

Asymmetric Synthesis of a Chiral Buckybowl, Trimethylsumanene

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Buckybowls, bowl-shaped π -conjugated aromatic compounds corresponding to partial structures of fullerenes or cap structures of carbon nanotubes, are of importance not only as model compounds for fullerenes but also for their own chemical and physical properties.¹ The science of buckybawls has recently grown drastically since practical synthetic routes have been developed.^{2,3} However, there are still numerous potential buckybowl targets needed to clarify their physical properties dependent on their unique architectures. Among such structural features, many buckybawls possess "bowl chirality"⁴ derived from their three-dimensional geometry, similar to chiral fullerenes and carbon nanotubes.⁵ Methods to control the bowl chirality can potentially be applied to a variety of applications such as asymmetric molecular recognition, homochiral crystal organic materials, and chiral ligands for organometallic catalysis. Although racemic syntheses of chiral buckybawls have been reported,⁶ no asymmetric synthesis has appeared since the synthetic strategies have not yet been established. In this paper, we report the first asymmetric synthesis of a C_3 symmetric chiral buckybowl, (*C*)-(M)-8,13,18-trimethylsumanene (**1**),⁴ by a rational synthetic approach.

Most of the approaches toward the construction of bowl-shaped aromatic structures involve carbon–carbon bond formations in which planar π -conjugated precursors are converted to the bowl shape.^{2d–g,3,6} Such reactions usually require harsh conditions, therefore achieving asymmetrization of the bowl chirality during the bowl formation would be quite difficult.⁶ In contrast, the synthesis of sumanene features a stepwise conversion strategy through a bowl-shaped intermediate with sp^3 carbons under milder reaction conditions.^{2a} This strategy should be more amenable to the introduction of an asymmetric element by addition of functional groups or substituents at the desired positions of sumanene. Based on the synthesis of sumanene, our strategy for chiral buckybowl **1** relies on conversion from an sp^3 chirality to the bowl chirality. The key reaction steps for the asymmetric synthesis of (*C*)-**1** are summarized in Scheme 1. The aromatization step was designed for the final stage of synthesis, where the sp^3 chirality of **2** could be converted to the bowl chirality of (*C*)-**1**.

The bowl-to-bowl inversion energy barrier must be taken into account at this step, because this inversion corresponds to a racemization process for a chiral buckybowl (Figure 1). The bowl-to-bowl inversion energy barrier of **1** is estimated to be ca. 21 kcal/mol.⁷ Since the energy barrier corresponds to ca. 2 h half-life time of racemization at 0 °C, the aromatization step must be carried out at a low temperature. The bowl-shaped structure of **2** could be constructed from a benzonorbornene derivative **3** utilizing a tandem ring-opening/closing olefin metathesis approach. The benzonor-

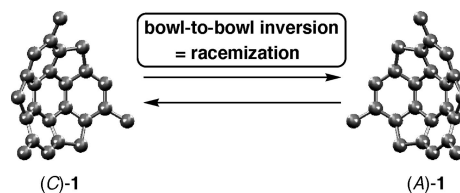
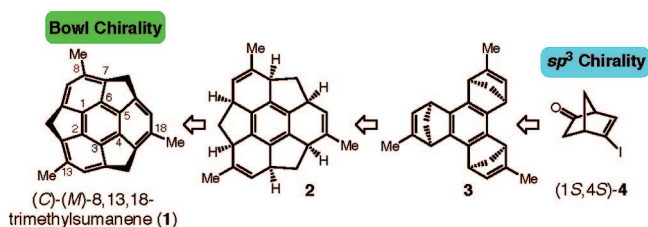


Figure 1. Racemization of **1** through a bowl-to-bowl inversion.

Scheme 1. Strategy for the Asymmetric Synthesis of (*C*)-(M)-**1**

bornene derivative **3** could be obtained by cyclotrimerization of a chiral halonorbornene derivative (1*S*,4*S*)-**4**. By adopting this approach, the bowl chirality of **1** is controlled by the sp^3 chirality of the starting norbornene derivative.

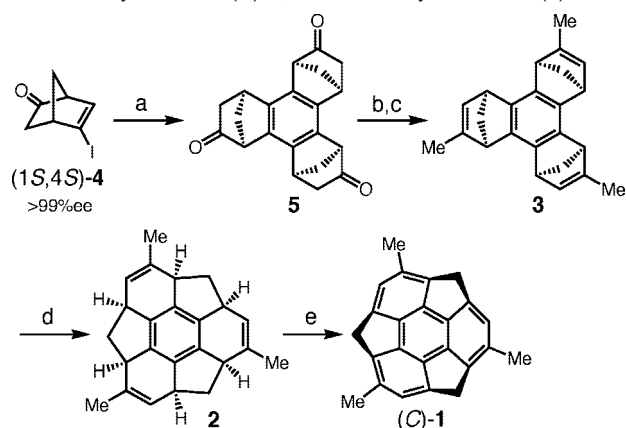
Selective formation of a *syn*-benzocyclotrimer through a regioselective cyclotrimerization of a halonorbornene derivative under palladium nanocluster conditions has been recently developed by our group.⁸ The conditions were applied to the cyclotrimerization of (1*S*,4*S*)-**4**⁹ to afford the desired *syn*-benzocyclotrimer **5** without contamination of the diastereomer *anti*-**5** (Scheme 2). The carbonyl groups of **5** were converted to methyl-substituted olefins through alkenyl phosphates by cross-coupling reactions with MeMgI,¹⁰ giving the desired benzonorbornene derivative **3**.

Treatment of **4** with Grubbs first generation catalyst resulted in a mixture of only ring-opening reaction products. Grubbs second generation catalyst was effective for the ring-closing reaction. Thus, the tandem ring-opening/closing olefin metathesis reactions were successfully achieved with successive treatment by these two catalysts. The final aromatization step was carried out with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone at 0 °C in a short time (1 min). The resulting reaction mixture was quickly purified by silica gel chromatography at low temperature (<–20 °C) to afford the desired chiral buckybowl (*C*)-**1**.

The chirality of thus-obtained (*C*)-**1** was confirmed by measurement of the circular dichroism (CD) spectra. The intensity of the CD spectra at –40 °C scarcely changed but gradually decreased at 10 °C (Figure 2). The bowl-to-bowl inversion energy barrier of **1** in CH₃CN was determined to be 21.6 kcal/mol by tracing the decay of the CD spectra at 247 and 282 nm at 10 °C (Supporting Information). This value is in good accordance with the estimated one.

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Scheme 2. Synthesis of (C)-8,13,18-Trimethylsumanene (1)^a

^a Reagents and conditions: (a) Pd(OAc)₂ 5 mol %, PPh₃ 10 mol %, Bu₄NOAc 1000 mol %, Na₂CO₃, MS 4 Å, 1,4-dioxane, 100 °C, 2 h, 55%; (b) NaN(SiMe₃)₂ 350 mol %, (2,6-diMePhO)₂P(O)Cl 350 mol %, P(O)(NMe₂)₃ 350 mol %, THF, −80 °C, 75%; (c) Pd(OAc)₂ 5 mol %, PCy₃·HBF₄ 10 mol %, MeMgI 400 mol %, THF, 40 °C, 2 h, 72%; (d) Grubbs 1st generation catalyst 50 mol %, CH₂Cl₂, under ethylene, 40 °C, 6 h, then Grubbs 2nd generation catalyst 50 mol %, CH₂Cl₂, 40 °C, 12 h, 24%; (e) 2,3-dichloro-5,6-dicyano-*p*-benzoquinone 600 mol %, CH₂Cl₂, 0 °C, 1 min, 68%.

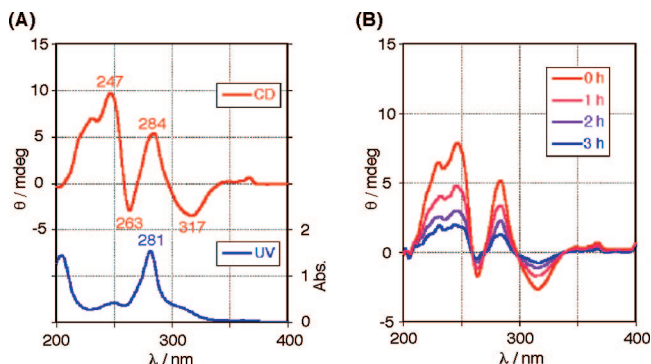
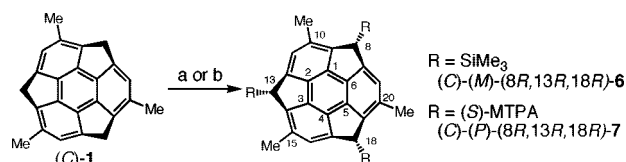


Figure 2. (A) CD spectra of (C)-1 in CH₃CN at −40 °C (red line) and UV spectra of (±)-1 in CH₃CN at room temp (blue line); (B) decay of CD spectra of (C)-1 in CH₃CN at 10 °C for 3 h.

Scheme 3. Determination of the Enantiomeric Excess of 1^a

^a Reagents and conditions: (a) (±)-1, LDA 1000 mol %, THF, 0 °C then Me₃SiCl 1000 mol %, (±)-6 45%; (b) (C)-1, LDA 600 mol %, THF, −40 °C, then (R)-Ph(CF₃)(MeO)CCOCl = (R)-MTPACl 1000 mol % 17%.

To determine the enantiomeric excess of synthetic **1**, we needed to derivatize **1** for avoiding racemization through a bowl-to-bowl inversion. Selective introduction^{2b} of trimethylsilyl groups at the exo positions of the dibenzyllic positions induces new chirality at the sp³ carbons which prevents the enantiomers from racemizing (Scheme 3).¹¹ However, we were unable to separate the enantiomers of **6** using chiral HPLC. Instead, (S)-Ph(CF₃)(OMe)CCO groups were introduced to enable the diastereomeric analysis. Finally the enantiomeric excess of **1** was determined as 90% ee on the basis of the ¹H NMR analysis of the diastereomeric ratio of **7**.

As described above, we have succeeded in the novel asymmetric synthesis and isolation of a C₃ symmetric chiral buckybowl **1** by employing a synthetic strategy with the conversion from sp³ chirality to bowl chirality. The present strategy will also provide a versatile path for derivatization of C₃ symmetric chiral buckybowls by introduction of a variety of substituents at desired positions.

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Supporting Information Available: Experimental procedures and spectral data for all new compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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- (7) DFT calculation (B3LYP/6-311+G**) predicts inversion energy barriers of 19.3 and 18.3 kcal/mol for **1** and sumanene, respectively. Since the observed value for sumanene was reported to be 19.7–20.4 kcal/mol, the real value for **1** was estimated to be ca. 21 kcal/mol. For the observed value of **1**, see the following reference: Amaya, T.; Sakane, H.; Muneishi, T.; Hirao, T. *Chem. Commun.* **2008**, *76*, 5–767.
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- (11) Even the bowl-to-bowl inversion of (C)-(8R,13R,18R)-**6** gives the diastereomer (A)-(8R,13R,18R)-**6**. Trimethylsilyl groups preferring the exo position freeze the bowl-to-bowl inversion as well (ref 2b).

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