The Paternò–Büchi Reaction of α-Alkyl-Substituted Enecarbamates and Benzaldehyde

Thorsten Bach,*[a] Jürgen Schröder[b]

[a] Technische Universität München, Lehrstuhl für Organische Chemie I, Lichtenbergstr. 4, 85747 Garching, Germany
E-mail: E-Mail: thorsten.bach@ch.tum.de

[b] Philipps-Universität Marburg, Fachbereich Chemie, 35032 Marburg, Germany

Received 18 December 2000

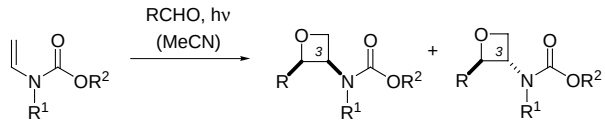
Abstract: The α-substituted enecarbamates and enamides **5a**–**d**, **5f** and **6** were prepared in two steps from the corresponding ketone, *N*-benzylamine and an appropriate acylating agent (Boc_2O, Ac_2O). The [2+2] photocycloaddition reactions of benzaldehyde to the alkenes **5a**–**d** which bear a primary or secondary alkyl substituent proceeded smoothly and gave the 3-aminooxetanes **8a**–**d** in moderate to good yields (46–71%). The α-phenyl-substituted enecarbamate **5f** did not produce a photocycloaddition product presumably due to rapid energy transfer (triplet sensitization) from the photoexcited aldehyde. For less obvious reasons the *tert*-butyl-substituted enamide **6** did not react in the Paternò–Büchi reaction either. The 3-alkyl-3-aminooxetanes **8** were obtained as a mixture of *cis*- and *trans*-diastereoisomers. An increase in the steric bulk of the alkyl substituent R shifted the diastereomeric ratio (*cis*-**8**/*trans*-**8**) in the direction of the thermodynamically more stable *cis*-product (29:71 for R = CH_3 up to 57:43 for R = cyclohexyl). The separated oxetane diastereoisomers *cis*-8a and *trans*-**8a** (R = CH_3) underwent a smooth ring opening/cyclization reaction upon treatment with trifluoroacetic acid. Oxetane *trans*-**8a** yielded the oxazolidinones **9** and *trans*-**10** (92%), oxetane *cis*-**8a** gave exclusively the oxazolidinone *cis*-**10** (54%).

Keywords: cycloadditions, heterocycles, oxetanes, Paternò–Büchi reactions, photochemistry

Introduction

The Paternò–Büchi reaction, i.e. the [2+2] photocycloaddition of an alkene and a carbonyl compound, is the most convenient and efficient way to synthesize substituted oxetanes.[1,2] Recent work has been directed towards the use of heteroatom-substituted alkenes as reaction partners which gives access to 3-heteroatom-substituted oxetanes.[3] Ring opening reactions lead to 1,2,3-trifunctional open chain products.[4] 3-Aminooxetanes are particularly attractive target compounds.[5] They exhibit interesting biological properties[6] and yield 1,2-amino alcohols and related products upon ring opening.[7] The choice of possible enamine substrates which act as alkene components in the Paternò–Büchi reaction is limited by the fact that electron-rich alkenes undergo electron transfer reactions with photoexcited carbonyl compounds. As a result the yields of 3-aminooxetanes are low.[8] Oxazolinones and oxazolines are suitable substrates for the Paternò–Büchi reaction.[9] Recently oxazoles have been successfully employed as alkene components. They yield interesting bicyclic products with high regio- and simple diastereoselectivity which can be further converted into 3-hydroxy-2-aminoketones upon hydrolysis.[10] The use of α-amino-substituted acrylonitriles in Paternò–Büchi reactions has been intensively studied.[11]

Research in our group has centered on the [2+2] photocycloaddition of α-unsubstituted *N*-acyl enamines (enamides) or *N*-alkoxycarbonyl enamines (enecarbamates) to aldehydes.[7,12] This reaction provides access to *N*-protected 3-aminooxetanes in good yields. As an example, the photocycloaddition of enecarbamates **1** to various aldehydes is depicted in Scheme 1. The regioselectivity in favor of the 3-heteroatom-substituted oxetane is high. The simple diastereoselectivity (*cis*-**2**/*trans*-**2**) is high for aromatic aldehydes and lower for aliphatic aldehydes. Consecutive reactions of the 3-aminooxetanes **2** have been investigated.[7] In these reactions the readily removable *N*-alkoxycarbonyl protective groups *tert*-butyloxycarbonyl (Boc) and trimethylsilylethoxycarbonyl (Teoc) proved more valuable and offered more flexibility than the *N*-acyl protective groups.



1 R = Aryl 56–77% d.r. = 90:10 *cis*-**2** *trans*-**2**
R = Alkyl 46–55% d.r. = 65:35

Scheme 1

As an extension of our work we became interested in the photocycloaddition of α-substituted enecarbamates with aldehydes. We chose to study the reaction of *N*-benzyl-*N*-Boc-substituted enamines varying the substituent in α-position. Major questions to be addressed were the chemoselectivity, regioselectivity and simple diastereoselectivity of the reaction. The selection of the protective group was based on the above-mentioned advantages associated with *N*-Boc vs *N*-acyl protection. In addition, the second protective group (*N*-benzyl) can also be readily cleaved if desired. Benzaldehyde was employed as the carbonyl substrate. From previous work it is known that several substituted aromatic aldehydes behave similarly to ben-

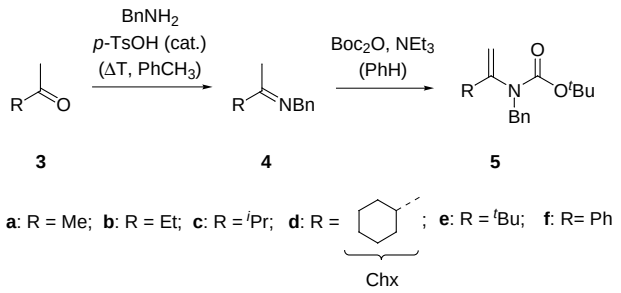
Synthesis 2001, No. 8, 18 06 2001. Article Identifier:
1437-210X,E;2001,0,08,1117,1124,fts,en;C10000SS.pdf.

ISSN 0039-7881

zaldehyde in the Paternò–Büchi reaction.[2,13] From a synthetic point of view the construction of 3-alkyl-3-amino-substituted oxetanes by photocycloaddition chemistry represents an interesting C–C-bond forming reaction. It should make *N*,*N*-diprotected *tert*-alkylsubstituted amines with an adjacent oxygen functionality available which are difficult to prepare by other methods. In the following account we present the results of our study.

Results and Discussion

Preparation of Enecarbamates: The preparation of the enecarbamates **5** was conducted in a straightforward fashion starting from the corresponding ketones **3** (Scheme 2). Their conversion to the imines **4** was achieved by heating a solution of the ketone **3** and *N*-benzyl amine in toluene and by concurrent azeotropic removal of water in a Dean–Stark apparatus.[14] The acetone imine **4a** was prepared under basic conditions (basic alumina, activity I).[15] The subsequent *N*-acylation was performed with di-*tert*-butyldicarbonate (Boc_2O) and Et_3N in benzene.[16] The deprotonation of the intermediate *N*-*tert*-butoxycarbonyl-substituted iminium ion occurred regioselectively at the less substituted, more accessible site. After stirring at room temperature benzene was distilled off at atmospheric pressure. According to our observations the comparably high temperature required for the distillation served to complete the reaction. With toluene as the solvent a double bond isomerization occurred in some instances. Unfortunately, we could not achieve a significant conversion of imine **4e** to the sterically congested compound **5e**. Several other transformations of **4** to **5** did only proceed in low or moderate yields. Still, an optimization of the reaction conditions was not attempted as the major aim of the study was the investigation of the photocycloaddition. The yields of the imines and enecarbamates prepared by the discussed route are listed in Table 1.



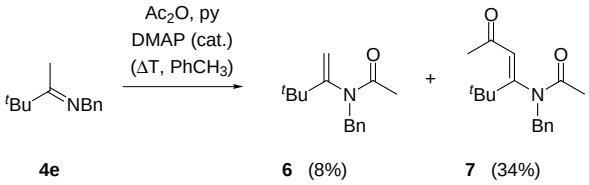
Scheme 2

As an alternative to compound **5e** whose synthesis was not viable despite an intensive effort, we looked into the *N*-acylation of imine **4e** with acetic acid anhydride. Indeed, it was possible to convert the imine **4e** into the enamide **6**, albeit in very low yield. The major product **7** was formed as the result of a Friedel–Crafts type acylation of enamide **6** (Scheme 3).

Table 1 *N*-Benzylimines **4** and Enamines **5** Prepared

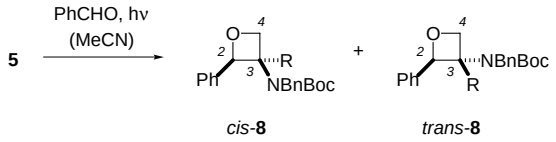
R	Imine	Yield (%)[a]	Enamine	Yield (%)[a]
Me	**4a**[b]	65	**5a**	49
Et	**4b**	75	**5b**	40
i-Pr	**4c**	82	**5c**	59
Chx	**4d**	85	**5d**	38
t-Bu	**4e**	85	**5e**	–[c]
Ph	**4f**	60	**5f**	26

[a] Yield of isolated product after distillation or chromatographic purification.
[b] The acetone imine was prepared from acetone (**3a**) and *N*-benzylamine on basic alumina (activity I).
[c] No product was obtained.



Scheme 3

Photocycloaddition Reactions: The Paternò–Büchi reactions were conducted with benzaldehyde and an excess of the enecarbamate **5** (2 equiv) in acetonitrile as the solvent (Scheme 4). Rayonet lamps RPR 3000 Å (λ = 300 nm) were employed as the irradiation source. The regioselectivity of the reaction was high. The formation of regioisomeric oxetane products could not be detected. Remarkably, the total yields were good for the simple alkyl-substituted enecarbamates **5a**–**c** indicating a high chemoselectivity. Although hydrogen abstraction at the allylic position of the α-alkyl substituted enecarbamates is conceivable this side reaction appears to be considerably slower than the addition of the photoexcited benzaldehyde to the double bond. The cyclohexyl-substituted substrate **5d** is expected to be most amenable to hydrogen abstraction which may account for the somewhat lower yield obtained with this enecarbamate. The acetophenone-derived enecarbamate **5f** did not react (Table 2). This behaviour can be explained by the low-lying triplet states of styrenes. Indeed, it is known that the Paternò–Büchi reaction of aromatic aldehydes to aryl-substituted alkenes fails if the the triplet energy of the alkene is lower than the triplet energy of the aldehyde.[2] Energy transfer (sensitization) prevails and subsequent photochemical and photophysical events occur from the styrene ππ*-triplet. The oxetanes **8** were obtained by the [2+2] photocycloaddition as a mixture of *cis*- and *trans*-products the ratio of which is summarized in Table 2. For comparison the result obtained with the α-unsubstituted enamide **5g** (R = H) has been included in Table 2.



Scheme 4

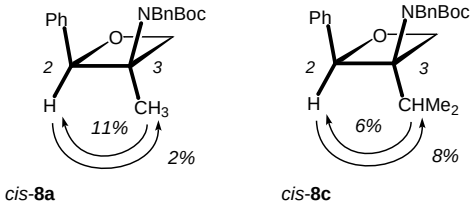
Table 2 [2+2]-Photocycloaddition of Enecarbamates **5** to Benzaldehyde

R	Substrate	Time (h)[a]	Product	Yield (%)[b]	dr[c]
Me	**5a**	5	**8a**	70	29:71
Et	**5b**	5	**8b**	69	34:66
i-Pr	**5c**[c]	3	**8c**	71	54:46
Chx	**5d**	4	**8d**	46	57:43
Ph	**5f**	–[d]	**8f**	–[d]	–[d]
H	**5g**	5	**8g**	77	87:13

[a] Time after which the reaction was complete according to GC.
[b] Combined yield of the isolated products *cis*- and *trans*-**8** after chromatographic purification.
[c] The diastereomeric ratio (dr = *cis*-**8**/*trans*-**8**) was determined in the crude product mixture by integration of appropriate ^{1}H NMR signals.
[d] No product was obtained.

The 3-alkyl-substituted oxetane diastereoisomers *cis*-**8** and *trans*-**8** were separable by flash chromatography although the separation was not always fully complete. Their relative configuration was deduced from ^{1}H NOE or NOESY studies. In general, the *cis*-diastereoisomers show a strong contact between H-2 and the protons attached to the alkyl (Me, Et, *i*-Pr, Chx) substituent at C-3. This phenomenon is illustrated in the Figure, which summarizes the pertinent NOE data recorded for the diastereoisomers *cis*-**8a** and *cis*-**8c**. The *trans*-diastereoisomers did not show significant NOEs between the substituents at C-3 and the proton H-2. The chemical shift of the proton H-2 is distinctly different in either pair of oxetane diastereoisomers *cis*- and *trans*-**8**. It resonates at lower field in the *trans*-isomer *trans*-**8** (δ = 5.66–5.83) and at higher field in the *cis*-isomer *cis*-**8** (δ = 5.21–5.43). The difference Δδ in each pair of diastereoisomers amounts to at least 0.3 ppm. As a consequence of the aromatic ring current, protons of alkyl groups, which are located *cis* to the phenyl substituent at C-2 are shielded. The CH_3 group of diastereoisomer *cis*-**8a** (CH_3 and Ph *trans*) for example resonates at 1.75 ppm whereas the CH_3 group of *trans*-**8a** (CH_3 and Ph *cis*) is responsible for an absorption at δ = 1.14.

Based on steric arguments the relative thermodynamic stability of the product oxetanes **8** can be roughly estimated. An increase in steric bulk for the substituents at C-3 in the order H < NBnBoc ≤ Me ≅ Et < *i* Pr ≅ Chx is realistic based on the tabulated A values.[17] If R = H the thermodynamically more stable isomer is the *trans*-product *trans*-**8g**, if R ≠ H the thermodynamically more stable isomers



cis-**8a** *cis*-**8c**

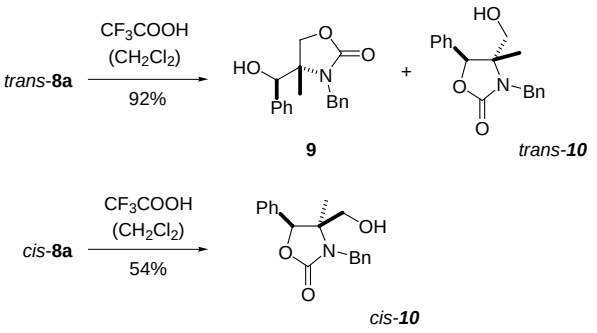
Figure 1 H NMR NOE data (360 MHz) obtained in DMSO-d_6 at 373 K for the *cis* diastereoisomers *cis*-**8a** and *cis*-**8c**

are the *cis*-products *cis*-**8**. It is experimentally observed that an increase in the size of the substituent R generally shifts the diastereomeric ratio *in favor of the more stable diastereoisomer*. Whereas enecarbamate **5g** (R = H) yields with high selectivity (dr = 87:13) the thermodynamically less favored diastereoisomer *cis*-**8g** the selectivity for the thermodynamically disfavored isomer *trans*-**8a** in the case of the α-substituted enecarbamate **5a** (R = Me) is less pronounced (dr = 29:71). It further decreases for enecarbamate **5b** (R = Et), which produces a selectivity of 34:66 in favor of *trans*-**8b**. For R = *i*-Pr the preference is in favor of the thermodynamically more stable *cis*-isomer *cis*-**8c** (dr = 54:46). This result is in line with the dr (57:43) recorded for the equally bulky cyclohexyl-substituted enecarbamate **5d**. It is unfortunate that we were not able to study the *tert*-butyl-substituted enecarbamate **5e** as it was expected to exhibit an even more pronounced *cis*-selectivity. Its potential enamide substitute **6** failed to yield an oxetane product upon irradiation with benzaldehyde.

A preference for thermodynamically more stable products in the Paternò–Büchi reaction has also been observed for α-alkyl-substituted silyl enol ethers.[18] It was associated with a competition between cleavage and ring closure in the intermediate 1,4-biradical. On the other hand, the preferential formation of the thermodynamically less stable oxetane product is precedented for a-unsubstituted and α-methyl-substituted cyclic enol ethers and related compounds.[19] The hypothesis of a kinetically controlled selection between diastereomeric 1,4-biradical conformations in the intersystem crossing step has been put forward by Griesbeck et al. to account for this behaviour.[20] This hypothesis can equally well be applied to α-unsubstituted enamides and enecarbamates, e.g. **5g**.[7] As the size of the substituent increases the kinetic control in the ISC step is possibly erased by the cleavage reaction and eventually the steric factors dominate as it is the case in the above-mentioned silyl enol ether photocycloaddition reactions.

Ring Opening to Oxazolidinones: The fact that the methyl-substituted oxetanes **8a** are separable allowed their isolation in diastereomerically pure form. When the diastereoisomers *cis*- and *trans*-**8a** were subjected to treatment with trifluoroacetic acid they underwent an interesting intramolecular substitution reaction which had previously been observed with simple 3-*N*-Boc-aminooxetanes, such as **8g**.[7] The reaction leads to oxazolidinones the relative configuration of which was proven by NMR

studies. In the case of compounds **8a** the reaction appeared interesting to study as the starting materials were available in diastereomerically pure form. The major diastereoisomer *trans*-**8a** yielded two products. One oxazolidinone **9** was the product of oxygen attack at the carbon atom C-4 of the oxetane, the other oxazolidinone was the pure *trans*-oxazolidinone *trans*-**10** which is a result of attack at C-2 (Scheme 5). Contrary to that, the ring opening of oxetane *cis*-**8a** occurred regioselectively at C-2 and gave the product *cis*-**10** with inversion of configuration (Scheme 5).



Scheme 5

Notably, there was no indication for an oxygen attack at C-2 under retention of configuration. This observation rules out a S_N1-type displacement mechanism which would involve a free carbeniumion. The conversion of the oxetanes **8a** to the products **10** proceeds stereospecifically in an S_N2-type process. Although this conclusion had been drawn earlier for the reaction of the unsubstituted oxetane **8g** it could not be proven unambiguosly at that point in time as the two diastereoisomers *cis*-**8g** and *trans*-**8g** were not separable.

Conclusion and Outlook

In summary, we have shown that α-alkyl substituted enecarbamates can be readily prepared from the corresponding imines and that these substrates undergo a clean [2+2] photocycloaddition to benzaldehyde. Primary and secondary alkyl substituents in the α-position are best suited to guarantee a high chemo- and regioselectivity. Although the simple diastereoselectivity of the photochemical reaction is low the method provides convenient and straightforward access to pure *N*,*N*-diprotected 3-alkyl-3-aminooxetanes. Mechanistic explanations for the simple diastereoselection have been put forward but they have not been verified by the traditional methods of organic photochemistry (determination of quantum yields, quenching experiments). Work along this line will be pursued and reported in due course.

All reactions involving water-sensitive compounds were carried out in flame-dried glassware with magnetic stirring under argon. Common solvents (TBME = *tert*-BuOMe, Et_2O, EA = EtOAc, P = pentane, CH = cyclohexane, CH_2Cl_2, MeOH and EtOH) and Ac_2O were distilled prior to use. Anhyd CH_2Cl_2 was distilled from CaH_2, anhyd benzene and toluene from Na prior to use. Et_3N was distilled from CaH_2. All other reagents and solvents were used as received. Melting points (uncorrected): Reichert hot bench. IR: Bruker IFS 88 FT-IR or Nicolet 510M FT-IR. MS: Varian CH7 (EI). ^1H and ^{13}C NMR: Bruker ARX-200, Bruker AC-300, Bruker AM-400, Bruker AMX-500, Varian uniti plus 600. ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$ as solvent at ambient temperature unless stated otherwise. Chemical shifts are reported relative to TMS as an internal reference. Interchangeable assignments are marked with an asteriks (*). NOESY contacts are reported as weak (‘), medium (‘‘) or strong (‘‘‘). Elemental analysis: Elementar vario EL. Optical rotations: Perkin-Elmer 241, determined at r.t. HPLC: Merck-Hitachi L6200A equipped with an UV spectrometer detector (254 nm). TLC: Merck aluminium sheets (0.2 mm silica gel 60 F_{254}. Detection by UV or by coloration with ceric ammonium molybdate (CAM). Flash chromatography:[21] Merck silica gel 60 (230–400 mesh ASTM) (ca. 50 g for 1 g of material to be separated).

tert-Butyl Benzyl(isopropenyl)carbamate (5a); Typical Procedure

Freshly prepared imine **4a**[15] (1.47 g, 10 mmol) and Et_3N (1.39 mL, 1.01 g, 10 mmol) were dissolved in benzene (4 mL). The mixture was stirred and cooled to 5–8 °C, and a solution of di-*tert*-butyl dicarbonate (Boc_2O, 2.18 g, 10 mmol) in benzene (2 mL) was added. After the addition, the mixture was stirred for 1.5 h at r.t. The solvent was distilled under atmospheric pressure, and the unconverted imine was removed by bulb-to-bulb distillation in vacuo. The residue was purified by flash chromatography (CH–EA, 95:5); yield: 1.23 g (49%); R_f 0.31 (CH–EA, 90:10).

IR (film): ν = 3070 (w, $C_{ar}H$), 2980 (s, $C_{al}H$), 2940 (s, $C_{al}H$), 1710 (vs, C=O), 1665 (m, C=C), 1380 (s), 1230 (s), 1170 cm^{-1} (s).

^1H NMR (300 MHz): δ = 1.45 [s, 9 H, $C(CH_3)_3$], 1.87 (dd, 3 H, *J* = 1.2, 0.4 Hz, CH_3), 4.61 (s, 2 H, CH_2Ph), 4.68 (q, 1 H, *J* = 1.2 Hz, =C*H*H), 4.73 (q, 1 H, *J* = 0.4 Hz, =CH*H*), 7.20–7.35 (m, 5 H_{arom}).

^{13}C NMR (75.5 MHz): δ = 21.6 (q, CH_3), 28.3 [q, $C(CH_3)_3$], 52.9 (t, CH_2Ph), 80.2 [s, $C(CH_3)_3$], 109.1 (t, C=CH_2), 126.9 (d, $C_{ar}H$), 127.4 (d, $C_{ar}H$), 128.3 (d, $C_{ar}H$), 138.9 (s, C_{ar}), 145.3 (s, C=CH_2), 154.2 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 190 (19) [$M^+ - C_4H_9$], 146 (19) [$M^+ - COOC_4H_9$], 130 (12), 91 (100) [$C_7H_7^+$], 77 (5) [$C_6H_5^+$], 65 (10) [$C_5H_5^+$], 57 (71) [$C_4H_9^+$], 41 (44) [$C_3H_5^+$].

Anal. Calcd for $C_{15}H_{21}NO_2$ (247.3): C, 72.84; H, 8.56; N, 5.66. Found: C, 72.97; H, 8.63; N, 5.73.

tert-Butyl Benzyl(1-ethylvinyl)carbamate (5b)

The enecarbamate **5b** was prepared from imine **4b**[14] (1.61 g, 10 mmol) following the procedure provided for the transformation **4a** to **5a**. Purification by flash chromatography (CH–EA, 95:5) yielded the desired product (0.92 g, 40%); R_f 0.53 (CH–EA, 90:10).

IR (film): ν = 3110 (w, $C_{ar}H$), 3065 (w, $C_{ar}H$), 3030 (w, $C_{ar}H$), 2975 (s, $C_{al}H$), 2935 (m, $C_{al}H$), 2880 (w, $C_{al}H$), 1700 (vs, C=O), 1650 (s, C=C), 1450 (s), 1390 (s), 1170 cm^{-1} (s).

^1H NMR (300 MHz): δ = 0.95 (t, 3 H, *J* = 7.4 Hz, CH_2CH_3), 1.46 [s, 9 H, $C(CH_3)_3$], 2.21 (q, 2 H, *J* = 7.4 Hz, CH_2CH_3), 4.58 (s, 2 H, CH_2Ph), 4.72 (s, 1 H, =C*H*H), 4.80 (t, 1 H, *J* = 1.4 Hz, =CH*H*), 7.23–7.33 (m, 5 H_{arom}).

^{13}C NMR (75.5 MHz): δ = 11.3 (q, CH_2CH_3), 26.9 (t, CH_2CH_3), 37.8 [q, $C(CH_3)_3$], 52.6 (t, CH_2Ph), 79.5 [s, $C(CH_3)_3$], 107.8 (t, C=CH_2), 127.3 (d, $C_{ar}H$), 127.4 (d, $C_{ar}H$), 127.7 (d, $C_{ar}H$), 138.7 (s, C_{ar}), 150.4 (s, C=CH_2), 153.9 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 205 (15) [$M^+ - C_4H_8$], 176 (6), 160 (22) [$M^+ - COOC_4H_9$], 146 (16), 91 (100) [$C_7H_7^+$], 77 (3) [$C_6H_5^+$], 57 (59) [$C_4H_9^+$], 41 (43) [$C_3H_5^+$].

Anal. Calcd for $C_{16}H_{23}NO_2$ (261.4): C, 73.53; H, 8.87; N, 5.36. Found: C, 73.43; H, 8.89; N, 5.30.

***tert*-Butyl Benzyl(1-isopropylvinyl)carbamate (5c)**

The enecarbamate **5c** was prepared from imine **4c**[14,22] (1.75 g, 10 mmol) following the procedure provided for the transformation **4a** to **5a**. Purification by flash chromatography (CH–EA, 95:5) yielded the desired product (1.62 g, 59%); R_f 0.31 (CH–EA, 90:10).

IR (film): ν = 3060 (w, $C_{ar}H$), 3025 (w, $C_{ar}H$), 2960 (s, $C_{al}H$), 2920 (m, $C_{al}H$), 2870 (w, $C_{al}H$), 1690 (s, C=O), 1640 (m, C=C), 1450 (m), 1385 (s), 1170 cm^{-1} (s).

^{1}H NMR (300 MHz, acetone-d_6): δ = 1.02 [d, 6 H, *J* = 6.9 Hz, $CH(CH_3)_2$], 1.45 [s, 9 H, $C(CH_3)_3$], 2.53–2.57 [m, 1 H, $CH(CH_3)_2$], 4.57 (s, 2 H, CH_2Ph), 4.70 (br s, 1 H, =C*H*H), 4.80 (d, 1 H, *J* = 1.2 Hz, =CH*H*), 7.18–7.35 (m, 5 H_{arom}).

^{13}C NMR (75.5 MHz, acetone-d_6): δ = 22.3 [q, $CH(CH_3)_2$], 28.9 [q, $C(CH_3)_3$], 33.6 [d, $CH(CH_3)_2$], 50.2 (t, CH_2Ph), 80.4 [s, $C(CH_3)_3$], 108.3 (t, C=CH_2), 128.1 (d, $C_{ar}H$), 129.0 (d, $C_{ar}H$), 129.4 (d, $C_{ar}H$), 140.9 (s, C_{ar}), 155.6 (s, C=CH_2), 157.0 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 218 (38) [$M^+ - C_4H_9$], 174 (28) [$M^+ - COOC_4H_9$], 160 (28), 146 (16), 91 (100) [$C_7H_7^+$], 65 (13) [$C_5H_5^+$], 57 (81) [$C_4H_9^+$], 41 (51) [$C_3H_5^+$].

Anal. Calcd for $C_{17}H_{25}NO_2$ (275.4): C, 74.14; H, 9.15; N, 5.09. Found: C, 73.86; H, 9.37; N, 5.17.

***tert*-Butyl Benzyl(1-cyclohexylvinyl)carbamate (5d)**

The enecarbamate **5d** was prepared from imine **4d**[14,23] (2.15 g, 10 mmol) following the procedure provided for the transformation **4a** to **5a**. Purification by flash chromatography (CH–EA, 95:5) yielded the desired product (1.28 g, 38%); R_f 0.53 (CH–EA, 90:10).

IR (film): ν = 3090 (w, $C_{ar}H$), 3065 (w, $C_{ar}H$), 3005 (w, $C_{ar}H$), 2975 (s, $C_{al}H$), 2930 (s, $C_{al}H$), 2850 (m, $C_{al}H$), 1700 (vs, C=O), 1640 (m, C=C), 1385 (s), 1320 (s), 1170 cm^{-1} (s).

^{1}H NMR (300 MHz): δ = 1.01–1.19 (m, 6 H, 3 CH_2), 1.44 [s, 9 H, $C(CH_3)_3$], 1.65–1.85 (m, 4 H, 2 CH_2), 2.11–2.19 [m, 1 H, $CH(CH_2)_2$], 4.55 (s, 2 H, CH_2Ph), 4.66 (s, 1 H, =C*H*H), 4.78 (s, 1 H, =CH*H*), 7.21–7.31 (m, 5 H_{arom}).

^{13}C NMR (75.5 MHz): δ = 26.3 (t, CH_2), 26.6 (t, CH_2), 28.3 [q, $C(CH_3)_3$], 32.1 (t, CH_2), 42.5 [d, $CH(CH_2)_2$], 55.8 (t, CH_2Ph), 79.9 [s, $C(CH_3)_3$], 108.3 (t, C=CH_2), 126.9 (d, $C_{ar}H$), 127.7 (d, $C_{ar}H$), 128.2 (d, $C_{ar}H$), 139.2 (s, C_{ar}), 154.4 (s, C=CH_2), 154.8 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 315 (<1) [M^+], 258 (39) [$M^+ - C_4H_9$], 214 (14) [$M^+ - COOC_4H_9$], 168 (17), 57 (100) [$C_4H_9^+$].

Anal. Calcd for $C_{20}H_{29}NO_2$ (315.5): C, 76.15; H, 9.29; N, 4.44. Found: C, 75.87; H, 9.08; N, 4.43.

***tert*-Butyl Benzyl(1-phenylvinyl)carbamate (5f)**

The enecarbamate **5f** was prepared from imine **4f**[14,22] (2.09 g, 10 mmol) following the procedure provided for the transformation **4a** to **5a**. Purification by flash chromatography (CH–EA, 95:5) yielded the desired product (0.82 g, 26%); R_f 0.31 (CH–EA, 90:10).

IR (film): ν = 3040 (w, $C_{ar}H$), 3015 (w, $C_{ar}H$), 2975 (m, $C_{al}H$), 2920 (w, $C_{al}H$), 1690 (s, CO), 1630 (m, C = C), 1385 (s), 1335 (s), 1150 (s), 700 cm^{-1} (s).

^{1}H NMR (300 MHz): δ = 1.24 [s, 9 H, $C(CH_3)_3$], 4.73 (s, 2 H, CH_2Ph), 4.96 (s, 1 H, =C*H*H), 5.26 (s, 1 H, =CH*H*), 7.27–7.33 (m, 10 H_{arom}).

^{13}C NMR (75.5 MHz): δ = 21.6 (q, CH_3), 28.3 [q, $C(CH_3)_3$], 52.9 (t, CH_2Ph), 80.2 [s, $C(CH_3)_3$], 109.1 (t, C=CH_2), 126.9 (d, $C_{ar}H$), 127.4 (d, $C_{ar}H$), 128.3 (d, $C_{ar}H$), 138.9 (s, C_{ar}), 145.3 (s, C=CH_2), 154.2 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 252 (33) [$M^+ - C_4H_9$], 208 (100) [$M^+ - CO_2C_4H_9$], 162 (16), 117 (5), 91 (97) [$C_7H_7^+$], 77 (15) [$C_6H_5^+$], 65 (15) [$C_5H_5^+$], 57 (73) [$C_4H_9^+$], 41 (44) [$C_3H_5^+$].

Anal. Calcd for $C_{20}H_{23}NO_2$ (309.4): C, 77.64; H, 7.49; N, 4.53. Found: C, 77.65; H, 7.46; N, 4.56.

***N*-Benzyl-*N*-[(1-*tert*-butyl)vinyl]acetamide (6)**

A solution of imine **4e**[14,22] (3.00 g, 15.8 mmol), Ac_2O (2.96 mL, 3.22 g, 15.8 mmol), pyridine (1.28 mL, 1.25 g, 15.8 mmol) and a catalytic amount of DMAP in toluene (60 mL) was refluxed for 1 h. Upon cooling to r.t. the mixture was poured into aq 0.1 M HCl (30 mL). The aqueous layer was extracted with Et_2O (3 × 30 mL). The combined organic layers were washed with brine (50 mL) and dried ($MgSO_4$). After filtration the solvent was removed in vacuo and the residue was purified by flash chromatography (P–TBME, 60:40). In addition to the desired product (300 mg, 8%) its acyl derivative **7** was isolated (1.51 g, 34%).

6

R_f 0.85 (P–TBME, 60:40).

IR (film): ν = 3105 (w, $C_{ar}H$), 3065 (w, $C_{ar}H$), 3030 (w, $C_{ar}H$), 2970 (s, $C_{al}H$), 2975 (w, $C_{al}H$), 2875 (w, $C_{al}H$), 1710 (s, C=O), 1650 (s, C=C), 1455 (s), 1390 (s), 1170 (s), 730 (s), 700 cm^{-1} (s).

^{1}H NMR (300 MHz): δ = 1.46 [s, 9 H, $C(CH_3)_3$], 2.09 (s, 3 H, CH_3), 3.87 (d, 1 H, *J* = 14.4 Hz, C*H*HPh), 4.58 (s, 1 H, =C*H*H), 5.18 (s, 1 H, =CH*H*), 5.50 (d, 1 H, *J* = 14.4 Hz, CH*H*Ph), 7.15–7.33 (m, 5 H_{arom}).

^{13}C NMR (75.5 MHz): δ = 22.4 (q, CH_3), 30.8 [q, $C(CH_3)_3$], 37.1 [s, $C(CH_3)_3$], 50.6 (t, CH_2Ph), 116.0 (t, C=CH_2), 127.1 (d, $C_{ar}H$), 128.1 (d, $C_{ar}H$), 128.8 (d, $C_{ar}H$), 137.5 (s, C_{ar}), 155.9 (s, C=CH_2), 170.6 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 232 (19) [M^+], 188 (34) [$M^+ - C_4H_9$], 140 (24), 106 (33), 91 (100) [$C_7H_7^+$], 57 (21) [$C_4H_9^+$], 43 (53).

HRMS: *m*/*z* calcd for $C_{15}H_{21}NO$ 231.1623; found 231.1622.

N-Benzyl-*N*-[(*E*)-3-oxobut-1-enyl]acetamide (**7**)

R_f 0.21 (P–TBME, 60:40).

IR (film): ν = 3185 (w, $C_{ar}H$), 3065 (w, $C_{ar}H$), 3030 (w, $C_{ar}H$), 2970 (s, $C_{al}H$), 2870 (w, $C_{al}H$), 1700 (s, C=O), 1650 (s, C=C), 1615 (s), 1385 (s), 1355 (s), 1150 (s), 720 (s), 700 cm^{-1} (s).

^{1}H NMR (300 MHz): δ = 1.25 [s, 9 H, $C(CH_3)_3$], 1.63 (s, 3 H, CH_3), 2.07 (s, 3 H, CH_3), 4.13 (d, 1 H, *J* = 14.6 Hz, C*H*HPh), 5.18 (d, 1 H, *J* = 14.6 Hz, CH*H*Ph), 6.27 (s, 1 H, =CH), 7.21–7.31 (m, 5 H_{arom}).

^{13}C NMR (75.5 MHz): δ = 22.7 (q, CH_3), 30.2 (q, CH_3), 30.9 [q, $C(CH_3)_3$], 38.0 [s, $C(CH_3)_3$], 50.9 (t, CH_2Ph), 126.4 (d, $C_{ar}H$), 127.4 (d, $C_{ar}H$), 128.6 (d, $C_{ar}H$), 130.0 (d, =CH), 136.6 (s, C_{ar}), 158.3 (s, C=CH), 170.5 (s, CO), 196.2 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 230 (51) [$M^+ - COCH_3$], 216 (2) [$M^+ - C_4H_9$], 174 (5), 91 (100) [$C_7H_7^+$], 65 (7) [$C_5H_5^+$], 57 (7) [$C_4H_9^+$], 43 (23).

Anal. Calcd for $C_{17}H_{23}NO_2$ (273.4): C, 74.69; H, 8.48; N, 5.12. Found: C, 74.61; H, 8.49; N, 5.17.

***tert*-Butyl Benzyl(3-methyl-2-phenyloxetan-3-yl)carbamate (8a); Typical Procedure**

In a quartz tube benzaldehyde (152 μL, 159 mg, 1.5 mmol) and the enecarbamate **5a** (741 mg, 3.0 mmol) were dissolved in MeCN (10 mL). This mixture was irradiated for period indicated in Table 2 (λ = 300 nm; light source: Rayonet RPR 3000). The course of the reaction was monitored by TLC and GC. Upon complete conver-

sion the solvent was evaporated in vacuo. The simple diastereoselectivity (dr = 29:71) was determined by ^{1}H NMR and GC analysis of the crude product mixture. The excess enecarbamate was recovered in the course of the subsequent flash chromatography (CH–EA, 90:10). The oxetanes *cis*-**8a** and *trans*-**8a** were fully separable. Total yield: 370 mg (70%).

IR (film): ν = 3085 (w, $C_{ar}H$), 3040 (w, $C_{ar}H$), 2985 (s, $C_{al}H$), 2895 (s, $C_{al}H$), 1690 (vs, C=O), 1170 (s), 1070 (s), 985 cm^{-1} (m, COC).

Anal. Calcd for $C_{22}H_{27}NO_3$ (353.5): C, 74.75; H, 7.70; N, 3.96. Found: C, 74.68; H, 7.85; N, 4.19.

Minor Diastereoisomer *cis*-**8a**
Yield: 115 mg (22%); R_f 0.55 (CH–EA, 60:40).

^{1}H NMR (360 MHz, DMSO-d_6, 373 K): δ = 1.18 [s, 9 H, C(CH_3)$_3$], 1.75 (s, 3 H, CH_3), 4.13–4.19 (m, 3 H, CH_2Ph, C*H*H), 5.13 (d, 1 H, *J* = 6.6 Hz, CH*H*), 5.21 (s, 1 H, PhC*H*O), 7.19–7.43 (m, 10 H_{arom}).

^{1}H NOE (360 MHz, DMSO-d_6, 373 K): H (1.75): $H_{(5.21)}$ [11.2%]; H (5.21): $H_{(1.74)}$ [1.8& hairsp;%].

^{13}C NMR (75.5 MHz): δ = 27.7 (q, CH_3), 27.7 [q, C(*C*H_3)$_3$], 48.3 (t, *C*H_2Ph), 61.3 (s, *C*CH_2), 78.0 (t, OCH_2), 79.7 [s, *C*(CH_3)$_3$], 93.0 (d, PhCHO), 126.4 (d, $C_{ar}H$), 126.9 (d, $C_{ar}H$), 127.3 (d, $C_{ar}H$), 128.3 (d, $C_{ar}H$), 128.5 (d, $C_{ar}H$), 128.6 (d, $C_{ar}H$), 138.3 (s, C_{ar}), 138.3 (s, C_{ar}), 155.0 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 266 (4) [M$^+$ – H_2CO – C_4H_9], 222 (4) [M$^+$ – H_2CO – $COOC_4H_9$], 190 (24), 146 (27), 130 (21), 91 (99) [$C_7H_7^+$], 77 (11) [$C_6H_5^+$], 65 (11) [$C_5H_5^+$], 57 (54) [$C_4H_9^+$], 41 (100) [$C_3H_5^+$].

Major Diastereoisomer *trans*-**8a**

Yield: 255 mg (48%); R_f 0.58 (CH–EA, 60:40).

^{1}H NMR (360 MHz, DMSO-d_6, 373 K): δ = 1.14 (s, 3 H, CH_3), 1.38 [s, 9 H, C(CH_3)$_3$], 4.28 (d, 1 H, *J* = 16.7 Hz, C*H*HPh), 4.28 (d, 1 H, *J* = 6.5 Hz, C*H*H), 4.50 (d, 1 H, *J* = 16.7 Hz, CH*H*Ph), 4.81 (d, 1 H, *J* = 6.5 Hz, CH*H*), 5.66 (s, 1 H, PhC*H*O), 7.20–7.45 (m, 10 H_{arom}).

^{1}H NOE (360 MHz, DMSO-d_6, 373 K): no significant NOEs between ring substituents.

^{13}C NMR (75.5 MHz): δ = 18.5 (q, CH_3), 28.3 [q, C(*C*H_3)$_3$], 47.8 (t, *C*H_2Ph), 63.3 (s, *C*CH_2), 79.5 (t, OCH_2), 81.6 [s, *C*(CH_3)$_3$], 86.9 (d, PhCHO), 126.1 (d, $C_{ar}H$), 126.8 (d, $C_{ar}H$), 127.0 (d, $C_{ar}H$), 128.1 (d, $C_{ar}H$), 128.3 (d, $C_{ar}H$), 128.6 (d, $C_{ar}H$), 137.6 (s, C_{ar}), 139.0 (s, C_{ar}), 155.0 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 266 (3) [M$^+$ – H_2CO – C_4H_9], 222 (2) [M$^+$ – H_2CO – $COOC_4H_9$], 190 (27), 146 (27), 130 (18), 91 (100) [$C_7H_7^+$], 77 (10) [$C_6H_5^+$], 65 (11) [$C_5H_5^+$], 57 (54) [$C_4H_9^+$], 41 (89) [$C_3H_5^+$].

tert-Butyl Benzyl(3-ethyl-2-phenyloxetan-3-yl)carbamate (8b)

The oxetanes **8b** were prepared from enecarbamate **5b** (783 mg, 3.0 mmol) and benzaldehyde (152 μL, 159 mg, 1.5 mmol) following the procedure provided for the transformation **5a** to **8a** (dr = 34:66). Purification by flash chromatography (CH–EA, 95:5) yielded the desired products (380 mg, 69%), which were not fully separable.

IR (film): = 3060 (w, $C_{ar}H$), 3015 (w, $C_{ar}H$), 2965 (s, $C_{al}H$), 2935 (s, $C_{al}H$), 2880 (m, $C_{al}H$), 1690 (vs, C=O), 1450 (s), 1170 (s), 990 cm^{-1} (m, COC).

Anal. Calcd for $C_{23}H_{29}NO_3$ (367.5): C, 75.14; H, 7.95; N, 3.81; found C, 75.23; H, 8.10; N, 3.87.

Minor Diastereoisomer *cis*-**8b**
R_f 0.28 (CH–EA, 90:10).

^{1}H NMR (600 MHz, DMSO-d_6, 373 K): δ = 0.99 (t, 3 H, *J* = 7.5 Hz, CH_2CH_3), 1.20 [s, 9 H, C(CH_3)$_3$], 2.23 (dq, 1 H, *J* = 14.3 Hz, *J* = 7.5 Hz, C*H*HCH_3), 2.37 (dq, 1 H, *J* = 14.3, 7.5 Hz, CH*H*CH_3), 3.87 (d, 1 H, *J* = 16.2 Hz, C*H*HPh), 4.29–4.32 (m, 2 H, OC*H*H, CH*H*Ph), 5.03 (d, 1 H, *J* = 6.6 Hz, OCH*H*), 5.26 (s, 1 H, PhC*H*O), 6.95–7.41 (m, 10 H_{arom}).

^{1}H NOE (360 MHz, DMSO-d_6, 373 K): H (2.23): $H_{(2.37)}$ [21.7%], $H_{(5.26)}$ [4.2%]; H (2.37): $H_{(2.23)}$ [10.4%], $H_{(5.26)}$ [2.4%]; H (5.26): $H_{(2.23)}$ [2.3%], $H_{(2.37)}$ [1.9%].

^{13}C NMR (75.5 MHz, DMSO-d_6): δ = 25.8 (q, CH_2CH_3), 27.2 [q, C(*C*H_3)$_3$], 27.7 (t, *C*$H_2$$CH_3$), 48.8 (t, *C*$H_2$Ph), 64.7 (s, *C*C$H_2$), 74.3 (t, OC$H_2$), 78.7 [s, *C*($CH_3$)$_3$], 90.2 (d, PhCHO), 125.8 (d, $C_{ar}H$), 125.9 (d, $C_{ar}H$), 126.4 (d, $C_{ar}H$), 126.5 (d, $C_{ar}H$), 126.8 (d, $C_{ar}H$), 127.0 (d, $C_{ar}H$), 138.3 (s, C_{ar}), 138.7 (s, C_{ar}), 154.0 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 280 (8) [M$^+$ – H_2CO – C_4H_9], 204 (22), 161 (15), 151 (36), 106 (18), 91 (97) [$C_7H_7^+$], 77 (5) [$C_6H_5^+$], 57 (100) [$C_4H_9^+$].

Major Diastereoisomer *trans*-**8b**
R_f 0.32 (CH–EA, 90:10).

^{1}H NMR (600 MHz, DMSO-d_6, 373 K): δ = 0.59 (t, 3 H, *J* = 7.5 Hz, CH_2CH_3), 1.35 [s, 9 H, C(CH_3)$_3$], 1.64 (dq, 1 H, *J* = 15.0 Hz, *J* = 7.5 Hz, C*H*HCH_3), 1.85 (dq, 1 H, *J* = 15.0, 7.5 Hz, CH*H*CH_3), 4.32 (d, 1 H, *J* = 6.8 Hz, OC*H*H), 4.32 (d, 1 H, *J* = 16.5 Hz, C*H*H-Ph), 4.51 (d, 1 H, *J* = 16.5 Hz, CH*H*Ph), 4.84 (d, 1 H, *J* = 6.8 Hz, OCH*H*), 5.69 (s, 1 H, PhC*H*O), 7.32–7.45 (m, 10 H_{arom}).

^{1}H NOE (360 MHz, DMSO-d_6, 373 K): no significant NOEs between ring substituents.

^{13}C NMR (75.5 MHz, DMSO-d_6): δ = 25.1 (q, CH_2CH_3), 25.8 (t, *C*$H_2$$CH_3$), 27.4 [q, C(*C*$H_3$)$_3$], 48.5 (t, *C*$H_2$Ph), 66.0 (s, *C*C$H_2$), 75.9 (t, OC$H_2$), 79.1 [s, *C*($CH_3$)$_3$], 86.6 (d, PhCHO), 125.5 (d, $C_{ar}H$), 126.0 (d, $C_{ar}H$), 126.4 (d, $C_{ar}H$), 127.3 (d, $C_{ar}H$), 127.4 (d, $C_{ar}H$), 127.8 (d, $C_{ar}H$), 137.3 (s, C_{ar}), 139.1 (s, C_{ar}), 154.0 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 367 (1) [M$^+$], 310 (2) [M$^+$– C_4H_9], 280 (13) [M$^+$ – H_2CO – C_4H_9], 248 (10), 204 (33), 105 (14), 91 (100) [$C_7H_7^+$], 77 (10) [$C_6H_5^+$], 57 (40) [$C_4H_9^+$].

tert-Butyl Benzyl(3-isopropyl-2-phenyloxetan-3-yl)carbamate (8c)

The oxetanes **8c** were prepared from enecarbamate **5c** (825 mg, 3.0 mmol) and benzaldehyde (152 μL, 159 mg, 1.5 mmol) following the procedure provided for the transformation **5a** to **8a** (dr = 54:46). Purification by flash chromatography (CH–EA, 90:10) yielded the desired products (338 mg, 71%), which were not fully separable.

IR (film): ν = 3090 (m, $C_{ar}H$), 3070 (m, $C_{ar}H$), 2980 (s, $C_{al}H$), 2925 (m, $C_{al}H$), 2855 (m, $C_{al}H$), 1705 (vs, C=O), 1460 (s), 1395 (s), 1170 (m), 990 cm^{-1} (m, COC).

Anal. Calcd for $C_{24}H_{31}NO_3$ (381.5): C, 75.56; H, 8.19; N, 3.67; found C, 75.35; H, 8.33; N, 3.74.

Major Diastereoisomer *cis*-**8c**
R_f 0.58 (CH–EA, 60:40).

^{1}H NMR (360 MHz, DMSO-d_6, 373 K): δ = 0.93 (d, 3 H, *J* = 7.0 Hz, CHCH_3), 1.18 [s, 9 H, C(CH_3)$_3$], 1.34 (d, 3 H, *J* = 7.0 Hz, CHCH_3), 2.43 [septet, 1 H, *J* = 7.0 Hz, C*H*(CH_3)$_2$], 3.70 (d, 1 H, *J* = 16.0 Hz, C*H*HPh), 4.29 (d, 1 H, *J* = 16.0 Hz, CH*H*Ph), 4.45 (d, 1 H, *J* = 7.0 Hz, OC*H*H), 4.97 (d, 1 H, *J* = 7.0 Hz, OCH*H*), 5.41 (s, 1 H, PhC*H*O), 7.15–7.55 (m, 10 H_{arom}).

^{1}H NOE (360 MHz, DMSO-d_6, 373 K): H (0.93): $H_{(5.41)}$ [2.7%]; H (1.34): $H_{(5.41)}$ [13.1%]; H (2.43): $H_{(5.41)}$ [8.1%]; H (5.41): $H_{(0.93)}$ [1.0%], $H_{(1.34)}$ [2.6%], $H_{(2.43)}$ [5.7%].

^{13}C NMR (75.5 MHz): δ = 16.8 [d, *C*H(CH_3)$_2$], 17.1 (q, CH*C*H_3), 17.3 (q, CH*C*H_3), 27.6 [q, C(*C*H_3)$_3$], 50.7 (t, *C*H_2Ph), 68.5 (s, *C*CH_2), 71.6 (t, OCH_2), 88.4 (d, PhCHO), 89.1 [s, *C*(CH_3)$_3$], 126.0

(d, $C_{ar}H$), 126.1 (d, $C_{ar}H$), 127.1 (d, $C_{ar}H$), 127.4 (d, $C_{ar}H$), 127.6 (d, $C_{ar}H$), 128.1 (d, $C_{ar}H$), 138.4 (s, C_{ar}), 1139.1 (s, C_{ar}), 154.3 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 294 (1) [$M^+ - H_2CO - C_4H_9$], 281 (1) [$M^+ - C_4H_8 - CO_2$], 218 (35) [M^+ – PhCHO – C_4H_9], 208 (5), 174 (16) [M^+ – PhCHO – $COOC_4H_9$],, 160 (13), 91 (100) [$C_7H_7^+$], 77 (10) [$C_6H_5^+$], 65 (11) [$C_5H_5^+$], 57 (62) [$C_4H_9^+$], 41 (55) [$C_3H_5^+$].

Minor Diastereoisomer *trans*-**8c**
R_f 0.53 (CH–EA, 60:40).

^{1}H NMR (360 MHz, DMSO-d_6, 373 K): δ = 0.44 (d, 3 H, *J* = 6.8 Hz, CHC*H*$_3$), 0.91 (d, 3 H, *J* = 6.8 Hz, CHC*H*$_3$), 1.30 [s, 9 H, C(C*H*$_3$)$_3$], 2.39 [septet, 1 H, *J* = 6.8 Hz, C*H*(CH$_3$)$_2$], 4.35–4.52 (m, 3 H, PhC*H*$_2$, OC*H*H), 4.86 (d, 1 H, *J* = 7.2 Hz, OCH*H*), 5.83 (s, 1 H, PhC*H*O), 7.15–7.55 (m, 10 H_{arom}).

^{1}H NOE (360 MHz, DMSO-d_6, 373 K): no significant NOEs between ring substituents.

MS (EI, 70 eV): *m*/*z* (%) = 294 (1) [$M^+ - H_2CO - C_4H_9$], 218 (9) [M^+ – PhCHO – C_4H_9], 174 (11) [M^+ – PhCHO – $COOC_4H_9$],, 160 (10), 91 (100) [$C_7H_7^+$], 77 (10) [$C_6H_5^+$], 65 (11) [$C_5H_5^+$], 57 (49) [$C_4H_9^+$], 41 (42) [$C_3H_5^+$].

tert-Butyl Benzyl(3-cyclohexyl-2-phenyloxetan-3-yl)carbamate (8d)

The oxetanes **8d** were prepared from enecarbamate **5d** (945 mg, 3.0 mmol) and benzaldehyde (152 μL, 159 mg, 1.5 mmol) following the procedure provided for the transformation **5a** to **8a** (dr = 57:43). Purification by flash chromatography (CH–EA, 95:5) yielded the desired products (290 mg, 46%), which were not fully separable.

IR (film): ν = 3090 (w, $C_{ar}H$), 3065 (w, $C_{ar}H$), 3030 (w, $C_{ar}H$), 2975 (m, $C_{al}H$), 2930 (s, $C_{al}H$), 2855 (m, $C_{al}H$), 1695 (vs, C=O), 1455 (m), 1390 (s), 1170 (m), 990 cm^{-1} (m, COC).

Anal. Calcd for $C_{27}H_{35}NO_3$ (421.3): C, 76.92; H, 8.37; N, 3.32. Found: C, 76.84; H, 8.24; N, 3.18.

Major diastereoisomer *cis*-**8d**
R_f 0.49 (CH–EA, 90:10).

^{1}H NMR (400 MHz, DMSO-d_6, 373 K): δ = 1.12–1.92 [m, 18 H, 9 Chx-H, C(C*H*$_3$)$_3$], 2.26–2.30 (m, 1 H, 1 Chx-H), 2.43–2.45 (m, 1 H, 1 Chx-H), 3.62 (d, 1 H, *J* = 16.3 Hz, C*H*HPh), 4.29 (d, 1 H, *J* = 16.3 Hz, CH*H*Ph), 4.46 (d, 1 H, *J* = 6.9 Hz, OC*H*H), 4.97 (d, 1 H, *J* = 6.9 Hz, OCH*H*), 5.43 (s, 1 H, PhC*H*O), 6.91–7.41 (m, 10 H_{arom}).

^{1}H NOESY (400 MHz, DMSO-d_6, 373 K): H (2.26–2.30)-H (5.43)‘‘‘, H (2.43–2.45)-H (5.43)‘‘‘.

^{13}C NMR (75.5 MHz, DMSO-d_6): δ = 25.5 (t, CH_2), 25.8 (t, CH_2), 25.9 (t, CH_2), 26.5 (t, CH_2), 26.8 (t, CH_2), 27.3 [q, C(*C*H)$_3$], 42.7 (s, CH), 49.9 (t, Ph*C*H$_2$), 67.6 (d, C*N*), 71.7 (t, O*C*H$_2$), 78.7 (s, *C*Me$_3$), 87.7 (d, Ph*C*H), 125.7 (d, $C_{ar}H$), 126.7 (d, $C_{ar}H$), 127.0 (d, $C_{ar}H$), 127.1 (d, $C_{ar}H$), 127.3 (d, $C_{ar}H$), 127.9 (d, $C_{ar}H$), 138.6 (s, C_{ar}), 138.7 (s, C_{ar}), 153.7 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 334 (10) [$M^+ - H_2CO - C_4H_9$], 282 (15), 258 (55) [M^+ – PhCHO – C_4H_9], 214 (8), 168 (16), 160 (24), 91 (100) [$C_7H_7^+$], 77 (2) [$C_6H_5^+$], 57 (83) [$C_4H_9^+$].

Minor Diastereoisomer *trans*-**8d**
R_f 0.46 (CH–EA, 90:10).

^{1}H NMR (400 MHz, DMSO-d_6, 373 K): δ = 0.62–1.87 [m, 16 H, 7 Chx-H, C(C*H*$_3$)$_3$], 1.49–1.53 (m, 1 H, 1 Chx-H), 1.70–1.73 (m, 1 H, 1 Chx-H), 1.82–1.86 (m, 1 H, 1 Chx-H), 2.00–2.06 (m, 1 H, 1 Chx-H), 4.30 (d, 1 H, *J* = 16.3 Hz, C*H*HPh), 4.43–4.46 (m, 2 H, CH*H*Ph, OC*H*H), 4.82 (d, 1 H, *J* = 7.1 Hz, OCH*H*), 5.79 (s, 1 H, PhC*H*O), 7.25–7.47(m, 10 H_{arom}).

^{1}H NOESY (400 MHz, DMSO-d_6, 373 K): no significant NOESY contacts between ring substituents.

^{13}C NMR (75.5 MHz, DMSO-d_6): δ = 26.9 (t, CH_2), 27.5 (t, CH_2), 27.7 (t, CH_2), 28.5 (t, CH_2), 28.6 (t, CH_2), 28.7 [q, C(*C*H)$_3$], 44.3 (s, CH), 51.4 (t, Ph*C*H$_2$), 70.4 (d, CN), 75.1 (t, O*C*H$_2$), 80.3 (s, *C*Me$_3$), 87.8 (d, Ph*C*H), 126.5 (d, $C_{ar}H$), 127.2 (d, $C_{ar}H$), 128.0 (d, $C_{ar}H$), 128.7 (d, $C_{ar}H$), 128.9 (d, $C_{ar}H$), 129.1 (d, $C_{ar}H$), 139.6 (s, C_{ar}), 140.9 (s, C_{ar}), 155.1 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 420 [M^+ – H], 364 (1) [$M^+ - C_4H_9$], 334 (14) [$M^+ - H_2CO - C_4H_9$], 321 (2) [$M^+ - CO_2C_4H_9$], 283 (8), 258 (63) [M^+ – PhCHO – C_4H_9], 214 (33) [M^+ – PhCHO – $CO_2C_4H_9$], 168 (40), 160 (55), 105 (42), 91 (91) [$C_7H_7^+$], 77 (14) [$C_6H_5^+$], 57 (100) [$C_4H_9^+$].

(4*R*)-3-Benzyl-4-[(*R*)-(hydroxy(phenyl)methyl]-4-methyl-1,3-oxazolidin-2-one (9)

To a stirred solution of trifluoroacetic acid (80 μL, 113 mg, 1 mmol) in CH_2Cl_2 (4 mL) oxetane *trans*-**8a** (176 mg, 0.5 mmol) in CH_2Cl_2 (0.5 mL) was added at –78 °C. The mixture was slowly warmed to r.t. The solution was concentrated in vacuo, and the trifluoroacetic acid was removed by azeotropic distillation with toluene (2 × 5 mL). The residue was dissolved in CH_2Cl_2 and washed with sat. aq Na_2CO_3 solution (15 mL). The aqueous layer was extracted with CH_2Cl_2 (3 × 30 mL). The combined organic layers were dried ($MgSO_4$) and filtered. After evaporation of the solvent in vacuo the residue so obtained was purified by flash chromatography (CH–EA, 80:20). Compound **9** was the major product and it was obtained as a white solid (99 mg, 67%). In addition, the diastereomerically pure oxazolidinone *trans*-**10** was isolated (37 mg, 25%).

9
R_f 0.41 (CH–EA, 40:60), mp 139–140 °C.

IR (KBr): ν = 3380 (s, br, OH), 3040 (w, $C_{ar}H$), 2960 (s, $C_{al}H$), 2930 (s, $C_{al}H$), 1750 cm^{-1} (vs, C=O).

^{1}H NMR (300 MHz, DMSO-d_6): δ = 1.02 (s, 3 H, CH_3), 3.39 (d, 1 H, *J* = 8.6 Hz, C*H*H), 4.36 (d, 1 H, *J* = 16.0 Hz, C*H*HPh), 4.48 (d, 1 H, *J* = 8.6 Hz, CH*H*), 4.56 (d, 1 H, *J* = 16.0 Hz, CH*H*Ph), 5.83 (d, 1 H, *J* = 3.9 Hz, PhC*H*OH), 7.22–7.55 (m, 10 H_{arom}).

^{13}C NMR (75.5 MHz): δ = 21.6 (q, CH3), 44.7 (t, *C*H$_2$Ph), 65.1 (s, *C*NCH$_3$), 69.0 (t, C*C*H$_2$), 75.2 (d, Ph*C*HOH), 127.1 (d, $C_{ar}H$), 127.9 (d, $C_{ar}H$), 128.0 (d, $C_{ar}H$), 128.5 (d, $C_{ar}H$), 128.6 (d, $C_{ar}H$), 129.0 (d, $C_{ar}H$), 138.1 (s, C_{ar}), 138.2 (s, C_{ar}), 158.9 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 298 (8) [M^+ – H], 266 (30), 222 (26), 190 (43) [$M^+ - C_7H_7O$], 130 (23), 105 (28), 91 (100) [$C_7H_7^+$], 77 (28) [$C_6H_5^+$], 65 (37) [$C_5H_5^+$].

Anal. Calcd for $C_{18}H_{19}NO_3$ (297.4): C, 72.71; H, 6.44; N, 4.71. Found: C, 72.79; H, 6.47; N, 4.72.

trans-**10**
R_f 0.22 (CH–EA, 40:60); mp 89–90 °C.

IR (KBr): ν = 3560 (m, OH), 3410 (s, OH), 3065 (w, $C_{ar}H$), 3040 (w, $C_{ar}H$), 2990 (w, $C_{al}H$), 2925 (w, $C_{al}H$), 1740 (vs, C=O), 1410 cm^{-1} (s).

^{1}H NMR (300 MHz, DMSO-d_6): δ = 0.46 (s, 3 H, CH_3), 3.39 (dd, 1 H, *J* = 11.7 Hz, *J* = 5.5 Hz, C*H*HOH), 3.58 (dd, 1 H, *J* = 11.7 Hz, *J* = 5.5 Hz, CH*H*OH), 4.23 (d, 1 H, *J* = 16.0 Hz, C*H*HPh), 4.47 (d, 1 H, *J* = 16.0 Hz, CH*H*Ph), 5.34 (t, 1 H, *J* = 5.5 Hz, CH_2O*H*), 5.47 (s, 1 H, PhC*H*O), 7.22–7.42 (m, 10 H_{arom}).

^{1}H NOE (300 MHz, DMSO-d_6): H (3.39): $H_{(5.47)}$ [2.5%]; H (3.58): $H_{(5.47)}$ [1.2%]; H (5.47): $H_{(3.39)}$ [1.0%], $H_{(3.58)}$ [0.3%].

^{13}C NMR (75.5 MHz): δ = 17.2 (q, CH_3), 44.7 (t, *C*H$_2$Ph), 64.8 (t, CH_2OH), 66.3 (s, *C*CH$_3$), 79.8 (d, Ph*C*HO), 126.2 (d, $C_{ar}H$), 127.7

(d, $C_{ar}H$), 128.2 (d, $C_{ar}H$), 128.5 (d, $C_{ar}H$), 128.6 (d, $C_{ar}H$), 129.1 (d, $C_{ar}H$), 135.4 (s, C_{ar}), 138.2 (s, C_{ar}), 158.4 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 266 (22) [$M^+ - CH_2OH$],, 222 (14), 105 (3), 91 (100) [$C_7H_7^+$], 77 (8) [$C_6H_5^+$], 65 (37) [$C_5H_5^+$].

Anal. Calcd for $C_{18}H_{19}NO_3$ (297.4): C, 72.71; H, 6.44; N, 4.71. Found: C, 72.78; H, 6.71; N, 4.78.

(4*S*,5*S*)-3-Benzyl-4-(hydroxymethyl)-4-methyl-5-phenyl-1,3-oxazolidin-2-one (*cis*-**10**)

The oxazolidinone *cis*-**10** was prepared from oxetane *cis*-**8a** (176 mg, 0.5 mmol) following the procedure provided for the transformation *trans*-**8a** to **9**. Purification by flash chromatography (CH–EA, 80:20) yielded the expected product in diastereomerically pure form (80 mg, 54%); R_f 0.39 (CH–EA, 40:60).

IR (KBr): ν = 3465 (s, OH), 3420 (s, OH), 3040 (w, $C_{ar}H$), 2940 (w, $C_{al}H$), 2885 (w, $C_{al}H$), 1755 cm^{-1} (vs, C=O).

^{1}H NMR (300 MHz, DMSO-d_6): δ = 1.14 (s, 3 H, CH_3), 2.81 (dd, 1 H, *J* = 11.7 Hz, *J* = 4.3 Hz, C*H*HOH), 3.16 (dd, 1 H, *J* = 11.7 Hz, *J* = 4.3 Hz, CH*H*OH), 4.18 (d, 1 H, *J* = 16.1 Hz, C*H*HPh), 4.55 (d, 1 H, *J* = 16.1 Hz, CH*H*Ph), 4.80 (t, 1 H, *J* = 4.3 Hz, CH_2OH), 5.30 (s, 1 H, PhC*H*O), 7.20–7.43 (m, 10 H_{arom}).

^{1}H NOE (300 MHz, DMSO-d_6): H (1.14): $H_{(5.30)}$ [1.7%], H (5.30): $H_{(1.14)}$ [1.7%].

^{13}C NMR (75.5 MHz): δ = 20.2 (q, CH_3), 44.3 (t, CH_2Ph), 61.8 (t, CH_2OH), 65.7 (s, CCH_3), 84.4 (d, PhCHO), 126.9 (d, $C_{ar}H$), 127.0 (d, $C_{ar}H$), 127.0 (d, $C_{ar}H$), 127.4 (d, $C_{ar}H$), 128.1 (d, $C_{ar}H$), 128.4 (d, $C_{ar}H$), 135.5 (s, C_{ar}), 139.1 (s, C_{ar}), 158.8 (s, CO).

MS (EI, 70 eV): *m*/*z* (%) = 266 (61) [$M^+ - CH_2OH$], 222 (12), 91 (100) [$C_7H_7^+$], 77 (3) [$C_6H_5^+$], 65 (6) [$C_5H_5^+$].

Anal. Calcd for $C_{18}H_{19}NO_3$ (297.4): C, 72.71; H, 6.44; N, 4.71. Found: C, 72.75; H, 6.58; N, 4.72.

Acknowledgements

This work was supported by the Deutsche Forschungsgemeinschaft (Ba 1372/3–2) and by the Fonds der Chemischen Industrie.

References

(1) (a) Paternò, E.; Chieffi, G. *Gazz. Chim. Ital.* **1909**, *39*, 341. (b) Büchi, G.; Inman, C. G.; Lipinsky, E. S. *J. Am. Chem. Soc.* **1954**, *76*, 4327.

(2) Reviews: (a) Mattay, J.; Conrads, R.; Hoffmann, R. In *Methoden der Organischen Chemie (Houben-Weyl)*, 4th ed., Vol. E 21c; Helmchen, G.; Hoffmann, R. W.; Mulzer, J.; Schaumann, E.; Eds, , Eds.; Thieme: Stuttgart, **1995**, 3133. (b) Porco, J. A.; Schreiber, S. L. In *Comprehensive Organic Synthesis*, Vol. 5; Trost, B., Ed.; Pergamon: Oxford, **1991**, 151. (c) Carless, H. A. J. In *Synthetic Organic Photochemistry*; Horspool, W. M., Ed.; Plenum Press: New York, **1984**, 425. (d) Jones, G. In *Organic Photochemistry*, Vol. 5; Padwa, A., Ed.; Marcel Dekker: New York, **1981**, 1.

(3) Reviews: (a) Bach, T. *Liebigs Ann./Recueil* **1997**, 1627. (b) Bach, T. *Synthesis* **1998**, 683.

(4) (a) Bach, T.; Jödicke, K.; Kather, K.; Fröhlich, R. *J. Am. Chem. Soc.* **1997**, *119*, 2437. (b) Bach, T.; Eilers, F. *Eur. J. Org. Chem.* **1998**, 2161.

(5) Review: Bach, T. *Synlett* **2000**, 1699.

(6) (a) Omura, S.; Murata, M.; Imamura, N.; Iwai, Y.; Tanaka, H.; Furusaki, A.; Matsumoto, T. *J. Antibiot.* **1984**, *37*, 1324. (b) Kawahata, Y.; Takatsuto, S.; Ikekawa, N.; Murata, M.; Omura, S. *Chem. Pharm. Bull.* **1986**, *34*, 3102.

(7) (a) Bach, T.; Schröder, J. *Tetrahedron Lett.* **1997**, *38*, 3707. (b) Bach, T.; Schröder, J. *J. Org. Chem.* **1999**, *64*, 1265.

(8) Kawanisi, M.; Kamogawa, K.; Okada, T.; Nozaki, H. *Tetrahedron* **1968**, *24*, 6557.

(9) (a) Scholz, K.-H.; Heine, H.-G.; Hartmann, W. *Tetrahedron Lett.* **1978**, *17*, 1467. (b) Sekretár, S.; Kopecky, J.; Martvon, A. *Collect. Czech. Chem. Commun.* **1982**, *47*, 1848. (c) Weuthen, M.; Scharf, H.-D.; Runsink, J. *Chem. Ber.* **1987**, *120*, 1023. (d) Weuthen, M.; Scharf, H.-D.; Runsink, J.; Vaßen, R. *Chem. Ber.* **1988**, *121*, 971.

(10) Griesbeck, A. G.; Fiege, M.; Lex, J. *Chem. Commun.* **2000**, 589.

(11) (a) Döpp, D.; Memarian, H. R.; Fischer, M. A.; vanEijk, A. M. J.; Varma, C. A. G. O. *Chem. Ber.* **1992**, *125*, 983. (b) Döpp, D.; Fischer, M.-A. *Recl. Trav. Chim. Pays-Bas* **1995**, *114*, 498.

(12) (a) Bach, T. *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 884. (b) Bach, T.; Schröder, J. *Liebigs Ann./Recueil* **1997**, 2265. (c) Bach, T.; Schröder, J.; Brandl, T.; Hecht, J.; Harms, K. *Tetrahedron* **1998**, *54*, 4507. (d) Bach, T.; Schröder, J.; Harms, K. *Tetrahedron Lett.* **1999**, *40*, 9003. (e) Bach, T.; Brummerhop, H. *Angew. Chem., Int. Ed. Engl.* **1998**, *37*, 3400. (f) Achenbach, T. V.; Brummerhop, H.; Bach, T.; Slater, E. P.; Müller, R. *Antimicrob. Agents Chemother.* **2000**, *44*, 2794. (g) Bach, T.; Brummerhop, H.; Harms, K. *Chem.–Eur. J.* **2000**, *6*, 3838.

(13) Bach, T. *Liebigs Ann. Chem.* **1995**, 855.

(14) Cornforth, J.; Patrick, V. A.; White, A. H. *Aust. J. Chem.* **1984**, *37*, 1453.

(15) Texier-Boullet, F. *Synthesis* **1985**, 679.

(16) Meth-Cohn, O.; Westwood, K. T. *J. Chem. Soc., Perkin Trans 1* **1984**, 1173.

(17) Eliel, E. L.; Wilen, S. H. *Stereochemistry of Organic Compunds*; Wiley: New York, **1994**, 696.

(18) Bach, T.; Jödicke, K. *Chem. Ber.* **1993**, *126*, 2457.

(19) (a) Griesbeck, A. G.; Stadtmüller, S. *J. Am. Chem. Soc.* **1990**, *112*, 1281. (b) Griesbeck, A. G.; Stadtmüller, S. *J. Am. Chem. Soc.* **1991**, *113*, 6923.

(20) Griesbeck, A. G.; Mauder, H.; Stadtmüller, S. *Acc. Chem. Res.* **1994**, *27*, 70.

(21) Still, W. C.; Kahn, M.; Mitra, A. J. *J. Org. Chem.* **1978**, *43*, 2923.

(22) Armesto, D.; Soledad, S.; Horspool, W. M.; Martin, J.-A. F.; Martinez-Alcazar, P.; Perez-Ossorio, R. *J. Chem. Soc., Perkin Trans. 1* **1989**, 751.

(23) Willoughby, C. A.; Buchwald, S. L. *J. Am. Chem. Soc.* **1994**, *116*, 8952.