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On the [3 + 2] Annulation of Cyclic Allylsilanes with *N*-Phenyltriazolinedione: An Enantio- and Diastereoselective Synthesis of *cis*-1,3-Diaminocyclitols

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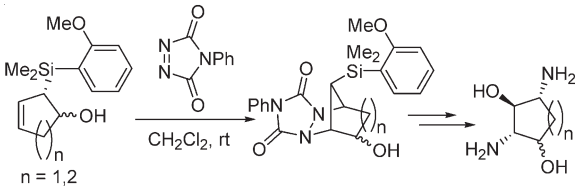

Improved conditions were found to trigger [3 + 2] annulation of cyclic allylsilanes with *N*-phenyltriazolinedione (PTAD); the products from this reaction were readily tailored into *cis*-1,3-diaminocyclitols in highly enantioenriched form with full stereochemical control of up to four contiguous stereogenic centers.

Introduction

Aminocyclitols represent a wide class of compounds with an attractive range of biological properties.[1,2] Several diaminocyclitols have been synthesized and reported to possess strong antibiotic activity.[3] These include the natural streptamine (**1**) and 2-deoxystreptamine (**2**), which feature a 1,3-arrangement of their amino groups (Figure 1). Moreover, there are applications of these compounds as substrates for mutasynthesis of new antibiotics[4] and as ligands in cytostatically active Pt^{II}-complexes.[5] In recent years, chemists from far-flung laboratories have also reported preparation of *cis*-1,3-diaminocyclopentitols, e.g., **3**[6,7] and *trans*-1,2-diaminocyclitols, e.g., **4**[8] and **5**.[8] Incidentally, over the years, the natural *trans*-1,4-diaminocyclitol sporamine (**6**)[9] has received intense interest from synthetic and medicinal chemists alike. Clearly, development of new and general synthetic strategies to these families of diaminocyclitols constitutes an important objective to allow a broader investigation of the utility of such compounds in biology and medicine.

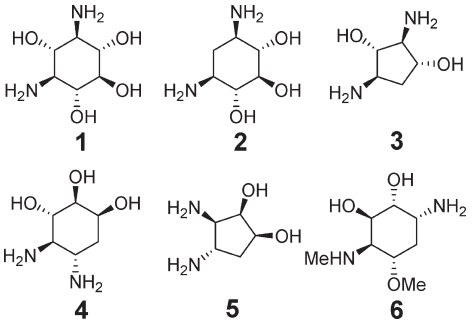

FIGURE 1. Some natural and non-natural diaminocyclitols.

In this paper, we report a novel route that provides access to both diaminocyclohexitols and diaminocyclopentitols in a highly enantio- and diastereocontrolled fashion. Our strategy to these species hinges on an efficient [3 + 2] annulation[10−12] of

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(8) Cong, X.; Liao, Q.-J.; Yao, Z.-J. *J. Org. Chem.* **2004**, *69*, 5314–5321.

(9) Knapp, S.; Patel, D. V. *J. Am. Chem. Soc.* **1983**, *105*, 6985–6986.

(10) For some early and pioneering work on [3 + 2] annulation of allylsilanes, see: (a) Colvin, E. W.; Monteith, M. *J. Chem. Soc., Chem. Commun.* **1990**, 1230–1232. (b) Knölker, H.-J.; Jones, P. G.; Pannek, J.-B. *Synlett* **1990**, 429–430. (c) Danheiser, R. L.; Dixon, B. R.; Gleason, R. W. *J. Org. Chem.* **1992**, *57*, 6094–6097. (d) Knölker, H.-J.; Foitzik, N.; Graf, R.; Goesmann, H. *Angew. Chem., Int. Ed.* **1993**, *32*, 1081–1083. (e) Knölker, H.-J.; Graf, R. *Tetrahedron Lett.* **1993**, *34*, 4765–4768. (f) Knölker, H.-J.; Foitzik, N.; Graf, R.; Pannek, J.-B.; Jones, P. G. *Tetrahedron* **1993**, *49*, 9955–9972.

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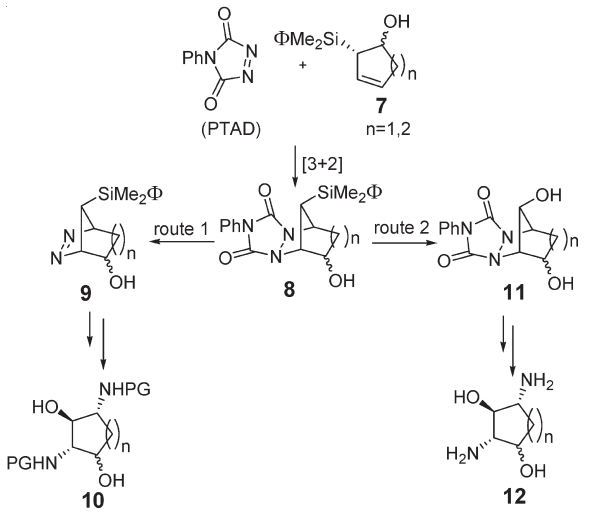
SCHEME 1. Strategy for the Synthesis of *cis*-1,3-Diaminocyclitols

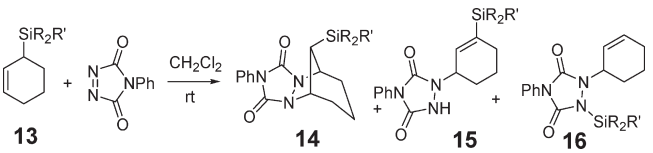


enantioenriched cyclic allylsilanes **7** with *N*-phenyltriazolinedione (PTAD) leading to the cycloadducts **8**,[13] which after saponification followed by oxidation would produce the diazene **9**. Further elaboration including reductive ring-opening of the diazene intermediates **9**, protection of the resulting diamine, and ultimately Tamao−Fleming oxidation gives access to various diaminocyclitols **10** in protected form (route 1, Scheme 1). Alternatively, Tamao−Fleming oxidation of the [3 + 2] adducts would produce the diols **11** (route 2, Scheme 1), which can be converted to the corresponding diazenes via saponification and oxidation. Finally, reductive ring-opening of the diazenes would produce the free diaminocyclitols **12**.

Results and Discussion

At the outset, we surmised that there could be two issues with the feasibility of the projected route as outlined in Scheme 1. First, the [3 + 2] annulation reaction of cyclic allylsilane **13** to **14** could be plagued by the accompanying side products, e.g., the H-ene product **15** and/or the metalla (M)-ene product **16** (Table 1). Indeed, as shown by Davies et al., the reaction of allylsilane **13a** with PTAD yields the annulation product as the minor component (25%) in a mixture containing both the H-ene (70%) and the M-ene products (5%).[14] Furthermore, change of ligands in the reaction can have a deleterious effect on the yield of the [3 + 2] adduct. For example, with allylsilane **13b** the yield of the

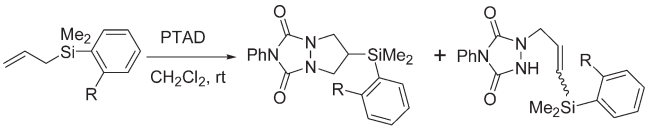
TABLE 1. Reactivity Profile of Cyclic Allylsilanes with PTAD



allylsilane **13**	[3 + 2] adduct **14**[a] (%)	H-ene **15**[a] (%)	M-ene **16**[a] (%)
13a, R = R′ = Et	25	70	5
13b, R = R′ = Ph	10	90	0[b]
13c, R = Me, R′ = Ph	46	31	23[c]

[a]By NMR spectroscopy. [b]This reaction was run in $CHCl_3$. [c]2.5 equiv of PTAD was used.

SCHEME 2. [3 + 2] Annulation of Acyclic Allylsilanes with PTAD



17a, R = H
17b, R = OMe
18a, 20%[11b]
18b, 50%
19a, 40%[11b]
19b, 30%

annulation product drops to a meagre 10%.[15] Our own independent studies with allylsilane **13c** showed that a higher yield of the [3 + 2] adduct (46%) is possible only when an excess (2.5 equiv) of PTAD is used in the reaction, but even here significant amounts of H-ene (31%) and M-ene (23%) products accompany the annulation product. Second, in bridged ring compounds where the silyl group is positioned next to the bridgehead carbon as in **14** Tamao oxidation is usually fraught with difficulties.[16]

To address both these issues, we decided to replace the phenyl group (Φ = Ph) in **7** by an electron-rich *o*-methoxyphenyl group on the premise that the latter group may facilitate both the Tamao oxidation[17] as well as the [3 + 2] annulation. This prognosis turned out to be correct. Indeed, a preliminary investigation of simple acyclic allylsilane **17b** bearing an *o*-methoxyphenyl ligand with PTAD provided promising results. Thus, while the reaction of allyldimethylphenylsilane (**17a**) with PTAD gave the urazole **18a** with a maximum yield of 20%,[11b] the reaction of **17b** with PTAD under identical conditions increased the yield of **18b** to 50% (Scheme 2). Even better results were obtained with cyclic allylsilanes. As shown in Table 2 the cyclic allylsilane **20a**[18] gave exclusively the [3 + 2] adduct **21a** (55%), and no traces of either the H-ene and/or the M-ene products could be detected in the crude reaction product by ^1H NMR. The reason as to why the reaction works well with systems bearing an *o*-methoxyphenylsilyl group is probably the increased electron density around silicon, which increases its migratory aptitude. This new finding is interesting given that in all previous studies on [3 + 2] annulation of allylsilanes increased steric hindrance around silicon was used as the key to

(11) For some recent work on [3 + 2] annulation of allylsilanes, see: (a) Romero, A.; Woerpel, K. A. *Org. Lett.* **2006**, *8*, 2127–2130. (b) Dey, R. T.; Haque, Sk. A.; Hazra, A.; Basak, S.; Sarkar, T. K. *Tetrahedron Lett.* **2007**, *48*, 6671–6673. (c) Schmidt, A. W.; Olpp, T.; Baum, E.; Stiffel, T.; Knölker, H.-J. *Synlett* **2007**, 2371–2374. (d) Huh, C. W.; Roush, W. R. *Org. Lett.* **2008**, *10*, 3371–3374. (e) Orac, M. C.; Bergmeier, S. C. *Tetrahedron Lett.* **2009**, *50*, 1261–1263. (f) Schmidt, A. W.; Olpp, T.; Schmid, S.; Jäger, A.; Knölker, H.-J. *Tetrahedron* **2009**, *65*, 5484–5490.

(12) For reviews on annulation reactions of allylsilanes, see: (a) Masse, C. E.; Panek, J. S. *Chem. Rev.* **1995**, *95*, 1293–1316. (b) Fleming, I.; Barbero, A.; Walter, D. *Chem. Rev.* **1997**, *97*, 2063–2192. (c) Knölker, H.-J. *J. Prakt. Chem.* **1997**, *339*, 304–314. (d) Chabaud, L.; James, P; Landais, Y. *Eur. J. Org. Chem.* **2004**, 3173–3199.

(13) The configuration of the silyl group is based on our previous investigation in a related area.[11b]

(14) Dang, H.-S.; Davies, A. G. *J. Chem. Soc., Perkin Trans. 2* **1991**, 2011–2020.

(15) Cai, J.; Davies, A. G. *J. Chem. Soc., Perkin Trans. 2* **1992**, 1743–1746.

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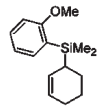
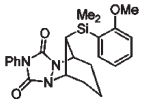
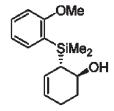
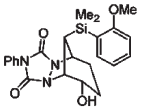
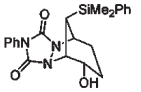
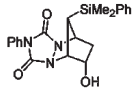
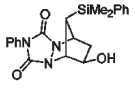
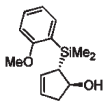
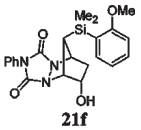
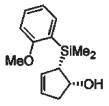
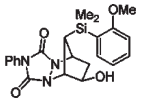
(17) Lee, W. T.; Corey, E. J. *Org. Lett.* **2001**, *3*, 3337–3339.

(18) **20a** was prepared from cyclohexene by exposure to Schlosser's base followed by treatment of the resulting species with $ClMe_2SiC_6H_4$-*o*-OMe.

TABLE 2. [3 + 2] Annulation of Cyclic Allylsilanes with PTAD[a]

Allylsilane **20**	[3+2] Adduct **21**[b]	Yield (%)[c]
 **20a**[18]	 **21a**	55
 **20b**	 **21b**	75
 **20c**[20]	 **21c**[d]	60
 **20d**[20]	 **21d**	65
 **20e**[19]	 **21e**	70
 **20f**	 **21f**	70
 **20g**	 **21g**	72

[a]All reactions were carried out in CH_2Cl_2 with 2.5 equiv of PTAD. [b]All compounds reported here were fully characterized by a complement of ^1H and ^{13}C NMR as well as mass spectra; **21c**, **21d**, and **21g** were further characterized by single-crystal X-ray crystallography. [c]Yields refer to chromatographically purified products. [d]13% H-ene product accompanied the [3 + 2] adduct.

facilitate the [3 + 2] pathway relative to other side reactions. Armed with this information, we then proceeded to make [3 + 2] adducts from oxygenated cyclic allylsilanes. Thus, the enantiomerically enriched allylsilanes, e.g., **20b** and **20f**, were prepared from **20h** and **20g**, respectively, via Mitsunobu inversion (PPh_3/DEAD/*p*-$NO_2C_6H_4CO_2H$), followed by saponification; **20h** and **20g**, in turn, were made following Roush's methodology[19] using **17b** (Scheme 3). Reaction of **20b** with PTAD provided the annulation product **21b** in high yield showing a clean chirality transfer. Once again, no H-ene or M-ene product accompanied the [3 + 2] annulation product **21b**. We then found that with oxygenated cyclic allylsilanes **20c**,[20] **20d**,[20] and **20e**[19] [3 + 2] annulation products **21c**−**e** could still be made in high yield, and the presence of the *o*-methoxyphenyl ligand on silicon was not an absolute necessity. While no traces of any H-ene/M-ene product formed from **20b**, little (13%) H-ene product accompanied the annulation product from **20c**. Incorporation of the *o*-methoxyphenyl ligand on silicon in the 5-membered cyclic β-hydroxyallylsilanes resulted in slight increase in the yields of the [3 + 2] adducts as shown by **20f** and **20g**, which gave **21f** (70%) and **21g** (72%), respectively . Again, complete chirality transfer was shown to take place in the conversion of enantiomerically enriched allylsilanes **20e**, **20f**, and **20g** to **21e**, **21f**, and **21g**, respectively.

The beneficial effect of the hydroxy substituent in these cases is interesting and is in marked contrast to the results obtained by Roberson and Woerpel[21] in the [3 + 2] annulation of cyclic β-alkoxyallylsilanes with chlorosulfonyl isocyanate where a deleterious effect of the alkoxy substituent was noted. However, at present, it is difficult to provide a clear rationale for the beneficial effect of the hydroxy substituent in our case. Interestingly, in the case of six-membered cyclic β-hydroxyallylsilanes, the relative configuration of the hydroxy group with respect to the silyl substituent plays a decisive role in the reaction with PTAD. For example, while the *anti*-β-hydroxyallylsilane **20c** gives the [3 + 2] adduct **21c** in high yield, the corresponding *syn*-isomer **20i**[19] followed a completely uncharted pathway thereby giving the α,β-unsaturated ketone **23** as the only product of the reaction with PTAD (Scheme 4). We believe that in this case PTAD abstracts the quasi-axial hydrogen on the carbon carrying the hydroxy group to give a carbocation **24** stabilized by β-effect of the neighboring silyl group. Loss of proton gives the α-silyl ketone **25**, which then undergoes H-ene reaction with another molecule of PTAD to give the product **23**. On the basis of this rationale, it is clear why allylsilanes **20e** and **20g** were immune to the alternative reaction pathway (Scheme 4) and instead gave the annulation products **21e** and **21g**, respectively. Obviously, here the geometry of the ring system precludes proton abstraction as the hydrogen and the silyl group are not disposed *trans*-diaxially, and there is no stabilization of the developing carbocation.

Having been unsuccessful in our attempt to obtain the [3 + 2] adduct, e.g., **21i** (Scheme 4), from the *syn*-β-hydroxyallylsilane **20i**, we then decided to make it in an indirect way. Thus, oxidation of the [3 + 2] adduct **21c** available from the *anti*-β-hydroxyallylsilane **20c** yielded the ketone **26**, the steric bias of which allowed complete stereoselective reduction with $NaBH_4$ to provide **21i** in excellent overall yield (Scheme 5).

After addressing the first issue, that is, the [3 + 2] annulation, we then turned to the other issue involving Tamao oxidation. Further work along this line fully justified our choice of the 2-methoxyphenyl substituent on silicon for successful Tamao−Fleming oxidation of a host of annulation products, e.g., **14c**, **21c**, and **21d**, with a phenyl substituent on silicon were

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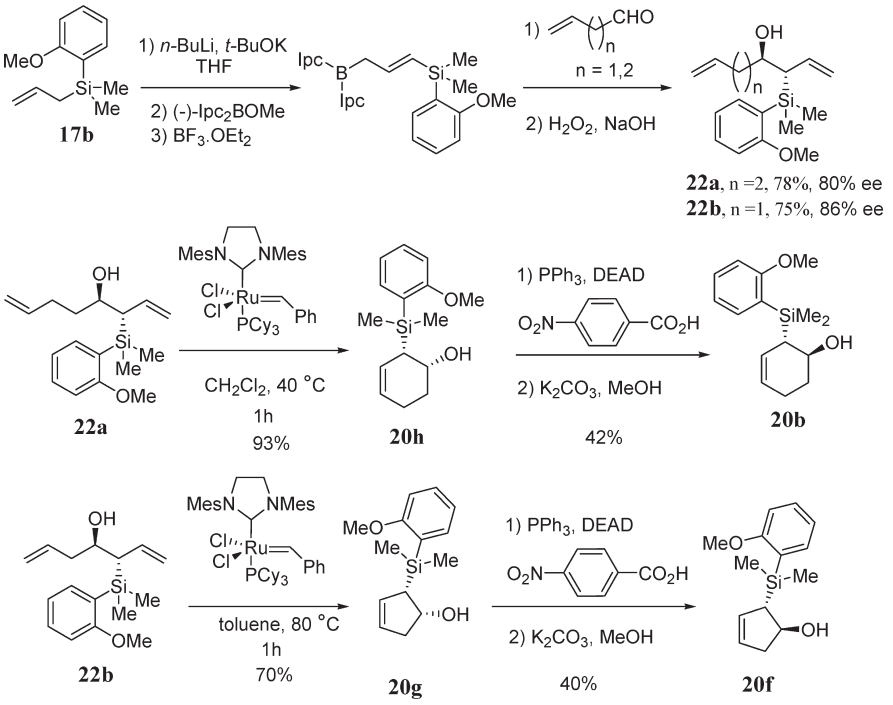
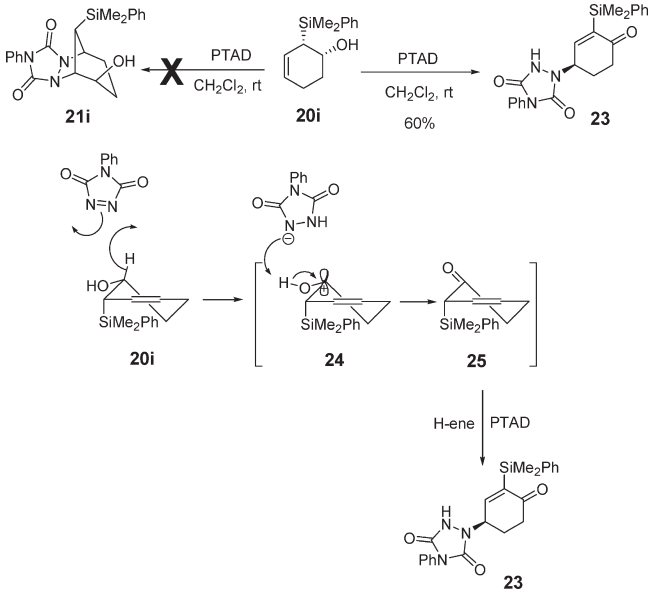
(20) Clive, D. L. J.; Zhang, C.; Zhou, Y.; Tao, Y. *J. Organomet. Chem.* **1995**, *489*, C35–C37.

(21) Roberson, C. W.; Woerpel, K. A. *J. Am. Chem. Soc.* **2002**, *124*, 11342–11348.

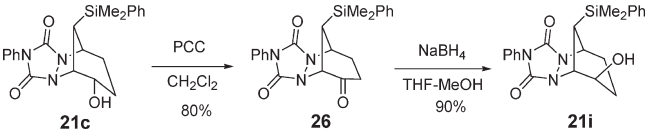
SCHEME 3. Preparation of Enantiomerically Enriched Allylsilanes



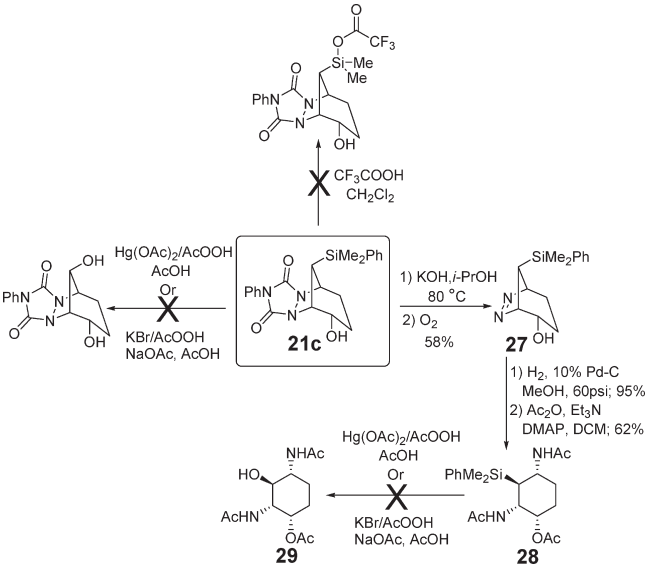
SCHEME 4. Bizarre Reaction of Allylsilane 20i with PTAD



SCHEME 5. Indirect Route to the Adduct 21i



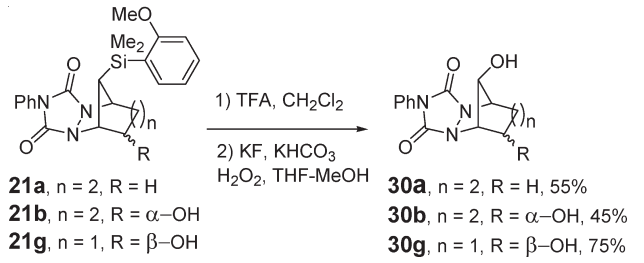
SCHEME 6. Some Recalcitrant Tamao−Fleming Reactions



uniformly unrewarding. Thus, while use of $Hg(OAc)_2$/AcOOH[22] in the case of **21c** (Scheme 6) returned about 80% of the starting materials with no traces of the desired product, use of KBr/AcOOH[22] yielded a complex product mixture containing none of the of the desired alcohol or the starting annulation product. Also, exposure of **21c** to CF_3COOH in CH_2Cl_2 showed no sign (TLC) of protodesilylation and returned the starting material quantitatively. At this stage, we also did a detour as outlined in Scheme 6 and attempted the Tamao oxidation on the ring-opened product **28** obtained from **21c** via exposure to alkali, oxidation, and then reductive ring-opening of the diazene **27** followed by acetylation. Once again Tamao−Fleming oxidation[22] of

(22) Fleming, I.; Henning, R.; Parker, D. C.; Plaut, H. E.; Sanderson, P. E. J. *J. Chem. Soc., Perkin Trans. 1* **1995**, 317–337.

SCHEME 7. Tamao−Fleming Oxidation of the [3 + 2] Adducts

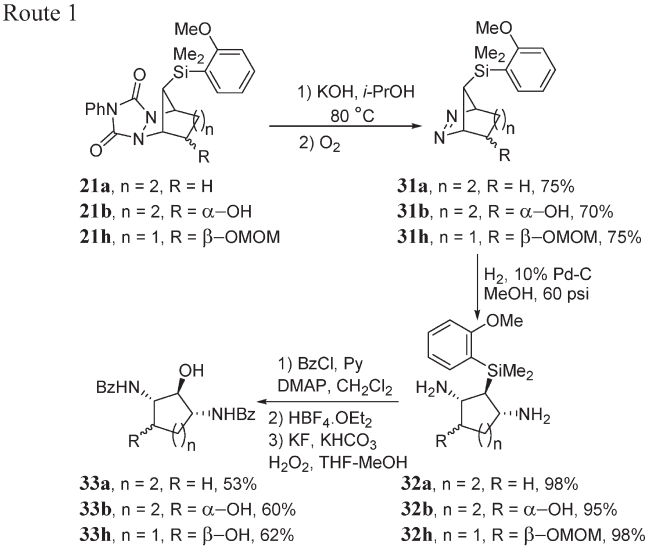


21a, n = 2, R = H
21b, n = 2, R = α–OH
21g, n = 1, R = β–OH

30a, n = 2, R = H, 55%
30b, n = 2, R = α–OH, 45%
30g, n = 1, R = β–OH, 75%

SCHEME 8. Synthesis of Aminocyclitols

Route 1



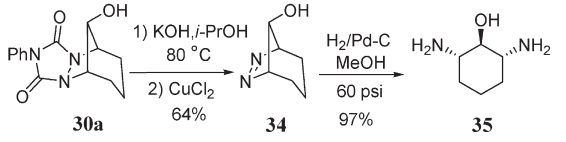
21a, n = 2, R = H
21b, n = 2, R = α–OH
21h, n = 1, R = β–OMOM

31a, n = 2, R = H, 75%
31b, n = 2, R = α–OH, 70%
31h, n = 1, R = β–OMOM, 75%

33a, n = 2, R = H, 53%
33b, n = 2, R = α–OH, 60%
33h, n = 1, R = β–OH, 62%

32a, n = 2, R = H, 98%
32b, n = 2, R = α–OH, 95%
32h, n = 1, R = β–OMOM, 98%

Route 2



30a **34** **35**

28 yielded complex product mixture containing no traces of the desired alcohol, e.g., **29**. The choice of *o*-methoxyphenyl group over phenyl group on silicon was successful at this stage. Tamao oxidation of the cycloadducts **21a**, **21b**, and **21g** can now be readily carried out under Corey's conditions[17] to afford the corresponding alcohols **30a**, **30b**, and **30g**, respectively, in moderate to good overall yields (Scheme 7).

Finally, different aminocyclitols were synthesized in both routes as outlined in Scheme 1. The cycloadducts **21a**, **21b**, and **21h** were first converted to the corresponding diazenes **31a**, **31b**, and **31h** (route 1, Scheme 8), respectively, which were reduced to the *cis*-1,3-diamines **32a**, **32b**, and **32h** via catalytic hydrogenation. Protection of the diamines followed by modified Tamao−Fleming oxidation gave the aminocyclitols **33a**, **33b**, and **33h** in protected form. Alternatively, route 2 gives direct access to unprotected aminocyclitols. For example, saponification of **30a** followed by oxidation using $CuCl_2$ gave the diazene **34** (route 2, Scheme 8) which was reduced to the *cis*-1,3-diaminocyclitol **35** via catalytic hydrogenation in good overall yield.

Conclusion

In summary, we have developed an enantioselective route to the pharmacologically significant *cis*-1,3-diaminocyclitols with full stereochemical control of up to four contiguous stereogenic centers. This strategy hinges on two key reactions: (i) [3 + 2] annulation and (ii) Tamao oxidation. We have demonstrated that an appropriate choice of the ligands on silicon is necessary for overall success.

Experimental Section

General experimental details are provided as Supporting Information.

Allyl(2-methoxyphenyl)dimethylsilane (17b). This allylsilane was prepared via two routes, both giving excellent yield. **Route 1:** To a stirred mixture of chloro(2-methoxyphenyl)dimethylsilane (7 g, 34.8 mmol) and Mg turnings (1.5 g, 61.7 mmol) in dry THF (32 mL) was added dropwise a solution of allyl bromide (2.95 mL, 34.8 mmol) in dry THF (10 mL) at room temperature at a rate sufficient to maintain gentle reflux. After the addition was over, the mixture was stirred at room temperature for 16 h. The reaction was then quenched by the addition of 5% aq NH_4Cl (80 mL) at 0 °C. The organic layer was separated, and the aqueous layer was extracted with Et_2O (3 × 30 mL). The organic layers were combined, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure to give a pale yellow oil which was purified by flash column chromatography (SiO_2, 9.5:0.5 petroleum ether/EtOAc eluent) to provide the desired allylsilane as a colorless oil (6.5 g, 91%). **Route 2:** To a cooled (−78 °C) solution of 2-bromoanisole (4 mL, 32.1 mmol) in 100 mL of dry THF was added 21.4 mL (32.1 mmol) of *n*-BuLi (1.5 M in hexane) at such a rate that the internal temperature did not rise above −55 °C. After the addition was complete, the clear colorless solution was allowed to stir at −78 °C for 30 min. Then allylchlorodimethylsilane (neat, 4.85 mL, 32.1 mmol) was added via syringe, and the mixture was stirred at −78 °C for 15 min. The mixture was then allowed to come to room temperature and concentrated. The residue was subjected to extractive workup with EtOAc/H_2O to provide a pale yellow oil which was purified by flash column chromatography (SiO_2, 9.5:0.5 petroleum ether/EtOAc eluent) to provide the desired allylsilane as a colorless oil (6.2 g, 94%): TLC (petroleum ether) R_f 0.48 (UV, I_2); ^{1}H (400 MHz, C_6D_6) δ 7.50 (dd, J = 7.2, 1.6 Hz, 1H), 7.30−7.26 (m, 1H), 7.00 (t, J = 7.2 Hz, 1H), 6.58 (d, J = 8.0 Hz, 1H), 6.01−5.90 (m, 1H), 5.07−4.99 (m, 2H), 3.35 (s, 3H), 2.01 (d, J = 8.0 Hz, 2H), 0.45 (s, 6H); ^{13}C (100 MHz, C_6D_6) δ 164.4, 135.4, 135.3, 130.9, 126.0, 120.6, 112.9, 109.5, 54.3, 23.5, −3.1; HRMS (ES+) m/z calcd for $C_{12}H_{18}SiONa$ $(M + Na)^+$ 229.10246, found 229.10191.

3-[(2-Methoxyphenyl)dimethylsilanyl]octa-1,7-dien-4-ol (22a). Allyl(2-methoxyphenyl)dimethyl silane **17b** (2.267 g, 10.99 mmol) was dissolved in dry THF (5 mL) and cooled to −78 °C. *t*-BuOK (1.5 M solution in THF, 6.69 mL, 10.04 mmol) was added via syringe followed by dropwise addition of *n*-BuLi (1.9 M solution in hexanes, 5.28 mL, 10.04 mmol) over 10 min. The deep red solution was stirred at −78 °C for 10 min, and then the flask was transferred into a −45 °C bath and stirred for 2 h. The flask was returned to the −78 °C bath, and freshly prepared (−)-Ipc_2BOMe[23] (10.04 mmol) in dry THF (16 mL) was added slowly via syringe. The deep orange mixture was stirred at −78 °C for 30 min. Then $BF_3\cdot OEt_2$ (1.66 mL, 13.09 mmol) was added dropwise followed immediately by slow addition of 4-penten-1-al (12.07 mmol). At this point, the solution became dense and the color became off-white. After being stirred for 4 h at −78 °C, the mixture was warmed to 0 °C and treated with 3 N NaOH solution

(23) Racherla, U. S.; Brown, H. C. *J. Org. Chem.* **1991**, *56*, 401–404.

(16.8 mL) and 30% H_2O_2 (10.3 mL). After being stirred for 2 h at room temperature, the mixture was extracted with EtOAc (3 × 50 mL). The extracts were combined, dried over Na_2SO_4, filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (SiO_2, 9:1 petroleum ether/EtOAc eluent) to provide 2.27 g of the β-hydroxyallylsilane **22a** as a colorless oil in 78% yield (80% ee, determined by Mosher ester analysis[24]): $[\alpha]^{28}_D = +7.2$ (*c* 1.13, $CHCl_3$); TLC (5% EtOAc/petroleum ether) R_f 0.38 (UV, I_2); ^{1}H (400 MHz, C_6D_6) δ 7.54−7.53 (m, 1H), 7.29−7.25 (m, 1H), 7.00 (t, J = 7.2 Hz, 1H), 6.57 (d, J = 8.4 Hz, 1H), 6.11 (dt, J = 17.2, 10.4 Hz, 1H), 5.85−5.75 (m, 1H), 5.11 (dd, J = 10.0, 2.4 Hz, 1H), 5.08−4.98 (m, 3H), 3.86−3.81 (m, 1H), 3.35 (s, 3H), 2.27 (dd, J = 10.8, 4.0 Hz, 1H), 2.17−2.09 (m, 2H), 1.62 (app q, J = 7.6 Hz, 2H), 0.56 (s, 3H), 0.51 (s, 3H); ^{13}C (100 MHz, C_6D_6) δ 163.9, 138.7, 136.1, 135.9, 130.9, 125.6, 120.9, 114.5, 114.1, 109.5, 70.6, 54.3, 41.8, 36.3, 30.3, −3.0, −3.5; HRMS (ES+) *m*/*z* calcd for $C_{17}H_{26}SiO_2Na$ (M + Na)$^+$ 313.15997, found 313.15880.

3-[(2-Methoxyphenyl)dimethylsilanyl]hepta-1,6-dien-4-ol (22b). This β-hydroxyallylsilane was obtained as a colorless oil in 75% yield following the same procedure as described for **22a** using 3-buten-1-al in place of 4-penten-1-al (86% ee, determined by Mosher ester analysis[24]): $[\alpha]^{27}_D = +6.5$ (*c* 1.13, $CHCl_3$); TLC (5% EtOAc/petroleum ether) R_f 0.20 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.38−7.34 (m, 2H), 6.97 (t, J = 7.2 Hz, 1H), 6.84 (d, J = 8.4 Hz, 1H), 5.86 (dt, J = 17.2, 10.4 Hz, 1H), 5.76−5.70 (m, 1H), 5.03−4.88 (m, 4H), 3.82 (s, 3H), 3.79−3.76 (m, 1H), 2.18−2.07 (m, 4H), 0.33 (s, 3H), 0.29 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 163.7, 135.8, 135.7, 135.5, 131.0, 125.3, 120.8, 117.0, 115.0, 109.6, 70.5, 55.0, 41.6, 41.3, −3.0, −3.6; HRMS (ES+) *m*/*z* calcd for $C_{16}H_{24}SiO_2Na$ (M + Na)$^+$ 299.1443, found 299.1438.

2-[(2-Methoxyphenyl)dimethylsilanyl]cyclohex-3-enol (20h). The diene **22a** (1 g, 3.45 mmol) was dissolved in CH_2Cl_2 (340 mL) and degassed under argon bubbling with sonication for 30 min. The solution was treated with Grubbs' second-generation catalyst (131.8 mg, 0.155 mmol, 4.5 mol %) in one portion and stirred for 1 h at 40 °C. The mixture was cooled to room temperature and concentrated under reduced pressure. The residue was purified by flash column chromatography (SiO_2, 10% EtOAc/petroleum ether) to provide 840 mg (93%) of cyclohexenylsilane **20h** as a pale yellow oil: $[\alpha]^{27}_D = +42.7$ (*c* 1.20, $CHCl_3$); TLC (10% EtOAc/petroleum ether) R_f 0.46 (UV, I_2); ^{1}H (400 MHz, C_6D_6) δ 7.60 (dd, J = 7.2, 1.2 Hz, 1H), 7.31−7.26 (m, 1H), 7.02 (t, J = 7.2 Hz, 1H), 6.59 (d, J = 8.4 Hz, 1H), 5.77−5.67 (m, 2H), 4.19−4.18 (m, 1H), 3.35 (s, 3H), 2.54−2.52 (m, 1H), 2.24−2.17 (m, 1H), 1.99−1.95 (m, 1H), 1.73−1.67 (m, 1H), 1.63−1.55 (m, 1H), 1.41 (d, J = 4.8 Hz, 1H), 0.69 (s, 3H), 0.59 (s, 3H); ^{13}C (100 MHz, C_6D_6) δ 164.1, 135.9, 130.7, 126.6, 126.1, 124.1, 120.8, 109.6, 67.7, 54.3, 33.5, 30.2, 21.4, −2.3, −2.4; HRMS (ES+) *m*/*z* calcd for $C_{15}H_{22}SiO_2Na$ (M + Na)$^+$ 285.12867, found 285.12804.

2-[(2-Methoxyphenyl)dimethylsilanyl]cyclohex-3-enol (20b). To a solution of the *syn*-β-hydroxyallylsilane **20h** (394 mg, 1.5 mmol), PPh_3 (787 mg, 3 mmol), and 4-nitrobenzoic acid (503 mg, 3.1 mmol) in 15 mL of dry THF was added a THF solution (2M) of DEAD (514 mg, 2.95 mmol) dropwise at 0 °C. The reaction mixture was allowed to warm to room temperature and stirred for 4 h. The solvent was then evaporated in vacuo. The resulting thick oil was diluted with CH_2Cl_2 (30 mL), washed with saturated aqueous sodium bicarbonate solution (30 mL) and brine (30 mL), and dried (Na_2SO_4). Solvent was removed under reduced pressure to give the crude product as a yellow thick oil which was dissolved in MeOH (15 mL), K_2CO_3 (1.2 g, 8.7 mmol) was added to it, and the resulting mixture was stirred at room temperature for 3 h. Then water was added, and the product was extracted into EtOAc, dried over Na_2SO_4, and concentrated under reduced pressure. Purification by flash column chromatography (SiO_2, 9:1 petroleum ether/EtOAc eluent) gave the desired *anti*-β-hydroxyallylsilane **20b** (165 mg, 42%) as a colorless oil: $[\alpha]^{27}_D = +70.9$ (*c* 0.66, $CHCl_3$); TLC (10% EtOAc/petroleum ether) R_f 0.26 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.50 (dd, J = 7.0, 1.2 Hz, 1H), 7.30−7.27 (m, 1H), 7.04−6.98 (m, 1H), 6.58−6.54 (m, 1H), 5.72−5.63 (m, 2H), 4.03−3.99 (m, 1H), 3.34 (s, 3H), 2.31−2.29 (m, 1H), 2.18−2.14 (m, 1H), 1.97−1.92 (m, 1H), 1.78−1.71 (m, 1H), 1.69−1.63 (m, 1H), 0.50 (s, 3H), 0.47 (s, 3H); ^{13}C (100 MHz, C_6D_6) δ 163.7, 135.5, 131.2, 125.5, 125.0, 124.1, 120.6, 109.5, 67.6, 54.9, 35.7, 29.2, 21.5, −3.4, −4.0; HRMS (ES+) *m*/*z* calcd for $C_{15}H_{22}SiO_2Na$ (M + Na)$^+$ 285.1287, found 285.1285.

2-[(2-Methoxyphenyl)dimethylsilanyl]cyclopent-3-enol (20g). The diene **22b** (60 mg, 0.22 mmol) was dissolved in toluene (22 mL) and degassed under argon bubbling with sonication for 10 min. The solution was treated with Grubbs' second-generation catalyst (13 mg, 0.015 mmol, 7 mol %) in one portion and stirred for 1 h at 80 °C. The mixture was cooled to room temperature and concentrated under reduced pressure. The residue was purified by flash column chromatography (SiO_2, 10% EtOAc/petroleum ether) to provide 38 mg (70%) of cyclopentenylsilane **20g** as a pale yellow oil: $[\alpha]^{27}_D = +54.7$ (*c* 2.15, $CHCl_3$); TLC (5% EtOAc/petroleum ether) R_f 0.14 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.45−7.43 (m, 1H), 7.38−7.34 (m, 1H), 6.97 (t, J = 7.2 Hz, 1H), 6.85 (d, J = 8.4 Hz, 1H), 5.69−5.64 (m, 2H), 4.71−4.69 (m, 1H), 3.82 (s, 3H), 2.67−2.57 (m, 2H), 2.28−2.24 (m, 1H), 1.85 (d, J = 5.6 Hz, 1H), 0.40 (s, 3H), 0.35 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 163.8, 135.5, 131.0, 130.8, 126.7, 126.1, 120.7, 109.7, 75.1, 54.9, 43.1, 42.8, −2.2, −2.6; HRMS (ES+) *m*/*z* calcd for $C_{14}H_{20}SiO_2Na$ (M + Na)$^+$ 271.11302, found 271.11222.

2-[(2-Methoxyphenyl)dimethylsilanyl]cyclopent-3-enol (20f). To a solution of the *syn*-β-hydroxyallylsilane **20g** (373 mg, 1.5 mmol), PPh_3 (787 mg, 3 mmol), and 4-nitrobenzoic acid (503 mg, 3.1 mmol) in 15 mL of dry THF was added a THF solution (2M) of DEAD (514 mg, 2.95 mmol) dropwise at 0 °C. The reaction mixture was allowed to warm to room temperature and stirred for 4 h. The solvent was then evaporated in vacuo. The resulting thick oil was diluted with CH_2Cl_2 (30 mL), washed with saturated aqueous sodium bicarbonate solution (30 mL) and brine (30 mL), and dried (Na_2SO_4). Solvent was removed under reduced pressure to give the crude product as a yellow thick oil which was dissolved in MeOH (15 mL), K_2CO_3 (1.2 g, 8.7 mmol) was added to it, and the resulting mixture was stirred at room temperature for 3 h. Water was then added, the product was extracted into EtOAc, dried over Na_2SO_4, and concentrated under reduced pressure. Purification by flash column chromatography (SiO_2, 9:1 petroleum ether/EtOAc eluent) gave the desired *anti*-β-hydroxyallylsilane **20f** (149 mg, 40%) as a pale yellow oil: $[\alpha]^{27}_D = +86.9$ (*c* 1.85, $CHCl_3$); TLC (20% EtOAc/petroleum ether) R_f 0.20 (UV, I_2); ^{1}H (200 MHz, $CDCl_3$) δ 7.39−7.32 (m, 2H), 6.99−6.91 (m, 1H), 6.88−6.82 (m, 1H), 5.71−5.68 (m, 1H), 5.58−5.53 (m, 1H), 4.40 (d, J = 5.4 Hz, 1H), 3.81 (s, 3H), 2.58−2.26 (m, 3H), 0.23 (s, 3H), 0.22 (s, 3H); ^{13}C (50 MHz, $CDCl_3$) δ 164.4, 135.6, 131.3, 130.8, 125.5, 124.3, 120.7, 109.8, 74.3, 55.1, 46.6, 43.6, −3.6, −4.1; HRMS (ES+) *m*/*z* calcd for $C_{14}H_{20}SiO_2Na$ (M + Na)$^+$ 271.11302, found 271.11167.

[3 + 2] Annulation: General Procedure. To a stirred solution of PTAD (2.5 mmol) in CH_2Cl_2 (2.5 mL) was added dropwise a solution of the allylsilane (1 mmol) in CH_2Cl_2 (1 mL) at room temperature. The reaction was monitored by TLC (the reactions are pretty fast; it usulally takes 1−5 min for complete conversion). After completion of the reaction, solvent was removed under reduced pressure, and the crude product was subjected to flash chromatography to give the desired [3 + 2] adduct.

(24) Dale, J. A.; Dull, D. L.; Mosher, H. S. *J. Org. Chem.* **1969**, *34*, 2543–2549.

11-(Dimethylphenylsilanyl)-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]-undecane-3,5-dione (14c): white solid; mp 168−170 °C; TLC (30% EtOAc/petroleum ether) R_f 0.48 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.60−7.33 (m, 10H), 4.60 (t, J = 4 Hz, 2H), 1.97−1.94 (m, 2H), 1.86−1.77 (m, 1H), 1.72−1.65 (m, 2H), 1.59−1.58 (m, 2H), 0.50 (s, 6H); ^{13}C (100 MHz, $CDCl_3$) δ 155.7, 136.0, 133.5, 131.7, 129.8, 129.0, 128.3, 128.0, 125.4, 60.2, 41.2, 27.1, 18.2, −1.5; HRMS (ES+) m/z calcd for $C_{22}H_{25}SiN_3O_2Na$ (M + Na)$^+$ 414.1614, found 414.1610.

11-[(2-Methoxyphenyl)dimethylsilanyl]-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]undecane-3,5-dione (21a): pale yellow gum; TLC (30% EtOAc/petroleum ether) R_f 0.43 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.49−7.32 (m, 7H), 6.99 (t, J = 7.4 Hz, 1H), 6.86 (d, J = 8.4 Hz, 1H), 4.62 (t, J = 4 Hz, 2H), 3.82 (s, 3H), 1.97−1.94 (m, 2H), 1.89−1.66 (m, 5H), 0.47 (s, 6H); ^{13}C (50 MHz, $CDCl_3$) δ 163.8, 156.2, 135.0, 132.0, 131.9, 129.1, 128.0, 125.5, 124.1, 120.9, 109.8, 61.0, 54.8, 40.5, 27.0, 18.4, −1.2; HRMS (ES+) m/z calcd for $C_{23}H_{27}SiN_3O_3Na$ (M+Na)$^+$ 444.1719, found 444.1711.

8-Hydroxy-11-[(2-methoxyphenyl)dimethylsilanyl]-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]undecane-3,5-dione (21b): white solid; mp 168−170 °C; $[\alpha]^{27}_D$ = +8.6 (c 1.45, $CHCl_3$); TLC (50% EtOAc/petroleum ether) R_f 0.53 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.45−7.39 (m, 5H), 7.37−7.32 (m, 2H), 6.99 (t, J = 7.4 Hz, 1H), 6.87 (d, J = 8 Hz, 1H), 4.58−4.57 (m, 2H), 3.96 (t, J=8 Hz, 1H), 3.84 (s, 3H), 2.17−2.11 (m, 1H), 2.04−1.95 (m, 2H), 1.76−1.56 (m, 3H), 0.46 (s, 3H), 0.45 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 163.6, 157.5, 156.5, 134.8, 132.0, 131.6, 129.0, 128.1, 125.4, 123.6, 120.9, 109.8, 67.6, 67.0, 60.1, 54.8, 39.5, 29.1, 27.1, −1.1, −1.5; HRMS (ESI) m/z calcd for $C_{23}H_{28}N_3O_4Si$ (M + H)$^+$ 438.18436, found 438.18396.

11-(Dimethylphenylsilanyl)-8-hydroxy-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]undecane-3,5-dione (21c): white solid; mp 206−208 °C; TLC (50% EtOAc/petroleum ether) R_f 0.32 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.50−7.34 (m, 10H), 4.58−4.55 (m, 2H), 3.89−3.86 (m, 1H), 2.23 (br s, 1H), 2.12−2.06 (m, 1H), 1.97−1.94 (m, 1H), 1.69−1.53 (m, 3H), 0.49 (s, 6H); ^{13}C (100 MHz, $CDCl_3$) δ 157.2, 156.1, 135.5, 133.5, 131.5, 130.0, 129.0, 128.4, 128.2, 125.3, 67.0, 66.8, 59.4, 40.2, 28.9, 27.4, −1.82, −1.88; HRMS (ES+) m/z calcd for $C_{22}H_{25}SiN_3O_3Na$ (M + Na)$^+$ 430.1563, found 430.1566.

10-(Dimethylphenylsilanyl)-8-hydroxy-4-phenyl-2,4,6-triazatricyclo[5.2.1.0^{2,6}]decane-3,5-dione (21d): white solid; mp 192−194 °C; TLC (50% EtOAc/petroleum ether) R_f 0.39 (UV, I_2); ^{1}H (500 MHz, $CDCl_3$) δ 7.06−6.92 (m, 10H), 4.21 (d, J = 2 Hz, 1H), 4.15 (s, 1H), 3.75 (dd, J = 7, 3 Hz, 1H), 2.50 (br s, 1H), 1.58−1.53 (m, 1H), 1.26 (t, J=1.5 Hz, 1H), 1.11−1.07 (m, 1H), 0.006 (s, 6H); ^{13}C (100 MHz, $CDCl_3$) δ 158.3, 156.4, 135.3, 133.3, 131.5, 130.1, 129.1, 128.4, 128.3, 125.5, 70.5, 68.6, 63.5, 41.9, 37.3, −2.60, −2.64; HRMS (ES+) m/z calcd for $C_{21}H_{23}SiN_3O_3Na$ (M + Na)$^+$ 416.1406, found 416.1408.

10-(Dimethylphenylsilanyl)-8-hydroxy-4-phenyl-2,4,6-triazatricyclo[5.2.1.0^{2,6}]decane-3,5-dione (21e): white solid; mp 112−114 °C; $[\alpha]^{29}_D$ = +5.9 (c 0.86, $CHCl_3$); TLC (30% EtOAc/petroleum ether) R_f 0.40 (UV, I_2); ^{1}H (500 MHz, $CDCl_3$) δ 7.46−7.44 (m, 2H), 7.39−7.35 (m, 4H), 7.32−7.27 (m, 4H), 4.68 (d, J = 2.5 Hz, 1H), 4.45 (s, 1H), 4.23 (d, J = 6 Hz, 1H), 2.17−2.12 (m, 1H), 1.81 (br s, 1H), 1.55−1.47 (m, 2H), 0.40 (s, 6H) ; ^{13}C (100 MHz, $CDCl_3$) δ 156.9, 156.7, 137.4, 133.6, 131.4, 129.5, 129.1, 128.3, 128.1, 125.2, 71.2, 67.8, 62.4, 40.0, 38.7, −1.3, −1.4; HRMS (ES+) m/z calcd for $C_{21}H_{23}SiN_3O_3Na$ (M + Na)$^+$ 416.1406, found 416.1402.

8-Hydroxy-10-[(2-methoxyphenyl)dimethylsilanyl]-4-phenyl-2,4,6-triazatricyclo[5.2.1.0^{2,6}]decane-3,5-dione (21f): white solid; mp 138−142 °C; $[\alpha]^{27}_D$ = +6.7 (c 1.00, $CHCl_3$); TLC (30% EtOAc/petroleum ether), R_f 0.15 (UV, I_2); ^{1}H (200 MHz, $CDCl_3$) δ 7.47−7.28 (m, 7H), 6.99 (t, J = 7.2 Hz, 1H), 6.87 (d, J = 8.2 Hz, 1H), 4.69−4.68 (m, 1H), 4.63 (s, 1H), 4.29−4.24 (m, 1H), 3.84 (s, 3H), 2.24 (br s, 1H), 2.17−2.08 (m, 1H), 1.69−1.67 (m, 1H), 1.58−1.50 (m, 1H), 0.40 (s, 3H), 0.39 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 163.7, 158.9, 157.1, 134.9, 132.1, 131.5, 129.1, 128.3, 125.4, 123.2, 121.0, 109.7, 70.4, 69.5, 64.4, 55.0, 41.5, 37.7, −2.08, −2.09; HRMS (ESI) m/z calcd for $C_{22}H_{26}N_3O_4Si$ (M + H)$^+$ 424.1693, found 424.1693.

8-Hydroxy-10-[(2-methoxyphenyl)dimethylsilanyl]-4-phenyl-2,4,6-triazatricyclo[5.2.1.0^{2,6}]decane-3,5-dione (21g): $[\alpha]^{28}_D$ = +5.6 (c 1.35, $CHCl_3$); TLC (40% EtOAc/petroleum ether) R_f 0.42 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.46−7.33 (m, 7H), 6.97 (t, J = 7.2 Hz, 1H), 6.86 (d, J = 8 Hz, 1H), 4.84 (s, 1H), 4.49 (s, 1H), 4.26 (d, J = 6.4 Hz, 1H), 3.85 (s, 3H), 2.28−2.23 (m, 1H), 1.68−1.62 (m, 2H), 0.45 (s, 3H), 0.41 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 163.5, 157.4, 157.2, 135.1, 131.53, 131.50, 129.1, 128.2, 125.5, 125.2, 120.8, 109.6, 71.4, 68.4, 63.2, 54.9, 39.8, 39.0, −1.0, −1.5; HRMS (ESI) m/z calcd for $C_{22}H_{26}N_3O_4Si$ (M + H)$^+$ 424.1693, found 424.1691.

1-[3-(Dimethylphenylsilanyl)-4-oxocyclohex-2-enyl]-4-phenyl-[1,2,4]triazolidine-3,5-dione (23). To a stirred solution of PTAD (0.1 g, 0.6 mmol) in CH_2Cl_2 (2 mL) was added dropwise a solution of the allylsilane **20i** (0.06 g, 0.26 mmol) in CH_2Cl_2 (0.5 mL) at room temperature. The mixture was stirred at room temperature for 2 h. Then solvent was removed under reduced pressure, and the crude product was subjected to flash chromatography (SiO_2, 6:4 petroleum ether/EtOAc eluent) to give the ketone **23** (0.063 g, 60%) as a pale yellow gum: $[\alpha]^{26}_D$ = +31.8 (c 0.80, $CHCl_3$); TLC (50% EtOAc/petroleum ether) R_f 0.42 (UV,I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.49−7.30 (m, 10H), 6.78 (s, 1H), 5.05−5.01 (m, 1H), 2.63−2.58 (m, 1H), 2.54−2.45 (m, 1H), 2.30−2.24 (m, 2H), 0.41 (s, 3H), 0.40 (s, 3H) ; ^{13}C (100 MHz, $CDCl_3$) δ 199.8, 154.7, 154.4, 152.9, 145.6, 136.3, 134.2, 130.6, 129.3, 129.2, 128.7, 127.8, 125.7, 54.6, 36.6, 26.1, −3.0, −3.2; HRMS (ES+) m/z calcd for $C_{22}H_{23}SiN_3O_3Na$ (M + Na)$^+$ 428.1406, found 428.1402.

11-(Dimethylphenylsilanyl)-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]-undecane-3,5,8-trione (26). To a solution of the [3 + 2] adduct **21c** (0.2 g, 0.5 mmol) in dry CH_2Cl_2 (5 mL) was added PCC (0.13 g, 0.6 mmol) at room temperature. The mixture was stirred for an additional 6 h at room temperature. Ether (15 mL) was added, and the mixture was filtered. Removal of solvents followed by flash chloumn chromatography (SiO_2, 7:3 petroleum ether/EtOAc eluent) afforded the ketone **26** (0.16 g, 80%) as a white solid: mp 214−216 °C; TLC (30% EtOAc/petroleum ether) R_f 0.44 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.49−7.38 (m, 10H), 4.69−4.66 (m, 2H), 2.80−2.74 (m, 1H), 2.40−2.33 (m, 2H), 1.97−1.92 (m, 2H), 0.45 (s, 3H), 0.43 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 201.6, 155.8, 155.5, 134.4, 133.6, 131.3, 130.2, 129.1, 128.4, 125.3, 67.8, 59.2, 41.0, 34.7, 28.9, −2.8, −3.4; HRMS (ES+) m/z calcd for $C_{22}H_{23}SiN_3O_3$ Na (M + Na)$^+$ 428.1406, found 428.1410.

11-(Dimethylphenylsilanyl)-8-hydroxy-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]undecane-3,5-dione (21i). To a solution of **26** (0.15 g, 0.4 mmol) in THF−MeOH (1:1, 5 mL) was added $NaBH_4$ (0.08 g, 2.0 mmol) at 0 °C (ice−water bath), and the mixture was stirred for 5 min. Water was added and the mixture extracted with CH_2Cl_2. The combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by flash column chromatography (SiO_2, 7:3 petroleum ether/EtOAc eluent) to obtain the alcohol **21i** (0.14 g, 93%) as a white solid: mp 179−181 °C; TLC (30% EtOAc/petroleum ether) R_f 0.35 (UV,I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.53−7.50 (m, 2H), 7.48−7.43 (m, 4H), 7.37−7.34 (m, 4H), 4.68 (s, 1H), 4.53−4.51 (m, 1H), 4.18 (s, 1H), 2.06−2.00 (m, 1H), 1.94−1.88 (m, 2H), 1.67−1.65 (m, 2H), 1.42 (s, 1H), 0.55 (s, 3H), 0.51 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 155.7, 155.6, 138.5, 133.5, 131.5, 129.3, 129.1, 128.2, 128.0, 125.4, 66.1, 63.4, 59.9, 38.8, 27.1, 24.6, −0.6, −0.5; HRMS (ES+) m/z calcd for $C_{22}H_{25}SiN_3O_3Na$ (M + Na)$^+$ 430.1563, found 430.1568.

Synthesis of the Diazene: General Procedure. A solution of the cycloadduct (0.5 mmol) in 2-propanol (15 mL) was sonicated

under argon bubbling for 15 min. To this solution was added solid potassium hydroxide (powder, 10 mmol), and the mixture was stirred at 80 °C for 2 h. The reaction mixture was then cooled to room temperature, and water (25 mL) was added to it at 0 °C (ice−water bath). The resulting solution was stirred at room temperature for 15 min (during this time the oxidation of the hydrazino intermediates was complete by the dissolved oxygen present in the medium) and then extracted with dichloromethane (4 × 25 mL). The combined organic extracts were dried (Na_2SO_4) and evaporated in vacuo to give the crude diazene, which was purified by flash column chromatography.

8-(Dimethylphenylsilanyl)-6,7-diazabicyclo[3.2.1]oct-6-en-2-ol (27): white solid; mp 89−91 °C dec; TLC (50% EtOAc/petroleum ether) R_f 0.30 (UV, I_2); ^{1}H (400 MHz, C_6D_6) δ 7.23−7.21 (m, 2H), 7.18−7.16(m, 3H), 5.12 (t, J = 3.6 Hz, 1H), 4.69−4.68 (m, 1H), 3.58−3.54 (m, 1H), 1.60−1.55 (m, 1H), 1.35−1.31 (m, 2H), 0.97−0.81 (m, 3H), 0.063 (s, 3H), 0.060 (s, 3H); ^{13}C (100 MHz, C_6D_6) δ 137.9, 134.1, 130.0, 128.1, 87.8, 80.9, 64.9, 34.5, 28.8, 19.0, −1.3, −1.4; HRMS (ES+) m/z calcd for $C_{14}H_{20}SiN_2ONa$ $(M + Na)^+$ 283.1242, found 283.1245.

8-[(2-Methoxyphenyl)dimethylsilanyl]-6,7-diazabicyclo[3.2.1]oct-6-ene (31a): pale yellow gum; TLC (15% EtOAc/petroleum ether), R_f 0.34 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.40−7.34 (m, 2H), 6.97 (t, J = 7.2 Hz, 1H), 6.85 (d, J = 8 Hz, 1H), 4.93 (t, J = 3.6 Hz, 1H), 3.80 (s, 3H), 1.62−1.57 (m, 2H), 1.50−1.42 (m, 2H), 1.36−1.25 (m, 1H), 1.21−1.18 (m, 1H), 1.01−0.91 (m, 1H), 0.43 (s, 6H); ^{13}C (100 MHz, $CDCl_3$) δ 163.8, 134.9, 131.3, 125.3, 120.6, 109.4, 81.4, 54.6, 33.6, 18.6, 16.7, −0.9, −1.1; HRMS (ES+) m/z calcd for $C_{15}H_{22}SiN_2ONa$ $(M + Na)^+$ 297.1399, found 297.1395.

8-[(2-Methoxyphenyl)dimethylsilanyl]-6,7-diazabicyclo[3.2.1]oct-6-en-2-ol (31b): pale yellow gum; $[\alpha]^{29}_D$ = +35.9 (c 0.75, $CHCl_3$); TLC (50% EtOAc/petroleum ether) R_f 0.27 (UV, I_2); ^{1}H (400 MHz, acetone-d_6) δ 7.41−7.34 (m, 2H), 6.98−6.93 (m, 2H), 4.99−4.98 (m, 1H), 4.87 (s, 1H), 3.87 (s, 3H), 3.73−3.69 (m, 1H), 1.69−1.64 (m, 1H), 1.51−1.44 (m, 2H), 1.16−1.14 (m, 1H), 0.75−0.65 (m, 1H), 0.41 (s, 3H), 0.40 (s, 3H); ^{13}C (100 MHz, acetone-d_6) δ 164.6, 135.4, 132.0, 125.7, 121.2, 110.3, 64.3, 55.0, 34.6, 28.1, 18.4, −1.1, −1.2; HRMS (ES+) m/z calcd for $C_{15}H_{22}SiN_2O_2Na$ $(M + Na)^+$ 313.1348, found 313.1347.

5-Methoxymethoxy-7-[(2-methoxyphenyl)dimethylsilanyl]-2,3-diazabicyclo[2.2.1]hept-2-ene (31h): pale yellow gum; $[\alpha]^{29}_D$ = −47.8 (c 0.73, $CHCl_3$); TLC (20% EtOAc/petroleum ether) R_f 0.35 (UV, I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.36−7.26 (m, 2H), 6.93 (t, J = 7.6 Hz, 1H), 6.83 (d, J = 8.4 Hz, 1H), 5.28 (s, 1H), 5.17 (s, 1H), 4.39 (d, J = 6.8 Hz, 1H), 4.26 (d, J = 6.8 Hz, 1H), 3.83 (s, 3H), 3.44−3.42 (m, 1H), 3.22 (s, 3H), 1.31−1.29 (m, 3H), 0.35 (s, 3H), 0.33 (s, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 163.5, 135.1, 131.0, 126.1, 120.4, 109.2, 94.6, 83.6, 77.8, 70.3, 55.4, 54.8, 42.3, 27.1, −1.3, −1.7; HRMS (ES+) m/z calcd for $C_{16}H_{25}SiN_2O_3$ $(M + H)^+$ 321.1634, found 321.1636.

Synthesis of the *cis*-1,3-Diaminocycloalkanes: General Procedure. The diazene (0.5 mmol) was dissolved in methanol (20 mL), and 10% Pd-on-carbon (150 mg) was added. The mixture was stirred at room temperature under hydrogen (60 psi) for 9 h. The catalyst was then removed by filtration (Celite) and washed with methanol, and the solvent was evaporated in vacuo to give the diamine, which was sufficiently pure to be used in the next step.

2-[(2-Methoxyphenyl)dimethylsilanyl]cyclohexane-1,3-diamine (32a): colorless oil; ^{1}H (400 MHz, CD_3OD) δ 7.40−7.36 (m, 2H), 6.95−6.92 (m, 2H), 3.79 (s, 3H), 3.33−3.32 (m, 2H), 2.88−2.84 (m, 1H), 1.89−1.74 (m, 3H), 1.59−0.86 (m, 4H), 0.41 (s, 6H); ^{13}C (100 MHz, CD_3OD) δ 163.8, 134.4, 131.1, 126.3, 120.6, 109.5, 53.9, 49.7, 42.2, 34.5, 20.5, −2.1; HRMS (ES+) m/z calcd for $C_{15}H_{27}SiN_2O$ $(M + H)^+$ 279.1892, found 279.1889.

2,4-Diamino-3-[(2-methoxyphenyl)dimethylsilanyl]cyclohexanol (32b): colorless oil; $[\alpha]^{28}_D$ = +4.65 (c 0.65, MeOH); ^{1}H (400 MHz, CD_3OD) δ 7.40−7.37 (m, 2H), 6.99−6.95 (m, 2H), 3.80−3.75 (m, 3H), 3.50−3.47 (m, 1H), 3.30 (s, 3H), 1.82−1.70 (m, 4H), 0.41 (s, 6H); ^{13}C (100 MHz, CD_3OD) δ 164.0, 135.1, 131.5, 123.7, 120.5, 109.6, 67.5, 54.1, 52.5, 33.6, 27.1, 22.1, −2.8, −2.9; HRMS (ES+) m/z calcd for $C_{15}H_{27}SiN_2O_2$ $(M + H)^+$ 295.1842, found 295.1842.

4-Methoxymethoxy-2-[(2-methoxyphenyl)dimethylsilanyl]-cyclopentane-1,3-diamine (32h): colorless oil; $[\alpha]^{26}_D$ = −3.34 (c 1.25, MeOH); ^{1}H (400 MHz, CD_3OD) δ 7.41−7.30 (m, 2H), 6.98−6.88 (m, 2H), 4.63−4.56 (m, 2H), 3.82 (s, 3H), 3.79−3.74 (m, 1H), 3.33 (s, 3H), 3.26−3.23 (m, 1H), 3.02−2.99 (m, 1H), 1.79−1.76 (m, 2H), 1.00−0.96 (m, 1H), 0.36 (s, 6H); ^{13}C (100 MHz, CD_3OD) δ 164.0, 135.1, 131.2, 124.6, 120.5, 109.4, 95.7, 84.9, 59.7, 54.2, 54.0, 51.0, 42.0, 40.0, −4.8, −4.9; HRMS (ES+) m/z calcd for $C_{16}H_{29}SiN_2O_3$ $(M + H)^+$ 325.1947, found 325.1943.

Tamao−Fleming Oxidation: General Procedure. To a stirred solution of the [3 + 2] adduct (0.15 mmol) in 1.5 mL of CH_2Cl_2 was added CF_3COOH (2.3 mmol) at room temperature. The solution was allowed to stir at room temperature for 10 h. The solvent and excess CF_3COOH were then removed under reduced pressure, and the crude was redissolved in 5 mL of THF−MeOH (1:1). KF (0.8 mmol) and $KHCO_3$ (0.8 mmol) were added, followed by dropwise addition of 30% H_2O_2 (3 mmol) at 0 °C (ice−water bath). The resulting mixture was allowed to warm to room temperature and stirred for 48 h, and then the reaction mixture was diluted with water (10 mL) and extracted with ethyl acetate (5 × 10 mL). The organic extracts were combined, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. Purification by flash column chromatography gave the desired alcohol.

11-Hydroxy-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]undecane-3,5-dione (30a): white solid; mp 230−234 °C; TLC (50% EtOAc/petroleum ether) R_f 0.20 (UV,I_2); ^{1}H (200 MHz, $CDCl_3$) δ 7.52−7.33 (m, 5H), 4.37−4.24 (m, 3H), 2.15−1.99 (m, 2H), 1.94−1.83 (m, 2H), 1.75−1.53 (m, 2H); ^{13}C (100 MHz, $CDCl_3$) δ 154.6, 131.6, 129.1, 128.1, 125.5, 70.6, 57.5, 21.9, 17.1; HRMS (ESI) m/z calcd for $C_{14}H_{15}N_3O_3Na$ $(M + Na)^+$ 296.1011, found 296.1007.

8,11-Dihydroxy-4-phenyl-2,4,6-triazatricyclo[5.3.1.0^{2,6}]undecane-3,5-dione (30b): white solid; mp >320 °C; $[\alpha]^{29}_D$ = +26.1 (c 0.25, MeOH); TLC (EtOAc) R_f 0.15 (UV,I_2); ^{1}H (200 MHz, DMSO-d_6) δ 7.48−7.36 (m, 5H), 6.00 (d, J = 3.8 Hz, 1H), 4.88 (d, J = 5.2 Hz, 1H), 4.43−4.36 (m, 1H), 4.15−4.11 (m, 1H), 4.06−3.99 (m, 2H), 1.97−1.81 (m, 2H), 1.66−1.40 (m, 2H); ^{13}C (100 MHz, DMSO-d_6) δ 155.8, 155.3, 132.3, 129.2, 128.5, 126.9, 70.8, 64.2, 63.3, 57.2, 27.4, 21.9; HRMS (ESI) m/z calcd for $C_{14}H_{15}N_3O_4Na$ $(M + Na)^+$ 312.0960, found 312.0958.

8,10-Dihydroxy-4-phenyl-2,4,6-triazatricyclo[5.2.1.0^{2,6}]decane-3,5-dione (30g): $[\alpha]^{29}_D$ = +12.6 (c 0.50, $CHCl_3$); TLC (50% EtOAc/petroleum ether) R_f 0.18 (UV,I_2); ^{1}H (400 MHz, $CDCl_3$) δ 7.47−7.35 (m, 5H), 4.53−4.51 (m, 2H), 4.34 (s, 1H), 4.28 (d, J = 6.4 Hz, 1H), 3.57 (br s, 2H), 2.46−2.41 (m, 1H), 2.13 (d, J = 14.4 Hz, 1H); ^{13}C (100 MHz, $CDCl_3$) δ 155.7, 155.5, 131.0, 129.2, 128.6, 125.4, 77.1, 71.0, 62.2, 61.3, 37.1; HRMS (ESI) m/z calcd for $C_{13}H_{13}N_3O_4Na$ $(M + Na)^+$ 298.0804, found 298.0810.

Diol 33b. To a solution of the diamine **32b** (150 mg, 0.5 mmol), pyridine (427 mg, 5.4 mmol), and DMAP (cat.) in dichloromethane (7 mL) was added benzoyl chloride (379 mg, 2.7 mmol) at 0 °C (ice−water bath). The resulting solution was allowed to warm to room temperature and stirred for 6 h. Water (10 mL) was added to the reaction mixture, the organic layer was separated, and the aqueous layer was extracted with ethyl acetate (3 × 5 mL). The organic extracts were combined, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure to afford a yellow oil which was dissolved in CH_2Cl_2 (5 mL). $HBF_4 \cdot OEt_2$ (268 mg, 1.65 mmol) was added to the solution at 0 °C (ice−water bath). The resulting mixture was allowed to warm to room temperature and stirred for 6 h. The reaction was quenched by dropwise addition of satd aq $NaHCO_3$

(at 0 °C). The organic layer was separated, and the aqueous layer was extracted with dichloromethane (3 × 10 mL). The organic extracts were combined, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure to give the crude fluorosilane which was dissolved in THF−MeOH (1:1, 10 mL). KF (145 mg, 2.5 mmol) and $KHCO_3$ (250 mg, 2.5 mmol) were added, and then 30% aq H_2O_2 (1 mL, 8.8 mmol) was added at 0 °C (ice−water bath). The resulting mixture was allowed to warm to room temperature and stirred for 48 h. Then the reaction mixture was diluted with water (10 mL) and extracted with ethyl acetate (5 × 10 mL). The organic extracts were combined, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. Purification by flash column chromatography (SiO_2, 8:2 EtOAc/petroleum ether eluent) gave the diol **33b** as a white solid (109 mg, 60%): $[\alpha]^{27}_D = +26.7$ (*c* 1.13, MeOH); mp 238−240 °C; TLC (80% EtOAc/petroleum ether), R_f 0.25 (UV, I_2); ^{1}H (400 MHz, CD_3OD) δ 7.89−7.83 (m, 4H), 7.53−7.50 (m, 2H), 7.47−7.42 (m, 4H), 4.17 (s, 1H), 4.06−4.03 (m, 2H), 3.95−3.92 (m, 1H), 1.90−1.76 (m, 4H); ^{13}C (100 MHz, CD_3OD) δ 169.1, 169.0, 134.5, 134.4, 131.1, 131.0, 128.1, 128.0, 126.99, 126.97, 70.4, 68.1, 57.9, 54.5, 29.4, 24.7; HRMS (ES+) *m*/*z* calcd for $C_{20}H_{22}N_2O_4Na$ $(M + Na)^+$ 377.1477, found 377.1476.

6,7-Diazabicyclo[3.2.1]oct-6-en-8-ol (34). A solution of the alcohol **30a** (305 mg, 1.12 mmol) in 2-propanol (15 mL) was sonicated under argon bubbling for 15 min. To this solution was added solid potassium hydroxide (1.2 g, 21.4 mmol), and the mixture was stirred at 80 °C for 2 h. The reaction mixture was cooled to room temperature, and water (25 mL) was added to it at 0 °C (ice−water bath). Concentrated HCl was added dropwise, and the pH was adjusted to 1−2. Then 12% aq NH_4OH was added to the mixture, and the pH was brought to 5−6 followed by addition of 15 mL of 2 N aq $CuCl_2$ solution. The resulting dark brown mixture was treated with 50 mL of 12% aq NH_4OH and 75 mL of hexane. The color immediately changed to deep blue. This was stirred at room temperature for 30 min. The organic layer was separated, and the aqueous layer was extracted with dichloromethane (4 × 25 mL). The combined organic extracts were dried (Na_2SO_4) and evaporated in vacuo to give a brown oil which was purified by flash column chromatography (SiO_2, 1:1 EtOAc/petroleum ether eluent) to give the diazene **34** (90 mg, 64%) as a pale brown oil: TLC (50% EtOAc/petroleum ether) R_f 0.22 (I_2); ^{1}H (400 MHz, $CDCl_3$) δ 4.60 (t, J = 4.4 Hz, 2H), 4.12 (t, J = 5.2 Hz, 1H), 2.12 (br s, 1H), 1.79−1.71 (m, 2H), 1.58−1.52 (m, 2H), 1.48−1.41 (m, 1H), 0.98−0.85 (m, 1H); ^{13}C (100 MHz, $CDCl_3$) δ 78.0, 70.6, 16.2, 15.1; HRMS (ESI) *m*/*z* calcd for $C_6H_{10}N_2ONa$ $(M + Na)^+$ 149.0691, found 149.0690.

2,6-Diaminocyclohexanol (35). The diazene **34** (30 mg, 0.24 mmol) was dissolved in methanol (15 mL), and 10% Pd-on-carbon (50 mg) was added. The mixture was stirred at room temperature under hydrogen (60 psi) for 9 h. The catalyst was then removed by filtration (Celite) and washed with methanol, and the solvent was evaporated in vacuo to give the diamino alcohol **35** (30 mg, 97%) as a colorless oil: ^{1}H (400 MHz, CD_3OD) δ 2.78 (t, J = 9.2 Hz, 1H), 2.50−2.44 (m, 2H), 1.86−1.83 (m, 2H), 1.70−1.66 (m, 1H), 1.38−1.31 (m, 1H), 1.23−1.16 (m, 2H); ^{13}C (50 MHz, CD_3OD) δ 81.4, 54.8, 32.4, 22.2; HRMS (ESI) *m*/*z* calcd for $C_6H_{14}N_2ONa$ $(M + Na)^+$ 153.1004, found 153.1008.

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Supporting Information Available: Experimental details and full spectral and X-ray crystallographic data (CCDC 768163-768165). This material is available free of charge via the Internet at http://pubs.acs.org.