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Synthesis of β-amino alcohols by ring opening of epoxides with amines catalyzed by sulfated tin oxide under mild and solvent-free conditions

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A B S T R A C T

One significant and elegant method for creating β-amino alcohols, which are useful intermediates for the synthesis of many different natural and synthetic pharmaceutical compounds, is to open the rings of epoxides with amines. When sulfated tin oxide catalyst (2 mol%) is present, epoxides can open their rings and react with amines to produce corresponding β-amino alcohols in good to high yields under mild circumstances. Under clean circumstances and in a short amount of time, the reaction demonstrated high regioselectivity and functioned well with both aromatic and aliphatic amines at room temperature.

1. Introduction

The bulk of chemicals that are known to exist are organic compounds, which are the foundation of all life on Earth. They serve as the foundation for, or are components of, a wide range of industrial goods, such as lubricants, solvents, polymers, fuels, and explosives, as well as pharmaceuticals, petrochemicals, and agrichemicals.[1-11] In synthetic chemistry, the ability to open the rings of epoxides and introduce amino functionality into oxiranes to produce β-amino alcohols is becoming increasingly important. β-amino alcohols are a significant class of chemical molecules with several applications, including the production of unnatural amino acids,[12] chiral auxillaries for asymmetric synthesis,[13] and a wide range of physiologically active natural and synthesized products.[14] Thus, a well-known method for producing β-amino alcohols is the nucleophilic opening of epoxides with amines.[15] The traditional method, which involves heating epoxides in the presence of amines, may not be the best choice for all functional groups or for amines that are not very nucleophilic.[16]

Better techniques have recently been discovered for this transformation.[17-26] These protocols do have certain drawbacks, though, like lengthy reaction times, high temperatures, poor regioselectivity, moderate yields, the need for stoichiometric amounts of catalyst and reagent, the possibility of allylic alcohol rearrangement, the potential dangers associated with handling moisture-sensitive reagents during catalyst preparation, and the fact that they are typically limited to aromatic amines.

The goal of green chemistry is to offer a way to minimize or completely do away with the usage of such dangerous, toxic solvents. Thus, the use of nontoxic chemicals, renewable resources, and solvent-free reaction conditions are essential components of the green synthetic approach.[27–28] Thus, there is a great need to design a better catalyst that will activate epoxides and make them more vulnerable to nucleophilic attack in mild conditions. In order to satisfy the principles of green

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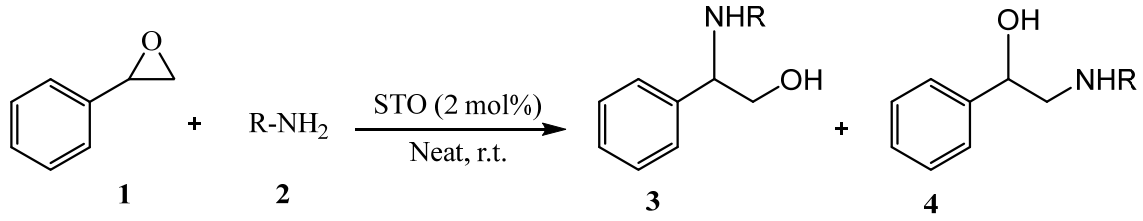
chemistry, a catalyst of choice should be readily available, reasonably priced, less toxic, and able to function in an environmentally benign manner. This will encourage interest in investigating the potential utility and widespread uses of the resulting amino alcohols.

In synthetic chemistry, the use of solid heterogeneous catalysts is known to provide predicted benefits, such as simple regeneration, reduced corrosiveness, affordability, ease of handling, and efficient reusing. Due to its low cost, greater stability, non-corrosive nature, reuse and recyclability, high efficiency, and large surface area, sulfated tin oxide (STO, SO_4^{-2}/SnO_2) has emerged as an effective and commercial catalyst. It is used extensively in chemical and industrial applications,[29-36] consisting of both sulfated and sulfonic acid moiety on heterogeneous solid bases.



Scheme 1. STO-Catalyzed ring opening of aromatic epoxides

In continuation of our strive to develop novel methodologies,[37-38] we, herein, present a novel method for the solvent-free, straightforward, and environmentally safe ring opening of epoxides with amines at room temperature using sulfated tin oxide catalyst (**Scheme 1**). As far as we are aware, there is no literature available regarding the synthesis of β-amino alcohols with STO catalyst.

2. Results and Discussion

First, a thorough investigation was conducted to assess the potential of sulfated tin oxide as a catalyst for the reaction of styrene oxide with aniline under a range of circumstances (**Table 1**). Without a catalyst, the reaction proceeded slowly (**Table 1**, entry 1), and when solvents were included, the reaction performed moderate (**Table 1**, entries 2-5). After that, we adjusted the amount of catalyst at room temperature in a solvent-free environment. We found that using only 2 mol% of the catalyst is enough to yield a high-quality product yield (**Table 1**, entry 9), while using more than 2 mol% of the catalyst did not improve the outcomes (**Table 1**, entries 10-11).

Table 1. Reaction of styrene oxide with aniline to yield **3** under various conditions.

Entry	Solvent	sulfated tin oxide (mol %)	Time min. [h]	Yield (%)[a]
1	neat	----	[10]	20
2	CH_2Cl_2	02	35	75
3	THF	02	40	65
4	CH_3CN	02	40	70
5	$CHCl_3$	02	40	75
6	neat	05	20	65
7	neat	1.0	25	80
8	neat	1.5	25	88
9	**neat**	**2.0**	**25**	**96**
10	neat	2.5	25	94
11	neat	3.5	30	92

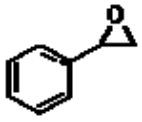
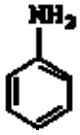
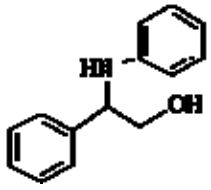
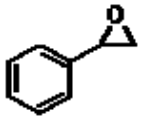
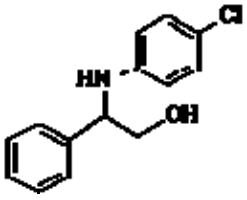
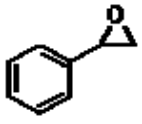
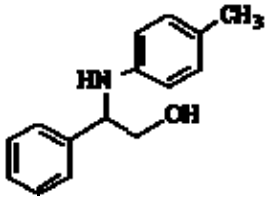
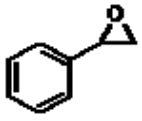
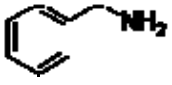
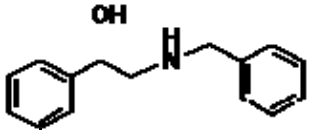
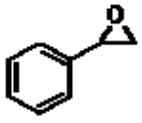
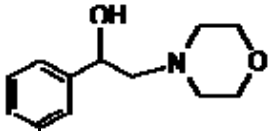
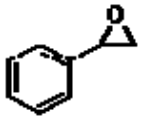
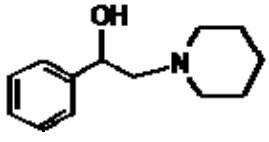
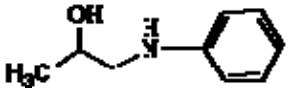
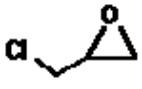
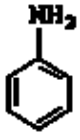
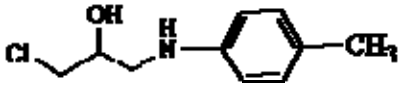
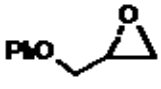
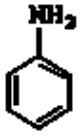
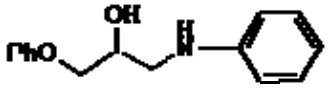
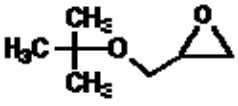
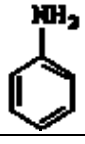
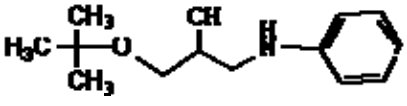
[a]Isolated yields

We are now able to extend the reaction's generality using a variety of amines (**Table 2**, entries a-j), thanks to this result. At room temperature, the reaction occurs effectively with a good product yield and great regioselectivity. During the reactions with aromatic primary amines, a selective synthesis of regio-isomeric product **3** was observed, resulting from nucleophilic attack at the benzylic carbon of styrene oxide (**Table 2**, entries a-c). Each of these reactions produced a single product, the structure of which was verified by ^{1}H NMR spectrum data. When benzyl amine was employed, the regioselectivity of the epoxide ring opening dropped to 20% (**Table 2**, entry d). The steric impact of the amine has caused a preferential attack at less hindered terminal carbon during the reactions of styrene oxide with aliphatic amines with outstanding regioselectivity under current conditions (**Table 2**, entries e-f).

A variety of aliphatic epoxides were treated with amines in order to demonstrate the generality of the current approach. The quantitative yield of preferred nucleophilic attack at the terminal carbon of the epoxide ring established the advantage of the new approach over previously published ones in each circumstance (**Table 2**, entries g-j). Moreover, the reaction circumstances permitted the compatibility of other capabilities as Cl, OPh, and O-^{t}Bu. With epichlorohydrin, excellent

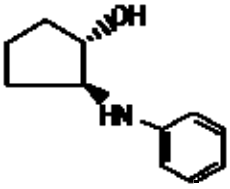
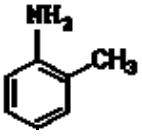
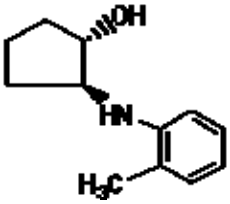
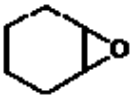
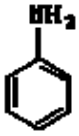
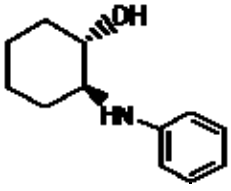
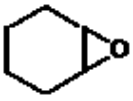
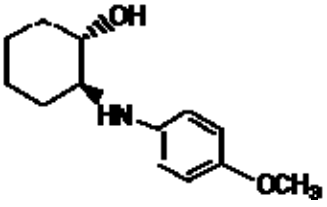
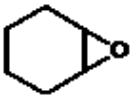
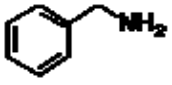
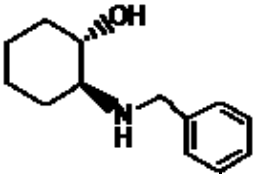
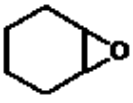
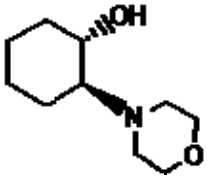
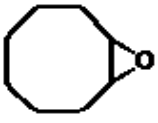
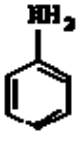
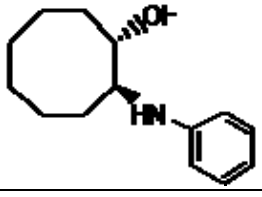
chemoselectivity was attained, yielding an 94% amino alcohol that resembled a nucleophilic attack at the terminal carbon of epoxide moiety.

Table 2. Sulfated tin oxide catalyzed ring opening of various epoxides with amines.

Entry	Epoxide	Amine	Product	Time (min)	Yield (%) 3:4
a				25	96:0
b				25	94:0
c				25	90:0
d				45	20:80
e				45	0:70
f				45	0:75
g				30	0:97
h				30	0:94
i				30	0:95
j				30	0:95

Several amines (1° and 2°) also reacted favourably with other epoxides, such as cyclopentene, cyclohexene oxides and cyclooctene oxide (**Table 3**), yielding good to excellent yields of the respective amino alcohols with *trans* stereospecificity (**Table 3**, entries 5a-g). The *trans* stereochemistry of β-amino alcohols in cyclohexene oxide was ascertained by analyzing the coupling constant of ring methine protons at δ 3.34 (ddd, 1H, J = 10.5, 10.5, and 4.5 Hz, CHOH) and δ 3.14 (ddd, 1H, J = 10.8, 10.5, and 3.9 Hz, CHNHPh) in the ^{1}H NMR spectrum, respectively (**Table 3**, entry c).

Table 3. Sulfated tin oxide catalyzed ring opening of cyclic epoxides with various amines.

Entry	Epoxide	Amine	Product	Time (min)	Yield (%)
a				25	95
b				25	94
c				25	98
d				25	98
e				40	92
f				40	96
g				30	92

When sulfated tin oxide findings are compared to recently published methodologies, **Table 4** shows that the current methodology performs better in terms of yield, catalyst loading (2 mol%), and reaction time. Furthermore, sensitivity of some of the catalysts to hydrolytic breakdown makes them difficult to handle; as a result, they cannot be reused and need a longer reaction time to achieve a modest yield of products.

Table 4. Epoxide opening by amines: A comparative study of catalysts reported in the literature with sulfated tin oxide

Sr. No.	Catalyst[6-15]	Loading (%)	Yields range (%)	Time (h)
1	Bu_3P	10	61-96	12
2	$ZrCl_4$	05	85-96	0.5
3	VCl_3	10	76-88	2.5-4.5
4	$ZnCl_2$	05	63-98	12 [80 ºC]
5	$[Bmim]BF_4$	100	80-91	3.5-8
6	$COCl_2$	10	60-96	3-24
7	Lanthanide	10	55-90	18 [40 ºC]
8	LiBr	05	75-85	5
9	$Cu(BF_4)_4.H_2O$	10	83-97	0.5
10	Montmorillonite K-10	10	81-97	3
11	$Sc(OTf)_3$	5	90-95	1-5
12	$RuCl_3$	20	78-88	8-12
13	Transition Metals based Lewis acids	5	45-92	12 [50 ºC]
14	**Sulfated tin oxide**	**2**	**70-98**	**0.5**

3. Experimental

3.1. Material and Methods

All chemicals were obtained from commercial vendors (Avra Chemicals, TCI Chemicals Co. Ltd., Tokyo, Japan and Alfa Aesar, Ward Hill, MA, USA) and used without further purification. TLC was performed on Merck Kieselgel 60, F254 plates, Column Chromatography was performed on silica gel (60-120 mesh) using ethyl acetate and hexane mixture as eluent. Melting points were recorded on Fisher John's melting point apparatus. IR spectra were recorded on a Perkin Elmer FTIR-240 C spectrophotometer. ^1H and ^{13}C NMR spectra were recorded on Bruker Avance 300 MHz spectrophotometer. Chemical shifts are given in ppm with respect to internal TMS and *J* values are quoted in Hz. Mass spectra were recorded in on a Finnigan Mat 1020 mass spectrophotometer operating at 70 eV.

3.2. Typical experimental procedure for reaction of epoxide with amine

Aniline (1 mmol) was applied to styrene oxide (1 mmol) at room temperature without the use of a solvent, while sulfated tin oxide (2 mol%) acted as a catalyst. Following the reaction's completion, which was tracked by TLC (ethyl acetate/*n*-hexane, 1:5 as eluent), the reaction liquid was diluted with 20 ml of diethyl ether, filtered, and the catalyst was cleaned with 4×5 ml of diethyl ether. The crude product was obtained by drying the organic layer on sodium sulphate and vacuum-concentrating it under water, aqueous $NaHCO_3$ solution, and brine, respectively. The resulting pure 2-amino-2-phenyl-1-ethanol was then chromatographed on a silica gel column, yielding an excellent 96% yield of the oil.

3.3. Spectral data of representative compounds

2-Anilino-2-phenyl-1-ethanol (Table 2, entry a): Colorless liquid; IR (neat): 3408 (O-H stretching), 3031 (C-H, aromatic), 2928 (C-H, aliphatic), 2873 (C-H, aliphatic), 1608 (C=C, aromatic), 1486 (C-N, aromatic stretching), 1219 (C-N, aliphatic stretching), 1061 (C-O stretching), 763 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.34-7.17 (m, 5H, Ar), 7.10 (t, *J* = 8 Hz, 2H, Ar)), 6.64 (t, *J* = 8 Hz, 1H, Ar), 6.50 (d, *J* = 8 Hz, 2H, Ar), 5.18 (brs, 1H, OH), 4.43 (dd, *J* = 10 and 6 Hz, 1H, CH, aliphatic), 3.86 (dd, *J* = 10 and 4 Hz, 1H, CH_2), 3.66 (dd, *J* = 10 and 7 Hz, 1H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 147.3 (=C-N), 140.2 (=C-CH), 129.2 (Ar), 128.9 (Ar), 127.6 (Ar), 126.8 (Ar), 117.9 (Ar), 113.9 (Ar), 67.4 (CH), 59.9 (CH_2); MF: $C_{14}H_{15}NO$; EIMS: *m/z* = 213 (M^+).

2-(4-Chlorophenyl)amino-2-phenyl-1-ethanol (Table 2, entry b): Colorless liquid; IR (neat): 3418 (O-H stretching), 2950 (C-H, aliphatic), 1640 (C=C, aromatic), 1449 (C-N, aromatic stretching), 1210 (C-N, aliphatic stretching), 1040 (C-O stretching), 830 (C-Cl stretching) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.32 (d, *J* = 8 Hz, 2H, Ar), 7.31 (d, *J* = 8 Hz, 2H, Ar), 7.20-7.10 (m, 5H, Ar), 5.20 (brs, 1H, OH), 4.35 (dd, *J* = 5 and 7 Hz, 1H, CH, aliphatic), 3.81 (dd, *J* = 10 and 5 Hz, 1H, CH_2), 3.68 (dd, *J* = 10 and 7 Hz, 1H, CH_2), 2.78 (brs, 1H, NH); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 145.9 (=C-N), 139.7 (=C-CH), 129.4 (Ar), 129.0 (Ar), 128.9 (Ar), 128.8 (Ar), 128.7 (Ar), 127.8 (Ar), 126.7 (Ar), 122.4 (Ar), 115.0 (Ar), 67.3 (CH), 60.0 (CH_2); MF: $C_{14}H_{14}NOCl$; EIMS *m/z* 247 (M^+).

2-(4-Methylphenyl)amino-2-phenyl-1-ethanol (Table 2, entry c): Colorless liquid; IR (neat): 3408 (O-H stretching), 3031 (C-H, aromatic), 2928 (C-H, aliphatic), 1617 (C=C, aromatic), 1486 (C-N, aromatic stretching), 1221 (C-N, aliphatic stretching), 1062 (C-O stretching), 765 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.28- 7.18 (m, 5H, Ar), 6.90 (d, *J* = 8.1 Hz, 2H, Ar), 6.50 (d, *J* = 8.1 Hz, 2H, Ar), 5.15 (brs, 1H, NH), 4.42 (dd, *J* = 7.4 and 4.2 Hz, 1H, CH-N), 3.88 (dd, *J* = 11.1 and 4.2 Hz, 1H, CH-O), 3.68 (dd, *J* = 11.1 and 7.4 Hz, 1H, CH-O), 2.76 (brs, 1H, OH), 2.06 (s, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 144.8 (Ar), 140.2 (Ar), 129.6 (Ar), 128.5 (Ar), 127.3 (Ar), 126.6 (Ar), 119.6 (Ar), 114.2 (Ar), 66.9 (-C-N, aliphatic), 60.30 (-C-O, aliphatic), 20.5 (C-H, aliphatic); MF: $C_{15}H_{17}NO$; EIMS *m/z* 227 (M^+).

2-*N*-Benzylamino-1-phenyl-1-ethanol (Table 2, entry d): Colorless viscous liquid; IR (KBr): 3293 (O-H stretching), 2906 (C-H, aliphatic), 2834 (C-H, aliphatic), 1454 (C-N, aromatic stretching), 1433 (C-N, aromatic stretching), 1063 (C-O stretching), 916 (C-H bending), 874 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.41-7.25 (m, 10H, Ar), 4.72 (dd, *J* = 8.8 and 3.6 Hz, 1H, CH-OH), 3.88 (s,2H, CH_2), 2.92 (dd, *J* = 3.6 and 12.2 Hz, 1H, CHN), 2.75 (dd, *J* = 8.8 and 12.2 Hz, 1H, CHN), 1.58 (brs, 2H, OH); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.8 (Ar), 140.2 (Ar), 128.8 (Ar), 127.8 (Ar),

127.4 (Ar), 126.2 (Ar), 72.1 (-C-O, aliphatic), 56.7 (-C-N, aliphatic), 53.8 (C-H, aliphatic); MF: $C_{15}H_{17}NO$; EIMS *m/z* 227 (M^+).

2-Morpholino-1-phenyl-1-ethanol (Table 2, entry e): Colorless liquid; IR (neat): 3439 (O-H stretching), 2928 (C-H, aliphatic), 1650 (C=C, aromatic), 1456 (C-N, aromatic stretching), 1219 (C-O stretching), 1109 (C-O stretching), 769 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.48- 7.38 (m, 5H, Ar), 4.15 (t, *J* = 6 Hz, 1H, CH-OH), 3.75 (m, 2H, CH_2), 3.63 (m, 4H, CH_2O), 3.20-2.95 (m, 4H, CH_2N), 1.90 (brs, 1H, OH); MF: $C_{12}H_{17}NO_2$; EIMS *m/z* 207 (M^+).

2-(1-Piperidino)-1-phenyl-1-ethanol (Table 2, entry f): Light yellowish liquid; IR (neat): 3460 (O-H stretching), 2950 (C-H, aliphatic), 1640 (C=C, aromatic), 1240 (C-O stretching), 1090 (C-O stretching), 830 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.32-7.20 (m, 5H, Ar), 4.71 (dd, *J* = 6.6 and 3.7 Hz, 1H, CH-OH), 2.71 (m, 2H, CH_2), 2.41 (m, 4H, CH_2N), 1.80 (brs, 1H, OH),1.60 (m, 4H, CH_2), 1.51 (m, 2H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.6 (Ar), 127.5 (Ar), 125.8 (Ar), 125.5 (Ar), 68.7 (-C-O, aliphatic), 66.9 (-C-N, aliphatic), 54.4 (-C-O, aliphatic ring), 26.2 (C-H, aliphatic), 24.4 (C-H, aliphatic), 21.2 (C-H, aliphatic); MF: $C_{13}H_{19}NO$; EIMS *m/z* 205 (M^+).

2-Anilino-1-methyl-1-ethanol (Table 2, entry g): Colorless liquid; IR (neat): 3408 (O-H stretching), 2950 (C-H, aliphatic), 1540 (C=C stretching, aromatic), 1360 (O-H bending), 1100 (C-O stretching), 730 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.38-7.20 (m, 5H, Ar), 3.70 (m, 1H, CH-OH), 3.39 (m, 2H, CH_2N), 3.11 (brs, 1H, NH), 2.80 (brs, 1H, OH), 1.30 (d, *J* = 6 Hz, 3H, CH_3); MF: $C_9H_{13}NO$; EIMS *m/z* 151 (M^+).

3-Chloro-2-(phenylamino)propan-1-ol (Table 2, entry h): Reddish brown sticky liquid; ^1H NMR (300 MHz, $CDCl_3$): δ 7.24-7.17 (m, 2H, Ar), 6.77 (t, *J* = 7.3 Hz, 1H, Ar), 6.67 (d, *J* = 8.6 Hz, 2H, Ar), 4.10-4.03 (m, 1H, CH-OH), 3.65 (qd, *J* = 11.3, 5.3 Hz, 2H, CH_2Cl), 3.38 (dd, *J* = 13.3, 4.4 Hz, 1H, CH_2N), 3.26-3.18 (m, 1H, CH_2N); ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.8 (=C-N, aromatic), 129.5 (Ar), 118.4 (Ar), 113.4 (Ar), 69.9 (-C-O, aliphatic), 47.8 (-C-N, aliphatic), 47.2 (-C-Cl, aliphatic); MF: $C_9H_{14}ClNO$; EIMS *m/z* 197 (M^+).

2-Anilino-1-phenoxymethyl-1-ethanol (Table 2, entry i): Colorless liquid; IR (neat): 3500 (O-H stretching), 1570 (C=C stretching, aromatic), 1360 (O-H bending), 1230 (C-O stretching), 1107 (C-O stretching), 760 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.25-7.07 (m, 5H, Ar), 6.67-6.56 (m, 5H, Ar), 3.98 (m, 1H, CH-OH), 3.48 (m, 2H, CH_2), 3.25 (dd, *J* = 12.5 and 4 Hz, 1H, CHN), 3.10 (dd, *J* = 12.5 and 7 Hz, 1H, CHN), 3.04 (brs, 2H, NH and OH); MF: $C_{15}H_{17}NO_2$; EIMS *m/z* 243 (M^+).

2-Anilino-1-^{t}butoxymethyl-1-ethanol (Table 2, entry j): Colorless liquid; IR (neat): 3530 (O-H stretching), 3075 (C-H, aromatic), 2950 (C-H, aliphatic), 1580 (C=C stretching, aromatic), 1501 (C=C stretching, aromatic), 1300 (O-H bending), 1100 (C-O stretching), 1075 (C-O stretching), 763 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.10-6.90 (m, 5H, Ar), 3.95 (m, 1H, CH-OH), 3.52 (m, 2H, CH_2O), 3.30 (dd, *J* = 11.5 and 3.5 Hz, 1H, CHN), 3.15 (dd, *J* = 11.5 and 6.5 Hz, 1H, CHN), 3.05 (brs, 2H, NH and OH), 0.91 (s, 9H, ^{t}Bu); MF: $C_{13}H_{21}NO_2$; EIMS *m/z* 223 (M^+).

***trans*-2-(phenylamino)-cyclopentanol (Table 3, entry a):** Viscous liquid; IR (neat): 3490 (O-H stretching), 3100 (C-H, aromatic), 1575 (C=C stretching, aromatic), 1108 (C-O stretching), 1070 (C-O stretching), 760 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.10-7.25 (m, 5H, Ar), 4.01 (ddd, *J* = 10.5, 8.9 and 4.5 Hz, 1H, CH-OH), 3.60 (ddd, *J* = 10.5, 8.0 and 4.5 Hz, 1H, CH-N), 2.6 (brs, 2H, NH and OH), 2.15-2.35 (m, 2H, CH_2), 1.91-2.05 (m, 2H, CH_2), 1.61-1.89 (m, 2H, CH_2); MF: $C_{11}H_{14}NO$; EIMS *m/z* 177 (M^+).

***trans*-2-(2-Methylphenylamino)cyclopentanol (Table 3, entry b):** Viscous liquid; IR ($CHCl_3$): 3430 (O-H stretching), 2970 (C-H, aliphatic), 1560 (C=C stretching, aromatic), 1460 (C=C stretching, aromatic), 1390 (O-H bending), 1270 (O-H bending), 1050 (C-O stretching), 725 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.23 (m, 2H, Ar), 6.80 (d, *J* = 8.7 Hz, 1H, Ar), 6.64 (d, *J* = 8.7, 1H, Ar), 4.21 (ddd, *J* = 11.5, 8.8 and 4.5 Hz, 1H, CH-OH), 4.01 (ddd, *J* = 11.5, 8.0 and 4.5 Hz, 1H, CH-N), 2.8 (s, 3H, CH_3), 2.62 (brs, 2H, NH and OH), 2.20-2.45 (m, 2H, CH_2), 1.55-1.85 (m, 2H, CH_2), 1.35-1.50 (m, 2H, CH_2); MF: $C_{12}H_{17}NO$; EIMS *m/z* 191 (M^+).

***trans*-2-(Phenylamino)cyclohexanol (Table 3, entry c):** White solid; Mp: 58-59 ^{0}C; IR (KBr): 3439 (C-H bending), 2940 (C-H, aliphatic), 2855 (C-H stretching, aliphatic), 1632 (C=C, aromatic), 1529 (C=C stretching, aromatic), 1213 (C-O stretching), 1067 (C-O stretching), 769 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ =7.20 (t, 2H, *J* = 8 Hz, Ar), 6.71-6.80 (m, 3H, Ar), 3.33 (ddd, *J* = 10.5, 10.5 and 4.5 Hz, 1H, CH-OH), 3.14 (ddd, *J* = 10.8, 10.5 and 3.9 Hz, 1H, CH-N), 2.51 (brs, 2H, NH and OH), 2.15-2.09 (m, 2H, CH_2), 1.76 (m, 2H, CH_2), 1.31 (m, 2H, CH_2), 1.07 (m, 2H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 147.7 (=C-N), 129.2 (Ar), 118.2 (Ar), 114.2 (Ar), 74.3 (-C-O, aliphatic), 60.0 (-C-N, aliphatic), 33.1 (C-H, aliphatic), 31.5 (C-H, aliphatic), 24.9 (C-H, aliphatic), 24.2 (C-H, aliphatic); MF: $C_{12}H_{17}NO$; EIMS *m/z* 191 (M^+).

***trans*-2-(4-Methoxyphenylamino)cyclohexanol (Table 3, entry d):**
White solid; Mp: 53-54 ^{0}C; IR (KBr): 3400 (O-H stretching), 2960 (C-H stretching, aliphatic), 1550 (C=C stretching, aromatic), 1460 (C=C stretching, aromatic), 1360 (O-H bending), 1250 (O-H bending), 1060 (C-O stretching), 850 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 6.88 (d, *J* = 8 Hz, 2H, Ar), 6.78 (d, *J* = 8 Hz, 2H, Ar), 3.73 (s, 3H, OCH_3), 3.31 (ddd, *J* = 9.6, 9.6 and 3.9 Hz, 1H, CH-OH), 3.16 (ddd, *J* = 10.9, 9.3 and 3.9 Hz, 1H, CH-N), 3.08 (br s, 2H, NH and OH), 2.05- 2.17 (m, 2H, CH_2), 1.71- 1.83 (m, 2H, CH_2), 1.30- 1.41 (m, 4H, CH_2 ^{13}C NMR (75 MHz, $CDCl_3$): δ = 152.73 (=C-O), 141.29 (=C-N), 116.28 (Ar), 114.67 (Ar), 74.03 (-C-O, aliphatic), 61.48 (-C-N, aliphatic), 55.56 (OCH_3), 33.07

(C-H, aliphatic), 31.25 (C-H, aliphatic), 24.86 (C-H, aliphatic), 24.15 (C-H, aliphatic); MF: $C_{13}H_{19}NO_2$; EIMS *m/z* 221 (M^+).

***trans*-2-(Benzylamino)cyclohexanol (Table 3, entry e):** Colorless oil; IR (neat): 3498 (O-H stretching), 3100 (C-H stretching, aromatic), 1550 (C=C stretching, aromatic), 1060 (C-O stretching), 763 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.20-7.50 (m, 5H, Ar), 4.50 (s, 2H, N-CH_2), 3.50 (ddd, *J* = 10.8, 10.5, 4.6 Hz, 1H, CH-OH), 3.28 (ddd, *J* = 10.8, 9.6, 3.6 Hz, 1H, CH-N), 3.05 (brs, 2H, NH and OH), 2.40-1.08 (m, 8H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.9 (Ar), 128.6 (Ar), 128.4 (Ar), 127.2 (Ar), 74.1 (C-N), 63.4 (C-O), 51.1 (C-N), 33.6 (C-H, aliphatic), 30.7 (C-H, aliphatic), 25.3 (C-H, aliphatic), 24.6 (C-H, aliphatic); MF: $C_{13}H_{19}NO$; EIMS *m/z* 205 (M^+).

***trans*-2-(Morpholin-4-yl)cyclohexanol (Table 3, entry f):** Oily liquid; IR (neat): 3501 (O-H stretching), 3110 (C-H stretching, aromatic), 1500 (C=C stretching, aromatic), 1080 (C-O stretching), 761 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 3.80 (m, 4H, CH_2O of morpholine), 3.61 (m, 4H, CH_2N of morpholine), 3.45 (ddd, *J* = 11.5, 9.6, 3.8 Hz, 1H, CH-OH), 3.28 (ddd, *J* = 11.5, 9.6, 4.8 Hz, 1H, CH-N), 2.70 (brs, 1H, NH and OH), 2.59 (m, 4H, CH_2), 2.10-1.60 (m, 4H, CH_2); MF: $C_{10}H_{19}NO_2$; EIMS *m/z* 185 (M^+).

***trans*-2-(Phenylamino)cyclooctonol (Table 3, entry g):** Viscous liquid; IR (neat): 3620 (O-H stretching), 3120 (C-H stretching, aromatic), 1560 (C=C stretching, aromatic), 1350 (O-H bending), 1081 (C-O stretching), 760 (C-H bending) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.24-7.41 (m, 2H, Ar), 6.78-6.82 (m, 3H, Ar), 3.56 (ddd, *J* = 9.5, 6.6 and 2.7 Hz, 1H, CH-OH), 3.45 (d, *J* = 6 Hz,1H, CH-N), 3.22 (brs, 2H, NH and OH), 1.86-1.97 (m, 4H, CH_2), 1.6-1.73 (m, 8H, CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 147.50 (=C-N), 129.35 (Ar), 118.84 (Ar), 115.11 (Ar), 74.93 (C-O), 60.02 (-C-N), 31.10 (C-H, aliphatic), 29.63 (C-H, aliphatic), 26.74 (C-H, aliphatic), 25.67 (C-H, aliphatic), 25.17 (C-H, aliphatic), 23.27 (C-H, aliphatic); MF: $C_{14}H_{21}NO$; EIMS *m/z* 219 (M^+).

4. Conclusions

Epoxides constitute essential organic intermediates used in the synthesis of many different kinds of organic compounds. We have shown a new, gentle, and very effective way to open the rings of epoxides with amines and a desirable way to generate C-N bonds using sulfated tin oxide catalyst (STO) as an efficient catalyst (2 mol%) under solvent-free conditions. The isolated yields are up to 98%, all products are known, and a total of 17 examples were conducted. Because of its neat reaction conditions, mild reaction conditions, shortened reaction times, affordable catalyst, and high product yields with excellent regio and chemoselectivity, the current methodology is expected to be environmentally friendly and potentially beneficial for industrial applications.

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