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Aziridine Synthesis in Protic Media by Using Lanthanide Triflates as Catalysts

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Abstract: Ln(OTf)$_3$-catalyzed aziridine synthesis from imines and diazo compounds was studied in a variety of protic media. The reactions proceeded readily under mild conditions and were highly selective, affording predominantly *cis* aziridines. The imines used were typically those derived from aromatic aldehydes and aromatic amines, with either electron-donating or electron-withdrawing substituents. N-benzyl aryl aldimines and imines derived from aromatic amines and hindered aliphatic aldehydes were also found to work well. Among the three diazo compounds examined, ethyl diazoacetate (EDA) and 3-nitrophenyl diazomethane were effective reagents for the aziridination. However, the reactions of ethyl diazoacetoacetate failed to give any desired product. Six lanthanides triflates as well as Sc(OTf)$_3$ and Y(OTf)$_3$ were tested as catalyst in the aziridination reaction. The formation of the by-products was also discussed.

Keywords: Aziridines; Diazo compounds; Imines; Lanthanides

INTRODUCTION

Aziridines are versatile building blocks for synthesis of a variety of biologically important molecules.[1] A number of methods are available for the synthesis of aziridines. However, the simplest approach is either the addition of a nitrene moiety to an olefin or the addition of a carbene moiety to an imine. Transition metals have been found to act as effective catalysts in both cases.[2,3] For example, treatment of a variety of imines with ethyl diazoacetate (EDA) in the presence of catalytic amount of Cu(OTf)$_2$ afforded a mixture of the corresponding *cis* and *trans* aziridines in good yields.[3b] The same reaction was also effectively catalyzed by methylrehenium trioxide.[3d] A recent report demonstrated that Lewis acids such as BF_3•OEt_2, $AlCl_3$ and $TiCl_4$ also catalyzed the synthesis of aziridines from EDA and imines.[4] Unlike the corresponding transition metal-catalyzed reaction where the first step was believed to be the formation of a transient metal carbene species, the Lewis acid-catalyzed reaction occurred via activation of the imine followed by a nucleophilic addition of EDA.[4,5]

Lanthanide triflates are unique Lewis acids that are water-stable and have recently attracted considerable research interest.[6,7] By using Ln(OTf)$_3$ we have realized a number of organic transformations in aqueous and

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protic media,[8-12] which are attractive reaction solvents for the development of environmentally benign chemical processes.[13] As one part of our ongoing program to explore organic transformations in environmentally friendly media, we recently investigated the aziridination reaction in a variety of protic media where catalytic formation of aziridines with high *cis* selectivity was achieved via lanthanide triflate-catalyzed reactions of imines with diazo compounds.[14]

RESULTS AND DISCUSSION

Lanthanide triflates were found to catalyze the aziridination reaction of diazo compounds with a variety of imines. It was noteworthy that the reaction proceeded smoothly not only in common solvents such as chloroform but also in protic media like ethanol (Scheme 1). Compared with chloroform, ethanol was found to give better stereoselectivity. Moreover, when conducting the reaction in common solvents, one has to use anhydrous $Ln(OTf)_3$ salts, since lanthanide triflates in their hydrated forms can hardly be dissolved in such solvents. Protic media, on the other hand, allow for the use of $Ln(OTf)_3$ hydrates, which are much less expensive.

Scheme 1

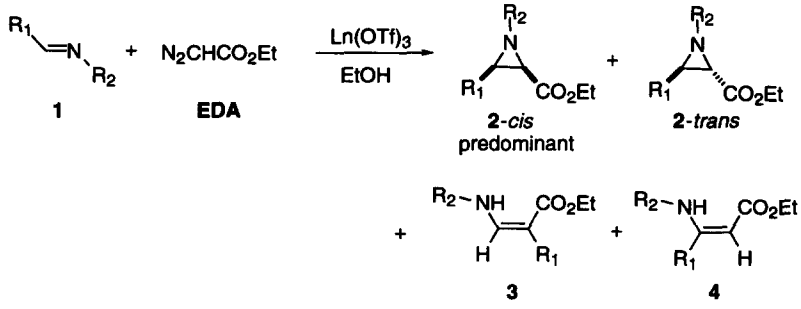


Table 1 $La(OTf)_3$ Catalyzed Reactions of Imines with EDA in EtOH[a]

entry	imine	R_1	R_2	Product (yield[b])		
1	**1a**	C_6H_5	C_6H_5	**2a** (53, *cis* only)	**3a** (13)	**4a** (17)
2	**1b**	C_6H_5	*p*-Cl-C_6H_4	**2b** (54, *cis:trans* 8:1)		
3	**1c**	*p*-Cl-C_6H_4	C_6H_5	**2c** (55, *cis* only		
4	**1d**	*p*-Cl-C_6H_4	*p*-Cl-C_6H_4	**2d** (60, *cis* only)		**4d**(15)
5	**1e**	*p*-Me-C_6H_4	*p*-Cl-C_6H_4	**2e** (57, *cis* only)	**3e** (10)	**4e** (13)
6	**1f**	C_6H_5	*p*-MeO-C_6H_4	**2f** (62, *cis:trans* 29:2)	**3f** (21)	
7	**1g**	C_6H_5	*o*-HO-C_6H_4	**2g** (49, *cis* only)		
8	**1h**	*p*-MeO-C_6H_4	C_6H_5	**2h** (51, *cis* only)		
9	**1i**	C_6H_5	$C_6H_5CH_2$	**2i** (55, *cis* only)		
10	**1j**	t-C_4H_9	C_6H_5	**2j** (52, *cis:trans* 5:1)		

[a] 10 mol% of $La(OTf)_3$ hydrate, 12 hrs at room temperature. [b] isolated yield.

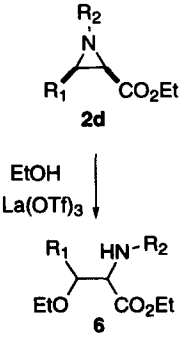
As summarized in Table 1, arylimines with either electron donating or electron withdrawing groups reacted readily with EDA in ethanol in the presence of $La(OTf)_3$ (10 mol%), affording the corresponding aziridines with high *cis* selectivities. In fact, for most reactions examined, only *cis* aziridines were isolated. No carbene-coupling product was detected under the experiment conditions. However, in several cases, the formation of the aziridines was accompanied by **3** and **4** in varied yields. It was suggested that the $La(OTf)_3$-catalyzed aziridination in ethanol proceeded in a similar manner as proposed previously for typical Lewis acids[4].

In addition to typical Schiff bases which were derived from aromatic amines and aromatic aldehydes, N-benzyl aryl aldimines (Table 1, entry 9) and imines derived from aromatic amines and hindered aliphatic aldehydes (Table 1, entry 10) were also found to work well. However, due to poor stability in protic solvents, most N-alkyl aliphatic aldimines failed to give any desired products under the reaction conditions.

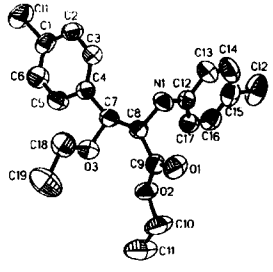
Interestingly, in a control experiment where EDA was stirred alone in ethanol with catalytic amount of $La(OTf)_3$ (no imine was added), $EtOCH_2CO_2Et$ (**5**) was afforded in 86% yield after two days. Without $La(OTf)_3$, no reaction took place. The formation of **5** most likely occurred via Lewis acid-activation of ethanol followed by protonic addition to EDA. The reason why **5** was not isolated in the $La(OTf)_3$-catalyzed aziridination reactions was that the rate of the protonic addition to EDA was significantly slower as monitored by TLC. In addition, the high binding affinity of $Ln(OTf)_3$ for imines[15] might be another reason that made the aziridination reaction proceed readily without interference.

Furthermore, in one of the reactions listed in Table 1 (entry 4) a small amount of **6** (3% yield) was isolated as a result of ring-opening of the corresponding aziridine **2d**. A separate experiment was carried out with pure **2d**, showing that the occurrence of the ring-opening under the aziridination conditions was rather sluggish. Even with 50 mol% of $La(OTf)_3$, the reaction still took several days to complete. Therefore in most cases, as long as the aziridination reaction was stopped promptly at its completion, the ring-opening reaction was not significant at all. Interestingly however, the $La(OTf)_3$-mediated ring-opening of **2d** proceeded in a highly regioselective fashion, as shown by NMR and X-ray structure analysis. The nucleophile, ethanol molecule, attacked preferentially at the C-3 position to afford **6** as the only product isolated (Scheme 2).

Scheme 2



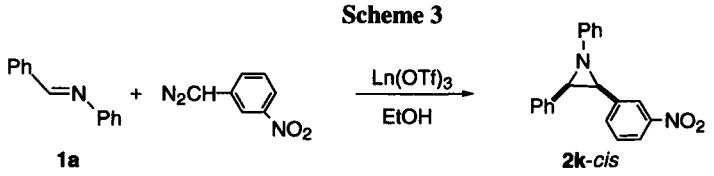
$R_1 = R_2 = Cl\text{-}C_6H_4$,



X-ray Crystal Structure of **6**

In addition to EDA, two other diazo compounds were also examined for the aziridination reaction. 3-nitrophenyl diazomethane, representing a family of easily accessible diazo compounds - aryl diazomethanes, reacted readily with N-benylideneanaline in the presence of catalytic amount of lanthanum triflate. The reaction gave the corresponding aziridine in 70% yield. No formation of the by-products **3** or **4** was detected. Again, the reaction was highly stereoselective. Only the *cis* aziridine was isolated (Scheme 3). The reaction of ethyl diazoacetoacetate, however, failed to afford any desired product, probably due to the steric effect caused by somehow hindered structure of the substrate.

Scheme 3



1a **2k-*cis***

Aziridination reactions in methanol, 1-propanol, 2-propanol and 1-butanol proceeded in a similar manner with comparable yields. A mixture of acetonitrile and water (5:1) as well as EtOH/H_2O (5:1) could also be employed as solvent for the reaction, with a slightly lower yield. However, the use of water increased the chance of the ring-opening product formation. The results of $La(OTf)_3$ catalyzed reaction of **1a** in deferent solvents are presented in Table 2.

Table 2 $La(OTf)_3$-Catalyzed Reaction of 1a with EDA in Different Solvents[a]

solvent	yield (%[b])		
	2a (*cis:trans*)	**3a**	**4a**
MeOH	59 (*cis* only)	18	9
1-PrOH	55 (*cis* only)	14	7
2-PrOH	50 (*cis* only)	6	8
1-BuOH	52 (*cis* only)	14	9
CH_3CN/H_2O[c]	47 (9:1[d])	11	13
EtOH/H_2O[e]	44 (*cis* only)[f]	8	15
$CHCl_3$	51 (7:2[d])	7	10

[a] 10 mol% of $La(OTf)_3$ hydrate (except for $CHCl_3$, where anhydrous $La(OTf)_3$ was used), 12 hrs at room temperature. [b] isolated yield. [c] CH_3CN/H_2O: 5/1. [d] estimated by ^1H NMR. [e] EtOH/H_2O: 5/1. [f] the reaction also afforded the corresponding ring-opening product in 15% yield.

Six other lanthanide triflates as well as $Sc(OTf)_3$ and $Y(OTf)_3$ were also tested as catalyst in the aziridination reaction. As shown in Table 3, $Nd(OTf)_3$ gave the best result in terms of yield. *cis*-Selectivities were observed in all cases. However, heavier lanthanides resulted in reduced selectivities. In the respect of the catalyst loading, use of 10-15 mol% of $Ln(OTf)_3$ was found most desirable. Lower loading would result in both prolonged reaction time and low yields. For instance, when using 5 mol % of $La(OTf)_3$, the reaction of **1a** with

EDA had a conversion of only 37% even after 4 days. On the other hand, higher catalyst loading reduced the reaction time, but increased the chance of by-products formation.

Furthermore, it was found that the formations of **3** and **4** could be remarkably reduced by performing the reaction at lower temperatures. Thus, when the reaction of **1a** with EDA was carried out at 0 °C with 15 mol% of $Nd(OTf)_3$ in ethanol, the combined yield of **3a** and **4a** was reduced to as low as 9%, whereas the yield of **2a** improved to 72%.

Table 3 Reactions of 1a with EDA Catalyzed by $Ln(OTf)_3$[a]

$Ln(OTf)_3$	**2a** (%)[b]	**3a** (%)[b]	**4a** (%)[b]
Sc	39 (*cis*)	13	6
Y	48 (*cis*)	8	12
La	53 (*cis*)	13	17
Nd	66 (*cis*)	15	12
Eu	58 (*cis*)	19	7
Gd	55 (*cis*)	11	14
Dy	47 (*cis*)	10	14
Er	52 (*cis/trans*: 11/1[c])	6	10
Yb	54 (*cis/trans*: 9/2[c])	13	11

[a] 10 mol% of $Ln(OTf)_3$ hydrates, 12 hrs in EtOH at room temperature. [b] isolated yield. [c] estimated by ^1H NMR

We have envisioned that by allowing for the use of unprotected saccharide-bearing imines (which can be readily dissolved in protic media, but not in most of the common solvents), the $Ln(OTf)_3$-catalyzed aziridine synthesis in protic media expects to provide a simple approach for the synthesis of aziridine compounds containing saccharide motifs . Unfortunately, our efforts to use imines derived directly from unprotected aldoses have not yet been successful.

In summary, we have demonstrated that aziridine synthesis in a variety of protic media can be effected by $Ln(OTf)_3$-catalyzed reactions of imines with diazo compounds. The reactions proceed readily under mild condition and are highly stereoselective, affording predominantly *cis* aziridines. Protic media allow for the use of $Ln(OTf)_3$ hydrates which are much less expensive than anhydrous $Ln(OTf)_3$ that are normally used when conducting reactions in common solvents. Also using protic media expects to eliminate the solubility problem for any unprotected-sugar-bearing substrates to be directly utilized in such reactions.

EXPERIMENTAL

^1H and ^{13}C NMR spectra were recorded either on a 300 MHz (GE) or 400 MHz (Varian) NMR spectrometer. Whaterman K6F Silica Gel 60 Å TLC plates and E. Merk Silica Gel 60 were used respectively for thin layer chromatography and column chromatography. Melting points were measured with an Electrothermal IA9100 melting point apparatus. All chemicals were from commercial sources and used as received. The

imines, except **1a** which was purchased from Aldrich, were made from the corresponding aldehydes and amines with anhydrous Na_2SO_4 in CH_2Cl_2. 3-nitrophenyl diazomethane was prepared from 3-nitrobenzaldehyde following a literature procedure.[16] Aziridination reactions were carried at room temperature unless otherwise specified. The stereochemistry of the aziridines were assigned by ^1H NMR based on the coupling constants between the two protons on 2- and 3-positions.[4]

General Procedure for the Ln(OTf)$_3$-Catalyzed Aziridination Reaction. A mixture of imine (1 mmol) and EDA (1 mmol) was stirred with Ln(OTf)$_3$ (10 mol%) in 10 ml of ethanol (or other solvent as specified) for 12 h (monitored by TLC). The solvent was removed under reduced pressure. The residue was extracted with CH_2Cl_2 and separated by flash column chromatography on silica gel with hexane/ethyl acetate (5: 1, v/v).

***cis*-Ethyl 1, 3-diphenylaziridine-2-carboxylate (2a-*cis*).** A white waxy solid, m.p. 64-65 °C (dec). ^1H NMR (400 MHz, $CDCl_3$) δ 0.97 (t, 3H), 3.18 (d, J=6.8 Hz, 1H), 3.58 (d, J=6.8 Hz, 1H), 3.90-4.10 (m, AB, 2H), 7.03-7.50 (m, 10H); ^{13}C NMR ($CDCl_3$) δ 13.9, 45.6, 47.1, 61.0, 119.9, 123.4, 127.7, 127.9, 128.0, 129.2, 134.7, 152.4, 167.7. MS (EI) *m/z* (%) 267 (M^+, 25), 194 (100), HRMS (EI) calcd for $C_{17}H_{17}NO_2$ 267.1259, found 267.1266.

***trans*-Ethyl 1, 3-diphenylaziridine-2-carboxylate (2a-*trans*).** A white crystalline solid, m.p. 80-82 °C. ^1H NMR (400 MHz, $CDCl_3$) δ 1.10 (t, 3H), 3.20 (d, J=2.8 Hz, 1H), 3.77 (d, J=2.8 Hz, 1H), 4.06 (q, AB, 2H), 6.82-6.98 (m, 3H), 7.17 (m, 2H), 7.21-7.30 (br, 5H); ^{13}C NMR ($CDCl_3$) δ 14.0, 45.9, 46.2, 61.4, 120.1, 122.8, 126.9, 128.0, 128.2, 128.6, 128.8, 129.3, 136.3, 148.4, 167.5. MS (EI) *mlz* (%) 267 (M^+, 19), 194 (100), HRMS (EI) calcd for $C_{17}H_{17}NO_2$ 267.1259, found 267.1256. Anal. calcd: C, 76.39; H, 6.42; N, 5.25. Found: C, 76.22; H, 6.47; N, 5.09.

Ethyl 3-(N-phenylamino)-2-phenylpropenoate (3a). A pale yellow oil. ^1H NMR (400 MHz, $CDCl_3$) δ 1.28 (t, 3H), 4.24 (q, 2H), 6.98-7.01(m, 2H), 7.20-7.33 (m, 3H), 7.40 (d, J=12.4, 1H), 10.32 (br d, J=12.4, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 60.1, 103.0, 115.7, 123.0, 125.8, 128.2, 129.2, 129.4, 137.8, 141.0, 143.4, 169.3. MS (EI) *m/z* (%) 267 (M^+, 65), 194 (100), HRMS (EI) calcd for $C_{17}H_{17}NO_2$ 267.1259, found 267.1262.

Ethyl 3-(N-phenylamino)-3-phenylpropenoate (4a). A pale yellow oil. ^1H NMR (400 MHz, $CDCl_3$) δ 1.31 (t, 3H), 4.21 (q, 2H), 5.08 (s, 1H), 6.58-6.87 (m, 2H), 7.15-7.30 (m, 3H), 10.34 (br s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 59.4, 90.7, 115.2, 121.9, 122.6, 127.8, 129.3, 129.4, 135.7, 140.2, 159.0, 169.8. MS (EI) *m/z* (%) 267 (M^+, 91), 221 (100), HRMS (EI) calcd for $C_{17}H_{17}NO_2$ 267.1259, found 267.1255. Anal. calcd: C, 76.39; H, 6.42; N, 5.25. Found C, 76.52; H, 6.51; N, 5.18.

***cis*-Ethyl 1-(*p*-chlorophenyl)-3-phenylaziridine-2-carboxylate (2b-*cis*).** A yellowish oil. ^1H NMR (300 MHz, $CDCl_3$) δ 1.01 (t, 3H), 3.19 (d, J=6.9 Hz, 1H), 3.60 (d, J=6.9 Hz, 1H), 3.93-4.05 (m, AB, 2H), 6.95-7.00 (quasi d, AA'BB', 2H), 7.20-7.49 (m, 7H); ^{13}C NMR ($CDCl_3$) δ 14.0, 45.6, 47.4, 61.2, 121.8, 127.3, 128.0, 128.2, 128.5, 129.4, 134.0, 149.6, 167.2. MS (EI) *m/z* (%) 301 (M^+, 43), 77 (100), HRMS (EI) calcd for $C_{17}H_{16}ClNO_2$ 301.0870, found 301.0874. Anal. calcd: C, 67.67; H, 5.35; N, 4.65. Found C, 67.61; H, 5.23; N, 4.50.

***trans*-Ethyl 1-(*p*-chlorophenyl)-3-phenylaziridine-2-carboxylate (2b-*trans*).** A yellowish oil. ^1H NMR (300 MHz, $CDCl_3$) δ 1.17 (t, 3H), 3.20 (d, J=2.1 Hz, 1H), 3.75 (d, J=2.1 Hz, 1H), 4.10 (m,

AB, 2H), 6.78 (quasi d, AA'BB', 2H), 7.14-7.32 (m, 7H); ^{13}C NMR ($CDCl_3$) δ 14.0, 46.0, 46.8, 61.6, 121.4, 127.0, 127.6, 128.1, 128.5, 129.0, 135.5, 147.0, 167.7. MS (EI) *m/z* (%) 301 (M^+, 29), 228 (100), HRMS (EI) caldc for $C_{17}H_{16}ClNO_2$ 301.0870, found 301.0874. Anal. calcd: C, 67.67; H, 5.35; N, 4.65. Found C, 67.54; H, 5.42; N, 4.57.

***cis*-Ethyl 1-phenyl-3-(*p*-chlorophenyl)-aziridine-2-carboxylate (2c-*cis*).** A pale yellow crystalline solid, m.p. 67-68 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.05 (t, 3H), 3.20 (d, J=6.9 Hz, 1H), 3.54 (d, J=6.9 Hz, 1H), 4.01-4.15 (m, AB, 2H), 7.03 (m, 2H), 7.25-7.34 (m, 5H), 7.46 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.0, 45.6, 46.4, 61.2, 119.9, 123.6, 128.3, 129.1, 129.2, 133.1, 133.8, 152.0, 167.4. MS (EI) *m/z* (%) 301 (M^+, 11), 139 (100), HRMS (EI) calcd for $C_{17}H_{16}ClNO_2$ 301.0870, found 301.0873.

***cis*-Ethyl 1-3-di(*p*-chlorophenyl)-aziridine-2-carboxylate (2d-*cis*).** A pale white crystalline solid, m.p. 59-61 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.05 (t, 3H), 3.16 (d, J=6.6 Hz, 1H), 3.51 (d, J=6.9 Hz, 1H), 3.97-4.10 (m, AB, 2H), 6.97 (AA'BB', 2H), 7.23 (AA'BB', 2H), 7.32 (AA'BB', 2H), 7.43 (AA'BB', 2H); ^{13}C NMR ($CDCl_3$) δ 14.0, 45.7, 46.6, 61.3, 121.2, 128.3, 128.5, 129.0, 129.2, 133.8, 136.3, 151.6, 166.9. MS (EI) *m/z* (%) 335 (M^+, 53), 262 (100), HRMS (EI) calcd for $C_{17}H_{15}Cl_2NO_2$ 335.0480, found 335.0477.

Ethyl 3-(N-*p*-chlorophenylamino)-3-(*p*-chlorophenyl)-propenoate (4d). A yellowish oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.31 (t, 3H), 4.21 (q, 2H), 5.05 (s, 1H), 6.58 (AA'BB', 2H), 7.06 (AA'BB', 2H), 7.28 (m, 4H), 10.21 (br s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.4, 59.5, 92.3, 116.8, 123.4, 128.8, 128.9, 129.4, 129.9, 130.7, 138.7, 155.3, 168.2. MS (EI) *m/z* (%) 335 (M^+, 26), HRMS (EI) calcd for $C_{17}H_{15}Cl_2NO_2$ 335.0480, found 335.0473.

***cis*-Ethyl 1-(*p*-chlorophenyl)-3-(*p*-tolyl)-aziridine-2-carboxylate (2e-*cis*).** A pale yellow solid, m.p. 73-75 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.29 (t, 3H), 2.33 (s, 3H), 3.20 (d, J=6.6 Hz, 1H), 3.60 (d, J=6.6 Hz, 1H), 3.93-4.11 (m, AB, 2H), 7.01 (quasi d, AA'BB', 2H), 7.14-7.35 (m, 6H); ^{13}C NMR ($CDCl_3$) δ 14.1, 20.6, 45.4, 46.7, 61.2, 119.3, 127.5, 128.0, 128.5, 129.3, 134.3, 138.5, 150.8, 167.2. MS (EI) *m/z* (%) 315 (M^+, 3), 230 (100), HRMS (EI) calcd for $C_{18}H_{18}ClNO_2$ 315.1026, found 315.1030. Anal. calcd: C, 68.47; H, 5.76; N, 4.45. Found C, 68.55; H, 5.83; N, 4.39.

Ethyl 3-(N-*p*-chlorophenylamino)-2-tolylpropenoate (3e). ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.30 (t, 3H), 2.70 (s, 3H), 4.26 (q, 2H), 6.92 (quasi d, AA'BB', 2H), 7.17-7.27 (m, 6H), 7.30 (d, J=12.8 Hz, 1H), 10.32 (d, 12.3 Hz, 1H); ^{13}C NMR ($CDCl_3$) 14.4, 21.1, 60.0, 103.6, 116.6, 127.3, 128.7, 129.4, 129.6, 134.6, 135.9, 139.5, 142.8, 169.4. MS (EI) *m/z* 315 (M^+, 100), HRMS (EI) calcd for $C_{18}H_{18}ClNO_2$ 315.1026, found 315.1034. Anal. calcd: C, 68.47; H, 5.76; N, 4.45. Found, C, 68.35; H, 5.90; N, 4.42.

Ethyl 3-(N-*p*-chlorophenylamino)-3-tolylpropenoate (4e). A yellowish oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.32 (t, 3H), 2.34 (s, 3H), 4.21 (q, 2H), 5.01 (s, 1H), 6.59 (AA'BB', 2H), 7.04 (AA'BB', 2H), 7.11-7.26 (m, 4H), 10.25 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.4, 21.3, 59.3, 91.5, 123.2, 125.7, 128.0, 128.8, 129.4, 129.9, 131.9, 133.2, 140.5, 166.0. MS (EI) *m/z* (%) 315 (M^+, 58), 269 (100), HRMS (EI) calcd for $C_{18}H_{18}ClNO_2$ 315.1026, found 315.1019. Anal. calcd: C, 68.47; H, 5.76; N, 4.45. Found, C, 68.51; H, 5.64; N, 4.56.

***cis*-Ethyl 1-(*p*-methoxyphenyl)-3-phenylaziridine-2-carboxylate (2f-*cis*).** A yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.01 (t, 3H), 3.15 (d, J=6.8 Hz, 1H), 3.55 (d, J=6.8 Hz, 1H), 3.79 (s, 3H), 3.95-

4.10 (m, AB, 2H), 6.85 (AA'BB', 2H), 7.02 (AA'BB', 2H), 7.29-7.40 (m, 3H), 7.51-7.55 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 13.9, 46.0, 48.7, 56.3, 61,0, 114.6, 121.1, 127.7, 127.8, 128.2, 135.0, 145.9, 155.6, 167.4. MS (EI) *m/z* (%) 297 (M^+, 21), 224 (100), HRMS (EI) calcd for $C_{18}H_{19}NO_3$ 297.1365, found 297.1373. Anal. calcd: C, 72.72; H, 6.45; N, 4.72. Found C, 72.69; H, 6.40; N, 4.81.

***trans*-Ethyl 1-(*p*-methoxyphenyl)-3-phenylaziridine-2-carboxylate (2f-*trans*).** A pale yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.21 (t, 3H), 3.24 (d, J=2.2 Hz, 1H), 3.75 (s, 3H), 3.80 (d, J=2.2 Hz, 1H), 4.15 (q, 2H), 6.77-6.82 (m, 4H), 7.28-7.33 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 14.0, 45.8, 46.6, 55.3, 61.4, 114.1, 121.0, 126.8, 128.1, 128.5, 136.0, 141.7, 155.1, 167.5. MS (EI) *m/z* (%) 297 (M^+, 36), 224 (100), HRMS (EI) calcd for $C_{18}H_{19}NO_3$ 297.1365, found 297.1370. Anal. calcd: C, 72.72; H, 6.45; N, 4.72. Found C, 72.83; H, 6.49; N, 4.67.

Ethyl 3-(N-*p*-methoxyphenylamino)-2-phenylpropenoate (3f). A yellowish oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.16 (t, 3H), 3.60 (s, 3H), 4.12 (q, 2H), 6.70 (AA'BB', 2H), 6.77 (AA'BB', 2H), 7.08-7.31 (m, 6H), 10.22 (br d, J=12.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.2, 55.1, 60.0, 102.1, 115.3, 117.5, 125.1, 128.1, 129.8, 134.9, 138.6, 145.2, 155.9, 169.5. MS (EI) *m/z* (%) 297 (M^+, 10), 224 (100), HRMS (EI) calcd for $C_{18}H_{19}NO_3$ 297.1365, found 297.1361. Anal. calcd: C, 72.72; H, 6.45; N, 4.72. Found C, 72.77; H, 6.57; N, 4.64.

***cis*-Ethyl 1-(*o*-hydroxyphenyl)-3-phenylaziridine-2-carhoxylate (2g-*cis*).** A pale yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.02 (t, 3H), 3.06 (d, J=6.8 Hz, 1H), 3.87 (d, J=6.8 Hz, 1H), 4.11 (m, AB, 2H), 6.55 (s, 1H), 6.85 (m, 2H), 7.02 (m, 2H), 7.31-7.49 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 14.0, 45.0, 48.0, 61.4, 115.8, 118.0,120.5, 125.8, 126.9, 128.4, 128.6, 133.9, 137.5, 151.1, 167.5. MS (EI) *m/z* (%) 283 (M^+, 38), 210 (100), HRMS (EI) calcd for $C_{17}H_{17}NO_3$ 283.1208, found 283.1214. Anal. calcd: C, 72.08; H, 6.06; N, 4.95. Found C, 72.16; H, 6.21; N, 4.87.

***cis*-Ethyl 1-phenyl-3-(*p*-methoxyphenyl)-aziridine-2-carboxylate (2h-*cis*).** A pale yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (t, 3H), 3.21 (d, J=6.8 Hz, 1H), 3.74 (d, J=6.8 Hz, 1H), 3.80 (s, 3H), 3.96-4.04 (m, AB, 2H), 6.83-7.72 (m, 9H); ^{13}C NMR ($CDCl_3$) δ 14.0, 45.7, 46.5, 55.8, 61.1, 114.0, 114.3, 121.0, 126.1, 129.1, 129.7, 130.1, 152.0, 167.1. MS (EI) *m/z* (%) 297 (M^+, 18), 224 (100) HRMS (EI) calcd for $C_{18}H_{19}NO_3$ 297.1365, found 297.1377. Anal. calcd: C, 72.72; H, 6.45; N, 4.72. Found C, 72.85; H, 6.60; N, 4.70.

$CH_3CH_2OCH_2CO_2CH_2CH_3$ (5). A solution of EDA (0.525 ml, 5 mmol) and La(OTf)$_3$ (0.293 g, 0.5 mmol) in EtOH (20 mL) was stirred in dark for 2 days. After removal of the solvent, column chromatography on silica gel (hexane/ethyl acetate 3:1) afforded 0.566 g (86% yield) of **5** as a colorless liquid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.22-125 (m, 6H), 3.58 (q, 2H), 4.05 (s, 2H), 4.22 (q, 2H); ^{13}C NMR ($CDCl_3$) δ 14.9, 15.7, 61.5, 67.8, 68.8, 171.2. MS (EI) *m/z* (%) 133 (M^+ + H, 8), 59 (100), HRMS (EI) calcd for ($C_6H_{12}O_3$+ H) 133.0865, found 133.0869.

Ethyl 3-ethoxyl-3-(*p*-chlorophenyl)-2-(N-*p*-chlorophenylamino) propanoate (6). 0.250 g (1 mmol) of **1d** and 0. 105 ml (1 mmol) of EDA were stirred with 0.060 g (0.1 mmol) of La(OTf)$_3$ in 10 ml of EtOH for 12 h. After removal of the solvent, the residue was chromatographed on a silica gel column (hexane/ethyl acetate5:1). In addition to **2d**-*cis* and **4d**, 0.012g (3% yield) of **6** was also isolated as a colorless crystalline solid. In another experiment, 0.168 g (0.5 mmol) of **2d**-*cis* was stirred with La(OTf)$_3$ (0.150 g, 0.25

mmol) in 5 ml of EtOH for 3.5 days as monitored by TLC. After column chromatography, 0.130 g (69% yield) of **6** was afforded. M.p 83-84 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.14-1.20 (m, 6H), 3.32-3.49 (m, AA'BB', 2H), 4.11 (q, 2H), 4.21 (d, J=6 Hz, 1H), 4.26 (br s, 1H), 4.61 (d, J=5.7 Hz, 1H), 6.53 (AA'BB', 2H), 7.07 (AA'BB', 2H), 7.25-7.34 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 14.1, 15.1, 61.2, 62.6, 65.2, 81.5, 115.1, 123.3, 128.4, 128.6, 129.0, 134.1, 136.6, 145.1, 171.2. MS (EI) *m/z* (%) 381 (M^+, 14), 169 (100), HRMS (EI) calcd for $C_{19}H_{21}Cl_2NO_3$ 381.0898, found 381.0879.

***cis*-Ethyl 1-benzyl-3-phenyl-aziridine-2-carboxylate (2i-*cis*).** A yellowish oil. ^{1}HNMR (400 MHz, $CDCl_3$) δ 0.95 (t, 3H), 2.60 (d, J=7.0 Hz, 1H), 3.01 (d, J=7.0 Hz, 1H), 3.60 (d, J=14.0 Hz, 1H), 3.80-4.05 (m, 3H), 7.19-7.43 (m, 10H); ^{13}C NMR ($CDCl_3$) δ 13.3, 45.4, 47.2, 60.1, 62.9, 126.7, 126.8, 127.0, 127.4, 127.5, 128.0, 134.6, 137.3, 167.3. HRMS (EI) calcd for $C_{18}H_{19}NO_2$ 281.1416, found 281.1423.

***cis*-Ethyl 1-phenyl-3-*tert*-butyl-aziridine-2-carboxylate (2j-*cis*).** A pale yellow oil. ^{1}HNMR (400 MHz, $CDCl_3$) δ 1.05 (s, 9H), 1.31 (t, 3H), 2.18 (d, J=6.8 Hz, 1H), 2.72 (d, J=6.8 Hz, 1H), 4.15-4.34 (m, 2H), 6.91-6.99 (m, 3H), 7.15-7.25 (m, 2H); ^{13}CNMR δ 14.0, 27.4, 31.8, 43.0, 55.2, 61.1, 120.0, 122.8, 129.0, 153.7, 169.5. HRMS (EI) calcd for $C_{15}H_{21}NO_2$ 247.1572, found 247.1560.

***trans*-Ethyl 1-phenyl-3-*tert*-butyl-aziridine-2-carboxylate (2j-*trans*).** A yellowish oil. ^{1}HNMR (400 MHz, $CDCl_3$) δ 1.04 (s, 9H), 1.06 (t, 3H), 2.65 (d, J=2.8 Hz, 1H), 3.04 (d, J=6.8 Hz, 1H), 4.00 (m, 2H), 6.80-6.99 (m, 3H), 7.14-7.27 (m, 2H); ^{13}CNMR δ 13.9, 26.8, 30.9, 39.4, 54.1, 61.0, 119.8, 122.4, 128.7, 150.3, 168.4. HRMS (EI) calcd for $C_{15}H_{21}NO_2$ 247.1572, found 247.1581.

***cis*-1-phenyl-2-(*m*-nitrophenyl)-3-phenyl-aziridine (2k-*cis*).** A pale yellow oil. ^{1}HNMR (300 MHz, $CDCl_3$) δ 3.71 (AB, J=6.6 Hz, 1H), 3.77 (AB, J=6.6 Hz, 1H), 7.07-7.37 (m, 11H), 7.59 (d, 1H), 7.99 (m, 1H), 8.18 (m, 1H); ^{13}CNMR δ 48.1, 49.5, 120.0, 122.4, 122.9, 123.5, 127.7, 127.9, 128.4, 129.0, 129.6, 133.9, 134.9, 138.5, 148.2, 153.8. HRMS (EI) calcd for $C_{20}H_{16}N_2O_2$ 316.1212, found 316.1205.

X-ray structural analysis of 6. Crystallographic data were collected at 295 K on a Siemens P4/CCD diffractometer with graphite-monochromated Mo Kα radiation. Crystal data: crystal dimensions 0.60 × 0.40 × 0.40 mm, triclinic, space group P(-1), a = 9.4031(3) Å, b = 10.0157(3) Å, c = 11.2358(3) Å, α = 71.4860(1) °, β = 80.1910(10) °, γ = 83.216(2) °, V = 986.42(5) Å^3, R_w = 0.0487.

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