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Synthesis, structure, and host ability of macrocycles based on the structural diversity of 1,3-diene

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Abstract—Macrocycles consisting of both a 1,3-diene unit and a polyether linkage were prepared by the reaction of muconic acid dichloride with diols containing a polyether linkage. The 1,3-diene moiety was complexed by iron carbonyl to furnish macrocycles bearing a (η^4 -diene)tricarbonyliron moiety. The structures of the macrocycles were determined by NMR and IR spectroscopy, and by X-ray structural analysis. The macrocycles formed complexes with some ammonium salts and their association constants varied according to whether the structure of the 1,3-diene moiety was complexed or uncomplexed. Ring-size effects of the macrocycles on the association constants were also studied. © 2001 Elsevier Science Ltd. All rights reserved.

Crown ethers and macrocyclic polyethers are typical representatives of host molecules.¹ A variety of synthetic receptors capable of varying their structures by external stimuli have been developed. These motifs include alkenes,^{1g} azobenzenes,^{1d,e} and bipyridines^{1f} causing *allosteric effects*.^{1h,i} 1,3-Dienes can be easily complexed by iron carbonyls to give $(\eta^4$ -diene)Fe(CO)₃ complexes, which are fairly stable toward water, air, and heating.² Decomplexation of $(\eta^4$ -diene)Fe(CO)₃ complexes can also be readily conducted by photo- and oxidation reactions leading to the original 1,3-dienes.³ These complexation and decomplexation are highly selective, and can be reversible in the presence of various substrates. Thus, the interconversion between 1.3diene and its Fe(CO)₃ complex can be another candidate of the driving force to realize allosteric effects.

While the C2–C3 single bond of the 1,3-diene rotates freely to make the conformation flexible, the 1,3-diene unit in the Fe(CO)₃ complex is fixed by the *s*-*cis* form so that the (η^4 -diene)Fe(CO)₃ complex has a rigid, planar structure (Scheme 1). Therefore, host molecules bearing a 1,3-diene moiety can be preorganized by the complexation with the Fe(CO)₃ group. Further, the transformation of the 1,3-diene to a $(\eta^4\text{-diene})\text{Fe}(\text{CO})_3$ complex results in an increase in the steric hindrance around the 1,3-diene and a decrease in the electron density of the diene unit. We now wish to report the preparation, structure, and host ability of macrocycles having both polyether linkages and 1,3-diene units, and the change of host ability by the conversion to the $(\eta^4\text{-diene})\text{Fe}(\text{CO})_3$ complex.

The synthesis of macrocycles **2**, bearing both 1,3-diene units and polyether linkages, is shown in Scheme 2. Cyclization of muconic acid dichloride and diols 1^4 having polyether linkages were carried out under high dilution conditions to afford **2** in moderate yields.⁵ The 1,3-diene units of **2** were complexed with diiron nonacarbonyl to give macrocycles **5** bearing a (η^4 -diene)tricarbonyliron moiety in good yields (Scheme 3).⁶ Complex **6a** was obtained from **5a** by ligand substitution with triphenylphosphine.⁷

The structures of the macrocycles 2, 5 and 6 were determined by the IR and NMR spectroscopy. The



Scheme 1.

Keywords: $(\eta_4$ -diene)Fe(CO)₃ complex; *s-cis, s-trans* configurations; molecular recognition. * Corresponding author. E-mail: takata@chem.osakafu-u.ac.jp

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Scheme 2.



Figure 1. X-Ray crystal structure of 5a. Hydrogen atoms are omitted for clarity.

complexed structure with a Fe(CO)₃ moiety was confirmed by X-ray crystal structure analysis of **5a**.⁸ The $(\eta^4$ -diene)Fe(CO)₃ moiety has an almost planar *s*-*cis* structure, judging from the dihedral angle between the C2–C3 and C4–C5 bonds (1.1°) (Fig. 1).

It was established from extraction experiments of picrate that macrocycles 2 and 5 were able to form complexes with some ammonium picrates derived from 4-methylaniline, benzylamine, 4-chloroaniline, and aniline. The complex-forming ability of the macrocycles with 4-methylanilinium picrate 7 was evaluated in terms of the structural diversity of a 1,3-diene. Job plots, which were obtained from the ¹H NMR spectra of a mixture of host and 7, indicated that 2a, 5a, and 5b furnish a 1:2 (host:guest) complex with 7, while the complexing ratios for 2a, 5a, and 5b could not be

Table	1.	Association	constants	of	4-meth	vlanilinium	picrate	7	and	macrocvc	les
						/					

Diene macrocycle (ring member)	Association constant $(K_a)^a$	Iron complex macrocycle (ring member)	Association constant $(K_a)^a$
2a (22)	$124 M^{-1}$	5a (22) 6a (22)	84 M^{-1} 8 M^{-1}
2b (28) 2c (34)	$\begin{array}{c} 2.10 \times 10^4 \ M^{-2} \\ 5.40 \times 10^5 \ M^{-2} \end{array}$	5b (28) 5c (34)	$\begin{array}{c} 3.12 \times 10^4 \ M^{-2} \\ 5.62 \times 10^5 \ M^{-2} \end{array}$

^a Determined by extraction of 4-methylanilinium picrate 7 from the aqueous layer to the CHCl₃ layer.



Scheme 3.

determined exactly because the changes in the NMR chemical shifts were too small. Complexation ratios were estimated as 1:2 for **5b** and 1:1 for **2a** and **5a**, referring to the ratios reported for macrocycles with 32 and 26 ring member hosts.⁹

Association constants (K_a) of the macrocycles with 4-methylanilinium picrate 7 were obtained by Cram's method in a CHCl₃-water bilayer system (Table 1).¹⁰ The K_{as} were compared with those having the same dimensions. For **2a** and **5a**, K_a decreased from 124 M⁻¹ (2a) to 84 M^{-1} (5a) by the transformation of the 1,3-diene unit to a $(\eta^4$ -diene)Fe(CO)₃ complex. The decrease is probably due to steric hindrance of the $Fe(CO)_3$ unit. The K_a decreased further to 8 M⁻¹ (6a) by the introduction of a Ph₃P group, which replaced the CO group as the ligand, due to the steric bulkiness of $(\eta^4$ -diene)Fe(CO)₂PPh₃. On the other hand, for **2b** and **5b**, the K_a increased from 2.10×10⁴ M⁻² (**2b**) to 3.12×10⁴ M^{-2} (5b) by the transformation of the 1,3-diene unit to a (η^4 -diene)Fe(CO)₃ complex. The rigid, planar s-cis η^4 -diene structure is more favorable for the complexation with 7 than the flexible 1,3-diene unit. As for macrocycles 2c and 5c, the K_a values were approximately the same, indicating the effects of steric hindrance and preorganization were counterbalanced.

In summary, we have demonstrated the synthesis, structure, and hosting ability of novel macrocycles containing 1,3-diene and $(\eta^4$ -diene)Fe(CO)₃ complex moieties. Structural variation of the 1,3-diene moiety, complexed or uncomplexed, could control the host ability, while the effect of the structural change of 1,3-diene depends on the ring size and the structure of the macrocycles. The K_{a} s decreased in a series of 22 ring member hosts (from 2a to 5a, negative allosteric effect), increased in 28 ring member (from 2b to 5b, positive allosteric effect), and was approximately the same in a series of 34 ring member hosts (from 2c to 5c), due to the transformation of a 1,3-diene to a $(\eta^4$ -diene)Fe(CO)₃ complex. These results suggest that the structural change of a 1,3-diene by ' $Fe(CO)_3$ ' is very effective for modifying the host ability of diene-containing macrocycles. Further application of this structural diversity of 1,3-diene is under investigation.

References

 (a) Smit, W. A.; Bochkov, A. F.; Caple, R. Organic Synthesis: The Science Behind the Art; Royal Society of Chemistry: Cambridge, 1998; p. 395; (b) Vögle, F. Supramolecular Chemistry; Wiley: New York, 1991; Chapter 7; (c) Shinkai, S.; Manabe, O. Top. Curr. Chem. 1984, 121, 76; (d) Shinkai, S.; Minami, T.; Kusano, Y.; Manabe, O. J. Am. Chem. Soc. 1983, 105, 1851; (e) Shinkai, S.; Ogawa, T.; Kusano, Y.; Manabe, O. Chem. Lett. 1980, 283; (f) Rebeck, Jr., J. Acc. Chem. Res. 1984, 17, 258; (g) Sasaki, H.; Ueno, A.; Osa, T. Chem. Lett. 1980, 283; (h) Gagnaire, G.; Gellon, G.; Pierre, J.-L. Tetrahedron Lett. 1988, 22, 933; (i) Shinkai, S.; Inuzuka, K.; Miyazaki, O.; Manabe, O. J. Am. Chem. Soc. 1985, 107, 3950.

- (a) Peason, A. J. Iron Compounds in Organic Synthesis; Academic Press: London, 1994; p. 67; (b) Liebeskind, L. S. Advances in Metal–Organic Chemistry; JAI Press: Greenwich, 1995; Vol. 4, p. 129.
- (a) Knölker, H.-J.; Baum, E.; Gonser, P.; Rohde, G.; Röttele, H. Organometallics 1998, 17, 3916; (b) Knölker, H.-J.; Goesmann, H.; Klauss, R. Angew. Chem., Int. Ed. 1999, 38, 702.
- Anelli, P. L.; Ashton, P. R.; Ballardini, R.; Balzani, V.; Delgado, M.; Gandolfi, M. T.; Goodnow, T. T.; Kaifer, A. E.; Philp, D.; Pietraszkiewicz, M.; Prodi, L.; Reddington, M. V.; Slawin, A. M. Z.; Spencer, N.; Stoddart, J. F.; Vicent, C.; Williams, D. J. J. Am. Chem. Soc. 1992, 114, 193.
- All new compounds were characterized by their spectral data. Selected data for 2a: white solid; mp 151–153°C; IR (neat) 2945, 2879, 1719 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 7.15 (d, *J*=11.7 Hz, 2H, COCH=CH-), 7.00–6.83 (m, 4H, Ar-H), 6.01 (d, *J*=11.7 Hz, 2H, COCH=CH-), 4.39–4.37 (m, 4H, CO-OCH₂), 4.18 (t,

J = 5.86 Hz, 4H, Ar-OCH₂), 3.80–3.78 (m, 8H, OCH₂CH₂O).

- 6. Selected data for 5a: yellow needles; mp (dec.) 203–205°C; IR (neat) 2946, 2873, 2077, 2017, 1714 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 6.88–6.80 (m, 4H, Ar-H), 5.81 (d, *J*=6.34 Hz, 2H, COCH=CH-), 4.49–3.67 (m, 16H, OCH₂CH₂O), 1.32 (d, *J*=6.34 Hz, 2H, COCH=CH-).
- 7. Howell, A. S. J.; Bell, A. G. Organometallics 1993, 12, 2541.
- 8. Crystallographic data for **5a**: $C_{23}H_{24}FeO_{11}$, $F_W=532.28$, monoclinic, C2/c, a=33.942(2), b=8.82(5), c=15.79(9)Å, $\beta=96.30(2)^\circ$, V=4700.2(4) Å³, Z=8, $D_{calcd}=1.50$ g cm⁻³. The intensity data were collected at 23°C on a Rigaku RAXIS II imaging plate area detector with graphite monochromated Mo K α radiation. The 5706 independent reflections were measured over a 2θ range of $6-55.0^\circ$. All non-hydrogen atoms were refined anisotropically. The hydrogen atoms were included but these were not refined. Full-matrix least-squares refinement using 5367 reflections converged to final agreement factors of R=0.050 and $R_w=0.052$ with GOF=2.62.
- Bryant, W. A.; Guzei, A. I.; Rheingold, A. L.; Merola, J. S.; Gibson, H. W. J. Org. Chem. 1998, 63, 7634.
- The association constant (K_a) was determined using Cram's method. See: (a) Kyba, E. P.; Helgeson, R. C.; Madan, K.; Gokel, G. W.; Tarnowski, T. L.; Moore, S. S.; Cram, D. J. J. Am. Chem. Soc. 1977, 99, 2564; (b) Koenig, K. E.; Lein, G. M.; Stuckler, P.; Kaneda, T.; Cram, D. J. J. Am. Chem. Soc. 1979, 101, 3553.