Tetrahedron 68 (2012) 1407–1416

Contents lists available at SciVerse ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

Asymmetric *ortho*-lithiation of 1,*n*-dioxa[*n*]paracyclophane derivatives for the generation of planar chirality

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ARTICLE INFO

Article history:
Received 21 November 2011
Received in revised form 12 December 2011
Accepted 12 December 2011
Available online 19 December 2011

Keywords:
Enantioselective
ortho-Lithiation
Planar chirality
Paracyclophane

ABSTRACT

The asymmetric induction of planar chirality in 1,*n*-dioxa[*n*]paracyclophane derivatives via asymmetric *ortho*-lithiation is described. Enantioselective *ortho*-lithiation of unflippable 1,*n*-dioxa[*n*]paracyclophanes ($n \leq 11$) using *sec*-BuLi-(−)-sparteine at −78 °C and subsequent treatment with electrophiles gave the corresponding planar-chiral monosubstituted paracyclophanes with excellent ee. Further lithiation of these compounds and treatment with electrophiles gave planar-chiral paracyclophanes with two different substituents. Dilithiation of unflippable 1,*n*-dioxa[*n*]paracyclophanes gave the corresponding C_2-symmetrical disubstituted products with almost perfect ee. In the case of flippable 1,*n*-dioxa[*n*]paracyclophanes ($n \geq 12$), a stepwise reaction was required for the highly enantioselective formation of disubstituted products.

1. Introduction

Paracyclophane consists of a benzene ring with an ansa chain connecting the *para* positions.[1a,b,2] Unsubstituted paracyclophanes are symmetrical and achiral. In contrast, monosubstituted [*n*]paracyclophanes ($n \leq 11$) have planar chirality, and the enantiomers can be resolved at rt based on sterically hindered rotation of the ansa chain around the benzene ring.[2a–c] In the case of [*n*]paracyclophanes with longer ansa chains ($n \geq 12$), the enantiomers of monosubstituted compounds interconvert to each other at rt. However, disubstituted [*n*]paracyclophanes can be resolved into enantiomers when the ansa chain cannot be flipped.[2d] Due to their unique bridged structure, planar-chiral paracyclophanes have been widely applied as chiral motifs in functional materials and chiral reagents.[3a,b,4] Miyano used a planar-chiral paracyclophane as a chiral stationary phase for HPLC and a chiral auxiliary.[4a,b] They also reported the stereospecific conversion of planar-chiral naphthalenophane into axial-chiral binaphthyl.[4c] Scherf synthesized chiral poly(*para*-phenylene) polymers containing planar-chiral paracyclophane moieties and investigated their chiroptical properties.[4d,e] Kanomata used planar-chiral pyridinophanes as coenzyme NADH models,[4f,g] and their planar-chiral pyridinium ylides in an enantioselective cyclopropanation.[4h] Recently, Inoue and Kanomata reported the enantiodifferentiating photoisomerization of cyclooctenes sensitized by planar-chiral paracyclophane.[4i] In these cases, enantiomerically enriched compounds were generally prepared by the optical resolution of a racemic mixture or the asymmetric crystallization of diastereomers. For example, Kanomata achieved efficient stereocontrol of the planar chirality of [10]pyridinophanes and [11]paracyclophanes with a thermodynamically flexible ansa chain by the crystallization-induced or adsorption-induced dynamic resolution of diastereomeric mixtures.[5a–c]

On the other hand, a more straightforward approach to the synthesis of planar-chiral paracyclophanes is an enantioselective reaction.[6] A pioneering study by Zhu described an intramolecular S_NAr etherification using a stoichiometric amount of chiral quaternary ammonium salt (up to 20% ee).[6a] The chiral Rh- or Pd-catalyzed coupling of dithiol with dibromide has been reported as another protocol by Tanaka (up to 60% ee).[6b,c] We previously reported a dynamic kinetic resolution of diiodoparacyclophanes possessing a flippable ansa chain through the use of asymmetric consecutive Sonogashira coupling (up to 79% ee).[7] Recently, the Rh-catalyzed [2+2+2] cycloaddition of alkynes was reported for the synthesis of [*n*]paracyclophanes with short ansa chain ($n \leq 9$) by Tanaka (up to 75% ee).[6d] Among these previous examples, our protocol gave the best enantioselectivity,[7] but it was not excellent. Therefore, the development of a highly enantioselective and widely convertible synthesis of planar-chiral paracyclophanes is still a challenging topic.[8,9] In this report, we describe an asymmetric *ortho*-lithiation for the highly enantioselective synthesis of various paracyclophanes.[10a–c,11a–d] The asymmetric *ortho*-

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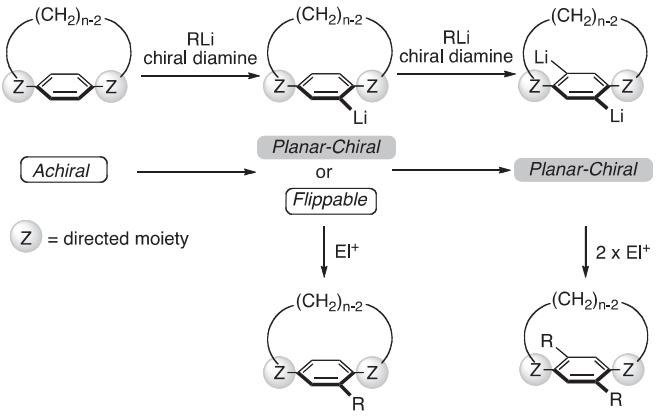
0040-4020/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tet.2011.12.031

lithiation of an achiral [*n*]paracyclophane with directed moieties at the 1 and *n* positions of its ansa chain would proceed with a chiral lithium reagent. Furthermore, the second lithiation would give a C_2-symmetric dilithio paracyclophane. Subsequent treatment of these aryllithiums with various electrophiles would afford mono- and disubstituted planar-chiral paracyclophanes, respectively (Scheme 1).[12]



Scheme 1. Concept of asymmetric *ortho*-lithiation of paracyclophane.

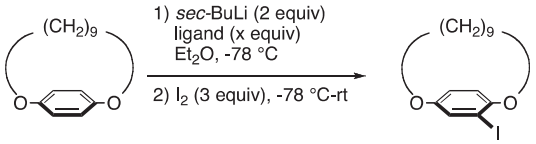
2. Results and discussion

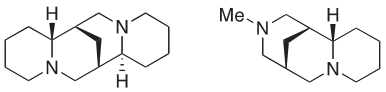
2.1. Enantioselective monosubstitution of 1,*n*-dioxa[*n*] paracyclophanes

First, we chose 1,11-dioxa[11]paracyclophane **1a** as a substrate for enantioselective *ortho*-lithiation. This paracyclophane has oxygen atoms as directed moieties, and the ansa chain is unflippable at rt.[2a–c] We examined the *ortho*-lithiation of **1a** using 2 equiv of *sec*-butyllithium at −78 °C in Et_2O along with the addition of iodine as an electrophile. As a result, the corresponding monoiodoparacyclophane **2aa** was obtained in moderate yield, and the enantiomers were resolved by HPLC analysis using a chiral column as expected (Table 1, entry 1). We next examined an enantioselective lithiation using 2 equiv of (−)-sparteine **L1** under the same reaction conditions, and planar-chiral (+)-**2aa** was obtained in high yield with excellent ee (entry 2). An equivalent amount of **L1** was sufficient to achieve high yield and excellent ee (entry 3). Even a catalytic amount of **L1** was enough to realize good enantioselectivity (entries 4 and 5).[13a–c,14a–k] (+)-Sparteine surrogate **L2**[15a,b] achieved the opposite enantioinduction to give (−)-**2aa** (entries 6 and 7).

We next examined various electrophiles (El) other than iodine (Table 2). Treatment of the monolithiated compound with chlorotrimethylsilane, chlorodiphenylphosphine, iodomethane, *N*,*N*-dimethylformamide (DMF), or benzophenone gave the corresponding planar-chiral silane **2ab**, phosphine **2ac**, methylated product **2ad**, aldehyde **2ae**, or tertiary alcohol **2af** with excellent ee (entries 1–5).[16] Enantioselective *ortho*-lithiation of 1,10-dioxa[10] paracyclophane **1b** with a shorter ansa chain also proceeded, and treatment of the aryllithium with iodine, chlorotrimethylsilane, or chlorodiphenylphosphine gave the corresponding iodinated product **2ba**, silylated product **2bb**, or phosphinated product **2bc** with excellent ee (entries 6–8).[17]

Table 1
Investigation of reaction conditions



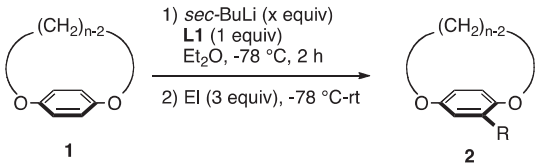


(-)-sparteine **L1** (+)-sparteine surrogate **L2**

Entry	Ligand	*x* (equiv)	Time (h)	Yield (%)	ee (%)[a]
1	None	—	5	57	—
2	**L1**	2	1	91	98 (+)
3	**L1**	1	2	89	97 (+)
4	**L1**	0.5	3	87	93 (+)
5	**L1**	0.2	5	84	76 (+)
6	**L2**	2	1	82	91 (−)
7	**L2**	0.2	4	79	74 (−)

[a] Signs of optical rotation are shown in the parentheses.

Table 2
Reaction of *ortho*-lithiated 1,*n*-dioxa[*n*]paracyclophane with various electrophiles

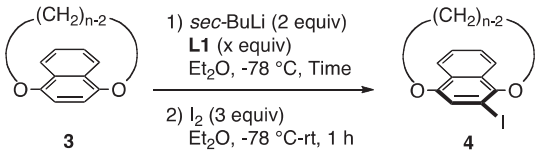


Entry	*n*	*x* (equiv)	Electrophiles	R	Yield (%)	ee (%)
1[a]	11 (**1a**)	2	Me_3SiCl	$SiMe_3$	75 (**2ab**)	97[a]
2	11 (**1a**)	2	Ph_2PCl	PPh_2	58 (**2ac**)	98
3	11 (**1a**)	2	MeI	Me	74 (**2ad**)	95
4	11 (**1a**)	2	DMF	CHO	70 (**2ae**)	97
5	11 (**1a**)	2	Benzophenone	$C(OH)Ph_2$	84 (**2af**)	95
6	10 (**1b**)	1.2	I_2	I	81 (**2ba**)	97
7	10 (**1b**)	1.2	Me_3SiCl	$SiMe_3$	75 (**2bb**)	97[a]
8	10 (**1b**)	1.2	Ph_2PCl	PPh_2	35 (**2bc**)	98

[a] ee was determined as **2aa** and **2ba** by the conversion of trimethylsilyl group into iodo one using *N*-iodosuccinimde.

We further investigated the reaction of achiral 1,*n*-dioxa[*n*](1,4) naphthalenophanes (Table 3). The enantioselective lithiation of 1,11-dioxa[11](1,4)naphthalenophane **3a** along with the addition of iodine gave the corresponding planar-chiral 2′-iodo product **4a** in high yield with excellent ee (entry 1). The catalytic reaction of **3a** also proceeded, and **4a** was obtained with good ee (entry 2). Enantioselective lithiation of [*n*](1,4)naphthalenophanes **3b** (*n*=12), **3c** (*n*=14), and **3d** (*n*=16) was also possible, and treatment of the resulting aryllithiums with iodine gave the corresponding

Table 3
Enantioselective *ortho*-lithiation of 1,*n*-dioxa[*n*](1,4)naphthalenophanes



Entry	*n*	*x* (equiv)	Time (h)	Yield (%)	ee (%)
1	11 (**3a**)	1	2	95 (**4a**)	97
2	11 (**3a**)	0.2	5	93 (**4a**)	81
3	12 (**3b**)	1	10	88 (**4b**)	93
4	12 (**3b**)	0.2	10	17 (**4b**)	ND[a]
5	14 (**3c**)	2	24	82 (**4c**)	94
6	16 (**3d**)	2	72	76 (**4d**)	92

[a] Not determined.

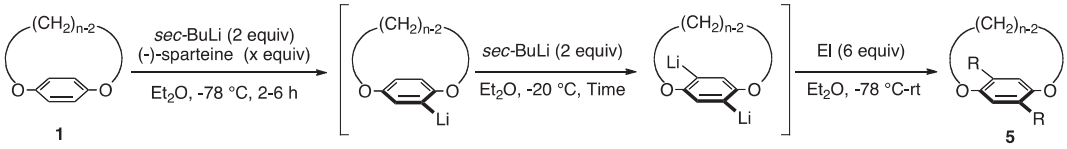
planar-chiral 2′-iodo products **4b**, **4c**, and **4d**[18] with more than 90% ee (entries 3, 5, and 6). However, the lithiation of [*n*](1,4)naphthalenophanes with longer ansa chains ($n \geq 12$) was sluggish, and a catalytic reaction gave the product **4b** in low yield (entry 4).

2.2. Enantioselective disubstitution via dilithiation

We next investigated dilithiation for the synthesis of planar-chiral disubstituted [*n*]paracyclophanes ($n=10$ or 11) with C_2 symmetry (Table 4). After the first lithiation at −78 °C, the second lithiation was examined by the addition of 2 equiv of *sec*-butyllithium at −20 °C along with treatment with iodine. The reaction of **1b** gave C_2-symmetrical planar-chiral diiododioxa[10]paracyclophane **5ba** in high yield with excellent ee with the use of a stoichiometric amount of sparteine (entry 1). The reaction of diiododioxa[11]paracyclophane **5aa** realized almost perfect enantioselectivity (entry 3). Moreover, its recrystallization yielded a single crystal, and the absolute configuration was determined to be *S* by X-ray diffraction analysis (Fig. 1).

In the case of enantioselective dilithiation, a catalytic amount of **L1** achieved higher ee (around 90%) than that in monolithiation (entries 2 and 4), since kinetic resolution occurred at the second lithiation. In fact, the ee of the monoiodo products **2ba** and **2aa**, which were obtained as by-products, was low (**2ba**: 11% ee in entry 2, **2aa**: 53% ee in entry 4). We also examined the enantioselective disubstitution of **1a** by using various electrophiles under the same reaction conditions: C_2-symmetrical diphosphine **5ac**, *para*-xylene derivative **5ad**, dialdehyde **5ae**, and diol **5af** were obtained with almost perfect enantioselectivity (entries 5–8). Next, we investigated the dilithiation of 1,*n*-dioxa[*n*]paracyclophane with a longer ansa chain ($n \geq 12$). In these cases, the reactivity and enantioselectivity of lithiation were lower than those with 1,*n*-dioxa[*n*]paracyclophane ($n \leq 11$). When 1,12-dioxa[12]paracyclophane **1c** was used, the ee was still high (82%) but the yield was low (38%) in the presence of 1 equiv of (−)-sparteine for 12 h (entry 9). The use of 4 equiv of (−)-sparteine with a longer reaction time drastically improved the yield and slightly increased the ee

Table 4
Enantioselective dilithiation of 1,*n*-dioxa[*n*]paracyclophanes



Entry	*n*	*x* (equiv)	Time (h)	El	R	Yield (%)	ee (%)
1	10 (**1b**)	1	12	I_2	I	91 (**5ba**)	98
2	10 (**1b**)	0.2	24	I_2	I	82 (**5ba**)	87
3	11 (**1a**)	1	12	I_2	I	79 (**5aa**)	99
4	11 (**1a**)	0.2	24	I_2	I	53 (**5aa**)	89
5	11 (**1a**)	1	12	Ph_2PCl	PPh_2	55 (**5ac**)	99[a]
6	11 (**1a**)	1	12	MeI	Me	76 (**5ad**)	99
7	11 (**1a**)	1	12	DMF	CHO	73 (**5ae**)	99
8	11 (**1a**)	1	12	benzophenone	$C(OH)Ph_2$	84 (**5af**)	99
9	12 (**1c**)	1	12	I_2	I	38 (**5ca**)	82
10	12 (**1c**)	4	24	I_2	I	60 (**5ca**)	88
11	13 (**1d**)	4	48	I_2	I	62 (**5da**)	89
12	14 (**1e**)	4	48	I_2	I	65 (**5ea**)	86
13	15 (**1f**)	4	48	I_2	I	48 (**5fa**)	84
14	16 (**1g**)	4	48	I_2	I	50 (**5ga**)	77
15	17 (**1h**)	4	72	I_2	I	53 (**5ha**)	—[b]
16	17 (**1h**)	4	72	Ph_2PCl	PPh_2	73 (**5hc**)	55[a]

[a] The obtained diphosphine were oxidized by hydrogen peroxide, and their ee was determined as the corresponding diphosphine oxides.
[b] HPLC analyses of racemic **5ha** using various chiral columns showed a single peak, and the value of optical rotation of the obtained **5ha** in entry 15 was almost zero.

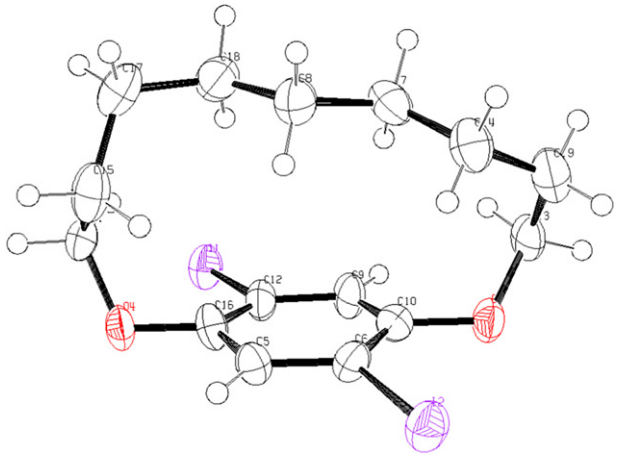
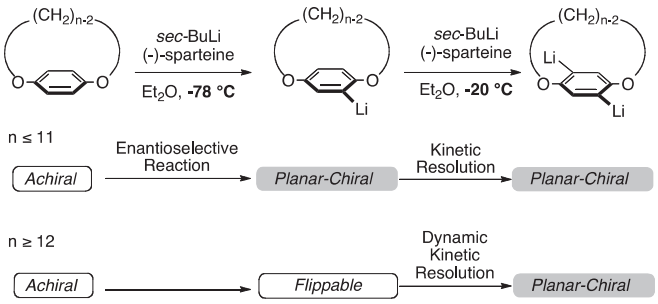


Fig. 1. ORTEP diagram of (*S*)-**5aa**.

(entry 10). The enantioselectivity gradually decreased along with the elongation of the ansa chain (entries 11–13). In particular, in the reaction of 1,16-dioxa[16]paracyclophane **1g**, the ee of the obtained product **5ga** was significantly decreased (entry 14). This difference in enantioselectivity depending on the length of the ansa chain can be explained as follows: monolithiated product with a short ansa chain ($n \leq 11$) is unflippable, and planar chirality was induced at the first lithiation at low temperature in a highly enantioselective manner. Therefore the subsequent second lithiation gave dilithiated product with excellent ee with the aid of kinetic resolution. On the other hand, monolithiated product with a longer ansa chain ($n \geq 12$) is considered to be flippable[2d] and chirality was not induced. Therefore, planar chirality was induced at the second lithiation at higher temperature only by dynamic kinetic resolution, which could not achieve excellent enantioselectivity (Scheme 2). Therefore, lithiation at low temperature is crucial for the induction of high enantioselectivity.



Scheme 2. Different asymmetric induction dependent on the length of ansa chains.

In the case of [17]paracyclophane, diiodo product **5ha** was probably flippable, and we did not observe planar chirality (entry 15). Therefore, we introduced diphenylphosphinyl groups as bulkier substituents than iodo groups. As a result, the induction of planar chirality was ascertained, and diphosphine **5hc** was obtained in 55% ee (entry 16). These results mean that dilithium complex derived from [17]paracyclophane could induce planar chirality.

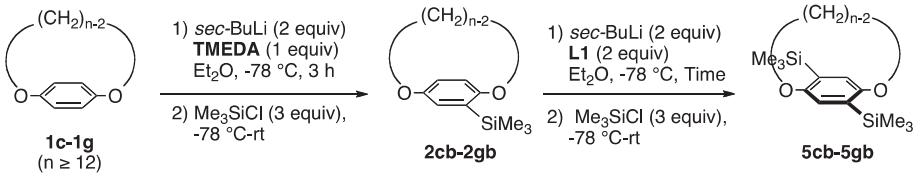
2.3. Enantioselective disubstitution via stepwise monolithiation

We focused on the enantioselective disubstitution of 1,*n*-dioxa[*n*]paracyclophane with a flippable ansa chain ($n \geq 12$) via stepwise monolithiation (Table 5). *ortho*-Lithiation of **1c**–**g** using *sec*-butyllithium and *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA) as an achiral amine at −78 °C along with treatment with chlorotrimethylsilane gave monosilylated paracyclophanes **2cb**–**gb**. Next, we examined the second *ortho*-lithiation of these silyl paracyclophanes using *sec*-butyllithium and (−)-sparteine as a chiral amine, and subsequent treatment with chlorotrimethylsilane gave a C_2-symmetrical disilylated product. In the case of [12]paracyclophane **2cb**, the enantioselective induction in the obtained disilylated product **5cb** was ascertained (18% ee),[19] but the ee was much lower than that of the diiodo product via dilithiation (entry 1). The reason for the low selectivity is that the ansa chain of **2cb** flips slowly at −78 °C, and dynamic kinetic resolution of **2cb** did not proceed selectively. On the other hand, the lithiation of monosilylated paracyclophane with a longer ansa chain, such as **2db**, **2eb**, **2fb**, and **2gb**, proceeded with excellent enantioselectivity, and C_2-symmetric disubstituted paracyclophanes were obtained (entries 2–5).

2.4. Enantioselective disubstitution using different electrophiles via stepwise monolithiation

Finally, we demonstrated disubstitution by stepwise monolithiation for the enantioselective synthesis of unsymmetrical paracyclophanes with two different substituents (Table 6). We synthesized chiral silylated paracyclophanes **2ab** and **2bb** under the conditions in Table 2. We next examined the *ortho*-lithiation of **2ab** and **2bb** using *sec*-butyllithium and TMEDA at −20 °C and treatment with various electrophiles, such as iodine, iodomethane, dimethylformamide, and benzophenone (entries 1–5). As a result, chiral paracyclophanes with iodo, methyl, formyl, and diphenylhydroxymethyl groups in addition to a silyl group were obtained without any loss of enantiopurity.

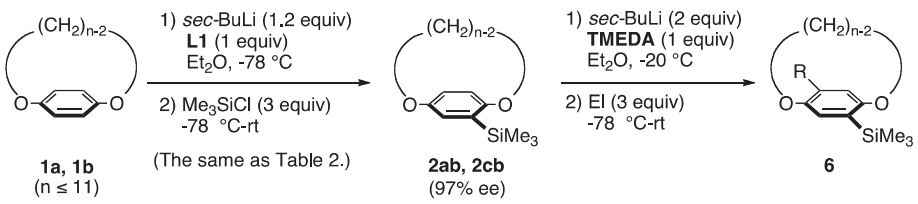
Table 5
Stepwise monolithiation of 1,*n*-dioxa[*n*]paracyclophane with a flippable ansa chain



Entry	*n*	Yield of **2** %	Time (h)	Yield of **5** (%)	ee of **5** (%)
1	12 (**1c**)	76 (**2cb**)	72	66 (**5cb**)	18[a]
2	13 (**1d**)	57 (**2db**)	48	73 (**5db**)	95[a]
3	14 (**1e**)	92 (**2eb**)	48	84 (**5eb**)	93[a]
4	15 (**1f**)	53 (**2fb**)	48	95 (**5fb**)	93[b]
5	16 (**1g**)	27 (**2gb**)	48	64 (**5gb**)	91[b]

[a] The disilylparacyclophanes were treated with NBS, and their ee was determined as the corresponding dibrominated products.
[b] The disilylparacyclophanes were treated with NIS, and their ee was determined as the corresponding diiodinated products.

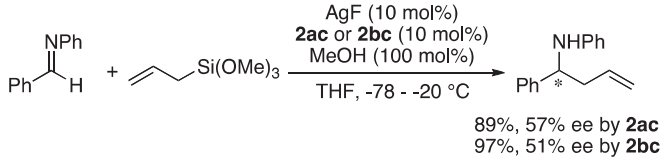
Table 6
Stepwise lithiation for asymmetric synthesis of planar-chiral 1,*n*-dioxa[*n*]paracyclophane with two different substituents



Entry	*n*	Electrophile (El)	R	Yield of **6** (%)	ee of **6** (%)
1	10 (**2bb**)	I_2	I	71 (**6ba**)	97
2	11 (**2ab**)	I_2	I	70 (**6aa**)	97
3	11 (**2ab**)	MeI	Me	78 (**6ad**)	96
4	11 (**2ab**)	DMF	CHO	73 (**6ae**)	97
5	11 (**2ab**)	Benzophenone	$C(OH)Ph_2$	82 (**6af**)	97

2.5. Use of obtained phosphines as chiral ligands

As a preliminary application of the obtained planar-chiral paracyclophanes as chiral ligands, we used monophosphines **2ac** and **2bc** in silver-catalyzed allylation of imine (Scheme 3).[20] As a result, moderate enantioselectivity was achieved by both of them.



Scheme 3. Ag-catalyzed enantioselective allylation of imine using monophosphines **2ac** and **2bc** as chiral ligands.

3. Conclusions

We have developed a highly enantioselective synthesis of planar-chiral 1,*n*-dioxa[*n*]paracyclophanes via asymmetric *ortho*-lithiation and dilithiation. In the case of paracyclophane with a short ansa chain ($n \leq 11$), which is unflippable, enantioselective *ortho*-lithiation using *sec*-butyllithium and sparteine at −78 °C and further lithiation at −20 °C gave planar-chiral monolithiated and C_2-symmetric dilithiated paracyclophanes, respectively, with excellent ee. Subsequent treatment of these lithium salts with various electrophiles gave planar-chiral mono- and disubstituted paracyclophanes. In the case of paracyclophane with a long ansa chain ($n \geq 12$), which is flippable, disubstitution by stepwise lithiation is required for high enantioselectivity: monosubstituted paracyclophanes were lithiated at −78 °C in the presence of sparteine and treated with various electrophiles to give disubstituted paracyclophanes with high ee. These protocols gave various planar-chiral 1,*n*-dioxa[*n*]paracyclophane derivatives with excellent ee, which could undergo further transformation.

4. Experimental section

4.1. General

All reactions were examined under an argon atmosphere in oven-dried glassware with a magnetic stirring bar. Hexane and cyclohexane solution of *sec*-butyllithium (1.0 M) were purchased from Kanto Chemical Co., Inc. Dehydrated diethyl ether, tetrahydrofuran (THF), and dichloromethane were purchased from Wako Pure Chemical Industries Ltd. (Wako), and purified by the method by Grubbs[21] before use. Other dehydrated solvents were purchased from Kanto or Wako, and dried over activated molecular sieves 3 Å or 4 Å. (−)-Sparteine **L1** was purchased from Tokyo Chemical Industry Co., Ltd. (TCI) and distilled from CaH_2 before use. Chiral diamine ligands **L2** was prepared according to the literature.[15] Other reagents were purchased from Wako, Kanto, TCI, or Aldrich and were used without further purification. Flash column chromatography was performed with silica gel (Kanto Chemical Co., Inc. 60 N 40–50 μm). Preparative thin-layer chromatography (PTLC) was performed with silica gel-precoated glass plates (Merck 60 GF_{254}) prepared in our laboratory. Gel permeation chromatography (GPC) was performed on JAI LC-908. IR spectra were recorded with Horiba FT730 spectrophotometer. NMR spectra were measured with JEOL AL-400 (400 MHz), JEOL ECS400 (400 MHz), JEOL ECX500 (500 MHz), or JEOL Lambda 500 (500 MHz) using TMS as an internal standard and $CDCl_3$ was used as a solvent. High-resolution mass spectra (HRMS) were measured on a JEOL JMS-SX102A with FAB (Fast Atomic Bombardment) method or JMS-T100CS with ESI (Electro Spray Ionization) method, and elemental analyses with Perkin–Elmer PE2400II. Optical rotations were measured with Jasco DIP-1000 polarimeter. X-ray crystallographic analyses were measured on a Rigaku R-AXIS RAPID diffractometer using graphite monochromated Mo Kα radiation. Physical properties of the compounds, which were already listed in the precedent communication,[12] were omitted.

4.2. Syntheses of 1,*n*-dioxa[*n*]paracyclophanes and 1,*n*-dioxa[*n*](1,4)naphthalenophanes 1

Hydroquinone or 1,4-dihydroxynaphthalene (5.0 mmol) and the corresponding dibromide (5.0 mmol) in dehydrated DMF (30 mL) were added dropwise over 12 h to a suspension of K_2CO_3 (12.5 mmol) in dehydrated DMF (50 mL) at 140 °C. The reaction mixture was cooled to rt and filtered with Celite. The filtrate was treated with saturated NH_4Cl aqueous solution and extracted with ethyl acetate. The organic layer was washed with water and brine. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The residue was filtered through a short plug of silica gel with dichloromethane and the filtrate was evaporated under reduced pressure. The crude products were purified by flash column chromatography (hexane/AcOEt=30/1∼20/1) and GPC (1,2-dichloroethane) to give dioxaparacyclophanes **1**.

*4.2.1. 1,12-Dioxa[12]paracyclophane (**1c**).* White solid. Mp 60 °C; IR (KBr) 2929, 2854, 1504, 1200, 843 cm^{-1}; ^1H NMR (400 MHz) δ 0.71–0.83 (m, 4H), 0.90–1.02 (m, 4H), 1.12–1.24 (m, 4H), 1.58–1.69 (m, 4H), 4.16–4.28 (t, *J*=5.6 Hz, 4H), 6.93 (s, 4H); ^{13}C NMR (100 MHz) δ 23.8, 27.0, 27.3, 28.2, 69.5, 119.5, 153.4; HRMS (FAB^+) for M^+ found *m*/*z* 248.1770, calcd for $C_{16}H_{24}O_2$ 248.1776.

*4.2.2. 1,13-Dioxa[13]paracyclophane (**1d**).* White solid. Mp 68 °C; IR (KBr) 2925, 2858, 1506, 1045, 837 cm^{-1}; ^1H NMR (400 MHz) δ 0.66–0.78 (m, 2H), 0.88–1.01 (m, 4H), 1.02–1.14 (m, 4H), 1.16–1.29 (m, 4H), 1.55–1.67 (m, 4H), 4.21 (t, *J*=5.6 Hz, 4H), 6.90 (s, 4H); ^{13}C NMR (100 MHz) δ 24.1, 26.8, 27.3, 28.0, 28.4, 68.9, 118.5, 152.9; HRMS (FAB^+) for M^+ found *m*/*z* 262.1940, calcd for $C_{17}H_{26}O_2$: 262.1933.

*4.2.3. 1,14-Dioxa[14]paracyclophane (**1e**).* White solid. Mp 47 °C; IR (KBr) 2927, 2854, 1506, 1460, 1241, 1224, 1205, 1011, 831 cm^{-1}; ^1H NMR (400 MHz) δ 0.89–1.01 (br s, 8H), 1.08–1.20 (m, 4H), 1.27–1.38 (m, 4H), 1.59–1.68 (m, 4H), 4.17 (t, *J*=5.7 Hz, 4H), 6.87 (s, 4H); ^{13}C NMR (100 MHz) δ 23.9, 27.2, 27.5, 27.8, 28.4, 68.4, 117.7, 152.4; HRMS (FAB^+) for M^+ found *m*/*z* 276.2082, calcd for $C_{18}H_{28}O_2$: 276.2089.

*4.2.4. 1,15-Dioxa[15]paracyclophane (**1f**).* Colorless oil; IR (neat) 2925, 2854, 1504, 1205, 827 cm^{-1}; ^1H NMR (400 MHz) δ 0.88–1.13 (m, 10H), 1.15–1.28 (m, 4H), 1.32–1.42 (m, 4H), 1.58–1.69 (m, 4H), 4.14 (t, *J*=5.6 Hz, 4H), 6.85 (s, 4H); ^{13}C NMR (100 MHz) δ 23.8, 27.4, 27.4, 28.0, 28.1, 29.5, 68.0, 117.2, 152.4; HRMS (FAB^+) for M^+ found *m*/*z* 290.2248, calcd for $C_{19}H_{30}O_2$: 290.2246.

*4.2.5. 1,16-Dioxa[16]paracyclophane (**1g**).* White solid. Mp 49 °C; IR (KBr) 2924, 2854, 1508, 1211, 1059, 820 cm^{-1}; ^1H NMR (400 MHz) δ 0.97–1.19 (m, 12H), 1.19–1.32 (m, 4H), 1.34–1.64 (m, 4H), 1.60–1.71 (m, 4H), 4.10 (t, *J*=5.9 Hz, 4H), 6.84 (s, 4H); ^{13}C NMR (100 MHz) δ 24.0, 27.1, 27.4, 27.9, 28.3, 28.8, 67.9, 116.6, 152.4; HRMS (FAB^+) for M^+ found *m*/*z* 304.2416, calcd for $C_{20}H_{32}O_2$: 304.2402.

*4.2.6. 1,17-Dioxa[17]paracyclophane (**1h**).* Colorless oil; IR (neat) 2925, 2854, 1506, 1236, 1207, 835 cm^{-1}; ^1H NMR (400 MHz) δ 1.01–1.23 (m, 14H), 1.23–1.34 (m, 4H), 1.37–1.48 (m, 4H), 1.62–1.73 (m, 4H), 4.07 (t, *J*=6.1 Hz, 4H), 6.83 (s, 4H); ^{13}C NMR (100 MHz) δ 24.1, 27.3, 27.7, 28.1, 28.3, 28.8, 29.2, 68.0, 116.4, 152.7;

HRMS (FAB$^+$) for M^+ found m/z 318.2574, calcd for $C_{21}H_{34}O_2$: 318.2559.

*4.2.7. 1,16-Dioxa[16](1.4)naphthalenophane (**3e**).* Colorless oil; IR (neat) 2925, 2854, 1595, 1460, 1269, 1234, 1093, 764 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.67–0.78 (m, 4H), 0.80–0.92 (m, 4H), 0.93–1.04 (m, 4H), 1.16–1.27 (m, 4H), 1.41–1.51 (m, 4H), 1.73–1.83 (m, 4H), 4.23 (t, J=6.0 Hz, 4H), 6.77 (s, 2H), 7.48 (dd, J=3.2, 6.4 Hz, 2H), 8.23 (dd, J=3.2, 6.4 Hz, 2H); ^{13}C NMR (100 MHz) δ 24.6, 27.1, 27.3, 27.9, 28.3, 28.5, 68.1, 106.0, 122.0, 125.5, 127.4, 148.1 HRMS (FAB$^+$) for M^+ found m/z 354.2569, calcd for $C_{24}H_{34}O_2$: 354.2559.

4.3. Experimental procedure for enantioselective monolithiation

A cyclohexane/hexane solution of *sec*-butyllithium (1.0 M, 0.2 mL, 0.2 mmol) was added dropwise to an ether solution (0.5 mL) of 1,*n*-dioxa[*n*]paracyclophane **1** (0.1 mmol) and (−)-sparteine **L1** (23 μL, 0.1 mmol) at −78 °C and the reaction mixture was stirred for the hours cited in Tables 2 and 3 at −78 °C. To the mixture was added dropwise iodine (76.1 mg, 0.3 mmol) in Et_2O (0.6 mL) at −78 °C, and the reaction mixture stirred for 2 h at rt. It was treated with saturated $Na_2S_2O_3$ aqueous solution, and extracted with ethyl acetate. The organic layer was washed with water and brine. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by PTLC to give a monoiodo-1,*n*-dioxa[*n*]paracyclophane **2**.

*4.3.1. 12-(Diphenylphosphino)-1,10-dioxa[10]paracyclophane (**2bc**).* After monolithiation of **1b**, chlorodiphenylphosphine (56 μL, 0.3 mmol) was added at −78 °C. Then the mixture was stirred for 2 h at rt. It was filtered through a short plug of silica gel with dichloromethane and the filtrate was evaporated under reduced pressure. The crude products were purified by PTLC (hexane/dichloromethane=3/1) to give **2bc**. White solid. Mp 110 °C; IR (KBr) 3052, 2925, 2866, 1473, 1456, 1192, 1028, 742, 696 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.32–0.50 (m, 1H), 0.55–1.08 (m, 6H), 1.28–1.66 (m, 4H), 1.67–1.83 (m, 1H), 3.71–3.86 (m, 1H), 3.99–4.12 (m, 1H), 4.19–4.37 (m, 2H), 6.35–5.39 (m, 1H), 6.95–7.01 (m, 2H), 7.26–7.39 (m, 10H); ^{13}C NMR (100 MHz) δ 24.0 (d, J=2.9 Hz), 24.1, 26.3, 26.6, 27.5 (d, J=2.9 Hz), 28.0, 71.7 (d, J=2.9 Hz), 72.0, 120.6 (d, J=2.9 Hz), 123.0, 125.7, 128.3 (d, J=6.7 Hz), 128.5, 128.5 (d, J=6.7 Hz), 129.0, 131.8 (d, J=13.4 Hz), 133.0 (d, J=19.2 Hz), 134.6 (d, J=21.1 Hz), 136.5 (d, J=45.1 Hz), 136.6 (d, J=47.9 Hz), 153.2, 155.2 (d, J=16.6 Hz); ^{31}P NMR (160 MHz) δ −20.2; HRMS (FAB$^+$) for M^+ found m/z 404.1906, calcd for $C_{26}H_{29}O_2P$: 404.1905. $[\alpha]_D^{27}$ +7.1 (c 1.13, $CHCl_3$, 98% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 0.5 mL/min, retention time: 8.9 min for minor isomer and 9.5 min for major isomer).

*4.3.2. 18-Iodo-1,16-dioxa[16](1.4)naphthalenophane (**4d**).* Pale yellow viscous oil; IR (neat) 2925, 2854, 1572, 1458, 1444, 1321, 1269, 1259, 1097, 960, 765, 709 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.60–1.50 (m, 20H), 1.59–1.83 (m, 3H), 1.90–2.07 (m, 1H) 4.14–4.45 (m, 4H), 7.11 (s, 1H), 7.43–7.55 (m, 2H), 8.06–8.14 (m, 1H), 8.18–8.26 (m, 1H); ^{13}C NMR (100 MHz) δ 24.6, 26.4, 27.3, 27.4, 27.7, 27.9, 28.0, 28.2, 28.2, 28.4, 28.7, 31.6, 67.7, 74.3, 85.9, 115.0, 122.4, 122.6, 125.7, 126.6, 126.8, 129.4, 148.9, 151.1; HRMS (FAB$^+$) for M^+ found m/z 480.1519, calcd for $C_{24}H_{33}IO_2$: 480.1525. $[\alpha]_D^{26}$ 6.6 (c 1.82, $CHCl_3$, 92% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IB: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 1.0 mL/min, retention time: 6.3 min for minor isomer and 9.1 min for major isomer).

4.4. Enantioselective synthesis of 12-trimethylsilyl-1,10-dioxa[10]paracyclophane and 13-trimethylsilyl-1,11-dioxa[11]paracyclophane

A cyclohexane/hexane solution of *sec*-butyllithium (1.0 M, 1.2 mL, 1.2 mmol) was added dropwise to an Et_2O solution (5.0 mL) of a 1,*n*-dioxa[*n*]paracyclophane **1** (*n*=8 or 9, 1.0 mmol) and (−)-sparteine **L1** (0.23 mL, 1.0 mmol) at −78 °C, and the reaction mixture was stirred for 3 h at −78 °C. To the mixture was added dropwise chlorotrimethylsilane (76.1 mL, 2.0 mmol) at −78 °C and the mixture stirred for overnight at rt. It was treated with saturated NH_4Cl aqueous solution, and extracted with ethyl acetate. The organic layer was washed with water and brine. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by flash column chromatography (hexane/dichloromethane=3/1) to give trimethylsilyl-1,*n*-dioxa[*n*]paracyclophane **2**.

*4.4.1. 13-(Trimethylsilyl)-1,11-dioxa[11]paracyclophane (**2ab**).* Color less oil; IR (neat) 2952, 2925, 2856, 1567, 1473, 1475, 1390, 1373, 1254, 1246, 1194, 1130, 1063, 1037, 1012, 1007, 893, 883, 839, 766, 700, 625 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.30 (s, 9H), 0.58–0.75 (m, 1H), 0.75–1.11 (m, 9H), 1.49–1.78 (m, 4H), 4.09–4.27 (m, 3H), 4.30–4.43 (m, 1H), 6.94 (d, J=8.5 Hz, 1H), 7.00–7.09 (m, 2H); ^{13}C NMR (100 MHz) δ −0.3, 25.4, 26.1, 26.3, 26.8, 27.8, 29.3, 29.9, 69.9, 72.1, 117.3, 121.9, 127.0, 131.6, 153.5, 159.2; HRMS (FAB$^+$) for M^+ found m/z 306.2028, calcd for $C_{18}H_{30}O_2Si$: 306.2015. $[\alpha]_D^{23}$ −23.2 (c 1.39, $CHCl_3$, 97% ee). Compound **2ab** was treated with NIS, and the ee was determined as the corresponding iodinated products **2aa**. (Daicel Chiralpak IB: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 1.0 mL/min, retention time: 5.1 min for minor isomer and 6.3 min for major isomer).

*4.4.2. 12-(Trimethylsilyl)-1,10-dioxa[10]paracyclophane (**2bb**).* Colorless oil; IR (neat) 2954, 2925, 2856, 1567, 1473, 1244, 1390, 1365, 1190, 1126, 1033, 839, 767, 700, 625 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.08–0.25 (m, 1H), 0.29 (s, 9H), 0.53–0.71 (m, 1H), 0.71–1.07 (m, 6H), 1.18–1.34 (m, 1H), 1.35–1.49 (m, 1H), 1.51–1.64 (m, 1H), 1.82–1.98 (m, 1H), 3.95–4.04 (m, 1H), 4.09–4.25 (m, 2H), 4.32–4.41 (m, 1H), 6.85 (d, J=8.2 Hz, 1H), 6.98 (dd, J=3.7, 8.2 Hz, 1H), 7.09 (d, J=3.7 Hz, 1H); ^{13}C NMR (100 MHz) δ −0.53, 22.8, 24.8, 26.0, 26.5, 26.7, 29.4, 69.7, 73.1, 118.3, 123.0, 127.5, 132.6, 152.3, 158.1; HRMS (FAB$^+$) for M^+ found m/z 202.1849, calcd for $C_{17}H_{28}O_2Si$: 292.1859. $[\alpha]_D^{33}$ −22.3 (c 1.03, $CHCl_3$, 97% ee). Compound **2bb** was treated with NIS, and the ee was determined as the corresponding iodinated products **2ba**. (Daicel Chiralpak IB: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 1.0 mL/min, retention time: 5.2 min for minor isomer and 6.0 min for major isomer).

4.5. Synthesis of trimethylsilyl-1,*n*-dioxa[*n*]paracyclophane (*n*≥12)

A cyclohexane/hexane solution of *sec*-butyllithium (1.0 M, 2.0 mL, 2.0 mmol) was added dropwise to an Et_2O solution (5.0 mL) of 1,*n*-dioxa[*n*]paracyclophane **1** (1.0 mmol) and TMEDA (0.23 mL, 1.0 mmol) at −78 °C, and the reaction mixture was stirred for 3 h at −78 °C. To the mixture was added dropwise chlorotrimethylsilane (76 μL, 0.3 mmol) at −78 °C and the mixture stirred for overnight at rt. It was treated with saturated NH_4Cl aqueous solution, and extracted with ethyl acetate. The organic layer was washed with water and brine. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by flash column chromatography (hexane/dichloromethane=3/1) to give a trimethylsilyl-1,*n*-dioxa[*n*]paracyclophane **2**.

*4.5.1. 14-(Trimethylsilyl)-1,12-dioxa[12]paracyclophane (**2cb**).* Colorless oil; IR (neat) 2949, 2929, 2898, 2856, 1573, 1473, 1259, 1246, 1196, 1136, 1072, 1045, 1022, 1004, 860, 837, 764, 704, 625 cm^{-1}; ^1H NMR (400 MHz) δ 0.27 (s, 9H), 0.48–0.65 (m, 1H), 0.70–1.23 (m, 11H), 1.45–1.62 (m, 2H), 1.62–1.75 (m, 1H), 1.75–1.89 (m, 1H), 4.06–4.16 (m, 1H), 4.20 (t, J=5.7 Hz, 2H), 4.37–4.47 (m, 1H), 6.83 (d, J=8.7 Hz, 1H), 6.95 (dd, J=2.7, 8.7 Hz, 1H), 7.01 (d, J=2.7 Hz, 1H); ^{13}C NMR (100 MHz) δ −0.5, 23.5, 24.2, 27.2, 27.3, 27.3, 27.5, 28.4, 67.6, 69.7, 114.6, 119.8, 125.8, 130.0, 152.4, 157.6 (A pair of peaks at the aliphatic region is overlapped.); HRMS (FAB$^+$) for M^+ found m/z 320.2184, calcd for $C_{19}H_{32}O_2Si$: 320.2172.

*4.5.2. 15-(Trimethylsilyl)-1,13-dioxa[13]paracyclophane (**2db**).* Colorless oil; IR (neat) 2925, 2900, 2856, 1576, 1473, 1259, 1244, 1200, 1138, 1061, 1045, 1002, 870, 837, 764, 704, 625 cm^{-1}; ^1H NMR (400 MHz) δ 0.27 (s, 9H), 0.61–0.76 (m, 2H), 0.87–1.26 (m, 12H), 1.49–1.74 (br s, 4H), 4.12–4.33 (m, 4H), 6.72 (d, J=9.0 Hz, 1H), 6.90 (dd, J=3.2, 9.0 Hz, 1H), 6.99 (d, J=3.2 Hz, 1H); ^{13}C NMR (100 MHz) δ −0.5, 24.3, 26.7, 27.4, 27.6, 27.8, 28.3, 28.3, 28.5, 67.1, 69.3, 112.9, 119.0, 124.8, 129.7, 151.8, 157.2 (A pair of peaks at the aliphatic region is overlapped.); HRMS (FAB$^+$) for M^+ found m/z 334.2321, calcd for $C_{20}H_{34}O_2Si$: 334.2328.

*4.5.3. 16-(Trimethylsilyl)-1,14-dioxa[14]paracyclophane (**2eb**).* Colorless oil; IR (neat) 2925, 2854, 1576, 1475, 1396, 1268, 1257, 1243, 1200, 1140, 1072, 1051, 1007, 883, 839, 763, 706, 627 cm^{-1}; ^1H NMR (400 MHz) δ 0.27 (s, 9H), 0.84–0.97 (m, 6H), 0.97–1.06 (m, 2H), 1.06–1.15 (m, 2H), 1.15–1.23 (m, 2H), 1.23–1.39 (m, 4H), 1.54–1.76 (m, 4H), 4.11–4.25 (m, 4H), 6.76 (d, J=8.3 Hz, 1H), 6.88 (dd, J=3.2, 8.3 Hz, 1H), 6.97 (d, J=3.2 Hz, 1H); ^{13}C NMR (100 MHz) δ −0.6, 23.9, 24.2, 27.1, 27.4, 27.5, 27.6, 27.7, 28.1, 28.3, 28.5, 66.5, 68.7, 111.8, 118.5, 124.1, 129.1, 151.4, 156.9; HRMS (FAB$^+$) for M^+ found m/z 348.2474, calcd for $C_{21}H_{36}O_2Si$: 348.2485.

*4.5.4. 17-(Trimethylsilyl)-1,15-dioxa[15]paracyclophane (**2fb**).* Colorless oil; IR (neat) 2925, 2854, 1577, 1473, 1396, 1269, 1244, 1203, 1147, 1068, 1045, 1005, 881, 839, 764, 710, 627 cm^{-1}; ^1H NMR (400 MHz) δ 0.26 (s, 9H), 0.85–1.47 (m, 18H), 1.54–1.81 (m, 4H), 4.14 (t, J=5.9 Hz, 4H), 6.74 (d, J=9.0 Hz, 1H), 6.85 (dd, J=2.9, 9.0 Hz, 1H), 6.96 (d, J=2.9 Hz, 1H); ^{13}C NMR (100 MHz) δ −0.61, 23.9, 24.0, 27.4, 27.4, 27.6, 27.6, 27.8, 28.1, 28.2, 28.2, 29.6, 66.3, 68.4, 111.0, 117.4, 124.0, 1129.2, 151.5, 157.0; HRMS (FAB$^+$) for M^+ found m/z 362.2649, calcd for $C_{22}H_{38}O_2Si$: 362.2641.

*4.5.5. 18-(Trimethylsilyl)-1,16-dioxa[16]paracyclophane (**2gb**).* Colorless oil; IR (neat) 2925, 2854, 1577, 1468, 1396, 1271, 1244, 1205, 1142, 1058, 1045, 883, 839, 763, 713, 686, 627 cm^{-1}; ^1H NMR (400 MHz) δ 0.27 (s, 9H), 0.95–1.50 (m, 20H), 1.57–1.80 (m, 4H), 4.08 (t, J=5.9 Hz, 2H), 4.13 (t, J=5.9 Hz, 2H), 6.74 (d, J=9.0 Hz, 1H), 6.85 (dd, J=3.4, 9.0 Hz, 1H), 6.95 (d, J=3.4 Hz, 1H); ^{13}C NMR (100 MHz) δ −0.65, 23.7, 24.1, 26.6, 27.2, 27.4, 27.4, 27.8, 28.0, 28.0, 28.6, 28.6, 29.2, 65.9, 68.0, 110.6, 117.2, 123.3, 128.9, 151.4, 157.2; HRMS (FAB$^+$) for M^+ found m/z 376.2809, calcd for $C_{23}H_{40}O_2Si$: 376.2798.

4.6. Typical experimental procedure for enantioselective dilithiation

To an Et_2O solution (0.5 mL) of a 1,*n*-dioxa[*n*]paracyclophane **1** (0.1 mmol) and **L1** (23 μL, 0.1 mmol) was added dropwise a cyclohexane/hexane solution of *sec*-butyllithium (1.0 M, 0.2 mL, 0.2 mmol) at −78 °C and stirred for 2 h at −78 °C Then a cyclohexane/hexane solution of *sec*-butyllithium (1.0 M, 0.2 mL, 0.2 mmol) was added dropwise to the mixture at −78 °C and stirred for the hours cited in Table 4 at −20 °C. Iodine (152.3 mg, 0.6 mmol) in Et_2O (1.2 mL) was added dropwise at −78 °C and the mixture stirred for 2 h at rt. It was treated with $Na_2S_2O_3$ aqueous solution, and extracted with ethyl acetate. The organic layer was washed with water and brine. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by thin-layer chromatography to give a diiodo-1,*n*-dioxa[*n*]paracyclophane **5**.

*4.6.1. (S)-13,16-Diiodo-1,11-dioxa[11]paracyclophane (**5aa**).* White solid. Mp 70 °C; IR (KBr) 2924, 2854, 1471, 1448, 1335, 1187, 1043 cm^{-1}; ^1H NMR (400 MHz) δ 0.69–0.85 (m, 2H), 0.86–1.08 (m, 8H), 1.47–1.64 (m, 2H), 1.74–1.90 (m, 2H), 4.16–4.25 (m, 2H), 4.31–4.40 (m, 2H), 7.37 (s, 2H); ^{13}C NMR (100 MHz) δ 25.3, 25.9, 28.0, 29.7, 72.7, 90.5, 129.6, 154.6; Anal. Calcd for $C_{15}H_{20}I_2O_2$: C, 37.06; H, 4.15. found: C, 37.23; H, 4.04.; HRMS (FAB$^+$) for M^+ found m/z 485.9557, calcd for $C_{15}H_{20}I_2O_2$: 485.9553. $[\alpha]_D^{25}$ +58.9 (*c* 1.87, $CHCl_3$, 99% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 1.0 mL/min, retention time: 4.5 min for minor isomer and 5.8 min for major isomer). Crystal data for $C_{15}H_{20}I_2O_2$, M=486.13, orthorhombic, space group $P2_12_12_1$ (no. 19), a=10.2806(9) Å, b=10.712(1) Å, c=14.605(2) Å, V=1608.4(3) Å^3, T=173 K, Z=4, μ(Mo Kα)= 39.085 cm^{-1}; number of reflections measured: total 25,616 and unique 3682, $R1$=0.0785, $wR2$=0.2027, Flack parameter (Friedel pairs=1579) 0.02(8). CCDC 852454.

*4.6.2. 14,17-Diiodo-1,12-dioxa[12]paracyclophane (**5ca**).* White solid. Mp 98 °C; IR (KBr) 2927, 2854, 1471, 1456, 1336, 1263, 1192, 1045, 981, 872, 804, 739 cm^{-1}; ^1H NMR (400 MHz) δ 0.63–0.83 (br s, 4H), 0.83–1.04 (m, 2H), 1.04–1.35 (m, 6H), 1.57–1.77 (m, 4H), 4.17–4.30 (m, 2H), 4.30–4.43 (m, 2H), 7.30 (s, 2H); ^{13}C NMR (100 MHz) δ 23.8, 27.4, 27.4, 27.6, 70.6, 89.1, 127.0, 152.7; HRMS (FAB$^+$) for M^+ found m/z 499.9710, calcd for $C_{16}H_{22}I_2O_2$: 499.9709. $[\alpha]_D^{24}$ +54.6 (*c* 1.40, $CHCl_3$, 88% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% CH_2Cl_2 in hexane, flow rate: 1.0 mL/min, retention time: 4.8 min for minor isomer and 7.3 min for major isomer).

*4.6.3. 15,18-Diiodo-1,13-dioxa[13]paracyclophane (**5da**).* White solid. Mp 115 °C; IR (KBr) 2924, 2852, 1473, 1456, 1338, 1196, 1045, 839, 744 cm^{-1}; ^1H NMR (400 MHz) δ 0.67–0.84 (m, 2H), 0.84–1.12 (m, 6H), 1.12–1.34 (m, 6H), 1.52–1.67 (m, 2H), 1.67–1.83 (m 2H), 4.29 (t, J=5.4 Hz, 4H), 7.30 (m, 2H); ^{13}C NMR (100 MHz) δ 24.1, 27.1, 27.1, 28.4, 28.6, 70.5, 88.3, 125.8, 153.0; HRMS (FAB$^+$) for M^+ found m/z 513.9885, calcd for $C_{17}H_{24}I_2O_2$: 513.9866. $[\alpha]_D^{24}$ +54.1 (*c* 1.46, $CHCl_3$, 95% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% CH_2Cl_2 in hexane, flow rate: 1.0 mL/min, retention time: 4.4 min for minor isomer and 6.4 min for major isomer).

*4.6.4. 16,19-Diiodo-1,14-dioxa[14]paracyclophane (**5ea**).* White solid. Mp 101 °C; IR (KBr) 2924, 2852, 1473, 1460, 1338, 1261, 1200, 1047, 862, 800, 736 cm^{-1}; ^1H NMR (400 MHz) δ 0.85–1.03 (br, 8H), 1.03–1.46 (m, 8H), 1.49–1.67 (m, 2H), 1.67–1.83 (m, 2H), 4.13–4.35 (m, 4H), 7.26 (s, 2H); ^{13}C NMR (100 MHz) δ 24.0, 26.8, 27.5, 28.0, 28.6, 69.6, 87.3, 124.6, 151.8; HRMS (FAB$^+$) for M^+ found m/z 528.0014, calcd for $C_{18}H_{26}I_2O_2$: 528.0022. $[\alpha]_D^{24}$ +59.4 (*c* 1.41, $CHCl_3$, 93% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% CH_2Cl_2 in hexane, flow rate: 1.0 mL/min, retention time: 4.4 min for minor isomer and 6.4 min for major isomer).

*4.6.5. 17,20-Diiodo-1,15-dioxa[15]paracyclophane (**5fa**).* White solid. Mp 84 °C; IR (KBr) 2924, 2852, 1475, 1460, 1340, 1201, 1049, 987, 858, 733 cm^{-1}; ^1H NMR (400 MHz) δ 0.91–1.20 (m, 10H), 1.20–1.55 (m, 8H), 1.59–1.74 (m, 4H), 4.20 (t, J=5.5 Hz, 4H), 7.24 (s, 2H); ^{13}C NMR (100 MHz) δ 24.0, 27.2, 27.5, 28.1, 28.3, 29.4, 69.4, 87.2, 124.0, 152.2;

HRMS (FAB$^+$) for M^+ found m/z 542.0179, calcd for $C_{19}H_{28}I_2O_2$: 542.0179. $[\alpha]_D^{24}$ +58.9 (c 0.70, $CHCl_3$, 91% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% CH_2Cl_2 in hexane, flow rate: 1.0 mL/min, retention time: 4.4 min for minor isomer and 6.9 min for major isomer).

*4.6.6. 18,21-Diiodo-1,16-dioxa[16]paracyclophane (**5ga**).* White solid. Mp 74 °C; IR (KBr) 2924, 2852, 1483, 1462, 1340, 1205, 1051, 860, 746 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.90–1.45 (m, 16H), 1.45–1.95 (m, 8H), 4.05–4.28 (m, 4H), 7.21 (s, 2H); ^{13}C NMR (100 MHz) δ 23.7, 26.7, 27.2, 27.9, 28.3, 29.0, 68.9, 86.5, 123.3, 151.9; HRMS (FAB$^+$) for M^+ found m/z 556.0309, calcd for $C_{20}H_{30}I_2O_2$: 556.0335. $[\alpha]_D^{26}$ +43.4 (c 1.00, $CHCl_3$, 91% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% CH_2Cl_2 in hexane, flow rate: 1.0 mL/min, retention time: 4.0 min for minor isomer and 6.0 min for major isomer).

*4.6.7. 19,22-Diiodo-1,17-dioxa[17]paracyclophane (**5ha**).* Yellowish viscous oil; IR (KBr) 2924, 2852, 1483, 1460, 1342, 1205, 1051, 1002, 856 cm^{-1}; ^{1}H NMR (400 MHz) δ 1.00–1.45 (m, 20H), 1.47–1.71 (m, 4H), 1.71–1.91 (m, 2H), 4.04–4.21 (m, 4H), 7.21 (s, 2H); ^{13}C NMR (100 MHz) δ 24.3, 27.1, 27.8, 28.2, 28.3, 28.9, 29.2, 69.2, 86.6, 123.3, 152.3; HRMS (FAB$^+$) for M^+ found m/z 570.0484, calcd for $C_{21}H_{32}I_2O_2$: 570.0492.

*4.6.8. 19,22-Bis(diphenylphosphino)-1,17-dioxa[17]paracyclophane (**5hc**).* After dilithiation of **1g**, chlorodiphenylphosphine (112 μL, 0.6 mmol) was added at −78 °C. Then the mixture was stirred for 2 h at rt. It was filtered through a short plug of silica gel with dichloromethane and the filtrate was evaporated under reduced pressure. The crude products were purified by PTLC (hexane/dichloromethane=3/2) to give **5hc**. White solid. 50 °C; IR (KBr) 2925, 2852, 1463, 1434, 1344, 1196, 724, 696 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.99–1.44 (m, 26H), 3.60–3.84 (m, 4H), 6.22 (t, J=4.6 Hz, 2H), 7.22–7.44 (m, 20H); ^{13}C NMR (100 MHz) δ 24.3, 27.5, 27.7, 28.0, 28.5, 28.8, 29.2, 67.9, 117.4, 128.1 (d, J=14.4 Hz), 128.3, 128.4, 128.4, 128.6 (d, J=13.4 Hz), 133.7 (d, J=20.1 Hz), 134.1 (d, J=20.1 Hz), 136.6 (d, J=12.5 Hz), 137.3 (d, J=11.5 Hz), 153.8 (d, J=16.3 Hz); ^{31}P NMR (160 MHz) δ −16.3: HRMS (FAB$^+$) for M^+ found m/z 686.3441, calcd for $C_{45}H_{52}O_2P_2$: 686.3443. $[\alpha]_D^{27}$ +8.2 (c 1.03, $CHCl_3$, 55% ee). Compound **5hc** was treated with hydrogen peroxide, and the ee was determined as the corresponding phosphine oxide. (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 70% 2-propanol in hexane, flow rate: 1.0 mL/min, retention time: 15.2 min for major isomer and 21.5 min for minor isomer).

4.7. Asymmetric lithiation of trimethylsilyl-1,*n*-dioxa[*n*] paracyclophanes (*n*≥12)

To a solution of trimethylsilyl-1,n-dioxa[n]paracyclophanes **2** (0.2 mmol) and **L1** (92 μL, 0.4 mmol) in Et_2O (1.0 mL) was added dropwise a cyclohexane/hexane solution of *sec*-butyllithium (1.0 M, 0.4 mL, 0.4 mmol) at −78 °C and stirred for the hours cited in Table 5 at −78 °C. Then to the mixture was added dropwise trimethylsilylchloride (76 μL, 0.6 mmol) at −78 °C and stirred for 1 h at rt. The mixture was added NH_4Cl solution, and extracted with ethyl acetate. The organic layer was washed with water and brine, dried over Na_2SO_4. The solvent was removed under reduced pressure, and the crude products were purified by PTLC to give bis(trimethylsilyl) 1,n-dioxa[n]paracyclophanes **5**.

*4.7.1. 14,17-Bis(trimethylsilyl)-1,12-dioxa[12]paracyclophane (**5cb**).* Colorless oil; IR (neat) 2952, 2925, 2900, 2854, 1468, 1333, 1246, 1184, 1107, 1049, 839, 761, 633 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.29 (s, 18H), 0.54–0.72 (m, 2H), 0.74–0.90 (m, 2H), 0.90–1.20 (m, 8H), 1.37–1.56 (m, 2H), 1.69–1.88 (m, 2H), 4.00–4.17 (m, 2H), 4.36–4.53 (m, 2H), 6.92 (s, 2H); ^{13}C NMR (100 MHz) δ −0.4, 24.5, 27.3, 27.6, 28.0, 68.4, 120.9, 130.6, 156.3; HRMS (FAB$^+$) for M^+ found m/z 392.2574, calcd for $C_{22}H_{40}O_2Si_2$: 392.2567. $[\alpha]_{Hg435}^{24}$ −6.3 (c 1.33, $CHCl_3$, 18% ee). Compound **5cb** was treated with NBS, and the ee was determined as the corresponding dibrominated product. (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 1.0 mL/min, retention time: 4.8 min for minor isomer and 5.9 min for major isomer).

*4.7.2. 15,18-Bis(trimethylsilyl)-1,13-dioxa[13]paracyclophane (**5db**).* Colorless oil; IR (neat) 2952, 2925, 2900, 2854, 1465, 1335, 1246, 1186, 1107, 1057, 837, 762, 633 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.27 (s, 18H) 0.59–0.76 (m, 2H), 0.84–1.27 (m, 12H), 1.43–1.61 (m, 2H), 1.61–1.77 (m, 2H), 4.03–4.16 (m, 2H), 4.33–4.45 (m, 2H), 6.91 (s, 2H); ^{13}C NMR (100 MHz) δ −0.34, 24.8, 26.6, 27.8, 28.6, 28.8, 67.8, 119.7, 130.4, 156.7; HRMS (FAB$^+$) for M^+ found m/z 406.2704, calcd for $C_{23}H_{42}O_2Si_2$: 406.2723. $[\alpha]_D^{23}$ −11.0 (c 1.29, benzene, 89% ee). Compound **5db** was treated with NBS, and the ee was determined as the corresponding dibrominated product. (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 1.0 mL/min, retention time: 4.3 min for minor isomer and 5.2 min for major isomer).

*4.7.3. 16,19-Bis(trimethylsilyl)-1,14-dioxa[14]paracyclophane (**5eb**).* Colorless oil; IR (neat) 2952, 2925, 2900, 2856, 1468, 1336, 1244, 1192, 1107, 1055, 837, 762, 633 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.27 (s, 18H), 0.64–1.53 (m, 18H), 1.80–1.97 (m, 2H), 3.98–4.10 (m, 2H), 4.34–4.45 (m, 2H), 6.85 (s, 2H); ^{13}C NMR (100 MHz) δ −0.2, 23.9, 27.1, 27.8, 28.0, 28.4, 66.6, 118.1, 129.3, 155.5; HRMS (FAB$^+$) for M^+ found m/z 420.2862, calcd for $C_{24}H_{44}O_2Si_2$: 420.2880. $[\alpha]_D^{28}$ +22.6 (c 1.33, $CHCl_3$, 93% ee). Compound **5eb** was treated with NBS, and the ee was determined as the corresponding dibrominated product. (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 20% dichloromethane in hexane, flow rate: 1.0 mL/min, retention time: 4.1 min for minor isomer and 5.3 min for major isomer).

*4.7.4. 17,20-Bis(trimethylsilyl)-1,15-dioxa[15]paracyclophane (**5fb**).* Colorless oil; IR (neat) 2951, 2925, 2902, 2854, 1466, 1338, 1244, 1194, 1107, 1057, 839, 762, 633 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.28 (s, 18H), 0.76–1.20 (m, 12H), 1.20–1.42 (m, 6H), 1.48–1.65 (m, 2H), 1.66–1.83 (m, 2H), 3.96–4.10 (m, 2H), 4.26–4.39 (m, 2H), 6.87 (m, 2H); ^{13}C NMR (100 MHz) δ −0.40, 24.4, 27.7, 28.0, 28.2, 28.3, 29.5, 66.7, 117.7, 129.6, 156.2; HRMS (FAB$^+$) for M^+ found m/z 434.3021, calcd for $C_{25}H_{46}O_2Si_2$: 434.3036. $[\alpha]_{Hg435}^{24}$ +30.0 (c 1.38, $CHCl_3$, 93% ee). Compound **5fb** was treated with NIS, and the ee was determined as the corresponding diiodinated product **5fa**.

*4.7.5. 18,21-Bis(trimethylsilyl)-1,16-dioxa[16]paracyclophane (**5gb**).* Colorless oil; IR (neat) 2949, 2925, 2902, 2856, 1464, 1338, 1244, 1196, 1107, 837, 762, 633 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.27 (s, 18H), 0.80–1.02 (m, 8H), 1.05–1.32 (m, 10H); 1.37–1.53 (m, 2H), 1.56–1.69 (m, 2H), 1.70–1.84 (m, 2H), 3.94–4.03 (m, 2H), 4.23–4.32 (m, 2H), 6.84 (s, 2H); ^{13}C NMR (100 MHz) δ −0.5, 23.5, 26.7, 27.5, 27.8, 27.9, 29.2, 65.7, 116.8, 129.1, 156.0; HRMS (FAB$^+$) for M^+ found m/z 448.3201, calcd for $C_{26}H_{48}O_2Si_2$: 448.3193. $[\alpha]_D^{28}$ +13.0 (c 1.44, $CHCl_3$, 91% ee). Compound **5gb** was treated with NIS, and the ee was determined as the corresponding diiodinated product **5ga**.

4.8. Asymmetric lithiation of planar-chiral trimethylsilyl-1,*n*-dioxa[*n*]paracyclophanes (*n*≤11)

To a solution of trimethylsilyl-1,n-dioxa[n]paracyclophanes **2** (0.1 mmol) and TMEDA (15 μL, 0.1 mmol) in Et_2O (1.0 mL) was

added dropwise a cyclohexane/hexane solution of *sec*-butyllithium (1.0 M, 0.2 mL, 0.2 mmol) at −78 °C and stirred for 2 h at −20 °C.

*4.8.1. 12-Iodo-15-trimethylsilyl-1,10-dioxa[10]paracyclophane (**6ba**).* After lithiation of **2bb**, iodine (76.1 mg, 0.3 mmol) in Et_2O (0.6 mL) was added dropwise at −78 °C and stirred for 1 h at rt. The mixture was treated with $Na_2S_2O_3$ aqueous solution, and extracted with ethyl acetate. The organic layer was washed with water and brine. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by thin-layer chromatography to give **6ba**. Yellowish viscous oil; IR (neat) 2954, 2925, 2873, 2856, 1566, 1537, 1471, 1450, 1324, 1244, 1174, 839, 764, 690, 628 cm^{-1}; ^1H NMR (400 MHz) δ 0.11–0.37 (m, 1H), 0.27 (s, 9H), 0.53–0.72 (m, 1H), 0.72–1.13 (m, 6H), 1.18–1.36 (m, 1H), 1.49–1.70 (m, 2H), 1.83–2.04 (m, 1H), 4.00–4.25 (m, 2H), 4.28–4.45 (m, 2H), 7.03 (s, 1H), 7.27 (s, 1H); ^{13}C NMR (100 MHz) δ −0.7, 22.5, 25.0, 26.0, 26.1, 26.6, 29.1, 70.1, 74.3, 92.8, 126.8, 128.2, 133.1, 152,.3, 158.3; HRMS (FAB$^+$) for M^+ found *m*/*z* 418.0840, calcd for $C_{17}H_{27}IO_2Si$: 418.0825. $[\alpha]_D^{23}$ +42.5 (*c* 1.69, $CHCl_3$, 97% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 10% CH_2Cl_2 in hexane, flow rate: 0.5 mL/min, retention time: 10.9 min for minor isomer and 12.1 min for major isomer).

*4.8.2. 13-Iodo-16-trimethylsilyl-1,11-dioxa[11]paracyclophane (**6aa**).* After lithiation of **2ab**, iodine (76.1 mg, 0.3 mmol) in Et_2O (0.6 mL) was added dropwise at −78 °C and stirred for 1 h at rt. The mixture was treated with $Na_2S_2O_3$ aqueous solution, and extracted with ethyl acetate. The organic layer was washed with water and brine. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by thin-layer chromatography to give **6aa**. Pale yellow viscous oil; IR (neat) 2951, 2925, 2897, 2856, 1567, 1469, 1456, 1431, 1244, 1182, 829, 771, 690 cm^{-1}; ^1H NMR (500 MHz) δ 0.28 (s, 9H), 0.55–0.71 (m, 1H), 0.76–1.15 (m, 9H), 1.43–1.58 (m, 1H), 1.59–1.73 (m, 2H), 1.73–1.88 (m, 1H), 4.08–4.24 (m, 2H), 4.28–4.45 (m, 2H), 6.98 (s, 1H), 7.32 (s, 1H); ^{13}C NMR (125 MHz) δ −0.58, 24.8, 26.1, 26.2, 26.6, 27.8, 29.2, 29.6, 70.0, 72.7, 92.2, 126.3, 126.7, 131.7, 152.7, 159.7; HRMS (FAB$^+$) for M^+ found *m*/*z* 432.0979, calcd for $C_{18}H_{29}IO_2Si$: 432.0981. $[\alpha]_D^{14}$ +31.1 (*c* 1.51, $CHCl_3$, 97% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IB: 4×250 mm, 254 nm UV detector, rt, eluent: 10% CH_2Cl_2 in hexane, flow rate: 0.5 mL/min, retention time: 8.4 min for minor isomer and 9.7 min for major isomer).

*4.8.3. 13-Methyl-16-trimethylsilyl-1,11-dioxa[11]paracyclophane (**6ad**).* After lithiation of **2ab**, MeI (19 μL, 0.3 mmol) was added at −78 °C. Then the mixture was stirred for 12 h at rt. It was treated with saturated NH_4Cl aqueous solution and extracted with ethyl acetate. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by PTLC to give **6ad**. Colorless oil; IR (neat) 2952, 2925, 2900, 2856, 1600, 1479, 1352, 1244, 1178, 1033, 839, 750, 636 cm^{-1}; ^1H NMR (400 MHz) δ 0.21 (s, 9H), 0.49–0.66 (m, 1H), 0.67–1.06 (m, 9H), 1.35–1.64 (m, 4H), 2.20 (s, 3H), 4.00–4.17 (m 3H), 4.21–4.32 (m, 1H), 6.69 (s, 1H), 6.92 (s, 1H); ^{13}C NMR (100 MHz) δ −0.2, 16.7, 25.1, 25.9, 26.1, 26.6, 28.1, 29.9, 30.1, 69.8, 71.8, 119.0, 126.6, 128.2, 131.9, 151.8, 159.6; HRMS (FAB$^+$) for M^+ found *m*/*z* 320.2166, calcd for $C_{19}H_{32}O_2Si$: 320.2172. $[\alpha]_D^{23}$ −19.0 (*c* 1.39, $CHCl_3$, 97% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 10% CH_2Cl_2 in hexane, flow rate: 0.5 mL/min, retention time: 10.6 min for minor isomer and 11.3 min for major isomer).

*4.8.4. 13-(16-Trimethylsilyl-1,11-dioxa[11]paracyclophane)carbaldehyde (**6ae**).* After lithiation of **2ab**, DMF (23 μL, 0.3 mmol) was added at −78 °C. Then the mixture was stirred for 2 h at rt. It was treated with saturated NH_4Cl aqueous solution and extracted with ethyl acetate. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by PTLC to give **6ae**. Yellowish oil; IR (neat) 2951, 2927, 2900, 2856, 1685, 1597, 1471, 1458, 1398, 1354, 1244, 1178, 1132, 1057, 978, 841, 769, 640 cm^{-1}; ^1H NMR (500 MHz) δ 0.31 (s, 9H), 0.45–0.62 (m, 1H), 0.62–0.78 (m, 1H), 0.78–1.07 (m, 8H), 1.49–1.64 (m, 2H) 1.64–1.82 (m, 2H), 4.12–4.39 (m, 3H), 4.41–4.55 (m, 1H), 7.17 (s, 1H), 7.34 (s, 1H) 10.47 (s, 1H); ^{13}C NMR (125 MHz) δ −0.7, 24.2, 25.9, 26.3, 26.7, 27.5, 28.5, 29.8, 69.2, 73.9 112.3, 128.2, 129.4, 140.8, 156.7, 159.2, 190.0; HRMS (ESI) for M+Na found *m*/*z* 357.1853, calcd for $C_{19}H_{30}NaO_3Si$: 357.1862. $[\alpha]_D^{18}$ −48.9 (*c* 1.22, $CHCl_3$, 97% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 10% CH_2Cl_2 in hexane, flow rate: 1.0 mL/min, retention time: 9.2 min for minor isomer and 12.8 min for major isomer).

*4.8.5. 13-(1-Hydroxy-1,1-diphenylmethyl)-16-trimethylsilyl-1,11-dioxa[11]paracyclophane (**6af**).* After lithiation of **2ab**, benzophenone (54.7 mg, 0.3 mmol) in Et_2O (0.6 mL) was added at −78 °C. Then the mixture was stirred for 12 h at rt. It was treated with saturated NH_4Cl aqueous solution and extracted with ethyl acetate. The extract was dried over Na_2SO_4 and evaporated under reduced pressure. The resulting residue was purified by PTLC to give **6af**. Colorless oil; IR (neat) 3479, 3058, 2952, 2924, 2898, 2854, 1596, 1475, 1446, 1340, 1246, 1176, 1034, 862, 839, 756, 700, 677 cm^{-1}; ^1H NMR (500 MHz) δ 0.29 (s, 9H), 0.64–1.19 (m, 10H), 1.33–1.64 (m, 4H), 3.79–3.91 (m, 1H), 3.92–4.04 (m, 1H), 4.07–4.19 (m, 1H), 4.29–4.42 (m, 1H), 6.03 (s, 1H), 6.11 (s, 1H), 7.03 (s, 1H), 7.14–7.42 (m, 10H); ^{13}C NMR (125 MHz) δ −0.32, 25.4, 25.5, 27.0, 27.1, 27.7, 28.9, 29.2, 70.3, 71.4, 82.3, 119.5, 124.6, 127.2, 127.2, 127.7, 127.7, 127.8, 128.2, 129.9, 137.9, 145.7, 147.1, 150.5, 157.8; HRMS (ESI) for M+Na found *m*/*z* 511.2627, calcd for $C_{31}H_{40}O_3Si$: 511.2644. $[\alpha]_D^{13}$ +46.3 (*c* 2.03, $CHCl_3$, 97% ee). ee was determined by HPLC analysis using a chiral column (Daicel Chiralpak IA: 4×250 mm, 254 nm UV detector, rt, eluent: 10% CH_2Cl_2 in hexane, flow rate: 1.0 mL/min, retention time: 5 min for major isomer and 13 min for minor isomer).

Acknowledgements

K.K. is grateful to the Japan Society for the Promotion of Science for the fellowship support. This work was supported by Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan (No. 23655091). We also thank Asahi Glass Foundation and the Global COE program 'Center for Practice Chemical Wisdom' by MEXT. We also thank Ms. T. Koike (Waseda Univ.) for her experimental assistance in the preliminary work.

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17. Monosubstituted 1,10-dioxa[10]paracyclophanes **2ba** and **2bc**, which are solid, and **2bb**, which is oil, were not racemized at all at rt for as long as 8 months.
18. 2′-Iodo[16](1,4)naphthalenophane **4d**, which is amorphous, was gradually racemized at rt (from 92% ee to 72% ee for 10 days).
19. When **1c** was first lithiated by using sparteine, and the obtained **2c** was further lithiated by using TMEDA (inverse procedure against entry 1 in Table 5), the ee of **5cb** was almost zero. This result means that dynamic kinetic resolution occurred in the reaction of 1,12-dioxa[12]paracyclophane **2cb**.
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