Functionalized Carbosilane Dendritic Species as Soluble Supports in Organic Synthesis

Neldes J. Hovestad, Allan Ford, Johann T. B. H. Jastrzebski, and Gerard van Koten*

Debye Institute, Department of Metal-Mediated Synthesis, Utrecht University, Padualaan 8, 3584 CH Utrecht, The Netherlands

g.vankoten@chem.uu.nl

Received November 4, 1999

A new methodology, which is compatible with the use of reactive organometallic reagents, has been developed for the use of carbosilane dendrimers as soluble supports in organic synthesis. Hydroxy-functionalized dendritic carbosilanes $Si[CH_2CH_2CH_2SiMe_2(C_6H_4CH(R)OH)]_4$ (G_0-OH, R = H or (*S*)-Me) and $Si[CH_2CH_2CH_2Si[CH_2CH_2CH_2SiMe_2(C_6H_4CH(R)OH)]_3]_4$ (G_1-OH, R = H or (*S*)-Me) were prepared and subsequently converted into the esters $Si[CH_2CH_2CH_2SiMe_2(C_6H_4CH(R)OC(O)CH_2Ph)]_4$ (R = H or (*S*)-Me) and $Si[CH_2CH_2CH_2Si[CH_2CH_2CH_2SiMe_2(C_6H_4CH(R)OC(O)CH_2C_6H_4R')]_3]_4$ (R = H and R′ = H or R = (*S*)-Me and R′ = H or R = H and R′ = Br). As an example the latter compound was functionalized under Suzuki conditions. The functionalized carboxylic acid was obtained in high yield after cleavage from the dendritic support. Moreover, the ester functionalized dendrimers were converted to the corresponding zinc enolates followed by a condensation reaction with an imine to a β-lactam in excellent yield and purity. Furthermore, it was demonstrated that a small combinatorial library of β-lactams could be prepared starting from a carbosilane dendrimer functionalized with different ester moieties. These results show that carbosilane dendrimers can be applied as soluble substrate carriers for the generation of low molecular weight organic molecules. In combination with nanofiltration techniques, separation and recycling of the dendrimers can be realized.

Introduction

In pharmaceutical chemistry the use of insoluble supports has been incorporated into numerous synthetic methodologies.[1] Central to the effectiveness of these methods is the easy removal of (excess) reagents and solvents from the support by washing. This allows the use of large reagent excesses to drive reactions to completion and so enables the efficient synthesis and purification of resin-bound products. However, often the synthetic and analytical methodologies used in solution processes are not compatible with the properties of insoluble supports. Therefore, a number of groups have looked into the use of soluble polymeric supports.[2] Janda and co-workers[3] have described the use of soluble poly(ethylene glycol) supports in the preparation of combinatorial organic libraries. A crucial feature of this method is that the compounds of interest are attached to a device that controls the solubility of the support. Through the special solubility properties of these devices the isolation of the desired material from reaction mixtures can be realized, and as a result the advantages of homogeneous-phase chemistry can be combined with the utility of solid-phase purification.

Dendritic polymers[4] are currently generating interest as soluble supports as a result of (i) their well-defined molecular composition that provides supports with precise spatial arrangement of the active reaction sites, (ii) the high loading that can be achieved at the dendrimer surface, and (iii) the possibility to apply nanofiltration techniques as an alternative approach for the separation of the dendritic support from products and reagents. The application of nanofiltration techniques allows not only the use of (large) excesses of reagents during the synthesis but also easy recycling of the support. Recently, Kim et al. described the preparation of small libraries of indoles anchored on polyamidoamine (PAMAM) dendrimers via a so-called dendrimer-supported combinatorial chemistry (DCC) approach.[5] Here, the products are

* Tel: +3130 2533120. Fax: +3130 2523615.

(1) (a) Leznoff, C. C. *Chem. Soc. Rev.* **1974**, *3*, 65. (b) Thompson, L. A.; Ellman, J. A. *Chem. Rev.* **1996**, *96*, 555. (c) Terret, N. K.; Gardner, M.; Gordon, D. W.; Kobylecki, R. J.; Steele, J. *Tetrahedron* **1995**, *51*, 8135. (d) Balkenhohl, F.; von dem Bussche-Hünnefeld, C.; Lansky, A.; Zechel, C. *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 2288. (e) Marx, M. A.; Grillot, A.-L.; Louer, C. T.; Beaver, K. A.; Bartlett, P. A. *J. Am. Chem. Soc.* **1997**, *119*, 6153. (f) Hermkens, P. H. H.; Ottenheijm, H. C. J.; Rees, D. C *Tetrahedron* **1997**, *53*, 5643. (g) Guillermo, A. M.; Corbett, J. W.; DeGrado, W. F. *J. Org. Chem.* **1998**, *63*, 1172−1177. (h) Kearney, P. C.; Fernandez, M.; Flygare, J. A. *J. Org. Chem.* **1998**, *63*, 196−200.

(2) (a) Geckeler, K.; Pillai, V. N. R.; Mutter, M. *Adv. Polym. Sci.* **1981**, *39*, 65. (b) Braca, G.; Di Girolamo, M.; Raspolli Galletti, A. M.; Sbrana, G.; Brunelli, M.; Bertolini, G. *J. Mol. Catal.* **1992**, *74*, 421. (c) Shah, J. N.; Ram, R. N. *J. Mol. Catal.* **1992**, *77*, 235. (d) van de Kuil, L. A.; Grove, D. M.; Zwikker, J. W.; Jenneskens, W.; Drenth, W.; van Koten, G. *Chem. Mater.* **1994**, *6*, 1676. (e) Bergbreiter, D. E.; Case, B. L.; Liu, Y.-S.; Caraway, J. W. *Macromolecules* **1998**, *31*, 6053.

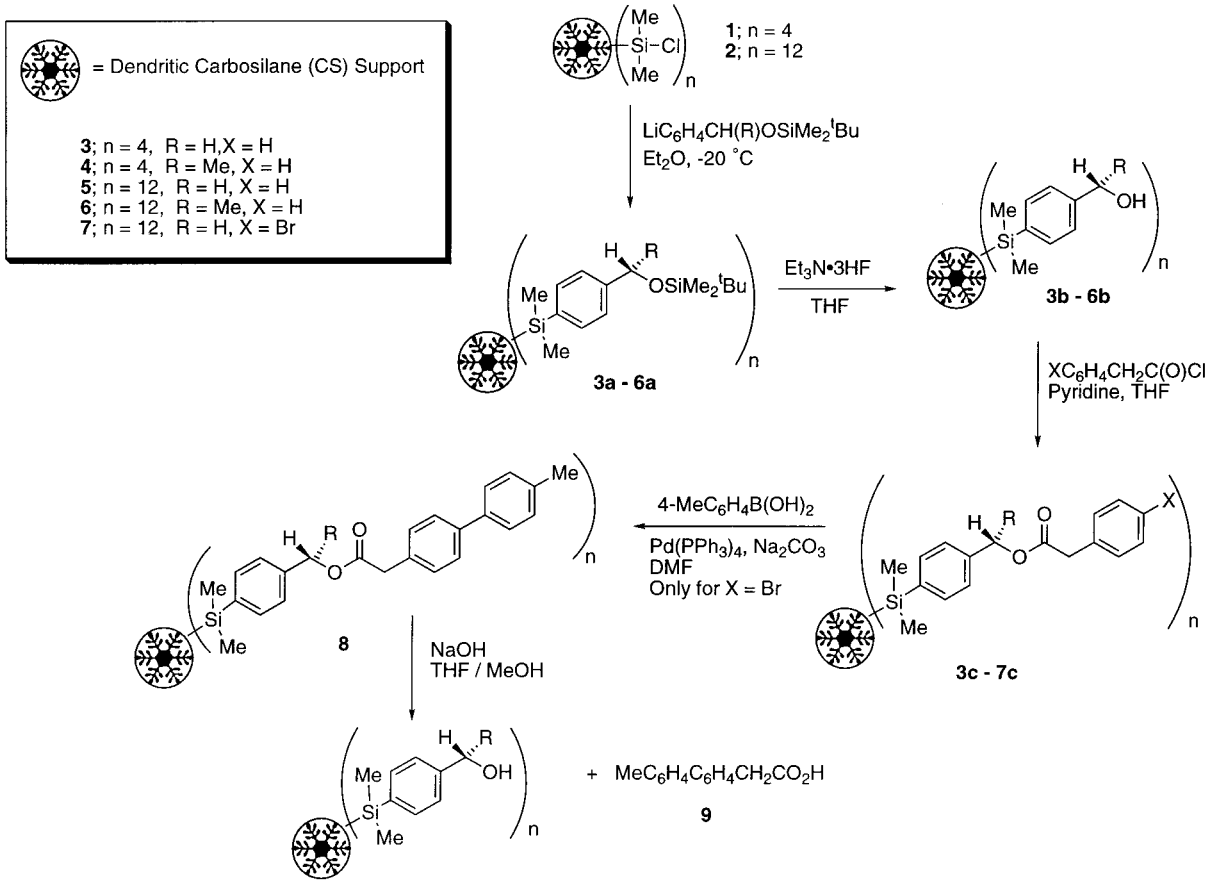
(3) Gravert, D. J.; Janda, K. D. *Chem. Rev.* **1997**, *97*, 489.

(4) (a) Tomalia, D. A.; Durst, H. D. *Top. Curr. Chem.* **1993**, *165*, 193. (b) Fréchet, J. M. J. *Science* **1994**, *263*, 1710. (c) Newkome, G. R.; Moorefield, C. N.; Vögtle, F. *Dendritic Molecules-Concepts, Synthesis, Perspectives*; VCH: Weinheim, 1996. (d) Vögtle, F. *Dendrimer Topics in Current Chemistry*; Springer-Verlag: Berlin, Heidelberg, 1998. (e) Fischer, M.; Vögtle, F. *Angew. Chem., Int. Ed. Engl.* **1999**, *38*, 884. (f) Knapen, J. W. J.; van der Made, A. W.; de Wilde, J. C.; van Leeuwen, P. W. N. W.; Wijkens, P.; Grove, D. M.; van Koten, G. *Nature* **1994**, *372*, 659. (g) van Koten, G.; Jastrzebski, J. T. B. H. *Polym. Mater. Sci. Eng.* **1997**, *77*, 75. (h) Hovestad, N. J.; Hoare, J. L.; Jastrzebski, J. T. B. H.; Canty, A. J.; Smeets, W. J. J.; Spek, A. L.; van Koten, G. *Organometallics* **1999**, *18*, 2970. (i) Wells, N. J.; Basso, A.; Bradley, M. *Biopolymers* **1998**, *47*, 381.

(5) Kim, R. M.; Manna, M.; Hutchins, S. M.; Griffin, P. R.; Yates, N. A.; Bernick, A. M.; Chapman, K. T. *Proc. Natl. Acad. Sci. U.S.A.* **1996**, *93*, 10012.

10.1021/jo991726k CCC: $19.00
Published on Web 09/01/2000

Scheme 1



assembled into an enlarged dendritic molecule and separation is achieved by molecular size.

Recently we set out to explore the use of functionalized carbosilane dendrimers as supports[6] or catalysts[7] in organic synthesis. Such dendrimers are of special interest because of their inertness toward organometallic reagents. In this paper, we describe two applications: (1) the synthesis of products at the carbosilane support and the use of the dendritic species as a leaving group in the last step, and (2) the multistep synthesis of products at the dendritic surface followed by cleavage and separation from the dendritic species.

Separation of the dendritic support from the products can be achieved by (nano)filtration techniques, which allows the recycling (i.e., multiple use) of the carbosilane support. This opens up the possibility to develop methods for the use of (soluble) dendritic supports in the continuous as well as the batch-wise production of organic compounds.

Results and Discussion

Synthesis of Functionalized Dendrimers. Recently we have shown that Me_2SiCl terminated carbosilane dendritic molecules, i.e., $Si[CH_2CH_2CH_2SiMe_2Cl]_4$ (**1**) and $Si[CH_2CH_2CH_2Si(CH_2CH_2CH_2SiMe_2Cl)_3]_4$ (**2**), are valuable starting materials for the synthesis of functionalized dendrimers and are readily available via a hydrosilylation reaction of allyl terminated corbosilane dendrimers[8] and dimethylchlorosilane. The presence of terminal SiCl functionalities in these molecules allows the straightforward introduction of functional molecules, via an organolithium or Grignard route.[9]

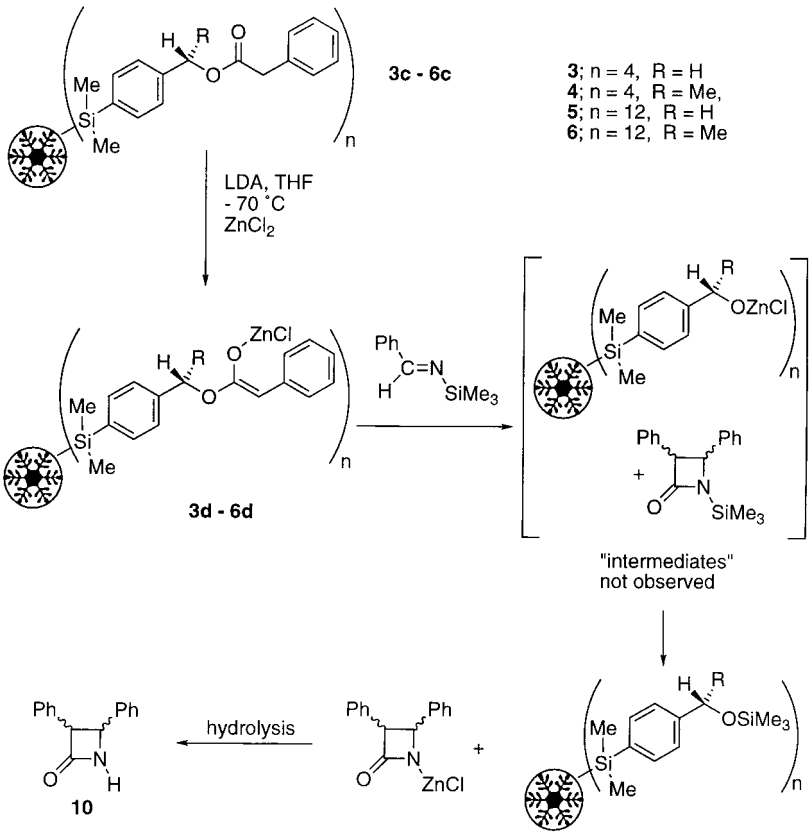
Using a similar approach we have synthesized the 4-(hydroxymethyl)phenyl substituted derivatives of **1** and **2**. The alcohol moieties in the obtained products may be regarded as the connecting functionalities to which a variety of organic substrates can be immobilized via, e.g., ester formation. In this respect it should be noted that we recently reported the synthesis of 4-(bromomethyl)-phenyl functionalized derivatives of **1** and **2** and its subsequent conversion into aryl ether derivatives.[4h]

Reaction of **1** or **2** with 4-lithiobenzyl *tert*-butyldimethylsilyl ether or (*S*)-4-lithio-α-methylbenzyl *tert*-butyldimethylsilyl ether afforded the protected 4-(hydroxymethyl)phenyl functionalized dendritic compounds **3a**−**6a** (see Scheme 1) in high yield. These new compounds were fully characterized by ^1H and ^{13}C NMR, elemental analysis, and MALDI-TOF-MS; see Experimental Section.

Removal of the protecting group, according to the reaction conditions in Scheme 1, afforded after workup the 4-(hydroxymethyl)phenyl substituted dendrimers **3b**−**6b** in high yield (see Experimental Section) and were fully characterized by ^1H and ^{13}C NMR, elemental analysis, and MALDI-TOF-MS. Subsequent reaction of

(6) Hovestad, N. J.; Jastrzebski, J. T. B. H.; van Koten, G. *Polym. Mater. Sci. Eng.* **1999**, *80*, 53.
(7) Hovestad, N. J.; Eggeling, E. B.; Heidbüchel, J. H.; Jastrzebski, J. T. B. H.; Kragl, U.; Keim, W.; Vogt, D.; van Koten, G. *Angew. Chem., Int. Ed.* **1999**, *38*, 1655.
(8) Van der Made, A. W.; van Leeuwen, P. W. M. N. *J. Chem. Soc., Chem. Commun.* **1992**, 1400.
(9) Wijkens, P.; Jastrzebski, J. T. B. H.; van der Schaaf, P. A.; Kolly, R.; Hafner, A.; van Koten, G. *Org. Lett.* **2000**, *2*, 1621.

Scheme 2



3b−**6b** with phenylacetyl chloride in the presence of pyridine in THF results in the formation of the dendritic esters **3c**−**6c** as light-yellow, viscous oils in high yield. For their full characterization, see Experimental Section. The 4-bromobenzyl ester **7c** was obtained from reaction of **5b** with (4-bromophenyl)acetyl chloride according to the reaction conditions given above.

Application of Functionalized Dendrimers as Substrate Carriers in Organic Reactions. To demonstrate the feasibility of functionalizing the dendrimer immobilized esters according to a procedure using insoluble supports, e.g., the Suzuki coupling (see ref 10 for precedents), **7c** was reacted with 4-methylphenyl boronic acid in the presence of $[Pd(PPh_3)_4]$ and Na_2CO_3 (see Scheme 1) to afford **8** in 80% yield (see Experimental Section). The funcionalized carboxylic acid, i.e., 4-(4-tolyl)phenylcarboxylic acid, **9**, was obtained in quantitative yield after basic hydrolysis of **8**, together with the 4-(hydroxymethyl)phenylcarbosilane carrier **5b** (see Scheme 1).

Previously we have investigated in detail the zinc mediated condensation of esters with imines to β-lactams.[11] This reaction involves several steps, and therefore it was a challenge to perform this multistep reaction using dendrimers as a substrate carrier, i.e., with esters connected to the periphery of a dendrimer. Moreover, at least to our knowledge, there are no precedents for this specific reaction, using solid or soluble supports.[12]

Deprotonation of one of the ester functionalized dendrimers **3c**−**6c** with LDA in THF at −78 °C and subsequent transmetalation with $ZnCl_2$ affords the corresponding zinc-enolate **3d**−**6d**, see Scheme 2. Figure 1 shows a schematic representation of the zinc-enolate derived from **5c**. Previously we have shown that usually zinc ester enolates are aggregated species.[13] Because **3d**−**6d** contain several zinc-enolate moieties, at forehand it cannot be excluded that inter- and intramolecular aggregation occurs, resulting in polymeric structures. However, because we observed that under the reaction conditions (−78 °C, THF) the resulting solutions remain homogeneous, such phenomena most probably does not occur. A possible explanation could be that intramolecular aggregation of suitable zinc enolate units with a proper spatial arrangement occurs as well as of zinc enolate units with lithium and zinc halides present in solution.

The in situ generated zinc-enolates were not isolated but reacted as such with *N*-(trimethylsilyl)phenylimine. The first step of this condensation reaction involves C−C bond formation resulting in a β-amino ester that is still

(10) (a) Backes, B. J.; Ellman, J. A. *J. Am. Chem. Soc.* **1994**, *116*, 11171. (b) Ruhland, B.; Bombrun, A.; Gallop, M. A. *J. Org. Chem.* **1997**, *62*, 7820. (c) Fenger, I.; Le Drian, C. *Tetrahedron Lett.* **1998**, *39*, 4287. (d) Wendeborn, S.; Berteina, S.; Brill, W. K.-D.; De Mesmaeker, A. *Synlett* **1998**, 671.

(11) (a) Jastrzebski, J. T. B. H.; van der Steen, F. H. van Koten, G. *Recl. Trav. Chim. Pays-Bas*, **1987**, *106*, 516. (b) Jastrzebski, J. T. B. H.; van Koten, G. *Bioorg. Med. Chem. Lett.* **1993**, *3*, 2351. (c) van Maanen, H. L.; Kleijn, H.; Jastrzebski, J. T. B. H.; Verweij, J.; Kieboom, A. P. G.; van Koten, G. *J. Org. Chem.* **1995**, *60*, 4331.

(12) Recently, Ruhland et al. reported the solid-phase combinatorial synthesis of β-lactams via a [2 + 2] cycloaddition reaction of ketenes with resin-bound imines derived from amino acids. Ruhland, B.; Bhandari, A.; Gordon, E. M.; Gallop, M. A. *J. Am. Chem. Soc.* **1996**, *118*, 253.

(13) (a) van der Steen F. H.; Boersma, J.; Spek, A. L.; van Koten, G. *J. Organomet. Chem.* **1990**, *390*, C21. (b) van der Steen, F. H.; Boersma, J.; Spek, A. L.; van Koten, G. *Organometallics* **1991**, *10*, 2468. (c) Kleijn, H.; van Maanen, H. L.; Jastrzebski, J. T. B. H.; van Koten, G. *Recl. Trav. Chim. Pays-Bas* **1992**, *111*, 497. (d) van Maanen, H. L.; Kleijn, H.; Jastrzebski, J. T. B. H.; van Koten, G. *Recl. Trav. Chim. Pays-Bas* **1994**, *113*, 567.

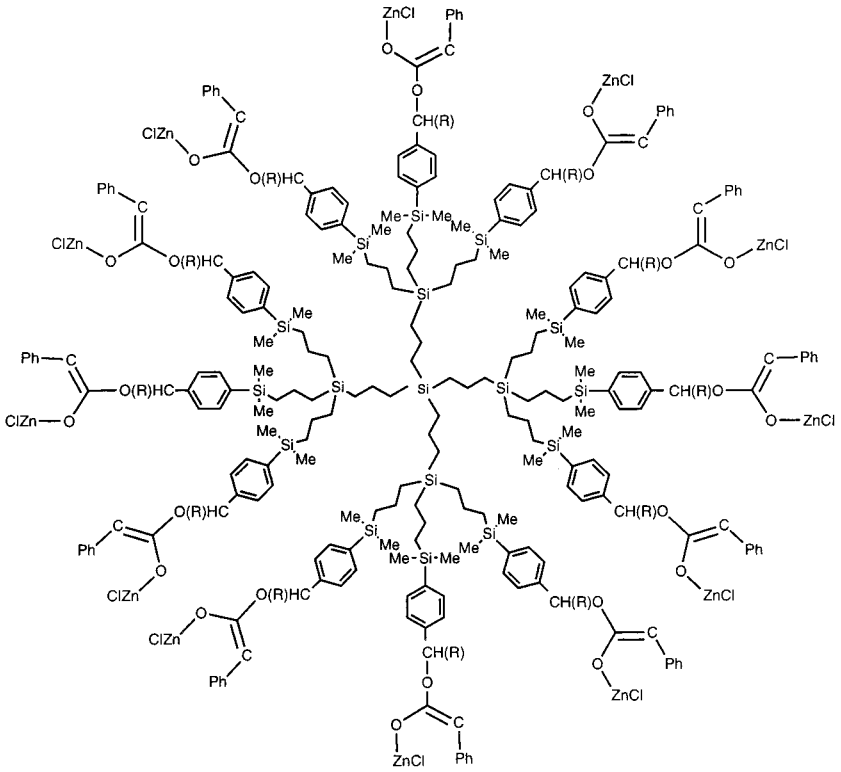


Figure 1.

Table 1. Synthesis of *trans*-*β*-Lactams via a Soluble Dendritic G_0 and G_1 Carbosilane[a]

entry	ester[a]	conv.	de [%]	ee [%][b]
1	**3c**, R = H	95	>95	
2	**4c**, R = Me	83	>95	31
3	**5c**, R = H	80	>95	
4	**6c**, R = Me	82	>95	30

[a] See Scheme 3. [b] HPLC using Diacel chiralcel OD column; eluents hexane/*i*-PrOH, 99:1; flow 1 mL/min.

connected to the dendrimer backbone via the ester linkage. In the second step a spontaneous ring-closure reaction occurs, resulting in a *β*-lactam with concomitant cleavage from the carbosilane support (see Scheme 2). It should be noted that the alcoholate moieties present at the peripheric sites of the carbosilane backbone might be regarded as the leaving groups. Initially, a *N*-trimethylsilyl-*β*-lactam is formed and the zinc ions are present in the form of zinc-alcoholate moieties connected to the carbosilane dendrimer. These species, however, were not observed, but a concomitant transmetalation reaction, i.e., the exchange of ZnCl and Me_3Si results, after hydrolysis, in the formation of *β*-lactam **10** and the trimethylsilyl derivative of **3b**−**6b**. After separation of the product from the trimethylsilyl functionalized substrate carrier, vide infra, **10** was isolated and was identified by ^{1}H and ^{13}C NMR and HPLC (see Table 1).

As expected for zinc-enolates[14] the *β*-lactam formation is highly *trans* selective, de > 95%. The moderate enantioselectivity (approximately 30%) observed for the reactions starting from the enantiopure ester **4c** or **6c** is not unexpected. In a separate experiment it was shown that reaction of the zinc-enolate derived from the enantiopure 1-phenylethanol ester of phenylacetic acid affords *β*-lactam **10** with identical diastereoselectivity (de 95% *trans*) and enantioselectivity (30%). Furthermore, it has been well established that the enantioselectivity of the zinc mediated condensation of enantiopure menthyl and bornyl esters with imines to *β*-lactams never exceeds 35%.[15]

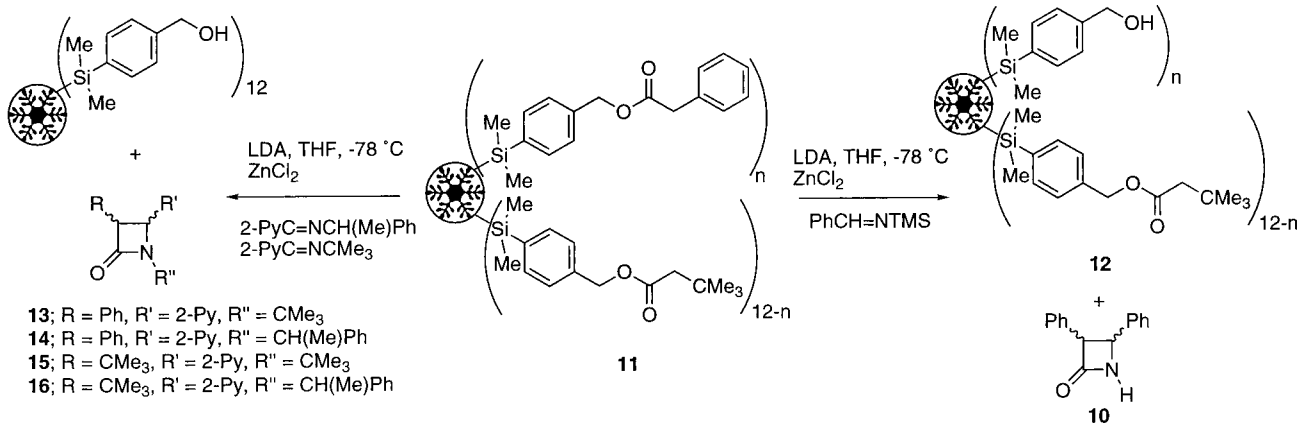
From the above-mentioned observations (see Table 1) it might be concluded that the use of carbosilanes as substrate carriers for the zinc mediated synthesis of *β*-lactams might be an alternative for the conventional route, i.e., the use of common esters, especially when the recovery of the alcohol moiety is required, e.g., when an expensive enantiopure alcohol is used. Moreover, the developed methodology might be advantageous from an environmental point of view, i.e., recovery and reuse (vide infra) of material that otherwise would be treated as chemical waste.

So far, for analytical purposes, separation and purification of the products, i.e., *β*-lactam **10**, and the trimethylsilyl ether functionalized dendrimer was performed making use of preparative GPC techniques (Sephadex LH-20). The application of membrane technology (nanofiltration) would be a large improvement. It should be noted, however, that the current commercially available membranes with a proper permeability are not or almost are not compatible with the applied reaction conditions, especially the use of organic solvents. Preliminary retention measurement experiments using a MPF-60 NF membrane, however, have shown that under proper conditions the functionalized dendrimers **5b** and **6b** are

(14) The excellent *cis*-*trans* selectivity was rationalized via a six-membered cyclic transition state, involving a (*Z*)-enolate and a (*E*)-imine, analogous to the transition state models for the related aldol reaction. See: Evans, D. A.; Nelson, J. V.; Taber, T. R. *Top. Stereochem.* **1982**, *13*, 1. Seebach, D. *Angew. Chem.* **1988**, *100*, 1685.

(15) van der Steen, H.; Kleijn, H.; Britovsek, G. J.; Jastrzebski, J. T. B. H.; van Koten, G. *J. Org. Chem.* **1992**, *57*, 3906.

Scheme 3



of sufficient size to be retained to a large extend. Recently we have shown that this type of membranes can be applied in a membrane reactor to retain a palladium catalyst immobilized at the peripheric sites of a carbosilane dendrimer to perform the hydrovinylation reaction of styrene with ethylene in a continueous process.[7]

The recovered trimethylsilyl ether derivatives of **3b**−**6b** can easily be reused as a substrate carrier because reaction of these compounds with an appropriate acid chloride affords the ester functionalized carbosilane dendrimer and Me_3SiCl in a straightforward reaction.

To demonstrate the feasibility to use carbosilane dendrimers as substrate carriers in a combinatorial approach we have synthesized an ester functionalized dendrimer containing two different ester moieties. Reaction of **5b** with a 1:1 mixture of phenylacetic acid chloride and pivaloyl chloride resulted after workup (see experimental part) in the formation of **11** (Scheme 3). A statistical mixture, *n* varying from 0 to 12, is expected. MALDI-TOF-MS analysis of **11** showed the presence of peaks that could be assigned to the presence of species for which $n = 5$, 6, and 7 (see Scheme 3).

Deprotonation of **11** with LDA and subsequent transmetalation with $ZnCl_2$ afforded after reaction with a 1:1 mixture of 2-PyCH═NCH(Me)Ph and 2-PyCN═NCMe$_3$ all four possible β-lactams, **13**−**16**, in equal amounts with an overall yield of 85% (see Scheme 3). A proper choice of a combination of imines is important because only certain combinations of ester-enolate and imine are reactive. It appeared, for example, that the zinc-enolate derived from pivalic acid is not reactive toward *N*-(trimethylsilyl)phenylimine. On the other hand, this "mismatch" in reactivity can be used to remove selectively particular ester groups from ester functionalized carbosilanes and opens the opportunity for the development of carbosilane dendrimers containing different functional groups at the periphery. Reaction of **11**, according to the reaction conditions given above with *N*-(trimethylsilyl)-phenyimine affords after hydrolysis β-lactam **10** together with **12**. MALDI-TOF-MS analysis of **12** showed the presence of peaks that could be assigned to presence of species for which $n = 5$, 6, and 7 (see Scheme 3), indicating that the pivaloyl moieties remain unaffected. The potential of these partly functionalized dendrimers and the introduction of a "second" functional group, e.g., to control the solubility properties of these materials, is currently under investigation.

Conclusion

We have presented a method to use functionalized carbosilane dendrimers as soluble supports in organic synthesis, using ester enolate-imine condensation and preparation of functionalized carboxylic acids as examples. To our knowledge, the present method is the first example of using a carbosilane dendritic species as a support in organic synthesis.

This study has shown that the use of dendritic soluble supports is of interest in repetitive batch or continuous processes for organic product formation. In our present study we used carbosilane dendritic species having only one functional group per peripheral Si-site. This approach was chosen to ensure that each site could be independently addressed during the subsequent synthetic step and no interactions between sites could occur. We are currently studying the influence on the synthetic procedures when the remaining sites at each peripheral Si-site also are used. We are also working to explore the use of dendritic supports in organic synthesis, as support or catalyst, and to isolate the dendrimer from the products in a membrane reactor to allow for reuse of the dendritic support. However, more stable nanofiltration membranes have to become available to assist the further development of this potentially important field in homogeneous phase supported organic synthesis and catalysis.

Experimental Section

General. All reactions were carried out using standard Schlenk techniques under an inert atmosphere of dry, oxygen-free nitrogen unless otherwise stated. Et_2O, THF, and hexane were carefully dried and distilled from Na/benzophenone prior to use. CH_2Cl_2 was distilled from CaH_2. Diisopropylamine was distilled at atmospheric pressure and stored over molecular sieves (3 Å). All other standard chemicals were purchased from ACROS Chimica or Aldrich Chemical Co. and used without further purification. Imines were prepared according literature procedures.[16] Dry $ZnCl_2$ was prepared via a literature procedure[17] and used as a 1.0 M stock solution in Et_2O. *n*-Butyllithium was obtained as a 1.6 M solution in hexanes from Aldrich. The starting materials 4-bromobenzyl *tert*-butyldimethylsilyl ether[18] and (*S*)-4-bromo-α-methyl

(16) Dayagi, S.; Degani, Y. *The Chemistry of the Carbon*−*Nitrogen Double Bond*; Patai, S., Ed.; Interscience: London, 1970; p 61.
(17) Hamilton, R. T.; Butler, J. A. *J. Chem. Soc.* **1932**, 2283.
(18) Brunner, J.; Richards, F. M. *J. Biol. Chem.* **1981**, *225*, 3319.

benzyl *tert*-butyldimethylsilyl ether[19] were prepared as previously described. The carbosilane dendrimers were prepared according to literature procedures.[8] GPC was performed on a 1.0 cm × 20 cm column using Sephadex LH-20 as the stationary phase and THF as the eluent. FAB-MS spectra were recorded either on a JEOL JMS SX/SX 102A four-sector mass spectrometer, operated at 10 kV accelerating voltage, equipped with a JEOL MS-FAB 10 D FAB gun operated at a 5 mA emission current, producing a beam of 6 keV xenon atoms, or a JEOL JMS AX 505 spectrometer, operated at 3 kV accelerating voltage, equipped with a JEOL MS-FAB 10 D FAB gun operated at a 10 mA emission current, producing a beam of 6 keV xenon. MALDI-TOF-MS spectra were acquired using a Voyager-DE BioSpectrometry Workstation (PerSeptive Biosystems Inc) mass spectrometer equipped with a nitrogen laser emitting at 337 nm. The instrument was operated in the linear mode at an accelerating voltage in the range 23 000−25 000 V. External calibration was performed using insulin (bovine), and detection was done by means of a linear detector and a digitizing oscilloscope operating at 500 MHz. Sample solutions with ∼30 mg/mL in THF were used, and the matrix was 3,5-dihydroxybenzoic acid in THF (36 mg/mL). A solution of sodium acetate in THF or a solution of silver(I) trifluoroacetate in THF was added to the sample to improve the peak resolution. The sample solution (0.2 μL) and the matrix solution (0.2 μL) were combined and placed on a gold MALDI target and analyzed after evaporation of the solvents. Elemental microanalysis were obtained from Dornis und Kolbe Mikroanalytisches Laboratorium, Mülheim a.d. Ruhr, Germany.

Synthesis of Si{(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH$_2$OSiMe$_2$*t*Bu}$_4$ (3a). To a solution of BrC$_6$H$_4$CH$_2$OSiMe$_2$*t*Bu (10.00 g, 33.2 mmol) in Et$_2$O (50 mL) was added *tert*-butyllithium (40.3 mL, 1.63 M solution in pentane, 65.7 mmol) at −78 °C. After the addition was complete, the solution was stirred for 30 min at −78 °C and then allowed to rise to −20 °C. A solution of G$_0$-SiMe$_2$Cl **1** (4.68 g, 8.23 mmol) in Et$_2$O (15 mL) was then added, and the mixture was stirred overnight at room temperature. The organic layer was separated, and the water layer was extracted with Et$_2$O (3 × 50 mL). The combined organic layers were dried over Na$_2$SO$_4$, and the solvent was removed in vacuo. The residue was purified by Kugelrohr distillation (140 °C, 0.5 mmHg) to give a slightly yellow viscous oil. Yield: 9.61 g, 7.23 mmol, 89%. Anal. Calcd for C$_{72}$H$_{132}$O$_4$Si$_9$ (1314.6): C, 65.78; H, 10.12; Si, 19.23. Found: C, 65.76; H, 10.11; Si, 19.15. ^{1}H NMR (CDCl$_3$; 298K): δ 7.48 (d, J = 7.9, 8H), 7.33 (d, J = 7.8, 8H), 4.76 (s, 8H), 1.33 (m, 8H), 0.94 (s, 36H), 0.79 (t, J = 7.9, 8H), 0.52 (t, J = 8.2, 8H), 0.25 (s, 24H), 0.13 (s, 24H). ^{13}C{^{1}H} NMR (CDCl$_3$, 298K): δ 142.0, 138, 133.5, 125.4, 65.0, 26.1, 20, 18.6, 18.5, 17.5, −2.7, −5.2. MALDI-TOF-MS *m*/*z*: 1421.4 [G$_0$-CH$_2$OSiMe$_2$*t*Bu + Ag]$^+$ (calcd 1421.7).

Synthesis of Si{(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH(Me)OSiMe$_2$*t*Bu}$_4$ (4a). The procedure was identical to that described for **3a**, starting from (*S*)-BrC$_6$H$_4$CH(Me)OSiMe$_2$*t*Bu (3.06 g, 9.7 mmol), *t*-BuLi (10.7 mL, 1.5 M solution in pentane, 16.1 mmol), and G$_0$-SiMe$_2$Cl **1** (1.01 g, 1.77 mmol). A slightly yellow viscous oil was obtained, yield 1.94 g (1.42 mmol, 80%). Anal. Calcd for C$_{72}$H$_{132}$O$_4$Si$_9$ (1370.7): C, 66.59; H, 10.29; Si, 18.44. Found: C, 66.65; H, 10.26; Si, 18.31. ^{1}H NMR (CDCl$_3$; 298K): δ 7.45 (d, J = 7.9, 8H), 7.32 (d, J = 7.9, 8H), 4.88 (q, J = 6.3, 4H), 1.42 (d, J = 6.3, 3H), 1.34 (m, 8H), 0.94 (s, 36H), 0.79 (t, J = 8.1, 8H), 0.52 (t, J = 8.2, 8H), 0.25 (s, 24H), 0.08 (s, 24H), 0.00 (s, 24H). ^{13}C{^{1}H} NMR (CDCl$_3$, 298K): δ 147.4, 137.7, 133.4, 124.5, 70.7, 27.2, 25.9, 20.7, 18.6, 18.3, 17.4, −2.7, −4.7. FAB-MS *m*/*z*: 1369.8 [G$_0$-CH(Me)OSiMe$_2$*t*Bu + H]$^+$ (calcd 1368.9). $[\alpha]^{20}_D$ = −40° (*c* 9.2, CHCl$_3$).

Synthesis of Si{(CH$_2$)$_3$Si[(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH$_2$OSiMe$_2$*t*Bu]$_3$}$_4$ (5a). The procedure was identical to that described for **3a**, starting from BrC$_6$H$_4$CH$_2$OSiMe$_2$*t*Bu (4.37 g, 14.5 mmol), *t*-BuLi (18.5 mL, 1.5 M solution in pentane, 27.8 mmol), and G$_1$-SiMe$_2$Cl **2** (2.00 g, 1.03 mmol). A slightly yellow viscous oil was obtained, yield 3.48 g (0.84 mmol, 82%). Anal. Calcd for C$_{228}$H$_{396}$O$_{12}$Si$_{29}$ (4168.3): C, 65.70; H, 10.16; Si, 19.54. Found: C, 65.56; H, 10.12; Si, 19.47. ^{1}H NMR (CDCl$_3$; 298K): δ 7.44 (d, J = 7.9, 24H), 7.29 (d, J = 7.7, 24H), 4.72 (s, 24H), 1.39−1.25 (m, 32H), 0.95 (s, 108H), 0.78 (t, J = 8, 24H), 0.55 (m, 40H), 0.21 (s, 72H), 0.11 (s, 72H). ^{13}C{^{1}H} NMR (CDCl$_3$, 298K): δ 142.0, 138.1, 133.5, 125.4, 64.9, 26.0, 20.7, 18.6, 18.5, 18.2, 17.7, 17.5, −2.7, −5.2. MALDI-TOF-MS *m*/*z*: 4278.4 [G$_1$-CH$_2$OSiMe$_2$*t*Bu + Ag]$^+$ (calcd 4277.2).

Synthesis of Si{(CH$_2$)$_3$Si[(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH(Me)OSiMe$_2$*t*Bu]$_3$}$_4$ (6a). The procedure was identical to that described for **3a**, starting from (*S*)-BrC$_6$H$_4$CH(Me)OSiMe$_2$*t*Bu (1.76 g, 5.6 mmol), *t*-BuLi (5.6 mL 1.5 M solution in pentane, 16.1 mmol), and G$_1$-SiMe$_2$Cl **2** (0.60 g, 0.31 mmol). A slightly yellow viscous oil was obtained, yield 1.21 g (0.28 mmol, 90%). Anal. Calcd for C$_{228}$H$_{396}$O$_{12}$Si$_{29}$ (4336.7): C, 66.47; H, 10.32; Si, 18.78. Found: C, 66.31; H, 10.26; Si, 18.60. ^{1}H NMR (CDCl$_3$; 298K): δ 7.42 (d, J = 7.9, 24H), 7.29 (d, J = 7.8, 24H), 4.86 (q, J = 6.2), 1.43 (d, J = 6.0, 36H), 1.38 (m, 32H), 0.92 (s, 108H), 0.80 (t, J = 8.0, 24H), 0.55 (m, 40H), 0.22 (s, 72H), 0.06 (s, 72H), −0.02 (s, 72H). ^{13}C{^{1}H} NMR (CDCl$_3$, 298K): δ 147.3, 137.7, 133.3, 124.5, 70.7, 27.2, 25.9, 20.7, 18.7, 18.3, 17.7, 17.5, −2.7, −5.2. MALDI-TOF-MS *m*/*z*: 4444.6 [G$_1$-CH(Me)OSiMe$_2$*t*Bu + Ag]$^+$ (calcd 4444.6). $[\alpha]^{20}_D$ = −37 ° (*c* 4.7, CHCl$_3$).

Synthesis of Si{(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH$_2$OH}$_4$ (3b). To a solution of **3a** (6.22 g, 4.74 mmol) in THF (30 mL) was added dropwise a solution of triethylamine trihydrofluoride (4.59 g, 28.4 mmol). After the addition was complete the reaction mixture was stirred overnight at room temperature. The volatiles were removed in vacuo, and CH$_2$Cl$_2$ (50 mL) and aqueous NaOH (50 mL, 3 M) were added. The organic layer was separated and washed with aqueous NaOH (2 × 30 mL, 3 M). The combined organic layers were extracted with H$_2$O/CO$_2$ (s) (2 × 50 mL). The organic layer was dried over Na$_2$SO$_4$, and the solvent was removed in vacuo. A slightly yellow oil was obtained. Yield: 3.00 g, 3.51 mmol, 74%. ^{1}H NMR (CDCl$_3$; 298K): δ 7.48 (d, J = 7.9 8H), 7.31 (d, J = 7.9, 8H), 4.62 (s, 8H), 2.21 (b s, 1H), 1.29 (m, 8H), 0.76 (t, J = 8.0, 8H), 0.50 (t, J = 8.2, 8H), 0.24 (s, 24H). ^{13}C{^{1}H} NMR (CDCl$_3$, 298K): δ 141.4, 139.1, 133.8, 126.4, 65.2, 20.6, 18.6, 17.4, −2.8. FAB-MS *m*/*z*: 879.4 [G$_0$-CH$_2$OH + Na]$^+$ (calcd 879.5). IR (CCl$_4$): 3330 cm^{-1} (OH).

Synthesis of Si{(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH(Me)OH}$_4$ (4b). The procedure was identical to that described for **3b**, starting from **4a** (2.36 g, 0.57 mmol) in THF (20 mL) and triethylamine trihydrofluoride (1.65 g, 10.25 mmol). The reaction mixture was heated under reflux overnight. A slightly yellow oil was obtained. Yield: 0.85 g, 0.46 mmol, 81%. ^{1}H NMR (CDCl$_3$; 298K): δ 7.48 (d, J = 7.8, 8H), 7.33 (d, J = 7.6, 8H), 4.85 (q, J = 6.7, 4H), 2.27 (s, 4H), 1.47 (d, J = 6.4, 12H), 1.31 (m, 8H), 0.79 (t, J = 8.1, 8H), 0.52 (t, J = 8.4, 8H), 0.25 (s, 24H). ^{13}C-{^{1}H} NMR (CDCl$_3$, 298K): δ 146.4, 138.7, 133.8, 124.6, 70.3, 25.0, 20.6, 18.6, 17.4, −2.8. FAB-MS: 935.5 [G$_0$-CH(Me)OH + Na]$^+$ (calcd 935.5). IR (CCl$_4$): 3320. $[\alpha]^{20}_D$ = −24° (*c* 2.9, CHCl$_3$).

Synthesis of Si{(CH$_2$)$_3$Si[(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH$_2$OH]$_3$}$_4$ (5b). The procedure was identical to that described for **3b**, starting from **5a** (2.36 g, 0.57 mmol) in THF (20 mL) and triethylamine trihydrofluoride (1.65 g, 10.25 mmol). A slightly yellow oil was obtained. Yield: 0.85 g, 0.46 mmol, 81%. ^{1}H NMR (CDCl$_3$; 298K): δ 7.43 (d, J = 7.8, 24H), 7.22 (d, J = 7.6, 24H), 4.52 (s, 24H), 2.67 (s, 12H), 1.36 (m), 0.77 (t, J = 7.7, 24H), 0.52 (m, 40H), 0.21 (s, 72H). ^{13}C{^{1}H} NMR (CDCl$_3$, 298K): δ 141.4, 138.8, 133.7, 126.4, 64.9, 20.6, 18.6, 18.1, 17.8, 17.4, −2.7. FAB-MS *m*/*z*: 2818.3 [G$_1$-CH$_2$OH + Na]$^+$ (calcd 2820.2). IR (CCl$_4$): 3315 cm^{-1} (OH).

Synthesis of Si{(CH$_2$)$_3$Si[(CH$_2$)$_3$SiMe$_2$(C$_6$H$_4$-4)CH(Me)OH]$_3$}$_4$ (6b). The procedure was similar to that described for **3b**, starting from **6a** (1.03 g, 0.25 mmol) in THF (20 mL) and triethylamine trihydrofluoride (0.73 g, 4.5 mmol). The reaction mixture was heated under reflux overnight. A slightly yellow oil was obtained. Yield: 0.63 g, 0.21 mmol, 84%. ^{1}H NMR (CDCl$_3$; 298K): δ 7.42 (d, J = 7.9, 24H), 7.29 (d, J = 7.8, 24H), 4.86 (q, J = 6.2, 12H), 2.27 (s, 4H), 1.43 (d, J = 6.0, 36H), 1.38 (m), 0.80 (t, J = 8.0, 24H), 0.55 (m, 40H), 0.22 (s, 72H). ^{13}C-

(19) Chandrasekharan, J.; Ramachandran, P. V.; Brown, H. C. *J. Org. Chem.* **1985**, *50*, 5446.

{^{1}H} NMR ($CDCl_3$, 298K): δ 146.4, 138.7, 133.7, 124.7, 70.2, 25.0, 20.7, 18.7, 18.2, 17.7, 17.5, −2.7. MALDI-TOF-MS *m/z*: 2983.6 [G_1-CH(Me)OH + Na]$^+$ (calcd 2983.7). IR (CCl_4): 3315 cm^{-1} (OH). $[\alpha]^{20}_D = -27°$ (*c* 2.1, $CHCl_3$).

Synthesis of Si{$(CH_2)_3SiMe_2(C_6H_4$-4$)CH_2OC(O)CH_2C_6H_5$}$_4$ (3c). To a solution of **3b** (0.71 g, 0.83 mmol) and pyridine (0.42 g, 5.3 mmol) in THF (20 mL) was added dropwise a solution of phenylacetyl chloride (0.77 g, 5.0 mmol) in THF (10 mL). After stirring overnight at room temperature the reaction mixture was poured onto a 4 M HCl (100 mL) solution. The water layer was washed with CH_2Cl_2 (3 × 50 mL). The combined organic layers were extracted with aqueous NaOH (3 × 50 mL, 3 M). The organic layer was dried over Na_2SO_4, and the solvent was removed in vacuo. A yellow oil was obtained. Yield: 0.91 g, 0.68 mmol, 82%. Anal. Calcd for $C_{80}H_{100}O_8Si_5$ (1330.1): C, 72.24; H, 7.58; Si, 10.56. Found: C, 72.34; H, 7.58; Si, 10.52. ^{1}H NMR ($CDCl_3$; 298K): δ 7.53 (d, J = 7.9 8H), 7.35 (m, 28H), 5.18 (s, 8H), 3.72 (s, 8H), 1.37 (m, 8H), 0.86 (t, J = 7.9, 8H), 0.60 (t, J = 8.1, 8H), 0.31 (s, 24H). ^{13}C{^{1}H} NMR ($CDCl_3$, 298K): δ 171.5, 140.0, 136.4, 134.0, 133.9, 129.4, 128.7, 127.5, 127.2, 66.7, 41.4, 20.6, 18.7, 17.5, −2.8. FAB-MS *m/z*: 1352.1 [G_0-$CH_2OC(O)CH_2Ph$ + Na]$^+$ (calcd 1352.1). IR (CCl_4): 1744 cm^{-1} (C=O).

Synthesis of Si{$(CH_2)_3SiMe_2(C_6H_4$-4$)CH(Me)OC(O)CH_2C_6H_5$}$_4$ (4c). The procedure was similar to that described for **3c**, starting from **4b** (1.22 g, 0.44 mmol), pyridine (0.48 g, 6.0 mmol) in THF (20 mL), and phenylacetyl chloride (0.89 g, 5.8 mmol) in THF (10 mL). A yellow oil was obtained. Yield: 1.86 g, 0.42 mmol, 96%. Anal. Calcd for $C_{84}H_{108}O_8Si_5$ (1386.2): C, 72.28; H, 7.85; Si, 10.13. Found: C, 72.29; H, 7.86; Si, 10.15. ^{1}H NMR ($CDCl_3$; 298K): δ 7.47 (d, J = 7.8 8H), 7.33 (m, 28H), 5.88 (q, 4H), 3.64 (s, 8H), 1.52 (d, J = 6.2, 12H), 1.35 (m, 8H), 0.81 (t, J = 8.0, 8H), 0.54 (t, J = 8.2, 8H), 0.23 (s, 24H). ^{13}C-{^{1}H} NMR ($CDCl_3$, 298K): δ 170.8, 141.9, 139.4, 134.0, 133.7, 129.3, 128.5, 127.0, 125.3, 72.7, 41.6, 22.1, 20.5, 18.6, 17.5, −2.8. FAB-MS *m/z*: 1408.8 [G_0-CH(Me)OC(O)CH_2Ph + Na]$^+$ (calcd 1407.7). IR (CCl_4): 1748 cm^{-1} (C=O) $[\alpha]^{20}_D = -62°$ (*c* 3.2, $CHCl_3$).

Synthesis of Si{$(CH_2)_3Si[(CH_2)_3SiMe_2(C_6H_4-4)CH_2OC(O)CH_2C_6H_5]_3$}$_4$ (5c). The procedure was identical to that described for **3c**, starting from **5b** (1.22 g, 0.44 mmol), pyridine (0.48 g, 6.0 mmol) in THF (20 mL), and phenylacetyl chloride (0.89 g, 5.8 mmol) in THF (10 mL). A yellow oil was obtained. Yield: 1.86 g, 0.42 mmol, 96%. Anal. Calcd for $C_{252}H_{324}O_{24}Si_{17}$ (4214.8): C, 71.81; H, 7.75; Si, 11.33; Found: C, 71.65; H, 7.62; Si, 11.42. ^{1}H NMR ($CDCl_3$; 298K): δ 7.46 (d, J = 7.8, 24H), 7.35 (m, 84H), 5.09 (s, 24H), 3.63 (s, 24H), 1.42 (m, 32H), 0.80 (t, J = 7.7, 24H), 0.58 (m, 40H), 0.22 (s, 72H). ^{13}C{^{1}H} NMR ($CDCl_3$, 298K): δ 171.4, 139.8, 136.3, 133.7, 133.7, 129.3, 128.6, 127.4, 127.2, 66.5, 41.3, 20.6, 19.6, 18.7, 17.5, −2.8. MALDI-TOF-MS *m/z*: 4234.5 [G_1-$CH_2OC(O)CH_2Ph$ + Na]$^+$ (calcd 4233.0). IR (CCl_4): 1752 cm^{-1} (C=O).

Synthesis of Si{$(CH_2)_3Si[(CH_2)_3SiMe_2(C_6H_4-4)CH(Me)OC(O)CH_2C_6H_5]_3$}$_4$ (6c). The procedure was identical to that described for **3c**, starting from **6b** (1.22 g, 0.44 mmol), pyridine (0.48 g, 6.0 mmol) in THF (20 mL), and phenylacetyl chloride (0.89 g, 5.8 mmol) in THF (10 mL). A yellow oil was obtained. Yield: 1.86 g, 0.42 mmol, 96%. Anal. Calcd for $C_{264}H_{348}O_{24}Si_{17}$ (4383.1): C, 72.34; H, 8.00; Si, 10.89. Found: C, 72.19; H, 8.11; Si, 10.76. ^{1}H NMR ($CDCl_3$; 298K): δ 7.46 (d, J = 7.8, 24H), 7.35 (m, 84H), 5.88 (q, 4H), 3.63 (s, 24H), 1.52 (d, J = 6.2, 12H), 1.42 (m, 32H), 0.80 (t, J = 7.7, 24H), 0.58 (m, 40H), 0.22 (s, 72H). ^{13}C{^{1}H} NMR ($CDCl_3$, 298K): δ 171.4, 139.8, 136.3, 133.7, 133.7, 129.3, 128.6, 127.4, 127.2, 72.7, 41.3, 22.1, 20.6, 19.6, 18.7, 17.5, −2.8. MALDI-TOF-MS *m/z*: 4234.5 [G_1-CH(Me)OC(O)CH_2Ph + Na]$^+$ (calcd 4401.2). IR (CCl_4): 1752 cm^{-1} (C=O). $[\alpha]^{20}_D = -62°$ (*c* 3.2, $CHCl_3$).

Synthesis of Si{$(CH_2)_3Si[(CH_2)_3SiMe_2(C_6H_4-4)CH_2OC(O)CH_2(C_6H_4-4)Br]_3$}$_4$ (7c). The procedure was similar to that described for **3c**, starting from **5b** (0.93 g, 0.33 mmol), pyridine (0.63 g, 8.28 mmol) in THF (20 mL), and 4-bromophenylacetyl chloride (1.63 g, 6.96 mmol) in THF (10 mL). A slightly yellow oil was obtained. Yield: 1.29 g, 0.42 mmol, 75%. ^{1}H NMR ($CDCl_3$; 298K): δ 7.48 (m, 48H), 7.19 (m, 48H), 5.09 (s, 24H), 3.58 (s, 24H), 1.36 (m, 32H), 0.80 (m, 24H), 0.62 (m, 40H), 0.23 (s, 72H). ^{13}C{^{1}H} NMR ($CDCl_3$, 298K): δ 171.0, 140.1, 136.8, 134.0, 133.0, 131.9, 131.3, 127.7, 121.4, 66.9, 40.9, 20.8, 18.9, 18.5, 18.1, 17.7, −2.5. MALDI-TOF-MS *m/z*: 5176.6 [G_1-$CH_2OC(O)CH_2C_6H_4Br$ + Na]$^+$ (calcd 5177.9). IR (CCl_4): 1765 cm^{-1} (C=O).

Synthesis of Si{$(CH_2)_3Si[(CH_2)_3SiMe_2(C_6H_4-4)CH_2OC(O)CH_2(C_6H_4-4C_6H_4-4Me)]_3$}$_4$ (8). To a solution of $Pd(PPh_3)_4$ (1.83 g, 6.0 mmol) in DMF (100 mL) was added **7c** (2.1 g, 0.4 mmol), an aqueous solution of Na_2CO_3 (2 M, 10 mL), and 4-methylboronic acid (0.9 g, 6.6 mmol). The solution was heated overnight at 100 °C under nitrogen atmosphere. The solvents were removed in vacuo, and the residue was purified by column chromatography (silica, CH_2Cl_2). Subsequently drying over Na_2SO_4 and removal of the solvent in vacuo afforded a slightly yellow viscous oil. Yield: 1.29 g, 0.42 mmol, 75%. ^{1}H NMR ($CDCl_3$, 298K): δ 7.48 (m, 48H), 7.19 (m, 48H), 5.09 (s, 24H), 3.58 (s, 24H), 1.36 (m, 32H), 0.80 (m, 24H), 0.62 (m, 40H), 0.23 (s, 72H). ^{13}C{^{1}H} NMR ($CDCl_3$, 298K): δ 171.0, 140.1, 136.8, 134.0, 133.0, 131.9, 131.3, 127.7, 121.4, 66.9, 40.9, 20.8, 18.9, 18.5, 18.1, 17.7, −2.5. MALDI-TOF-MS *m/z*: 5176.6 [G_1-$CH_2OC(O)CH_2C_6H_4C_6H_4Me$ + Na]$^+$ (calcd 5177.9). IR (CCl_4): 1765 cm^{-1} (C=O).

Aqueaus basic hydrolysis of **8** afforded acetic acid derivative **9** and **5b** in quantitative yield.

Synthesis of Si{$(CH_2)_3Si((CH_2)_3SiMe_2(C_6H_4-4)${$CH_2OC(O)CH_2C_6H_5)_n(C(O)CH_2$-*t*Bu$)_{12-n}$} ($n$ = 0−12) (11). The synthetic procedure is identical to that described for **5c**, starting from **5b** (1.02 g, 0.40 mmol), pyridine (0.42 g, 5.3 mmol) in THF (20 mL), and phenylacetyl chloride (0.39 g, 2.5 mmol) and *tert*-butylacetyl chloride (0.34 g, 2.5 mmol) in THF (10 mL). A yellow oil was obtained. Yield: 1.86 g, 0.38 mmol, 91%. ^{1}H NMR ($CDCl_3$, 298K): δ 7.46 (d, J = 7.8, 24H), 7.35 (m, 84H), 5.09 (s, 24H), 3.63 (s, 12H), 2.33 (s, 12H), 1.42 (m, 32H), 1.10 (s, 108H), 0.80 (t, J = 7.7, 24H), 0.58 (m, 40H), 0.22 (s, 72H). ^{13}C{^{1}H} NMR ($CDCl_3$, 298K): δ 171.4, 168.2, 139.8, 136.3, 133.7, 133.7, 129.3, 128.6, 127.4, 127.2, 66.5, 41.3, 29.7, 20.8, 20.6, 19.6, 18.7, 17.5, −2.8. MALDI-TOF-MS *m/z*: 4242.2 [n = 8 + Ag]$^+$ (calcd 4235.9), 4222.9 [n = 7 + Ag]$^+$ (calcd 4215.9.0), 4203.4 [n = 6 + Ag]$^+$ (calcd 4195.9) and 4182.3 [n = 5 + Ag]$^+$ (4175.9).

General Procedure for the *β*-Lactam Formation. A well-stirred solution of 0.51 g (5.0 mmol) of diisopropylamine in THF (25 mL) was cooled to −78 °C. The following reagents were subsequently added at 10 min intervals: (i) *n*-butyllithium (3.2 mL, 1.6 M solution in hexane, 5.0 mmol); (ii) 5.0 mmol of dendritic ester groups; (iii) 5.0 mmol of $ZnCl_2$ (5.0 mL, 1.0 M solution in Et_2O); (iv) 5.0 mmol of the appropriate imine. The reaction mixture was stirred at −78 °C for 1 h and allowed to rise to room temperature and stirred for another 17 h. The reaction mixture was quenched with a saturated NH_4Cl solution. The aqueous layer was extracted with Et_2O (3 × 10 mL), and the combined organic layers were dried over sodium sulfate, filtrered, and concentrated in vacuo. The organic products were analyzed by ^{1}H and ^{13}C NMR and HPLC. The specroscopic data of the obtained *β*-lactams are in agreement with the data earlier reported.[20]

Acknowledgment. The authors wish to thank Mrs. Anca van der Kerk and Mr. Kees Versluis from the Analytical Chemical Department for measuring the FAB-MS spectra. Dr. J. Verweij (DSM Gist) and Prof. dr. J.G. de Vries (DSM) are kindly acknowledged for their stimulating discussions. This work was supported by the Council for Chemical Sciences of The Netherlands Organization for Scientific Research (CW/NWO) and the Dutch Technology Foundation (STW) with financial aid from DSM Gist.

JO991726K

(20) van Maanen, H. L.; Kleijn, H.; Jastrzebski, J. T. B. H.; van Koten G. *Recl. Trav. Chim. Pays-Bas* **1994**, *113*, 567.