876, 1720, 1700, 1556, 1452, 1200, 1178, 1166, 1056, 920, 754, 724, 700; MS (70 eV, EI): *m/z* (%): 362 (6), 230 (100), 157 (11), 117 (56), 91 (43), 57 (54), 41 (56); $C_{21}H_{22}F_3NO_2$ (403.5): calcd C 68.47, H 6.00; found C 68.67, H 6.27.

(4*S*,1′*R*,2′*R*)-4-(2′-Trifluoroacetamido-1′-phenylpropoxy)non-1,5-diene (4l): According to general procedure 1, reaction of aldehyde **1l** (568 mg, 0.340 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4l** (540 mg, 1.46 mmol, 73%) as colourless needles. M.p. 48.2 °C; $[\alpha]_D^{20} = -40.5$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.90$ (t, $J = 6.0$ Hz, 3H), 1.25 (d, $J = 6.0$ Hz, 3H), 1.43 (oct, $J = 7.0$ Hz, 2H), 2.04 (q, $J = 6.5$ Hz, 2H), 2.32 (oct, $J = 7.0$ Hz, 2H), 3.60 (q, $J = 7.0$ Hz, 1H), 4.09 (m_c, 1H), 4.41 (d, $J = 4.0$ Hz, 1H), 4.99–5.13 (m, 2H), 5.24 (dd, $J_1 = 16$ Hz, $J_2 = 8.5$ Hz, 1H), 5.46 (dt, $J_1 = 16$ Hz, $J_2 = 6.5$ Hz, 1H), 5.75 (m_c, 1H), 6.62 (d, $J = 7.5$ Hz, 1H), 7.16–7.41 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 13.58$, 17.80, 22.28, 34.19, 40.57, 51.54, 77.23, 78.34, 115.9 (q, $^1J_{CF} = 285$ Hz), 117.1, 126.8, 128.2, 128.5, 129.1, 134.4, 136.2, 138.6, 156.4 (q, $^2J_{CF} = 35$ Hz); IR (KBr): $\tilde{\nu} = 3428$ cm^{-1}, 3310, 3106, 3078, 3032, 2984, 2962, 2932, 2874, 1726, 1706, 1564, 1458, 1254, 1210, 1184, 1164, 1066, 914, 762, 726, 702; MS (70 eV, EI): *m/z* (%): 230 (79), 140 (16), 123 (31), 117 (40), 107 (12), 81 (32), 67 (30), 41 (12); $C_{20}H_{26}F_3NO_2$ (369.4): calcd C 65.02, H 7.09; found C 65.30, H 7.11.

(4*RS*,1′*R*,2′*R*)-4-Phenyl-4-(2′-trifluoroacetamido-1′-phenylpropoxy)but-1-ene (4m): According to general procedure 1, reaction of aldehyde **1m** (425 mg, 0.400 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4m** (551 mg, 1.46 mmol, 73%) as colourless needles. M.p. 84.8 °C; $[\alpha]_D^{20} = -108.0$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 1.05$ (d, $J = 7.0$ Hz, 3H), 2.25–2.63 (m, 2H), 3.88–4.13 (m, 2H), 3.95 (d, $J = 3.5$ Hz, 1H), 4.95 (d, $J = 15$ Hz, 1H), 4.96 (d, $J = 13$ Hz, 1H), 5.50–5.73 (m, 1H), 6.48 (d, $J = 7.5$ Hz, 1H), 7.06–7.21 (m, 5H), 7.22–7.36 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.70$, 42.32, 51.37, 78.31, 79.43, 115.8 (q, $^1J_{CF} = 286$ Hz), 117.4, 127.1, 127.2, 128.3, 128.5, 128.6, 134.4, 138.0, 140.7, 156.4 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3412$ cm^{-1}, 3314, 3088, 3068, 3032, 2980, 2938, 2908, 2884, 1728, 1708, 1560, 1208, 1180, 1166, 1086, 916, 764, 724, 702; MS (70 eV, EI): *m/z* (%): 336 (1), 300 (1), 230 (83), 131 (100), 117 (65), 107 (29); $C_{21}H_{22}F_3NO_2$ (377.4): calcd C 66.83, H 5.88; found C 66.90, H 5.98.

(4*S*,1′*R*,2′*R*)-4-(*p*-Methoxyphenyl)-4-(2′-trifluoroacetamido-1′-phenylpropoxy)but-1-ene (4n): According to general procedure 1, reaction of aldehyde **1n** (545 mg, 0.490 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4n** (625 mg, 1.60 mmol, 80%) as colourless needles. M.p. 103.5 °C; $[\alpha]_D^{20} = -125.4$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 1.11$ (d, $J = 7.0$ Hz, 3H), 2.32–2.71 (m, 2H), 3.84 (s, 3H), 3.98–4.19 (m, 3H), 5.04 (d, $J = 15$ Hz, 1H), 5.05 (d, $J = 12$ Hz, 1H), 5.58–5.82 (m, 1H), 6.59 (d, $J = 7.5$ Hz, 1H), 6.92 (d, $J = 8.5$ Hz, 2H), 7.16 (d, $J = 8.5$ Hz, 2H), 7.18–7.46 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.73$, 42.27, 51.40, 55.21, 77.79, 79.10, 115.8 (q, $^1J_{CF} = 287$ Hz), 114.0, 117.3, 127.1, 128.4, 128.6, 132.5, 134.6, 138.2, 156.4 (q, $^2J_{CF} = 36$ Hz), 158.5; IR (KBr): $\tilde{\nu} = 3434$ cm^{-1}, 3316, 3102, 3072, 3038, 2994, 2960, 2900, 1728, 1708, 1564, 1458, 1430, 1242, 1210, 1182, 1162, 1078, 1034, 918, 830, 762, 726, 702; MS (70 eV, EI): *m/z* (%): 366 (9), 230 (100), 161 (29), 117 (33). $C_{22}H_{21}F_3NO_3$ (407.5): calcd C 64.85, H 5.19; found C 64.79, H 5.32.

(4*S*,1′*R*,2′*R*)-4-(*m*-Bromophenyl)-4-(2′-trifluoroacetamido-1′-phenylpropoxy)but-1-ene (4o): According to general procedure 1, reaction of aldehyde **1o** (740 mg, 0.470 mL, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **4o** (812 mg, 1.70 mmol, 89%) as colourless needles. M.p. 114.7 °C; $[\alpha]_D^{20} = -101.2$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 1.23$ (d, $J = 7.0$ Hz, 3H), 2.35–2.73 (m, 2H), 4.07–4.27 (m, 3H), 5.11 (d, $J = 17$ Hz, 1H), 5.12 (d, $J = 12$ Hz, 1H), 5.64–5.88 (m, 1H), 6.60 (d, $J = 7.5$ Hz, 1H), 7.17–7.58 (m, 9H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 17.73$, 42.35, 51.20, 77.65, 79.71, 115.8 (q, $^1J_{CF} = 287$ Hz), 117.9, 122.8, 125.6, 127.0, 128.6, 128.7, 130.1, 130.3, 131.3, 133.8, 137.6, 143.2, 156.4 (q, $^2J_{CF} = 36$ Hz); IR (KBr): $\tilde{\nu} = 3430$ cm^{-1}, 3300, 3104, 3084, 3028, 2984, 2938, 2892, 1728, 1706, 1564, 1212, 1186, 1168, 1160, 1070, 918, 880, 786, 764, 726, 702; MS (70 eV, EI): *m/z* (%): 414 (2), 315 (11), 230 (100), 211 (60), 130 (86), 117 (60), 107 (78); $C_{21}H_{21}BrF_3NO_2$ (456.3): calcd C 64.85, H 5.19; found C 64.79, H 5.32.

(*S*)-3-Methylpentanitrile (16): To a solution of the alcohol **14** (9.82 g, 111 mmol) in dry CH_2Cl_2 (500 mL) was added at 0 °C methanesulfonyl chloride (13.5 g, 9.16 mL, 118 mmol, 1.06 equiv) and subsequently triethylamine (13.5 g, 18.5 mL, 134 mmol, 1.20 equiv). After 2 h of stirring, the solution was poured into ice water and the organic layer was washed twice with water. Drying over K_2CO_3 and removal of the solvent led to a crude product, which was purified by Kugelrohr distillation. The colourless methanesulfonate **15** (17.9 g, 108 mmol, 97%) was dissolved in triethylene glycol (50 mL) together with NaCN (8.00 g, 163 mmol) in a round-bottom flask, and the mixture slowly heated to 120 °C. This temperature was kept for 30 min before being increased within 20 min to 180 °C; pure nitrile **16** (8.10 g, 83.4 mmol, 77%) was isolated by distillation. B.p. 152 °C; $[\alpha]_D^{20} = +9.0$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.93$ (t, $J = 7.0$ Hz, 3H), 1.07 (d, $J = 6.5$ Hz, 3H), 1.39 (m_c, 2H), 1.78 (oct, $J = 6.5$ Hz, 1H), 2.29 (m_c, 2H), ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 11.14$, 18.96, 24.01, 28.56, 32.00, 118.8; IR (film): $\tilde{\nu} = 2966$ cm^{-1}, 2880, 2246, 1462, 1384; MS (70 eV, EI): *m/z* (%): 96 (1), 82 (4), 68 (8), 57 (100), 41 (55); $C_6H_{11}N$ (97.16): calcd C 74.17, H 11.41; found C 74.27, H 11.43.

(*S*)-3-Methylpentanal (24a): A 1 M solution of DIBAH (150 mL, 150 mmol) in *n*-hexane was added at −70 °C to a solution of nitrile **16** (7.10 g, 73.1 mmol) in pentane (50 mL). After 30 min the reaction mixture was warmed to room temperature, and excess DIBAH was destroyed by addition of methanol (4.5 mL). The mixture was poured into saturated aqueous NH_4Cl solution (300 mL) and stirred for 30 min, before 10% H_2SO_4 solution (120 mL) was added. The layers were immediately separated, and the organic layer washed with saturated $NaHCO_3$ solution; the aqueous layer was extracted with Et_2O (4 × 50 mL) and the combined organic layers were dried over Na_2SO_4. Removal of the solvent yielded the aldehyde **24a** [13] (3.29 g, 32.8 mmol, 45%) as a colourless liquid. $[\alpha]_D^{20} = -4.0$ ($c = 0.5$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.92$ (t, $J = 7.0$ Hz, 3H), 0.99 (d, $J = 7.0$ Hz, 3H), 1.76 (m_c, 2H), 2.00 (oct, $J = 7.0$ Hz, 1H), 2.33 (m_c, 2H), 9.76 (t, $J = 2.0$ Hz, 1H).

(*S*)-3,7-Dimethyloctan-1-ol (18): (*S*)-Citronellol (**17**) (3.13 g, 20.0 mmol) dissolved in MeOH (200 mL) was hydrogenated under a pressure of 3 atm hydrogen with palladium on actived carbon (3.20 g 10% Pd/C) for 20 h. After removal of the catalyst by filtration over silica gel and concentration in vacuo, the alcohol **18** [14] was obtained in 64% yield (2.03 g, 12.8 mmol). $[\alpha]_D^{20} = -4.8$ ($c = 0.5$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.87$ (d, $J = 7.0$ Hz, 6H), 0.90 (d, $J = 6.0$ Hz, 3H), 1.04–1.70 (m, 10H), 3.67 (m_c, 2H).

(*S*)-3,7-Dimethyloctanal (24b): DMSO (1.66 g, 1.50 mL, 21.3 mmol) in 3 mL of CH_2Cl_2 was added slowly to a solution of oxalyl chloride (1.25 g, 0.85 mL, 9.80 mmol) in 10 mL of dry CH_2Cl_2 at −78 °C. After the mixture had been stirred for 30 min, the alcohol **18** (1.30 g, 8.20 mmol), dissolved in 3 mL of CH_2Cl_2, was added dropwise to the solution. Stirring was continued for 30 min. Then triethylamine (4.15 g, 5.70 mL, 41.0 mmol) was added and the mixture allowed to warm to room temperature within 2 h. After addition of 10 mL of water and 10 min of stirring, the mixture was extracted with CH_2Cl_2 (2 × 10 mL), and the combined organic layers washed with brine and dried over Na_2SO_4. Removal of the solvent and flash column chromatography (PE/Et_2O = 2:1) led to the aldehyde **24b** [14] (1.01 g, 6.47 mmol, 79%). $[\alpha]_D^{20} = -13.0$ ($c = 0.5$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.87$ (d, $J = 6.5$ Hz, 6H), 0.96 (d, $J = 6.5$ Hz, 3H), 1.06–1.39 (m, 6H), 1.53 (non, $J = 6.5$ Hz, 1H), 2.08 (oct, $J = 6.5$ Hz, 1H), 2.22 (ddd, $J = 16.0$ Hz, 6.0 Hz, 3.0 Hz, 1H), 2.41 (ddd, $J = 16.0$ Hz, 7.5 Hz, 3.0 Hz, 1H), 9.71 (t, $J = 3.0$ Hz, 1H).

(1′*S*,2′*S*,5′*R*)-6′,6′-Dimethylbicyclo[3.1.1]hept-2′-ylacetonitrile (21): To a solution of myrtanol (**19**) (6.04 g, 39.2 mmol) in CH_2Cl_2 (300 mL) was added at 0 °C methanesulfonyl chloride (4.71 g, 3.22 mL, 41.0 mmol, 1.05 equiv), followed by triethylamine (4.71 g, 6.44 mL 46.3 mmol, 1.20 equiv). The mixture was stirred for 2 h. After addition of water (50 mL) the organic layer was separated, washed with brine (100 mL) and dried over Na_2SO_4. The solvent was removed at 30 °C/20 mbar and the residue (9.50 g) purified by distillation at 0.05 mbar. The resulting colourless, liquid methanesulfonate **20** (8.90 g, 38.3 mmol, 89%) was heated with NaCN (2.30 g, 46.9 mmol, 1.20 equiv) in DMSO (40 mL) for 2 h at 130 °C. After cooling to room temperature the mixture was poured into a half-saturated aqueous NH_4Cl solution (200 mL) and extracted with Et_2O (4 × 100 mL). After having been dried over Na_2SO_4, the organic layer was filtered over silica gel (10 g), and the solvent removed at 50 °C/20 mbar. Purification of the residue by column chromatography (petroleum ether/Et_2O = 5:1) gave (5.33 g, 32.7 mmol, 85%) of the nitrile **21** as a colourless, viscous liquid. $[\alpha]_D^{20} = -13.3$ ($c = 1$ in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 0.82–1.00$ (m, 1H), 1.02 (s, 3H), 1.22 (s, 3H), 1.40–1.51 (m, 1H), 1.78–2.30 (m, 5H), 2.34–2.54 (m, 4H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 21.47$, 22.92, 24.26, 25.79, 27.78, 33.04, 37.89, 38.60, 40.88, 45.14, 119.44; IR (film): $\tilde{\nu} = 2988$ cm^{-1}, 2916, 2246, 1470, 1424, 1384; MS (70 eV, EI): *m/z* (%): 163 (3), 148 (22), 134 (50), 122 (45), 108 (49), 81 (90), 69 (100); $C_{11}H_{17}N$ (163.26): calcd C 80.67, H 10.46; found C 80.93, H 10.50.

(1′*S*,2′*S*,5′*R*)-6′,6′-Dimethylbicyclo[3.1.1]hept-2′-ylacetaldehyde (24c): A 1 M solution of DIBAH (50 mL, 50 mmol) in *n*-hexane was added at −70 °C to a solution of nitrile **21** (4.08 g, 25.0 mmol) in pentane (50 mL). After 30 min the reaction mixture was warmed to room temperature and stirred for 5 h. Excess amounts of DIBAH were destroyed by addition of methanol (4.5 mL). The mixture was poured into an aqueous saturated NH_4Cl solution (100 mL) and stirred for 30 min, before 10% H_2SO_4 (40 mL) was added. The layers were immediately separated and the organic layer washed with saturated $NaHCO_3$ solution. The aqueous layer was extracted with Et_2O (4 × 50 mL) and the combined organic layers were dried over Na_2SO_4. Removal of the solvent yielded the aldehyde **24c** (3.77 g, 22.7 mmol, 45%)

as a colourless, viscous liquid; $[\alpha]_D^{20} = -15.8$ ($c = 1$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 1.00$ (d, 1H), 1.02 (s, 3H), 1.19 (s, 3H), 1.30–1.54 (m, 1H), 1.55–2.17 (m, 5H), 2.27–2.43 (m, 1H), 2.46–2.57 (m, 2H), 2.57–2.75 (m, 1H), 9.70 (t, $J = 2.0$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 22.02$, 23.18, 26.44, 27.93, 33.40, 35.04, 38.68, 41.06, 46.27, 52.02, 202.88; IR (film): $\tilde{\nu} = 2984\ cm^{-1}$, 2940, 2816, 1724, 1468, 1384; MS (70 eV, EI): *m/z* (%): 166 (7), 151 (17), 123 (44), 122 (74), 107 (40), 93 (36), 79 (56), 55 (65), 41 (100); $C_{11}H_{18}O$ (166.26): calcd C 79.46, H 10.91; found C 79.59, H 11.00.

(*S*)-Methyl-3,4-dimethoxybutyrate (23): 1,8-Bisdimethylaminonaphthalene (8.40 g, 34.8 mmol, 3.50 equiv) and methyl Meerwein salt (5.00 g, 34.0 mmol, 3.40 equiv) were added to a solution of diol **22** (1.62 g, 12.1 mmol) in CH_2Cl_2 (60 mL). The solution was stirred for 5 d, poured into water (200 mL), extracted with CH_2Cl_2 (6 × 100 mL), dried over Na_2SO_4 and concentrated at 50 °C/100 mbar. The residue was filtered over silica gel and the product purified by column chromatography (*n*-pentane/Et_2O = 3:2) to give the dimethoxy compound **23** (1.01 g, 6.28 mmol, 52%); $[\alpha]_D^{20} = -2.4$ ($c = 1$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 2.57$ (d, $J = 6.5$ Hz, 2H), 3.38 (s, 3H), 3.42 (s, 3H), 3.46 (d, $J = 5.0$ Hz, 2H), 3.70 (s, 3H), 3.73–3.87 (m, 1H).

(*S*)-3,4-Dimethoxybutan-1-al (24d): The butyrate **23** (1.70 g, 10.5 mmol in 10 mL Et_2O) was added dropwise to a suspension of $LiAlH_4$ (330 mg, 8.64 mmol) in 30 mL of dry Et_2O. The mixture was refluxed for 2 h and then quenched with 50 mL of an aqueous, saturated Na–K tartrate solution. The organic layers were separated, extracted with Et_2O (4 × 30 mL) and dried over Na_2SO_4. Removal of the solvent in vacuo and column chromatography (100 g silica gel, Et_2O) led to the corresponding alcohol (1.13 g, 8.40 mmol).

A solution of dimethylsulfoxide (1.60 mL, 1.70 g, 21.8 mmol) in 2.5 mL of CH_2Cl_2 was slowly added to a solution of oxalyl chloride (0.87 mL, 1.28 g, 10.0 mmol) in 15 mL of CH_2Cl_2 at −70 °C. The mixture was stirred for 30 min, and a solution of the alcohol (1.13 mL, 8.40 mmol) in 4 mL of CH_2Cl_2 was then added. Stirring was continued for 30 min before triethylamine (5.80 mL, 4.25 g, 42.0 mmol) was added. The mixture was allowed to warm to room temperature. It was then quenched with water (10 mL) and extracted with CH_2Cl_2 (3 × 20 mL). The solvent was dried over Na_2SO_4 and evaporated. Column chromatography (50 g silica gel, petroleum ether/Et_2O = 3:2) led to the aldehyde **24d** (900 mg, 6.82 mmol, 65%); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 2.67$ (dd, $J = 7.0$ Hz, 2.0 Hz, 2H), 3.38 (s, 3H), 3.42 (s, 3H), 3.74 (d, $J = 6.0$ Hz, 2H), 3.87 (quint, $J = 6.0$ Hz, 1H), 9.81 (t, $J = 2.0$ Hz, 1H).

(4*R*,6*S*,1′*R*,2′*R*)-6-Methyl-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)oct-1-ene (25a): According to general procedure 1, reaction of aldehyde **24a** (401 mg, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **25a** (482 mg, 1.30 mmol, 65%) as colourless needles; 166 mg of **2** were recovered (0.520 mmol, 26%). M.p. 76.7 °C; $[\alpha]_D^{20} = +18.8$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 0.83$ (t, $J = 7.0$ Hz, 3H), 0.89 (d, $J = 7.0$ Hz, 3H), 0.95–1.69 (m, 5H), 1.28 (d, $J = 6.0$ Hz, 3H), 2.15 (t, $J = 7.0$ Hz, 2H), 3.46 (quint, $J = 6.0$ Hz, 1H), 4.02–4.21 (m, 1H), 4.41 (d, $J = 4.0$ Hz, 1H), 4.97 (d, $J = 17.0$ Hz, 1H), 5.01 (d, $J = 10.0$ Hz, 1H), 5.69 (ddt, $J = 17.0$ Hz, 10.0 Hz, 7.0 Hz, 1H), 6.59 (d, $J = 8.0$ Hz, 1H), 7.18–7.41 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): $\delta = 11.08$, 17.45, 19.70, 29.41, 30.96, 39.67, 40.49, 51.55, 75.87, 80.53, 115.95 (q, $^1J_{CF} = 288$ Hz), 117.13, 126.92, 128.25, 128.41, 134.74, 139.18, 156.60 (q, $^2J_{CF} = 37$ Hz); IR (KBr): $\tilde{\nu} = 3314\ cm^{-1}$, 3108, 3078, 2964, 2928, 1724, 1706, 1642, 1210, 1184, 1166, 1084, 910, 760, 702; MS (70 eV, CI): *m/z* (%): 389 (100) $[M^+ + NH_3 + H]$; $C_{20}H_{28}F_3NO_2$ (371.44): calcd C 64.67, H 7.60; found C 64.59, H 7.67.

(4*S*,6*S*,1′*S*,2′*S*)-6-Methyl-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)oct-1-ene (27a): According to general procedure 1, reaction of aldehyde **24a** (401 mg, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **27a** (527 mg, 1.42 mmol, 71%) as colourless needles; 108 mg of *ent*-**2** were recovered (0.340 mmol, 17%). M.p. 78.1 °C; $[\alpha]_D^{20} = +1.6$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 0.78$ (d, $J = 6.0$ Hz, 3H), 0.88 (t, $J = 7.0$ Hz, 3H), 1.01–1.50 (m, 5H), 1.27 (d, $J = 7.0$ Hz, 3H), 2.04–2.34 (m, 2H), 3.33–3.54 (m, 1H), 4.00–4.21 (m, 1H), 4.41 (d, $J = 4.0$ Hz, 1H), 5.01 (d, $J = 17.0$ Hz, 1H), 5.04 (d, $J = 10.0$ Hz, 1H), 5.74 (ddt, $J = 17.0$ Hz, 10.0 Hz, 7.0 Hz, 1H), 6.61 (d, $J = 7.0$ Hz, 1H), 7.20–7.38 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): $\delta = 11.30$, 17.57, 19.38, 30.16, 31.07, 39.19, 39.83, 51.57, 75.27, 79.90, 115.91 (q, $^1J_{CF} = 288$ Hz), 117.16, 126.97, 128.28, 128.44, 134.82, 139.03, 156.59 (q, $^2J_{CF} = 37$ Hz); IR (KBr): $\tilde{\nu} = 3312\ cm^{-1}$, 3108, 3084, 2962, 2930, 1724, 1704, 1644, 1208, 1186, 1162, 1080, 916, 760, 700; MS (70 eV, CI): *m/z* (%): 389 (100) $[M^+ + NH_3 + H]$; $C_{20}H_{28}F_3NO_2$ (371.44): calcd C 64.67, H 7.60; found C 64.75, H 7.68.

(4*R*,6*S*,1′*R*,2′*R*)-6,10-Dimethyl-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)undec-1-ene (25b): According to general procedure 1, reaction of aldehyde **24b** (625 mg, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **25b** (411 mg, 0.96 mmol, 48%) as colourless needles; 275 mg of **2** were recovered (0.860 mmol, 43%). M.p. 41.5 °C; $[\alpha]_D^{20} = +13.0$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 0.85$ (d, $J = 7.0$ Hz, 6H), 0.91 (d, $J = 6.5$ Hz, 3H), 0.90–1.67 (m, 6H), 1.26 (d, $J = 7.0$ Hz, 3H), 2.14 (t, $J = 6.0$ Hz, 2H), 3.46 (quint, $J = 6.0$ Hz, 1H), 4.01–4.21 (m, 1H), 4.41 (d, $J = 3.5$ Hz, 1H), 4.97 (d, $J = 17.0$ Hz, 1H), 5.02 (d, $J = 10.0$ Hz, 1H), 5.69 (ddt, $J = 17.0$ Hz, 10.0 Hz, 6.0 Hz, 1H), 6.58 (d, $J = 7.0$ Hz, 1H), 7.19–7.40 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): $\delta = 17.50$, 20.27, 20.56, 22.69, 24.51, 27.94, 29.49, 37.29, 39.12, 39.74, 41.00, 51.58, 75.94, 80.53, 115.87 (q, $^1J_{CF} = 288$ Hz), 117.16, 126.97, 128.29, 128.45, 134.78, 139.21, 156.48 (q, $^2J_{CF} = 37$ Hz); IR (KBr): $\tilde{\nu} = 3302\ cm^{-1}$, 3096, 3032, 2956, 2932, 1716, 1694, 1640, 1562, 1200, 1186, 1168, 1062, 916, 760, 702; MS (70 eV, CI): *m/z* (%): 445 (100) $[M^+ + NH_3 + H]$; $C_{24}H_{36}F_3NO_2$ (427.55): calcd C 67.42, H 8.49; found C 67.19, H 8.59.

(4*S*,6*S*,1′*S*,2′*S*)-6,10-Dimethyl-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)undec-1-ene (27b): According to general procedure 1, reaction of aldehyde **24b** (625 mg, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **27b** (462 mg, 1.08 mmol, 54%) as colourless needles; 218 mg of **2** were recovered (0.680 mmol, 34%). M.p. 40 °C; $[\alpha]_D^{20} = +6.0$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 0.77$ (d, $J = 6.0$ Hz, 3H), 0.87 (d, $J = 7.0$ Hz, 6H), 1.00–1.64 (m, 13H), 2.04–2.34 (m, 1H), 3.34–3.54 (m, 1H), 4.01–4.21 (m, 1H), 4.41 (d, $J = 4.0$ Hz, 1H), 5.02 (d, $J = 17.0$ Hz, 1H), 5.04 (d, $J = 10.0$ Hz, 1H), 5.74 (ddt, $J = 17.0$ Hz, 10.0 Hz, 7.0 Hz, 1H), 6.61 (d, $J = 8.0$ Hz, 1H), 7.19–7.42 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): $\delta = 17.60$, 19.84, 22.58, 22.67, 24.62, 27.94, 29.46, 37.91, 39.17, 40.29, 51.55, 75.19, 79.85, 115.81 (q, $^1J_{CF} = 288$ Hz), 117.13, 126.25, 128.25, 128.40, 134.77, 138.97, 156.51 (q, $^2J_{CF} = 35$ Hz); IR (KBr): $\tilde{\nu} = 3424\ cm^{-1}$, 3312, 3074, 2956, 2930, 1710, 1642, 1558, 1210, 1166, 1084, 914, 758, 702; MS (70 eV, CI): *m/z* (%): 445 (100) $[M^+ + NH_3 + H]$; $C_{24}H_{36}F_3NO_2$ (427.55): C 67.42, H 8.49; found C 67.40, H 8.63.

(4*R*,1′*R*,2′*R*,1″*S*,2″*S*,5″*R*)-5-(6″,6″-Dimethylbicyclo[3.1.1]hept-2″-yl)-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)pent-1-ene (25c): According to general procedure 1, reaction of aldehyde **24c** (665 mg, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **25c** (438 mg, 1.00 mmol, 50%) as colourless needles; 301 mg of **2** were recovered (0.940 mmol, 47%). M.p. 72.7 °C; $[\alpha]_D^{20} = -20.0$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 0.87$ (d, $J = 9.5$ Hz, 1H), 1.00 (s, 3H), 1.18 (s, 3H), 1.25 (d, $J = 6.5$ Hz, 3H), 1.25 (d, $J = 6.5$ Hz, 3H), 1.28–1.34 (m, 1H), 1.51 (ddd, $J = 14.0$ Hz, 6.0 Hz, 5.5 Hz, 1H), 1.71 (dt, $J = 14.0$ Hz, 4.5 Hz, 1H), 1.76–1.91 (m, 5H), 2.02–2.08 (m, 1H), 2.08–2.21 (m, 2H), 2.27–2.32 (m, 1H), 3.36 (quint, $J = 6.0$ Hz, 1H), 4.04–4.10 (m, 1H), 4.36 (d, $J = 3.5$ Hz, 1H), 4.97 (d, $J = 16.5$ Hz, 1H), 5.01 (d, $J = 10.0$ Hz, 1H), 5.68 (ddt, $J = 16.5$ Hz, 10.0 Hz, 7.0 Hz, 1H), 6.61 (d, $J = 7.5$ Hz, 1H), 7.21–7.34 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): $\delta = 17.68$, 22.68, 23.36, 26.38, 28.12, 33.52, 37.23, 38.67, 39.03, 40.99, 41.33, 47.05, 51.60, 75.65, 79.95, 115.50 (q, $^1J_{CF} = 290$ Hz), 117.11, 126.92, 128.28, 128.44, 134.95, 139.02, 156.25 (q, $^2J_{CF} = 38$ Hz); IR (KBr): $\tilde{\nu} = 3424\ cm^{-1}$, 3304, 3110, 3072, 2906, 2874, 1724, 1706, 1640, 1566, 1208, 1186, 1162, 1084, 916, 760, 700; MS (70 eV, CI): *m/z* (%): 455 (100) $[M^+ + NH_3 + H]$; $C_{25}H_{34}F_3NO_2$ (437.55): calcd C 68.63, H 7.83; found C 68.70, H 7.86.

(4*S*,1′*S*,2′*S*,1″*S*,2″*S*,5″*R*)-5-(6″,6″-Dimethylbicyclo[3.1.1]hept-2″-yl)-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)pent-1-ene (27c): According to general procedure 1, reaction of aldehyde **24c** (665 mg, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **27c** (429 mg, 0.980 mmol, 49%) as colourless needles; 243 mg of *ent*-**2** were recovered (0.760 mmol, 38%). M.p. 70.1 °C; $[\alpha]_D^{20} = -14.0$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 0.85$ (d, $J = 10.0$ Hz, 1H), 1.01 (s, 3H), 1.15 (s, 3H), 1.27 (d, $J = 7.0$ Hz, 3H), 1.34–2.38 (m, 12H), 3.38 (quint, $J = 6.0$ Hz, 1H), 4.02–4.18 (m, 1H), 4.38 (d, $J = 4.0$ Hz, 1H), 4.98 (d, $J = 16.5$ Hz, 1H), 5.03 (d, $J = 10.0$ Hz, 1H), 5.70 (ddt, $J = 16.5$ Hz, 10.0 Hz, 7.0 Hz, 1H), 6.61 (d, $J = 7.5$ Hz, 1H), 7.20–7.40 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): $\delta = 17.44$, 22.97, 23.32, 26.40, 28.11, 33.43, 37.31, 38.56, 39.47, 40.97, 41.32, 46.07, 51.49, 75.82, 80.35, 115.84 (q, $^1J_{CF} = 288$ Hz), 117.10, 127.00, 128.28, 128.41, 134.83, 139.02, 156.45 (q, $^2J_{CF} = 37$ Hz); IR (KBr): $\tilde{\nu} = 3422\ cm^{-1}$, 3310, 3102, 3078, 2944, 2896, 1724, 1702, 1642, 1562, 1206, 1180, 1166, 1084, 918, 758, 702; MS (70 eV, CI): *m/z* (%): 455 (100) $[M^+ + NH_3 + H]$; $C_{25}H_{34}F_3NO_2$ (437.55): calcd C 68.63, H 7.83; found C 68.56, H 7.99.

(4*S*,6*S*,1′*R*,2′*R*)-6,7-Dimethoxy-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)hept-1-ene (25d): According to general procedure 1, reaction of aldehyde **24d** (529 mg, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **25d** (473 mg, 1.10 mmol, 55%) as colourless oil; 218 mg of **2** were recovered (0.680 mmol, 34%). $[\alpha]_D^{20} = -31.0$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 1.08$ (d, $J = 6.0$ Hz, 3H), 1.77 (t, $J = 5.5$ Hz, 2H), 2.10 (t, $J = 6.0$ Hz, 2H), 3.30–3.60 (m, 4H), 3.38 (s, 3H), 3.42 (s, 3H), 4.08 (oct, $J = 6.0$ Hz, 1H), 4.29 (d, $J = 6.0$ Hz, 1H), 4.94 (d, $J = 17.0$ Hz, 1H), 4.98 (d, $J = 10.0$ Hz, 1H), 5.65 (ddt, $J = 17.0$ Hz, 10.0 Hz, 6.0 Hz, 1H), 7.24–7.41 (m, 5H), 7.56 (d, $J = 7.0$ Hz, 1H); ^{13}C NMR (250 MHz, $CDCl_3$): $\delta = 17.34$, 35.68, 39.69, 51.69, 57.29, 59.16, 74.27, 75.15, 77.28, 81.46, 115.97 (q, $^1J_{CF} = 288$ Hz), 117.24, 127.48, 128.44, 134.53, 139.07, 156.77 (q, $^2J_{CF} = 37$ Hz); IR (KBr): $\tilde{\nu} = 3426\ cm^{-1}$, 3292, 3076, 2980, 2932, 1720, 1642, 1210, 1184, 1160, 1104, 916, 762, 702; MS (70 eV, CI): *m/z* (%): 421 (100) $[M^+ + NH_3 + H]$; $C_{20}H_{28}F_3NO_4$ (403.44): calcd C 59.54, H 7.00; found C 59.65, H 6.95.

(4*R*,6*S*,1′*S*,2′*S*)-6,7-Dimethoxy-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)hept-1-ene (27d): According to general procedure 1, reaction of aldehyde **24d** (529 mg, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **27d** (282 mg, 0.700 mmol, 35%) as colourless oil; 218 mg of *ent*-**2** were recovered (0.680 mmol, 34%) together with an elimination product (0.420 mmol, 21%). $[\alpha]_D^{20} = -18.2$ ($c = 0.5$ in $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$): $\delta = 1.23$ (d, $J = 7.0$ Hz, 3H), 1.73 (t, $J = 6.0$ Hz, 2H), 2.14 (t, $J = 6.0$ Hz, 2H), 3.29–3.70 (m, 4H), 3.35 (s, 3H),

0947-6539/96/0209-1170 $ 15.00+.25/0 Chem. Eur. J. 1996, 2, No. 9

3.43 (s, 3H), 4.06–4.23 (m, 1H), 4.44 (d, J = 5.0 Hz, 1H), 4.97 (d, J = 16.5 Hz, 1H), 5.00 (d, J = 10.0 Hz, 1H), 5.68 (ddt, J = 16.5 Hz, 10.0 Hz, 6.0 Hz, 1H), 6.75 (d, J = 7.0 Hz, 1H), 7.22–7.42 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): δ = 17.17, 35.80 39.90, 51.38, 56.79, 59.19, 73.92, 74.75, 76.54, 80.86, 115.87 (q, $^1J_{CF}$ = 288 Hz), 117.43, 127.12, 128.40, 134.29, 138.97, 156.53 (q, $^2J_{CF}$ = 37 Hz); IR (KBr): $\tilde{\nu}$ = 3426 cm^{-1}, 3308, 3078, 2928, 2932, 1718, 1642, 1210, 1182, 1162, 1092, 916, 760, 704; MS (70 eV, CI): m/z (%): 421 (100) [$M^+ + NH_3 + H$]; $C_{20}H_{28}F_3NO_4$ (403.44): calcd C 59.54, H 7.00; found C 59.45, H 7.08.

(4*S*,1′*R*,2′*R*,1″*R*,5″*R*)-4-(6″,6″-Dimethylbicyclo[3.1.1]hept-2″-en-2″-yl)-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)but-1-ene (25e): According to general procedure 1, reaction of aldehyde **24e** (601 mg, 4.00 mmol) with **2** (639 mg, 2.00 mmol) gave the homoallylic ether **25e** (808 mg, 1.92 mmol, 96%) as colourless needles. M.p. 65.3 °C; $[\alpha]_D^{20}$ = − 53.0 (c = 0.5 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.80–0.95 (m, 1H), 1.00 (s, 3H), 1.12 (d, J = 8.5 Hz, 1H), 1.24 (d, J = 7.5 Hz, 3H), 1.34 (s, 3H), 2.08–2.50 (m, 5H), 3.62 (t, J = 6.5 Hz, 1H), 3.95–4.14 (m, 1H), 4.34 (d, J = 4.0 Hz, 1H), 5.03 (d, J = 11.0 Hz, 1H), 5.03 (d, J = 15.0 Hz, 1H), 5.30 (s, 1H), 5.70 (ddt, J = 15.0 Hz, 11.0 Hz, 7.0 Hz, 1H), 6.68 (d, J = 6.0 Hz, 1H), 7.14–7.40 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): δ = 17.70, 21.94, 26.17, 31.23, 32.14, 37.80, 39.03, 40.83, 41.21, 51.52, 78.30, 78.89, 115.96 (q, $^1J_{CF}$ = 290 Hz), 116.88, 121.67, 127.17, 128.37, 128.58, 135.05, 138.27, 146.75, 156.46 (q, $^2J_{CF}$ = 37 Hz); IR (KBr): $\tilde{\nu}$ = 3302 cm^{-1}, 3108, 3070, 2920, 2884, 1726, 1708, 1640, 1566, 1214, 1184, 1162, 1084, 902, 762, 700; MS (70 eV, CI): m/z (%): 439 (100) [$M^+ + NH_3 + H$]; $C_{24}H_{30}F_3NO_2$ (421.50): calcd C 68.40, H 7.17; found C 68.54, H 7.18.

(4*R*,1′*S*,2′*S*,1″*R*,5″*R*)-4-(6″,6″-Dimethylbicyclo[3.1.1]hept-2″-en-2″-yl)-4-(1′-phenyl-2′-trifluoroacetylaminopropoxy)but-1-ene (27e): According to general procedure 1, reaction of aldehyde **24e** (601 mg, 4.00 mmol) with *ent*-**2** (639 mg, 2.00 mmol) gave the homoallylic ether **27e** (800 mg, 1.90 mmol, 95%) as colourless needles. M.p. 62.9 °C; $[\alpha]_D^{20}$ = + 24.8 (c = 0.5 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.80 (s, 3H), 0.85–1.10 (m, 1H), 1.22 (d, J = 7.0 Hz, 3H), 1.15–1.30 (m, 1H), 1.33 (s, 3H), 1.96–2.56 (m, 6H), 3.62 (dd, J = 9.0 Hz, 5.0 Hz, 1H), 3.95–4.14 (m, 1H), 4.31 (d, J = 5.0 Hz, 1H), 5.05 (d, J = 11.0 Hz, 1H), 5.07 (d, J = 15.0 Hz, 1H), 5.28 (s, 1H) 5.77 (ddt, J = 15.0 Hz, 11.0 Hz, 7.0 Hz, 1H), 6.66 (d, J = 7.0 Hz, 1H), 7.15–7.41 (m, 5H); ^{13}C NMR (250 MHz, $CDCl_3$): δ = 17.71, 21.61, 26.15, 31.32, 31.88, 37.76, 38.11, 40.96, 51.61, 78.61, 78.80, 115.88 (q, $^1J_{CF}$ = 288 Hz), 116.86, 122.56, 127.00, 128.26, 128.50, 135.11, 138.55, 146.56, 156.44 (q, $^2J_{CF}$ = 37 Hz); IR (KBr): $\tilde{\nu}$ = 3420 cm^{-1}, 3302, 3106, 3074, 2940, 2886, 1726, 1706, 1640, 1564, 1216, 1182, 1164, 1078, 904, 764, 702; MS (70 eV, CI): m/z (%): 439 (100) [$M^+ + NH_3 + H$]; $C_{24}H_{30}F_3NO_2$ (421.50): calcd C 68.40, H 7.17; found: C 68.47, H 7.21.

General procedure 2—synthesis of the homoallylic alcohols 5 from the homoallylic ethers 4: Condensed ammonia (40 mL) was added at − 78 °C to a solution of homoallylic ether **4** (0.5 mmol) in THF (1 mL). Solid sodium (2.5 equiv) was then added under vigorous stirring. When the solution turned deep blue, the reaction was quenched with methanol (5 mL). After concentration, the residue was dissolved in Et_2O (20 mL) and the solution obtained washed with brine and dried over Na_2SO_4. The solvent was evaporated and the crude product purified by column chromatography on silica gel to give the homoallylic alcohol **5**. For the formation of the acetate the alcohol **5** was dissolved in CH_2Cl_2 (4 mL); pyridine (0.6 mmol), DMAP (0.05 mmol) and Ac_2O (0.6 mmol) were added at room temperature. Stirring for 8 h, removal of the solvent in vacuo and purification of the residue by column chromatography on silica gel gave the corresponding acid ester of the homoallyl alcohol. For the formation of the Mosher ester, the crude alcohol **5** was dissolved in pyridine (1.5 mL) and (*S*)-(+)-α-methoxy-α-trifluorometyl-α-phenylacetyl chloride (177 mg, 138 μL, 0.700 mmol, 1.4 equiv) was added at room temperature. After 2 h the reaction was quenched by addition of 3-dimethylamino-1-propylamine (102 mg, 125 μL, 1.00 mmol) and the crude Mosher ester was purified by column chromatography on silica gel.

(4*R*)-1-Penten-4-yl-(α*R*)-α-methoxy-α-trifluoromethylphenylacetate (5a): According to general procedure 2, **4a** (157 mg, 0.50 mmol) was cleaved and **5a** transformed into its Mosher ester (144 mg, 0.475 mmol, 95%). $[\alpha]_D^{20}$ = + 47.5 (c = 1 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.27 (t, J = 6.5 Hz, 3H), 2.28–2.54 (m, 2H), 3.54 (s, 3H), 5.04–5.19 (m, 1H), 5.22 (sext, J = 6.5 Hz, 1H), 5.64–5.88 (m, 1H), 7.36–7.47 (m, 3H), 7.48–7.62 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 19.18, 40.02, 55.47, 73.27, 84.62 (q, $^2J_{CF}$ = 25 Hz), 118.5, 123.4 (q, $^1J_{CF}$ = 287 Hz), 127.4, 128.4, 129.6, 132.4, 133.1, 166.1; IR (film): $\tilde{\nu}$ = 3078 cm^{-1}, 3032, 2984, 2952, 2850, 1744, 1644, 1452, 1268, 1170, 1122, 1082, 994, 922, 766, 718, 698; MS (70 eV, EI): m/z (%): 302 (2), 189 (100), 105 (13), 69 (22), 41 (26); $C_{15}H_{17}F_3O_3$ (302.29): calcd C 59.61, H 5.67; found C 59.58, H 5.71.

(4*R*)-1-Hexen-4-yl-(α*R*)-α-methoxy-α-trifluoromethylphenylacetate (5b): According to general procedure 2, **4b** (165 mg, 0.50 mmol) was cleaved and **5b** transformed into its Mosher ester (149 mg, 0.470 mmol, 94%). $[\alpha]_D^{20}$ = + 49.8 (c = 1 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.80 (t, J = 7.5 Hz, 3H), 2.61 (quint, J = 7.5 Hz, 2H), 2.41 (t, J = 7.0 Hz, 2H), 3.54 (s, 3H), 5.00–5.19 (m, 3H), 5.64–5.88 (m, 1H), 7.35–7.48 (m, 3H), 7.49–7.64 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.259, 26.27, 37.89, 55.51, 77.82, 84.57 (q, $^2J_{CF}$ = 25 Hz), 118.4, 123.5 (q, $^1J_{CF}$ = 287 Hz), 127.5, 128.3, 129.6, 132.5, 133.2, 166.3; IR (film): $\tilde{\nu}$ = 3078 cm^{-1}, 3030, 2974, 2950, 2854, 1746, 1644, 1452, 1268, 1170, 1122, 1082, 994, 920, 766, 718, 698; MS (70 eV, EI): m/z (%): 316 (1), 189 (100), 105 (16), 83 (25), 41 (18); $C_{16}H_{19}F_3O_3$ (316.32): calcd C 60.75, H 6.05; found C 61.13, H 5.94.

(4*R*)-*O*-Acetyl-1-nonen-4-ol (5c): According to general procedure 2, **4c** (186 mg, 0.50 mmol) was cleaved and **5c** transformed into its acetate (78.3 mg, 0.425 mmol, 85%). $[\alpha]_D^{20}$ = + 27.3 (c = 1 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.88 (t, J = 7.0 Hz, 3H), 1.12–1.41 (m, 6H), 1.42–1.62 (m, 2H), 2.02 (s, 3H), 2.30 (t, J = 6.0 Hz, 2H), 4.92 (quint, J = 6.0 Hz, 1H), 5.05 (d, J = 10 Hz, 1H), 5.06 (d, J = 16 Hz, 1H), 5.64–5.87 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 13.99, 21.23, 22.53, 24.97, 31.64, 33.54, 38.65, 73.36, 117.5, 133.8, 170.8; IR (film): $\tilde{\nu}$ = 3080 cm^{-1}, 2956, 2932, 2862, 1742, 1644, 1462, 1374, 1242, 996, 916; MS (70 eV, EI): m/z (%): 143 (100), 113 (16), 83 (97), 67 (49), 55 (74), 41 (79); $C_{11}H_{20}O_2$ (184.28): calcd C 71.70, H 10.94; found C 71.64, H 10.92.

(4*R*)-*O*-Acetyl-1-decen-4-ol (5d): According to general procedure 2, **4d** (193 mg, 0.50 mmol) was cleaved and subsequently transformed into the acetate **5d** (86.3 mg, 0.435 mmol, 87%). $[\alpha]_D^{20}$ = + 23.7 (c = 1 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.88 (t, J = 7.0 Hz, 3H), 1.12–1.41 (m, 8H), 1.42–1.62 (m, 2H), 2.02 (s, 3H), 2.30 (t, J = 6.0 Hz, 2H), 4.92 (quint, J = 6.0 Hz, 1H), 5.05 (d, J = 10 Hz, 1H), 5.06 (d, J = 16 Hz, 1H), 5.63–5.87 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 13.98, 21.13, 22.52, 25.21, 29.07, 31.67, 33.55, 38.60, 73.30, 117.4, 133.8, 170.7; IR (film): $\tilde{\nu}$ = 3080 cm^{-1}, 2956, 2930, 2862, 1740, 1644, 1462, 1374, 1242, 996, 916; MS (70 eV, EI): m/z (%): 157 (9), 97 (48), 55 (22), 43 (100), 41 (39); $C_{12}H_{22}O_2$ (198.31): calcd C 72.68, H 11.18; found C 72.60, H 11.15.

(4*R*)-Dodec-1-en-4-ol (5e): According to general procedure 2, **4e** (207 mg, 0.50 mmol) was cleaved to give the alcohol **5e** (85.0 mg, 0.460 mmol, 92%). $[\alpha]_D^{20}$ = +10.8 (c = 1 in $CHCl_3$), $[\alpha]_D^{20}$ = +10.5 (c = 1 in CCl_4); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.90 (t, J = 7.0 Hz, 3H), 1.18–1.66 (m, 15H), 2.04–2.39 (m, 2H), 3.65 (s, 1H), 5.07–5.20 (m, 2H), 5.72–5.94 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 14.05, 22.63, 25.65, 29.26, 29.56, 29.65, 31.85, 36.79, 41.92, 70.65, 117.9, 134.9; MS (70 eV, EI): m/z (%): 143 (33), 97 (8), 83 (54), 69 (100), 57 (25), 55 (41), 43 (23); $C_{12}H_{24}O$ (184.32): calcd C 78.20, H 13.12; found C 78.32, H 13.13.

(4*S*)-5-Ethyl-1-hepten-4-ol (5f): According to general procedure 2, **4f** (186 mg, 0.50 mmol) was cleaved into the alcohol **5f** (62.6 mg, 0.440 mmol, 88%). $[\alpha]_D^{20}$ = +1.4 (c = 0.5 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.90 (t, J = 7 Hz, 6H), 1.20–1.66 (m, 6H), 2.04–2.38 (m, 2H), 4.60 (quint, J = 5.0 Hz, 1H), 5.14 (d, J = 12 Hz, 1H), 5.15 (d, J = 16 Hz, 1H), 5.72–5.86 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 11.67, 21.25, 22.00, 38.82, 46.15, 71.86, 117.9, 135.7; IR (film): $\tilde{\nu}$ = 3404 cm^{-1}, 3078, 2962, 2934, 2876, 1642, 1464, 1380, 1140, 998, 918; MS (70 eV, EI): m/z (%): 101 (79), 83 (38), 71 (23), 59 (100), 55 (45), 43 (64), 41 (50); $C_9H_{18}O$ (142.24): calcd C 76.00, H 12.75; found C 76.17, H 12.81.

(4*S*)-5,5-Dimethyl-1-hexen-4-ol (5g): According to general procedure 2, **4g** (179 mg, 0.50 mmol) was cleaved to give alcohol **5g** (52.6 mg, 0.410 mmol, 82%). $[\alpha]_D^{20}$ = + 0.1 (c = 0.5 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.93 (s, 9H), 1.72 (s, 1H), 1.89–2.47 (m, 2H), 3.28 (dd, J = 11 Hz, 2.5 Hz, 1H), 5.12–5.25 (m, 1H), 5.78–6.03 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 25.67, 34,57, 36.52, 78.06, 117.6, 136.5; IR (film): $\tilde{\nu}$ = 3370 cm^{-1}, 3020, 2970, 2928, 2868, 1642, 1422, 1382, 1216, 1114, 924; MS (70 eV, EI): m/z (%): 87 (100), 71 (47), 69 (71), 57 (78), 43 (89), 41 (96); $C_8H_{16}O$ (128.21): calcd C 74.94, H 12.58; found C 75.16, H 12.59.

(4*S*)-4-Cyclohexyl-1-buten-4-ol (5h): According to general procedure 2, **4h** (192 mg, 0.50 mmol) was cleaved to give alcohol **5h** (69.4 mg, 0.450 mmol, 90%). $[\alpha]_D^{20}$ = + 0.1 (c = 0.5 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.97–1.96 (m, 11H), 2.04–2.43 (m, 2H), 3.33–3.46 (m, 1H), 5.13 (d, J = 12 Hz, 1H), 5.14 (d, J = 16 Hz, 1H), 5.72–5.97 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 26.11, 26.25, 26.48, 28.08, 29.06, 38.78, 43.06, 74.72, 117.8, 135.5; IR (film): $\tilde{\nu}$ = 3382 cm^{-1}, 3076, 2976, 2924, 2854, 1640, 1450, 1314, 1144, 986, 912; MS (70 eV, EI): m/z (%): 113 (38), 95 (100), 85 (31), 83 (45), 67 (17); $C_{10}H_{18}O$ (154.25): calcd C 77.87, H 11.76; found C 78.16, H 11.65.

(4*S*)-4-(*p*-Methoxyphenyl)-1-buten-4-ol (5n): According to general procedure 2, **4n** (204 mg, 0.50 mmol) was cleaved to give alcohol **5n** (66.8 mg, 0.375 mmol, 75%). $[\alpha]_D^{20}$ = − 27.4 (c = 0.5 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.98 (s, 1H), 2.49 (t, J = 7 Hz, 2H), 3.79 (s, 3H), 4.69 (t, J = 7 Hz, 1H), 5.12 (d, J = 11 Hz, 1H), 5.15 (d, J = 17 Hz, 1H), 5.69–5.91 (m, 1H), 6.89 (d, J = 8.5 Hz, 2H), 7.29 (d, J = 8.5 Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3$): δ = 43.72, 55.21, 72.93, 113.7, 118.1, 127.0, 134.6, 136.1, 159.0; IR (film): $\tilde{\nu}$ = 3410 cm^{-1}, 3074, 2972, 2934, 2880, 1612, 1458, 1110, 918, 832; MS (70 eV, EI): m/z (%): 178 (1), 137 (100), 109 (26), 94 (21), 77 (23), 41 (12); $C_{11}H_{14}O_2$ (178.23): calcd C 74.13, H 7.92; found C 74.08, H 7.99.

Acknowledgement: Generous financial support by the Deutsche Forschungsgemeinschaft and the Fonds der Chemischen Industrie is gratefully appreciated.

Received: January 19, 1996 [F282]

[1] Reviews: Y. Yamamoto, N. Asao, *Chem. Rev.* **1993**, *93*, 2207. W. R. Roush in *Comprehensive Organic Synthesis, Vol. 2* (Ed.: C. H. Heathcock), Pergamon, Oxford, **1991**, p. 1.

[2] a) R. W. Hoffmann, U. Weidmann, *Chem. Ber.* **1985**, *118*, 3966. b) R. W. Hoffmann, T. Herold, *ibid.* **1981**, *114*, 375. c) H. C. Brown, P. K. Jadhav, *J. Am. Chem. Soc.* **1983**, *105*, 2092. d) H. C. Brown, K. S. Bhat, *ibid.* **1986**, *108*, 293. e) H. C. Brown, P. K. Jadhav, K. S. Bhat, *ibid.* **1988**, *110*, 1535. f) H. C. Brown, P. K. Jadhav, *J. Org. Chem.* **1984**, *49*, 4089. g) H. C. Brown, R. S. Randad, K. S. Bhat, M. Zaidlewicz, U. S. Racherla, *J. Am. Chem. Soc.* **1990**, *112*, 2389. h) U. S. Racherla, H. C. Brown, *J. Org. Chem.* **1991**, *56*, 401. i) H. C. Brown, U. S. Racherla, Y. Liao, V. V. Khanna, *ibid.* **1992**, *57*, 6608. j) J. Garcia, B. M. Kim, S. Masamune, *ibid.* **1987**, *52*, 4831. k) R. P. Short, S. Masamune, *J. Am. Chem. Soc.* **1989**, *111*, 1892. l) W. R. Roush, A. E. Walts, L. K. Hoong, *ibid.* **1985**, *107*, 8186. m) W. R. Roush, K. Ando, D. B. Powers, A. D. Palkowitz, R. L. Halterman, *ibid.* **1990**, *112*, 6339. n) W. R. Roush, K. Ando, L. Banfi, *ibid.* **1988**, *110*, 3979. o) E. J. Corey, C. M. Yu, S. S. Kim, *ibid.* **1989**, *111*, 5495. p) K. Ditrich, T. Bube, R. Stürmer, R. W. Hoffmann, *Angew. Chem.* **1986**, *98*, 1016; *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 1028.

[3] a) M. T. Reetz, T. Zierke, *Chem. Ind.* **1988**, 663. b) Review: R. O. Duthaler, A. Hafner, *Chem. Rev.* **1992**, *92*, 807. c) A. Hafner, R. O. Duthaler, R. Marti, G. Rihs, P. Rothe-Streit, F. Schwarzenbach, *J. Am. Chem. Soc.* **1992**, *114*, 2321.

[4] a) D. Seebach, R. Imwinkelried, G. Stucky, *Helv. Chim. Acta* **1987**, *70*, 448. b) S. E. Denmark, N. G. Almstead, *J. Am. Chem. Soc.* **1991**, *113*, 8089. c) W. S. Johnson, J. D. Elliot, *ibid.* **1983**, *105*, 2088. d) J. M. McNamara, Y. Kishi, *ibid.* **1982**, *104*, 7371. e) H. G. Howell, P. R. Brodfuehrer, C. Sapino, *J. Org. Chem.* **1985**, *50*, 2598. f) S. F. Martin, C. Gluchowsky, C. L. Campbell, R. C. Chapman, *ibid.* **1984**, *49*, 2513. g) D. Seebach, R. Imwinkelried, G. Stucky, *Angew. Chem.* **1986**, *98*, 182; *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 178. h) A. Mekhalfia, I. E. Markó, *Tetrahedron Lett.* **1991**, *32*, 4779.

[5] a) A. L. Costa, M. G. Piazza, E. Tagliavini, C. Trombini, A. Umani-Ronchi, *J. Am. Chem. Soc.* **1993**, *115*, 7001. b) G. E. Keck, K. H. Tarbet, L. S. Geraci, *ibid.* **1993**, *115*, 8467. c) K. Ishihara, M. Mouri, Q. Gao, T. Maruyama, K. Furuta, H. Yamamoto, *ibid.* **1993**, *115*, 11490.

[6] L. F. Tietze, U. Beifuss, *Angew. Chem.* **1993**, *105*, 137; *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 131.

[7] A short communication of the work has already appeared: L. F. Tietze, A. Dölle, K. Schiemann, *Angew. Chem.* **1992**, *104*, 1366; *Angew. Chem. Int. Ed. Engl.* **1992**, *31*, 1372.

[8] L. F. Tietze, K. Schiemann, C. Wegner, *J. Am. Chem. Soc.* **1995**, *117*, 5851.

[9] A. P. Davis, M. Jaspars, *Angew. Chem.* **1992**, *104*, 475; *Angew. Chem. Int. Ed. Engl.* **1992**, *31*, 470.

[10] a) D. Seebach, R. Imwinkelried, G. Stucky, *Helv. Chim. Acta* **1987**, *70*, 448.b) W. S. Johnson, P. H. Crackett, J. D. Elliott, J. J. Jasodzinski, S. D. Lindell, S. Natarajan, *Tetrahedron Lett.* **1984**, *25*, 3951.

[11] D. Sames, Y. Liu, L. DeYoung, R. Polt, *J. Org. Chem.* **1995**, *60*, 2153. J. L. Broeker, R. W. Hoffmann,K. N. Houk, *J. Am. Chem. Soc.* **1991**, *113*, 5006.

[12] It has been shown that chiral acetals are excellent elements for stereocontrol: a) A. Alexakis, P. Mangeney, *Tetrahedron: Asymmetry* **1990**, *1*, 477. b) S. E. Denmark, N. G. Almstead, *J. Am. Chem. Soc.* **1991**, *113*, 8089. c) S. E. Denmark, N. G. Almstead, *J. Org. Chem.* **1991**, *56*, 6458. d) *ibid.* **1991**, *56*, 6485. e) I. Mori, K. Ishihara, L. A. Flippin, K. Nozaki, H. Yamamoto, P. A. Bartlett, C. H. Heathcock, *ibid.* **1990**, *55*, 6107. f) C. Agami, F. Couty, C. Lequesne, *Tetrahedron Lett.* **1994**, *35*, 3309. g) G. Poli, E. Maccagni, L. Manzoni, T. Pilati, C. Scolastico, *Synlett* **1995**, 71. h) H. Pellissier, R. Faure, M. Santelli, *J. Chem. Soc. Chem. Commun.* **1995**, 1847. i) L. Colombo, M. Di Giacomo, G. Brusotti, G. Delogu, *Tetrahedron Lett.* **1994**, *35*, 2063. j) K. C. Frieboes, T. Harder, D. Aulbert, C. Strahringer, M. Bolte, D. Hoppe, *Synlett* **1993**, 921.

[13] S. Masamune, W. Choy, J. S. Petersen, L. R. Sita, *Angew. Chem.* **1985**, *97*, 1; *Angew. Chem. Int. Ed. Engl.* **1985**, *24*, 1.

[14] C. Djerassi, L. E. Geller, *J. Am. Chem. Soc.* **1959**, *81*, 2789.

[15] H. S. Forrest, J. Walker, *J. Chem. Soc.* **1949**, 2002.

[16] R. W. Hoffmann, A. Schlapbach, *Tetrahedron* **1992**, *48*, 1959.

 0947-6539/96/0209-1172 $ 15.00+.25/0