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PAPER

Conformationally restricted dynamic supramolecular catalysts for substrate-selective epoxidations†

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A second generation of a substrate-selective dynamic supramolecular catalytic system consisting of a catalyst part and a receptor part, connected by a hydrogen-bonding motif, has been realized based on rational design. The results from analyses of the equilibrium mixture of the species generated by the components of the first generation system led us to selectively lock the cisoid conformation of the catalyst part to increase the amount of the substrate-selective catalytic cavity in the equilibrium mixture. This was realized by strapping the catalyst part by organic synthesis. This strapping led to an increase in substrate selectivity in the pair-wise competitive epoxidations of pyridyl- *vs.* phenyl-appended styrenes and pyridyl- *vs.* phenyl-appended stilbenes of both *Z*- and *E*- configuration compared to the first generation system, reaching 3.4 : 1 as the highest substrate selectivity for *Z*-mono-pyridyl-stilbene (**27a**) *vs.* the corresponding all-carbon analogue (**28a**) and for *E*-dipyridyl-stilbene (**26b**) *vs.* the corresponding all-carbon analogue (**28b**), respectively.

Introduction

Substrate-selective catalysis is important in cases where there is more than one substrate that could react and the product of only one substrate is the desired one. However, the tremendous development of homogeneous catalysis in terms of high regio- and enantioselectivity[1] has not been seen in substrate-selective catalysis.

We want to address the somewhat neglected substrate-selective catalysis by designing a kinetically dynamic catalytic cavity. We argue that a substrate-selective process is more amenable for design when it involves homogeneous catalysis compared to heterogeneous, due to the presence of discrete molecular species in the former case. Known examples are still scarce for homogeneous catalysis and include cases where the catalyst part and receptor part have been covalently[2] as well as supramolecularly[3] connected, to form catalytic cavities. However, a supramolecular approach might not be optimal because as Sanders has pointed out, the lack of dynamics is a major short-coming in supramolecular catalysts,[4] leading to, among other things, non-optimal transition-states and product inhibition. Following the lines above, we recently presented an approach to substrate-selective catalysis by attaching a recognition site close to a catalytic site by employing a kinetically labile hydrogen-bonding motif.[3d,e] The hydrogen bonding introduces dynamics into the system due to its labile nature and facilitates the assembly of the substrate-selective catalytic cavity from the two components compared to using covalent synthesis. The principle of the formation of our substrate-selective catalytic cavity is shown in Fig. 1, case **a**. The catalyst part and the receptor part self-assemble to form a catalytic cavity, a cyclic heterodimer. Due to the presence of a receptor moiety in the vicinity of the catalyst part, a substrate containing a recognition element will react faster than a substrate without a recognition element, leading to substrate selectivity.

We have realized such a system synthetically.[3d,e] Our system is based on the Jacobsen–Katsuki catalyst[5] as the catalyst part (**1**) and a Zn(II) porphyrin as the receptor part (**2**) (Fig. 2). The catalyst part and the receptor part are connected by the kinetically labile 2-pyridone hydrogen-bonding motif. The system was originally designed to promote the formation of a substrate-selective cavity, compound **3** (Fig. 2) corresponding to a simple **1** + **2** ⇌ **3** model (schematically depicted in Fig. 1, case **a**). The original goal was to obtain selective epoxidation of *Z*-pyridyl-appended substrates over phenyl-appended ones (Table 1).

The epoxidation of olefins is attractive for the study of substrate selectivity, firstly because olefins are industrially obtained as a mixture of different homologues, regio-, and diastereomers; the ability to selectively epoxidize one olefin in a mixture would render the difficult separation process of rather similar olefins unnecessary to obtain one specific olefin as substrate for the epoxidation. After the substrate-selective epoxidation, the desired epoxide product could be more easily separated from the

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† Electronic supplementary information (ESI) available: Details about the competitive epoxidations: calibration curves, chromatograms and NMR spectra. NMR spectra of compounds **4b** and **6b**. See DOI: 10.1039/c2ob06859a

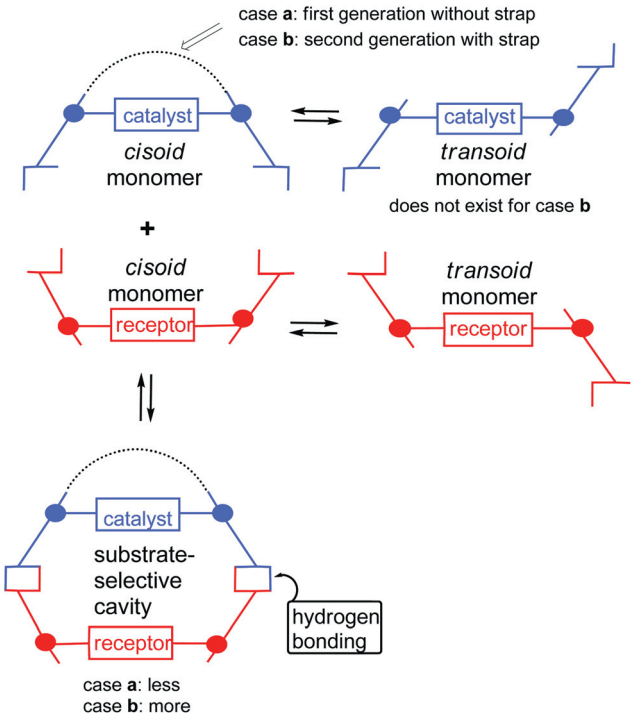


Fig. 1 The principles of our substrate-selective epoxidation catalysis. The substrate-selective catalytic cavity self-assembles from the equilibrium mixture of its monomers. *First generation* (**a**): the catalyst part does not contain a strap. *Second generation* (**b**): the catalyst part contains a strap forcing the catalyst part to be in a cisoid conformation, thus increasing the amount of the substrate-selective cyclic cavity and hampering non-selective catalysis on the outside of the cavity. The formation of oligomers of the catalyst part and the receptor part is omitted for clarity.

mixture of olefins due to the large difference in physical properties between the two compound classes. Secondly, epoxides are important bulk chemicals that can be converted to fine chemicals.[6] There are many epoxidation catalysts for olefins;[7] however, only a few have demonstrated substrate selectivity,[2a,f,3a,d,e] making our designed system potentially one of those few.

Indeed, substrate selectivity (1.5 : 1) was observed in the competitive epoxidations of a pyridyl-appended styrene (**4a**) over a phenyl-appended one (**5a**) using the first generation catalytic system **1** + **2** (Table 1, entries 1 and 2). The observed selectivities were the same both at 20%[3d,e] and at 40% conversion which is not surprising given that the rate law for the two reactions is expected to be the same and that the reactions are irreversible.‡ This system was recognized as one of the design principles of supramolecular catalysts, despite its relatively low substrate selectivities.[8]

The initial assumption that the catalyst part and the receptor part would self-assemble exclusively to the desired catalytic cavity (Fig. 1) corresponding to compound **3** (Fig. 2), implying a simple equilibrium model, was proven wrong by a complete analysis of all possible equilibria involved.[3e,9] The system turned out to be far more complicated due to the many degrees of conformational freedom of its molecular components, generating the substrate-selective catalytic cavity **3** along with free monomers, homo- and hetero-oligomers of catalyst **1** and receptor **2**, and a

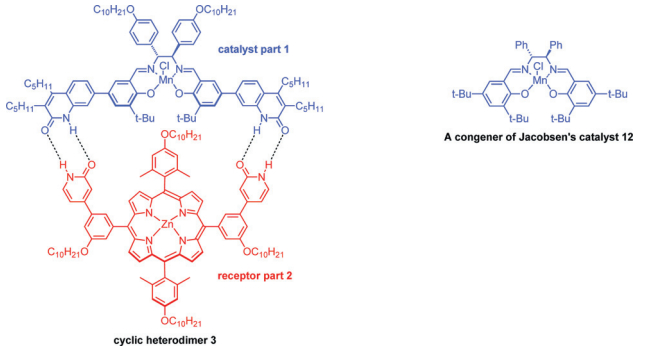


Fig. 2 The first generation of the supramolecular catalytic system (model: **1** + **2** ⇌ **3**). A congener of Jacobsen's catalyst,[5a] compound **12**.

cyclic trimer of **2**. Importantly, it was demonstrated that not only **3** contributed to the observed substrate selectivity but also linear hetero-oligomers having **1** and **2** as adjacent neighbours.

Results and discussion

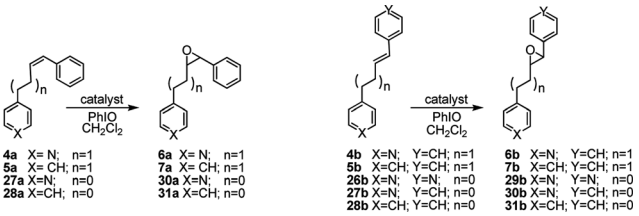
Based on the complete analysis of the equilibria above,[3e,9] we designed a second generation of our system: we reasoned that it is easier to improve the substrate selectivity by increasing the amount of the cyclic heterodimer (the cavity) **3** than to increase the ratio of **1** and **2** as adjacent neighbours in the linear hetero-oligomers. The amount of the substrate-selective catalytic cavity can be increased by strapping the catalyst part in a cisoid conformation (Fig. 1, case **b**).§ The strapping should also diminish unselective catalysis that could take place on the *exo*-side of the catalyst part. The corresponding molecular compound corresponding to the strapped cartoon catalyst in Fig. 1, case **b**, is the strapped catalyst part **8** shown in Fig. 3. We reasoned that a more complete blockage of the *exo*-position of the catalytic subunit could be realized by positioning a pyridine *N*-oxide moiety centrally in the strap, resulting in catalytic part **9** (Fig. 3).¶ Hence, the components of the second generation catalytic system are catalyst parts **8** and **9**, and receptor part **2**, ideally self-assembling to catalytic cavities **10** and **11**, respectively (Fig. 3).

We now want to investigate substrate-selective epoxidations using the second generation catalytic systems **8** + **2** and **9** + **2**, respectively, and comparing them to the first generation system, **1** + **2**, and a congener of Jacobsen's catalyst with the same 1,2-diamino component as **8** and **9**, compound **12** (Fig. 2).

Synthesis

Catalyst part. The synthesis of the strapped catalyst part **8** is outlined in Scheme 1. In the first step commercially available 5-chloro-2-nitroaniline was converted to 5-methoxy-2-nitroaniline (**13**) by nucleophilic aromatic substitution.[10] Subsequent bromination using NBS led to 4-bromo-5-methoxy-2-nitroaniline (**14**) that was further transformed into 5-bromo-2-iodo-4-methoxyaniline (**15**) in a two-step-one-pot procedure involving a Sandmeyer reaction to install one iodine atom and a subsequent Fe–HCl reduction to finalize the aniline. Aniline **15** was Boc-protected, resulting in compound **16**, which was in turn converted to 2-quinolone **17** in a palladium-catalysed carbonylation–annelation

Table 1 The selectivity in the epoxidation of the styrene and stilbene analogues catalysed by the different supramolecular systems[a]



		Selectivity (GC+NMR)[b]				
Entry	Cat. system (mM)	**4a** : **5a**	**4b** : **5b**	**27a** : **28a**	**26b** : **28b**	**27b** : **28b**
1	**1** (5) + **2** (5)	1.5	1.5	0.7	1.7	1.2
2	**1** (5) + **2** (15)	1.7	1.6	0.6	2.4	1.4
3	**1** (0.5) + **2** (0.5)	1.3	1.3	n.d.	n.d.	n.d.
4	**8** (5) + **2** (5)	1.7	1.9	1.9	1.9	1.3
5	**8** (5) + **2** (15)	1.8	2.6	3.3	3.3	1.5
6	**9** (5) + **2** (5)	1.8	2.0	2.1	2.2	1.2
7	**9** (5) + **2** (15)	1.9	2.9	3.4	3.4	1.5
8	**9** (0.5) + **2** (0.5)	1.4	1.8	n.d.	n.d.	n.d.
9	**9** (5) + ZnTPP (5)	1.0	1.0	n.d.	n.d.	n.d.
10[c]	**9** (5) + **2** (5)	1.0	1.1	n.d.	n.d.	n.d.
11[d]	**9** (5) + **2** (5)	1.3	1.7	n.d.	n.d.	n.d.
12	**12** (5)	1.1	1.2	1.1	1.3	1.1
13	**12** (15)	1.2	1.3	1.3	1.5	1.2

[a] General procedure: catalyst part **1**, or **8**, or **9** (3 μmol each), receptor part **2** (3 or 9 μmol each), substrate pairs (30 μmol each), PhIO (24 μmol), internal standard benzyl benzoate (15 μmol), DCM (0.6 or 6 mL), and rt. Consistently 70% of the product was epoxide (GC). [b] The disappearance of starting material as determined in ref. 3*d*. [c] Receptor without Zn. [d] 4-Ethylpyridine (90 μmol) added. n.d. = not determined.

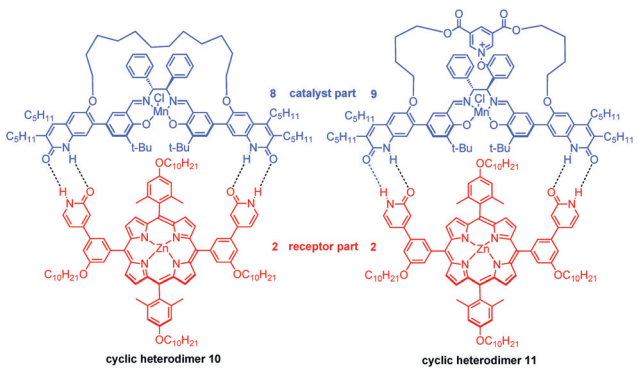
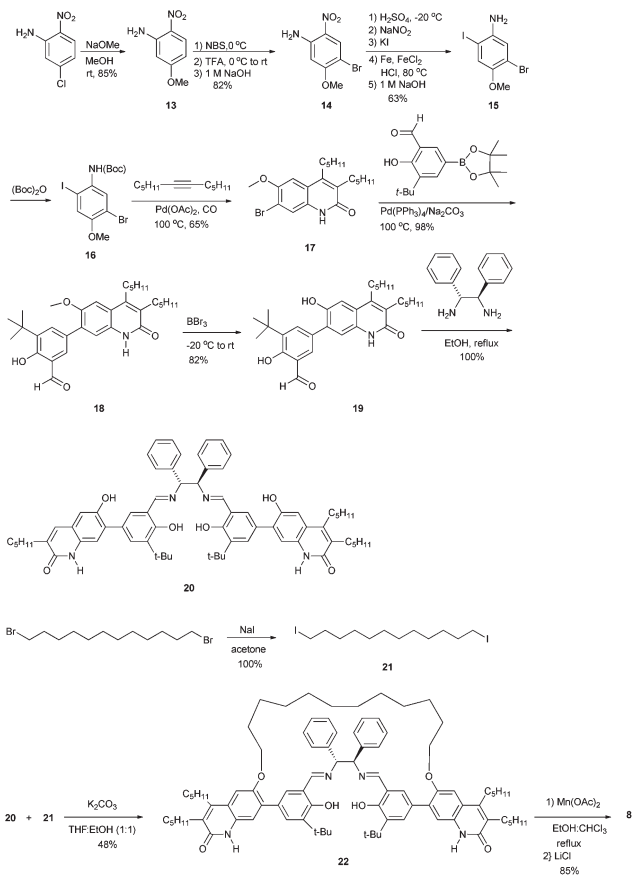
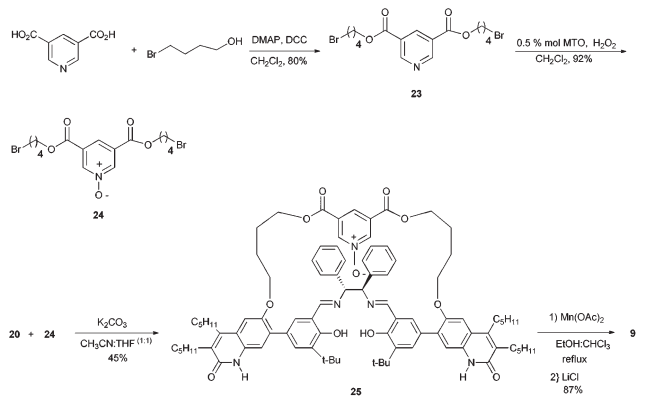


Fig. 3 The second generation of the supramolecular catalytic system (model: **8** + **2** ⇌ **10** and **9** + **2** ⇌ **11**) systems.

reaction with 6-dodecyne related to Larock's methodology.[11] The salicylic moiety, 3-*tert*-butyl-2-hydroxy-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl) benzaldehyde[12] was attached to **17** by Miyaura–Suzuki coupling,[13] yielding salicylaldehyde **18**. Deprotection of aldehyde **18** by BBr_3 resulted in salicylaldehyde **19**. The Schiff base condensation of compound **19** with (1*R*,2*R*)-1,2-diamino-1,2-diphenylethane gave salen **20**. The synthesis of the all-carbon strap started from 1,12-dibromododecane which was converted into the corresponding diiodo compound **21** using the Finkelstein reaction.[14] The so-formed strap **21** was reacted with salen **20** in a Williamson ether synthesis, resulting in the strapped salen **22**. The insertion of a manganese ion into **22** took place under standard conditions[5a] except that a more lipophilic



Scheme 1 Synthesis of strapped catalyst part **8**.



Scheme 2 Synthesis of strapped catalyst part **9**.

solvent mixture was used, resulting in the strapped catalyst part **8** in good yield.

The synthesis of the strapped catalyst part **9** is outlined in Scheme 2. The pyridine-containing strap was synthesized from commercially available pyridine-3,5-dicarboxylic acid which was condensed with 4-bromo-1-butanol using DCC and DMAP, resulting in ester **23**. Ester **23** was converted to the corresponding *N*-oxide, compound **24**, using H_2O_2 and MTO catalysis. The so-formed strap, compound **24**, was reacted further in the same way as strap **21**. Thus, strapped salen **25** was formed in a Williamson ether synthesis between salen **20** and strap **24**. Finally a manganese ion was inserted in salen **25**, resulting in the strapped catalyst part **9**.

Receptor part. The synthesis of the receptor part was conducted as previously reported.[3e]

Substrates. Substrates **28a**, **26b**, **27b** and **28b** are available from commercial sources. The syntheses of the substrates **5b**,[15] **27a**,[16] **4a**[3e] and **5a**[3e] are described in the literature. Substrate **4b** was synthesized following a general procedure.[17]

Epoxide products. Synthesis and characterization of the epoxide products for reference purposes are according to the literature for **6a**,[3e] **7a**,[3e] **7b**,[18] **30a**,[19] **31a**,[20] **29b**,[21] **30b**[19] and **31b**.[20] Epoxide product **6b** was synthesized directly from olefin **4b** using *m*-CPBA and was isolated from the side-product, the *N*-oxide of **4b**, using flash chromatography.

Catalysis

Styrene series. We started the investigation of substrate selectivity of the second generation catalysts **8** + **2** and **9** + **2**, respectively, by studying the competitive epoxidation between the same two *Z*-styrenes that gave the best result with the first generation system **1** + **2** (Fig. 2), substrate pair **4a** : **5a** (1 : 1) (Table 1). In the search for substrate pairs that would give high substrate selectivity, the corresponding *E*-substrates **4b**[17] and **5b**[15] were also investigated. The investigation was conducted as pair-wise competitive epoxidations and the substrate selectivity was determined at 40% conversion.‡ The results showed that the selectivity of the pyridyl- over the phenyl-appended styrenes increased for both *Z*- and *E*-styrenes, **4a** *vs.* **5a** and **4b** *vs.* **5b**, respectively, according to the series **1** + **2** < **8** + **2** < **9** + **2** (entries 1, 4 and 6). This means that the substrate selectivity is increased by the strapping of the catalyst and even more so by also including the pyridine *N*-oxide moiety in the strap. This result supports our assumption that the concentration of substrate-selective cyclic heterodimer in the equilibrium mixture is increasing as [**3**] < [**10**] < [**11**]. This conclusion is further supported by the fact that the increase in substrate selectivity is in general highest for the strapped catalytic systems, compared to the unstrapped, when the ratio between receptor to catalyst is increased (compare entries 1 and 2, entries 4 and 5, and entries 6 and 7).‖ All this can be explained by the fact that the systems having one component strapped in a cisoid conformation will form the substrate selective cyclic heterodimer, the catalytic cavity, to a higher extent than systems with a non-strapped component (Fig. 1). In addition, the strapped systems block unselective reactions on the *exo*-face of the catalyst, an effect most probably also contributing to increase the substrate selectivity. The highest substrate selectivity in the styrene series, 2.9 for *E*-substrates **4b** *vs.* **5b** and 1.9 for *Z*-substrates, **4a** *vs.* **5a**, is observed for this particular series of substrates when receptor **2** is in excess in relation to the catalyst part **9** (Table 1, entry 7), promoting the formation of the substrate-selective cyclic heterodimer, according to the simple equilibrium model.‖

As expected, when the systems are diluted, the substrate selectivity drops, most probably due to the formation of less of the supramolecular catalytic cavity (Table 1, entries 3 and 1, and 8 and 6) according to the same equilibrium model. Furthermore, the strapped catalyst part **9**, having no Zn inserted in the receptor part or a ZnTPP as receptor, showed no substrate selectivity (entries 9 and 10). This shows that the catalyst and receptor part must be connected to each other in system **9** + **2** and that a Zn ion must be inserted in the receptor part to obtain substrate selectivity in the epoxidations. The addition of an excess of 4-ethylpyridine to system **9** + **2**, intended to block the receptor part, resulted only in a minor decrease in substrate selectivities (entries 11 and 6), mirroring the performance of system **1** + **2**.[3d]

Stilbene series. We also wanted to evaluate the substrate scope by including substrates more available than the styrene series. Our attention was drawn to stilbenes and their pyridine analogues (Table 1, n = 0 in table figure) as their reactivities are similar to the ones of styrenes and they are easily available from commercial sources (stilbenes **26b**,** **27b**, **28a** and **28b**), or by simple synthesis (stilbene **27a**).[16] The highest substrate selectivities are also obtained for these types of substrates using strapped catalyst parts **8** or **9** together with receptor **2** (Table 1, entries 5 and 7), supporting the design of the system of the second generation system. Furthermore, the mono-pyridyl-stilbene *Z*-substrate **27a** gave higher substrate selectivity than the corresponding styrene *E*- and *Z*-substrates **4b** and **4a** (entry 7). In fact mono-pyridyl-stilbene *Z*-substrate **27a** together with the di-pyridyl *E*-stilbene **26b** gave the highest substrate selectivity of all the substrates in our investigation, 3.4 (entry 7). The result for the latter compound is not surprising since it has two times higher chance to bind to the receptor, due to its two recognition elements.

Promoting the formation of catalytic cavities **3**, **10**, and **11** by increasing the amount of receptor,‖ increased the substrate

selectivity for both the first and second generation catalytic systems (Table 1, entries 2 *vs.* 1, 5 *vs.* 4 and 7 *vs.* 6) as demonstrated for both the styrene and stilbene series of substrates. Interestingly, the substrate selectivity **27a** : **28a** is reversed for the unstrapped system **1** + **2** (entry 1), indicating that little coordination of **27a** takes place in the catalytic cavity since there is less of such a cavity in system **1** + **2** compared to strapped systems **8** + **2** and **9** + **2**. Instead, in the former case, we speculate that the pyridine substrate **27a** just coordinates to a receptor part in an oligomer, because it is lacking the CH_2CH_2 tether that **4a** has, which leads to the alkene moiety not reaching an adjacent catalyst part and consequently **27a** does not react in this state.

Finally, the influence of the pyridine-*N*-oxide strap compared to the all carbon-strap is small for the styrene and the stilbene series of substrates indicating that the *N*-oxide coordinates weakly to the Mn ion.

Conclusions

We have designed and synthesized supramolecular catalytic systems based on the connection of a Mn-salen catalyst to a Zn-porphyrin receptor by hydrogen bonding, forming a kinetically labile catalytic system. These systems are able to selectively epoxidize pyridyl-appended styrenes and pyridyl-appended stilbenes over phenyl ones, and as such constitute examples of the systems designed for homogeneous substrate-selective catalysis. Analysis of the equilibria between the different species in this first generation system resulted in a new design for the second generation system. The design of the second generation system involved the reduction of the conformational freedom of the catalyst part by strapping it in a cisoid conformation, leading to a larger part of the supramolecular system existing as the substrate-selective catalytic cavity. The strapping also most probably hampers the non-selective epoxidation on the outside of the cavity. The new design led to a doubling of substrate selectivity in the second generation system, however it is still low (3.4 : 1).

We will continue to explore the system by investigating the equilibria involved in the second generation system in the same way as was done for the first generation, to reach conclusions about the design of a third generation supramolecular system. One obvious action to take is the strapping of the receptor part.

Finally, our design methodology has a bearing on other supramolecular catalytic systems: analysis of the equilibria involved leading to a new design involving specific reductions in conformational freedom that in turn generates higher selectivity.

Experimental

General methods

All commercial chemicals were used as received. PhIO was synthesized by hydrolysis of $PhI(OAc)_2$ following a literature procedure.[22] NMR spectra were recorded on a Bruker DRX400 NMR spectrometer in $CDCl_3$, at ambient temperature, ^1H NMR at 400 MHz, ^{13}C NMR at 100 MHz. Chemical shifts are reported in ppm relative to an internal standard of residual chloroform peak (δ = 7.27 ppm for ^1H NMR and 77.00 ppm for ^{13}C NMR). IR spectra were recorded on a Bruker Alpha FT-IR spectrometer. $CDCl_3$ was stored over MS 4 Å. Melting points were recorded on a Sanyo Gallenkamp Melting Point Apparatus and are uncorrected. Elemental analyses were performed by A. Kolbe, Mikroanalytisches Laboratorium, Germany. GC was performed on a Perkin-Elmer Autosystem XL Gas Chromatogragh. Optical rotations were measured on a Perkin-Elmer Model-343 digital polarimeter operating at the sodium D line using a 100 mm path cell. Dry CH_2Cl_2 was obtained from a MB SPS-800 dry solvent dispenser system. Methanol was dried by distillation from sodium. THF was dried by distillation from benzophenone ketyl. CH_3CN was dried by distillation from CaH_2 prior to use. Pyrrole was distilled at reduced pressure (15 mmHg) prior to use. Catalytic reaction mixtures were filtered through an Acrodisc® CR 13 mm syringe filter with a 0.2 μm PTFE membrane. Matrex silica (particle size: 35–70 μm, pore size: 60 Å) was used for chromatography. Boiling point fraction 40–60 °C of petroleum ether (PE) was used for chromatography. 5-Chloro-2-nitroaniline, 6-dodecyne, 1,12-dibromododecane, pyridine-3,5-dicarboxylic acid, and (1*R*,2*R*)-1,2-diamino-1,2-diphenylethane were purchased from commercial sources.

Catalyst part

*5-Methoxy-2-nitroaniline (**13**)*[10]. NaOMe (24.4 g, 0.452 mol) was dissolved in dry MeOH (380 mL) and 5-chloro-2-nitroaniline (39.0 g, 0.226 mol) was added. The reaction mixture was stirred under nitrogen for 28 h. When all the starting material was consumed, the solvent was evaporated to half amount, 200 mL water was added and the pH of the solution was adjusted to 8–9 by adding 2 M HCl. The solution was evaporated to dryness *in vacuo*. Crystallization of the residue from methanol gave 32.3 g (85% yield) of product **13**.

*4-Bromo-5-methoxy-2-nitroaniline (**14**).* Compound **13** (28.8 g, 0.171 mol) and NBS (30.0 g, 0.171 mol) were dissolved in CH_3CN (840 mL) and cooled to 0 °C using an ice-bath. Then TFA (12.7 mL, 0.171 mol) was poured drop-wise into the solution. The ice-bath was removed and the reaction was stirred for 24 h at rt. Water (400 mL) was added and the pH was adjusted to 8 by adding 1 M NaOH. The so-formed precipitate was recrystallized from methanol to give 38.6 g (82% yield) of **14** as a yellow solid: mp 166.7–167.5 °C; Anal. calc. for $C_7H_7BrN_2O_3$: C, 34.03; H, 2.86; Br, 32.34; N, 11.34. Found: C, 33.70; H, 3.07; N, 11.06; IR (neat) ν 3460, 3336, 2351, 1630, 1478, 1259, 1221 cm^{-1}; δ_H (400 MHz, $CDCl_3$) 8.36 (1H, s, ArH), 6.26 (2H, br s, NH), 6.18 (1H, s, ArH), 3.93 (3H, s, OMe); δ_C (100 MHz, $CDCl_3$) 161.30, 146,13, 130.74, 126.71, 100.04, 98.66, 56.69; MS (FAB^+): *m/z* $C_7H_7BrN_2O_3$ 247 $[M + 1]^+$.

*5-Bromo-2-iodo-4-methoxyaniline (**15**).* To a solution of **14** (26.0 g, 0.105 mol) in CH_3CN (860 mL), H_2SO_4 (conc., 14.2 mL) was added drop-wise at −20 °C. Then a solution of $NaNO_2$ (14.5 g, 0.210 mol) in 85 ml H_2O was added slowly. The mixture was stirred for 30 min. Finally a solution of KI (70.0 g, 0.422 mol) in 85 ml H_2O was added slowly at −20 °C. The aqueous phase was extracted with CH_2Cl_2 (3 × 200 mL). The combined organic phases were dried ($MgSO_4$) and evaporated *in vacuo*. The residue was crystallized from PE to afford 34.3 g (91% yield) of 1-bromo-4-iodo-2-methoxy-5-nitrobenzene after drying *in vacuo* at 50 °C. This compound (34.0 g) was dissolved in EtOH (dry, 550 mL). Then Fe powder (53.2 g, 0.953 mol), $FeCl_2{\cdot}4H_2O$ (18.9 g, 0.095 mol) and HCl (1 M,

112 mL) were added. The reaction mixture was heated at 80 °C for 2–3 h under nitrogen atmosphere with a mechanical stirrer. After reaching rt, the mixture was filtered and the pH of the solution was adjusted to 8 by the addition of 1 M NaOH. The resulting aqueous phase was extracted with CH_2Cl_2 (3 × 150 ml). The combined organic phases were dried ($MgSO_4$) and evaporated *in vacuo* to give 19.6 g (63% yield from **14**) of a white solid, compound **15**: mp 93.7–94.0 °C; Anal. calc. for C_7H_7BrINO: C, 25.64; H, 2.15; N, 4.27. Found: C, 25.39; H, 2.44; N, 4.09; δ_H (400 MHz, $CDCl_3$) 7.16 (1H, s, ArH), 6.99 (1H, s, ArH), 3.84 (2H, br s, NH), 3.82 (3H, s, OMe); δ_C (100 MHz, $CDCl_3$) 148.12, 140.85, 121.49, 117.83, 111.84, 80.95, 56.09. ESI-MS *m*/*z* (%) 329.9 (100), 327.9 (100) $[M + 1]^+$.

N-*Boc-5-bromo-2-iodo-4-methoxyaniline (**16**).* Di-*tert*-butyl dicarbonate (16.6 g, 0.0761 mol) and compound **15** (12.5 g, 0.0381 mol) were dissolved in ether (dry, 75 mL). The reaction mixture was stirred for 7 days at 40 °C. The ether was removed *in vacuo*, water (200 ml) was added and the resulting phase was extracted with CH_2Cl_2 (3 × 100 mL). The combined organic phases were dried ($MgSO_4$) and evaporated *in vacuo*. The crude product was purified by chromatography (PE : CH_2Cl_2 5 : 1) to afford 15.0 g (92% yield) of **16** as a pale solid: mp 124.0–124.4°C; Anal. calc. for $C_{12}H_{15}BrINO_3$: C, 33.67; H, 3.53; Br, 18.67; I, 29.65; N, 3.27. Found: C, 33.73; H, 3.48; N, 3.22; δ_H (400 MHz, $CDCl_3$) 8.22 (1H, br s, CONH), 7.23 (1H, s, ArH), 6.56 (1H, bs, ArH), 3.86 (3H, s, OMe), 1.54 (9H, s, 3Me); δ_C (100 MHz, $CDCl_3$) 152.59, 152.27, 133.25, 125.05, 121.36, 87.42, 81.19, 56.68, 28.26; IR (neat) ν 3391, 3113, 1719, 1565, 1510, 1352, 1153, 1020 cm^{-1}; HRMS(FAB^+) *m*/*z* calcd 427.9330, found 427.9332 $[M + 1]^+$.

*7-Bromo-6-methoxy-3,4-dipentylquinolin-2(1H)-one (**17**).* Compound **16** (500 mg, 1.17 mmol), Bn_4NCl (325 mg, 1.17 mmol) and $Pd(OAc)_2$ (27 mg, 10 mol%) were charged in a dry flask under nitrogen and 6-dodecyne (583 mg, 3.50 mmol), pyridine (185 mg, 2.33 mmol) and dry DMF (Aldrich, 25 mL) were added. The atmosphere was changed to CO (balloon). After 4 h at 100 °C all of **22** was consumed. After cooling to rt, the reaction mixture was diluted with EtOAc and the solvents were removed *in vacuo*. 1 M ethanolic sodium hydroxide (50 mL) was added and the mixture was left for 1 h at rt under stirring. Then NH_4Cl (aq, sat) was added and the solution was extracted with EtOAc and water 3 times each. The combined organic phases were evaporated. The crude product was purified by chromatography (PE : EtOAc 4 : 1) to afford 299 mg (65% yield) of **17** as a pale white solid: mp 141.0–143.0 °C; Anal. calc. for $C_{20}H_{28}BrNO_2$: C, 60.91; H, 7.16; N, 3.55. Found: C, 61.04; H, 6.57; N, 3.20; δ_H (400 MHz, $CDCl_3$) 11.44 (1H, br s, CONH), 7.55 (1H, s, ArH), 7.08 (1H, s, ArH), 3.94 (3H, s, OMe), 2.85 (2H, t, J = 8.0 Hz, CH_2), 2.73 (2H, t, J = 8.0 Hz, CH_2), 1.66–1.36 (12H, m, CH_2), 0.97 (6H, m, CH_3); δ_C (100 MHz, $CDCl_3$) 163.18, 151.24, 146.52, 132.26, 132.12, 120.50, 120.00, 114.41, 106.05, 56.64, 32.26, 32.16, 29.29, 29.02, 28.97, 27.15, 22.56, 22.42, 14.08, 14.01; IR (neat) ν 2951, 2922, 2859, 1651, 1453, 1397, 1355, 1221, 1054 cm^{-1}; HRMS(FAB^+) *m*/*z* calcd 394.1329, found 394.1382 $[M + 1]^+$.

3-tert-*Butyl-2-hydroxy-5(6-methoxy-2-oxo-3,4-dipentyl-1,2-dihydroquinolin-7-yl)benzaldehyde (**18**).* Compound **17** (5.70 g, 14.4 mmol), 3-*tert*-butyl-2-hydroxy-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl) benzaldehyde[12] (5.51 g, 18.1 mmol) and Na_2CO_3 (3.06 g, 28.9 mmol) were charged into a round-bottom flask equipped with a stirring bar. Then $Pd(PPh_3)_4$ (1.69 g, 1.45 mmol) was added under nitrogen. A mixture of degassed dioxane (360 mL) and water (50 mL) was added to the solution and the mixture was heated to 100 °C. The reaction was followed by TLC and the starting material was consumed after 4–5 h at which time the reaction was cooled to rt. The reaction mixture was extracted with CH_2Cl_2 (3 × 100 mL). The combined organic phases were dried ($MgSO_4$) and purified by chromatography (PE : EtOAc 2.5 : 1) to afford 7.00 g (98% yield) of **18** as a white solid: mp 165.5–166.0 °C; Anal. calc. for $C_{31}H_{41}NO_4$: C, 75.73; H, 8.41; N, 2.85. Found: C, 75.68; H, 8.31; N, 2.83; δ_H (400 MHz, $CDCl_3$) 11.89 (1H, s, CHO), 11.32 (1H, br s, CONH), 9.96 (1H, s, ArH), 7.79 (1H, d, J = 2.1 Hz, ArH), 7.68 (1H, d, J = 2.1 Hz, ArH), 7.28 (1H, s, ArH), 7.20 (1H, s, ArH), 3.89 (3H, s, OMe), 2.92 (2H, t, J = 7.8 Hz, CH_2), 2.76 (2H, t, J = 7.8 Hz, CH_2),1.76–1.31 (21H, m, CH_2), 0.97 (3H, d, J = 7.2 Hz, Me), 0.87 (3H, d, J = 7.2 Hz, Me); δ_C (100 MHz, $CDCl_3$) 197.22, 163.37, 160.78, 152.13, 146.82, 138.03, 135.65, 132.78, 132.15, 131.97, 131.65, 128.29, 120.45, 120.00, 117.59, 105.55, 35.00, 32.33, 32.20, 29.39, 29.30, 29.14, 29.03, 27.11, 22.54, 22.46, 18.44, 14.01, 13.97; IR (neat) ν 2958, 2921, 2871, 1643, 1359, 1216, 776, 622 cm^{-1}; HRMS(FAB^+) *m*/*z* calcd 492.3106, found 492.3114 $[M + 1]^+$.

3-tert-*Butyl-2-hydroxy-5(6-hydroxy-2-oxo-3,4-dipentyl-1,2-dihydroquinolin-7-yl)benzaldehyde (**19**).* To a solution of compound **18** (3.50 g, 7.12 mmol) in dry CH_2Cl_2 (150 mL) at −20 °C, was added BBr_3 (21.35 mL, 1 M in CH_2Cl_2). The mixture was left stirring at rt and the reaction was followed by TLC. When all the starting material was consumed, the reaction was quenched with water (100 mL) and the solution was extracted with CH_2Cl_2 three times. The organic phases were collected and the solvent was evaporated *in vacuo* resulting in brownish crystals. The product was crystallized twice from EtOH to afford 2.79 g (82% yield) of **19** as bright yellow crystals: mp 219.8–220.3 °C; Anal. calc. for $C_{30}H_{39}NO_4$: C, 75.44; H, 8.23; N, 2.93. Found: C, 75.07; H, 7.91; N, 2.69; δ_H (400 MHz, $CDCl_3$) 11.93 (1H, br s, ArOH), 11.63 (1H, br s, CONH), 9.90 (1H, s, CHO), 7.72 (1H, d, J = 2.1 Hz, ArH), 7.62 (1H, d, J = 2.1 Hz, ArH), 7.28 (1H, s, ArH), 7.21 (1H, s, ArH), 5.32 (1H, br, s, ArOH), 2.84 (2H, t, J = 7.8, CH_2), 2.72 (2H, t, J = 7.8, CH_2), 1.63–1.25 (21H, m CH_2 CH_3), 0.97 (3H, d, J = 7.2 Hz, Me), 0.87 (3H, d, J = 7.2 Hz, Me); δ_C (100 MHz, $CDCl_3$) 197.02, 163.29, 161.12, 148.32, 147.09, 139.31, 135.05, 132.39, 131.56, 130.23, 127.22, 120.83, 120.67, 117.15, 109.95, 35.10, 32.35, 32.18, 29.58, 29.20, 29.10, 27.10, 22.53, 22.51, 14.03, 13.98; IR (neat) ν 31200, 2958, 2922, 2871, 1643, 1546, 1358, 1270, 1216, 1159 cm^{-1}; HRMS(FAB^+) *m*/*z* calcd 478.2932, found 478.2957 $[M + 1]^+$.

N,N′-*Bis[3*-tert-*butyl-(6,6′-dihydroxy-3,4-dipentyl-2-oxo-1,2-dihydroquinolin-7yl)salicylidene]-(1*R,2R*)-diphenyl-1,2-diaminoethane (**20**).* A solution of salicylaldehyde **19** (1.00 g, 2.09 mmol) and (1*R*,2*R*)-1,2-diamino-1,2-diphenylethane (222 mg, 1.05 mmol) in dry EtOH (150 mL) was refluxed overnight to afford 1.18 g (100% yield) of **20** as yellow crystals: mp 235.5–236.1 °C; $[\alpha]_D^{20}$ = +57.1° (*c* 0.0133 in $CHCl_3$); Anal. calc. for $C_{74}H_{90}N_4O_6$·EtOH: C, 77.51; H, 8.22; N, 4.76. Found: C, 77.77; H, 8.02; N, 4.56; δ_H (400 MHz, $CDCl_3$) 14 (2H, br s, CONH), 10.39 (2H, br s, OH), 8.43 (2H, s, HC═N), 7.71 (2H,

s, ArH), 7.28–7.19 (12H, m, ArH), 7.11 (2H, s, ArH), 6.99 (2H, s, ArH), 6.12 (2H, br s, OH), 4.82 (2H, s, NC–CH), 2.81 (4H, m, CH_2), 2.68 (4H, m, CH_2), 1.61–1.25 (42H, m, CH_2), 0.97 (6H, d, J = 7.2 Hz, CH_3), 0.87 (6H, d, J = 7.2 Hz, CH_3); δ_C (100 MHz, $CDCl_3$) 166.89, 162.94, 160.28, 148.26, 146.95, 138.73, 138.29, 131.28, 130.95, 130.00, 128.45, 128.00, 127.73, 125.81, 120.50, 118.74, 116.97, 109.79, 34.99, 32.32, 32.14, 31.58, 29.55, 29.20, 29.09, 27.11, 22.65, 22.50, 14.00, 13.97; IR (neat) ν 3500, 2956, 2922, 2867, 1641, 1620, 1396, 1262, 1216, 1159, 696 cm^{-1}; HRMS(FAB^+) m/z calcd 1131.6978, found 1131.6939 $[M + 1]^+$.

*1,12-Diiodododecane (**21**).* To a solution of 1,12-dibromododecane (4.00 g, 0.0123 mol) in acetone (40 mL), NaI (7.33 g, 0.0488 mol) was added. The reaction mixture was refluxed under nitrogen for 24 h. The solvent was evaporated *in vacuo* and water (20 mL) was added. The aqueous phase was extracted with CH_2Cl_2 (3 × 20 mL) and dried ($MgSO_4$). The crude product was crystallized from acetone yielding **21** as white crystals in quantitative yield: mp 39.8–41.8 °C; Anal. calc. for $C_{12}H_2I_2$: C, 34.14; H, 5.73. Found: C, 34.12; H, 5.76; δ_H (400 MHz, $CDCl_3$) 3.20 (4H, t, J = 7.14 Hz, CH_2–I), 1.83 (4H, p, J = 7.11 Hz, CH_2), 1.39 (4H, m, CH_2), 1.28 (12H, m, CH_2); δ_C (100 MHz, $CDCl_3$) 33.53, 30.47, 29.44. 29.36, 28.50, 7.33; HRMS(FAB^+) m/z calcd 421.9974, found 421.9968 $[M]^+$.

*N,N′-Bis[3-tert-butyl-(6,6′-dodecamethylenedioxy-3,4-dipentyl-2-oxo-1,2-dihydroquinolin-7-yl)salicylidene]-(1R,2R)-1,2-diamino-1,2-diphenylethane (**22**).* Salen **20** (530 mg, 0.468 mmol), compound **21** (297 mg, 0.703 mmol) and K_2CO_3 (464 mg, 4.68 mmol) were dissolved in dry THF (424 mL) and CH_3CN (424 mL). The reaction mixture was heated under reflux and the progress of the reaction was monitored by TLC. After 24–48 h, the starting material **27** was consumed and the solvents were evaporated *in vacuo*. The crude material was filtered through a pad of Celite using CH_2Cl_2 as eluant and the filtrate was evaporated to dryness *in vacuo*. The resulting material was purified using chromatography (benzene : acetone 6 : 1) to afford 291 mg (48% yield) of **22** as yellow crystals: mp 215.2–215.9 °C; $[\alpha]_D^{20}$ = +133.3° (c 0.01156 in $CHCl_3$); Anal. calc. for $C_{86}H_{112}N_4O_6$·acetone: C, 78.54; H, 8.77; N, 4.13. Found: C, 78.83; H, 8.56; N, 4.06; δ_H (400 MHz, $CDCl_3$) 13.95 (2H, br s, CONH), 11.78 (2H, br s, OH), 8.53 (2H, s, HC═N), 7.65 (2H, d, J = 2.1 Hz, ArH), 7.41 (2H, d, J = 2.1 Hz ArH), 7.38–7.21 (12H, m ArH), 7.14 (2H, s, ArH), 4.94 (2H, s, NC–CH), 4.17–3.98 (2H, m, OCH_2), 3.94–3.90 (2H, m, OCH_2), 2.87 (4H, m, CH_2), 2.72 (4H, m, CH_2), 2.67 (4H, m, CH_2), 1.73–1.23 (57H, m, CH_2), 0.96 (6H, m, CH_3), 0.80 (3H, m, CH_3); δ_C (100 MHz, $CDCl_3$) 166.85, 163,48, 160.06, 151.80, 146.62, 139.34, 136.76, 133.75, 132.07, 131.49, 131.18, 131.14, 128.40, 128.29, 127.62, 127.01, 119.48, 118.46, 117.34, 107.40, 79.19, 69.56, 34.95, 32.33, 32.12, 29.40, 29.38, 29.33, 29.27, 29.13, 28.98, 27.06, 26.31, 22.51, 22.47, 14.04, 13.97; IR (neat) ν 2923, 2855 1622, 1438, 1257, 698 cm^{-1}; HRMS(FAB^+) m/z calcd 1297.7991, found 1297.8660 $[M + 1]^+$.

*N,N′-Bis[3-tert-butyl-(6,6′-dodecamethylene-1,12-dioxy-3,4-dipentyl-2-oxo-1,2-dihydroquinolin-7-yl)salicylidene]-(1R,2R)-1,2-diamino-1,2-diphenylethanemanganese(III) chloride (**8**).* $Mn(OAc)_2·4H_2O$ (90.9 mg, 0.370 mmol) was added to a yellow solution of strapped salen **22** (160 mg, 0.123 mmol) in abs. EtOH (6.5 mL) and $CHCl_3$ (2.6 mL). The resulting brown mixture was refluxed for 1 h, and during the last 30 min, air was bubbled through the solution. Then LiCl (26.1 mg, 0.616 mmol) was added and the dark brown mixture was refluxed for 1 h. The solvents were removed *in vacuo* and the crude product was washed first with water (3 × 5 ml) and then ether (3 × 5 ml). The product was dried *in vacuo* overnight, giving 145 mg of **8** (85% yield) as a brown solid: mp 250 °C (decomposition); Anal. calc. for $C_{86}H_{110}ClMnN_4O_6·2H_2O$: C, 72.63; H, 8.08; N, 3.94. Found: C, 72.71; H, 7.66; N, 3.57; IR (neat) ν 2923, 2853 1644, 1602, 1259, 1174 cm^{-1}; HRMS(FAB^+) m/z calcd 1450.7831, found 1450.7884 $[M + 1 - Cl]^+$.

*Bis(4-bromobutyl)pyridine-3,5-dicarboxylate (**23**).* A solution of dicyclohexylcarbodiimide (DCC) (9.36 g, 45.4 mmol) and 4-bromo-1-butanol (5.00 g, 32.7 mmol) in dry CH_2Cl_2 (60 mL) was added to a solution of pyridine-3,5-dicarboxylic acid (2.48 g, 14.8 mmol) and DMAP (363 mg, 2.97 mmol) in dry CH_2Cl_2 (160 mL) at −5 °C. The reaction was stirred for 30 h and the progress of the reaction was followed by TLC. The precipitated dicyclohexylurea was filtered off, the collected solid was washed with EtOAc (200 mL) and the filtrate was evaporated to dryness *in vacuo*. The crude was subjected to column chromatography on silica gel (PE : EtOAc 5 : 1) to afford 5.2 g (80% yield) of **23** as a white solid: mp 87.4–88.2 °C; Anal. calc. for $C_{15}H_{19}Br_2NO_4$: C, 41.21; H, 4.38; N, 3.20. Found: C, 41.36; H, 4.44; N, 3.26; δ_H (400 MHz, $CDCl_3$) 9.38 (2H, d, J = 1.2 Hz, ArH), 8.83 (1H, t, J = 1.2 Hz, ArH), 4.43 (4H, t, J = 6.18 Hz, OCH_2), 3.47 (4H, t, J = 6.18 Hz, CH_2Br), 2.07–1.94 (8H, m, CH_2); δ_C (100 MHz, $CDCl_3$) 164.29, 154.06, 138.06, 126.08, 64.90, 32.87, 29.20, 27.24; HRMS(FAB^+) m/z calcd 435.9746, found 435.9748 $[M + 1]^+$.

*Bis(4-bromobutyl)pyridine-N-oxide-3,5-dicarboxylate (**24**).* MTO (13.0 mg, 0.506 mmol) was added to a solution of pyridine **23** (4.43 g, 10.1 mmol) dissolved in CH_2Cl_2 (4.12 mL) followed by drop-wise addition of 30% H_2O_2 (8.25 ml; 20.3 mmol). The reaction mixture was stirred for 36 h at rt. Then a small amount of MnO_2 was added to destroy the excess H_2O_2 and the mixture was stirred for an additional 1 h. Water (50 mL) and CH_2Cl_2 (50 mL) were added and the phases separated. The organic phase was dried ($MgSO_4$) and evaporated *in vacuo*. The crude material was purified by chromatography (PE : EtOAc 1 : 1) to afford 4.37 g (92% yield) of **24** as a white solid: mp 95.0–97.0 °C; Anal. calc. for $C_{15}H_{19}Br_2NO_5$: C, 39.76; H, 4.23; N, 3.09. Found: C, 39.88; H, 4.30; N, 2.99; δ_H (400 MHz, $CDCl_3$) 8.86 (2H, d, J = 1.2 Hz, ArH), 8.35 (1H, t, J = 1.2 Hz, ArH), 4.43 (4H, t, J = 6.18 Hz, OCH_2), 3.47 (4H, t, J = 6.18 Hz, CH_2Br), 2.07–1.94 (8H, m, CH_2); δ_C (100 MHz, $CDCl_3$) 162.01, 143.12, 129.90, 126.43, 65.69, 32.68, 29.05, 27.11; IR (neat) ν 1718, 1275, 1230, 982, 751 cm^{-1}; HRMS(FAB^+) m/z calcd 451.9704, found 451.9706 $[M]^+$.

*N,N′-Bis[3-tert-butyl-(6,6′-[bis(tetramethylene-4-oxy)pyridine-N-oxide-3,5-dicarboxylate]-3,4-dipentyl-2-oxo-1,2-dihydroquinolin-7yl)salicylidene]-(1R,2R)-1,2-diamino-1,2-diphenylethane (**25**).* Salen **20** (530 mg, 0.468 mmol), pyridine *N*-oxide **24** (318 mg, 0.703 mmol) and K_2CO_3 (464 mg, 4.68 mmol) were dissolved in dry THF (424 mL) and CH_3CN (424 mL). The reaction mixture was heated under reflux and the progress of the reaction was monitored by TLC. After 24–48 h, the starting material **20** was consumed and the solvents were evaporated *in vacuo*. The crude material was filtered through a pad of Celite using CH_2Cl_2

as eluant and the filtrate was evaporated to dryness *in vacuo*. The resulting material was purified using chromatography (benzene : acetone 6 : 1) to afford 300 mg (45% yield) of **25** as a yellow solid: mp 229.4–229.9 °C; $[\alpha]_D^{20}$ = +90.7° (*c* 0.00993 in $CHCl_3$); Anal. calc. for $C_{89}H_{107}N_5O_{11}$: C, 75.13; H, 7.58; N, 4.92. Found: C, 75.07; H, 7.54; N, 4.89; δ_H (400 MHz, $CDCl_3$) 14.04 (2H, br s, CONH), 11.28 (2H, br s, OH), 8.82 (2H, d, *J* = 1.4 Hz, ArH), 8.51 (2H, s, HC═N), 8.20 (1H, t, *J* = 1.4 Hz, ArH), 7.55 (2H, d, *J* = 2.1 Hz, ArH), 7.33 (2H, d, *J* = 2.1 Hz, ArH), 7.28–7.20 (12H, m, ArH), 7.12 (2H, s, ArH), 4.94 (2H, s, NC–CH), 4.38–4.26 (4H, m, OCH_2), 4.04–3.95 (4H, m OCH_2,), 2.85 (4H, m, CH_2), 2.67 (4H, m, CH_2), 1.86 (8H, m, CH_2), 1.74 (2H, s), 1.54–1.21 (40H, m, CH_2 and CH_3), 0.96 (6H, d, *J* = 7.2 Hz, CH_3), 0.80 (6H, d, *J* = 7.2 Hz, CH_3); δ_C (100 MHz, $CDCl_3$) 166.78, 163,25, 161.96, 160,14, 151.40, 146.56, 143.04, 139.41, 136.81, 133.78, 132.19, 131.41, 131.28, 130.91, 129.95, 128.33, 128,21, 127.64, 126.81, 125.94, 119.52, 118.47, 117.38, 107.62, 79.12, 76.72, 68.81, 66.26, 53.82, 34.91, 32.30, 32.13, 29.70, 29.34, 29.29, 29.10, 28.95, 26.00, 25.73, 22.51, 22.46, 14.05, 13.98; IR (neat) *ν* 2951, 2918, 2868 1733, 1623, 1507, 1359, 1244, 751, 698 cm^{-1}; HRMS(FAB^+) *m*/*z* calcd 1422.8053, found 1422.8045 $[M + 1]^+$.

N,N′-*Bis[3*-tert-*butyl-(6,6′-[bis(tetramethylene-4-oxy)pyridine*-N-*oxide-3,5-dicarboxylate]-3,4-dipentyl-2-oxo-1,2-dihydroquinolin-7yl)salicylidene]-(1*R,2R*)-1,2-diamino-1,2-diphenylethanemanganese(III)chloride (9).* $Mn(OAc)_2{\cdot}4H_2O$ (116 mg, 0.472 mmol) was added to a yellow solution of strapped salen **25** (216 mg, 0.152 mmol) in abs. EtOH (8 mL) and $CHCl_3$ (3.2 mL). The resulting brown mixture was refluxed for 1 h, and during the last 30 min, air was bubbled through the solution. Then LiCl (32.2 mg, 0.759 mmol) was added and the dark brown mixture was refluxed for 1 h. The solvents were removed *in vacuo* and the crude product was washed first with water (3 × 5 ml) and then ether (3 × 5 ml). The product was dried *in vacuo* overnight, giving 200 mg of **9** (87% yield) as a brown solid: mp 250 °C (decomposition); Anal. calc. for $C_{89}H_{105}ClMnN_5O_{11}{\cdot}3E\text{-}tOH{\cdot}H_2O$: C, 68.43; H, 7.56; N, 4.20. Found: C, 68.38; H, 7.85; N, 4.02; IR (neat) *ν* 3382, 2924, 1601, 255 cm^{-1}; HRMS(FAB^+) *m*/*z* calcd 1475.7228, found 1475.7269 $[M + 1 - Cl]^+$.

Substrates

***4b**: Synthesis following the general procedure in ref. 17* Yield: Quantitative, colour: off-white; δ_H (400 MHz, $CDCl_3$) 8.52 (2H, dd, *J* = 4.4, 1.6 Hz, PyH), 7.37–7.28 (4H, m, ArH); 7.26–7.21 (1H, m, ArH); 7.13 (2H, dd, *J* = 4.4 and 1.6 Hz, PyH), 6.42 (1H, d, *J* = 15.8 Hz, CH), 6.21 (1H, dt, *J* = 15.8 and 6.8 Hz, CH); 2.77 (2H, t, *J* = 7.5 Hz, CH_2), 2.54 (2H, dd, *J* = 6.8 and 7.5 Hz, CH_2); δ_C (100 MHz, $CDCl_3$) 150.50, 149.59, 137.37, 131.11, 128.87, 128.57, 127.21, 126.06, 123.96, 35.04, 33.55; ESI-MS: *m*/*z* 210.1 (M + 1).

Epoxide products

***6b**.* To a solution of **4b** (650 mg, 3.11 mmol,) and Na_2HPO_4 (1.340 g, 7.76 mmol) in dry benzene (20 mL) was added *m*-CPBA (1.102 g, 7.76 mmol) at rt. The mixture was stirred for 2 h at rt. The solution was treated with saturated aqueous $NaHCO_3$ and $Na_2S_2O_3$ and extracted with CH_2Cl_2. The organic layer was dried with $MgSO_4$ and concentrated to give crude containing the epoxide from starting material and the byproduct, the *N*-oxide of **6b**. Column chromatography using ethyl acetate–methanol (95 : 5) gave 0.3 g (50%) of **6b** as a colourless liquid: R_f 0.4 (PE : MeOH,1 : 1); δ_H (400 MHz, $CDCl_3$); 8.23–8.17 (2H, m, PyH); 7.40–7.30 (3 H, m, ArH); 7.27–7.21 (2H, m, ArH or PyH); 7.20–7.15 (2H, d, m, PyH or ArH); 3.63 (1H, *J* = 2 Hz, CH), 3.03–2.97 (1H, m, CH), 2.96–2.79 (2H, m, CH_2), 2.16–2.05 (1H, m, CH), 2.03–1.92 (1H, m, CH); δ_C (100 MHz, $CDCl_3$) 141.05, 139.07, 136.92, 128.58, 128.37,126.08,125.46, 61.67, 58.74, 32.76.

Catalytic reactions

Styrene substrates and epoxides. General procedure: catalyst part **1**, **8** or **9** (3 μmol each), receptor part **2** (3 or 9 μmol each), substrate pairs of **4** and **5** (30 μmol each), PhIO (24 μmol), internal standard benzyl benzoate (15 μmol) and CH_2Cl_2 (0.6 ml or 6 mL), were stirred at rt for 24 h. Then this solution was filtered through a silica plug (1.4 g, 0.4 cm diameter) to remove the catalyst. The plug was washed with EtOAc (25 ml). After removal of the solvent *in vacuo*, the residue was dissolved in 2–3 ml ether and the mixture was filtered through a membrane to remove any residual catalyst. The ether was removed *in vacuo* before dry $CDCl_3$ (0.6 ml) was added for NMR analysis to determine the substrate selectivity. To separate peaks ZnTTP (2 mg) was added. A few drops of the NMR solution were taken for GC analysis to assess the substrate selectivity. To determine the substrate selectivity by GC the following protocol was used: Varian Factor Four capillary column, VR-1 ms, 28–29 m × 0.25 mm × 0.25 μm, helium as a carrier gas, flow gradient is from 0.5 ml min^{-1} to 3 ml min^{-1} with ramp 0.1 ml min^{-1}, oven temperature: 140 to 185 °C with ramp 3 °C min^{-1}, then to 220 °C with ramp 10 °C min^{-1}, then hold for 6 min. The injections were repeated three times. *Retention time for internal standard (IS) (benzyl benzoate) and substrates*: IS: 13.3 min, **4a**: 15.8 min, **5a**: 13.1 min, **4b**: 17.5 min, **5b**: 15.0 min. *Retention times for products*: **6a**: 18.6 min, **7a**: 16.1 min, **6b**: 18.9 min, **7b**: 16.8 min. The procedure to calculate substrate selectivities is the same as used by us previously.[3d] In this case the results are based only on the consumption of starting material. After analysis of the NMR sample, the content was passed through a 0.4 × 8 cm plug of silica using PE : EtOAc (6 : 1) to separate epoxide **6a** from **7a**. The fraction containing **6a** was evaporated to dryness *in vacuo* and 0.6 ml diethyl ether was added. The procedure was repeated for **7a**.

Stilbene substrates and epoxides. Catalyst part **1**, **8** or **9** (3 μmol each), receptor part **2** (3 or 9 μmol each), substrates pairs **26**, **27**, **28** (30 μmol each), PhIO (24 μmol), internal standard (benzyl benzoate) (15 μmol) and DCM (0.6 ml) were stirred at rt for 24 h. Then as for styrene substrates above. *Retention times for substrates are*: **27a**: 9.9 min, **28a**: 8.0 min, **26b**: 16.1 min, **27b**: 14.3 min, **28b**: 12.1 min. *Retention times for products*: **30a**: 12.3 min, **31a**: 9.6 min, **29b**: 18.7 min, **30b**: 15.9 min, **31b**: 13.2 min.

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Notes and references

‡ In all pair-wise competitive reactions consistently 70% of the product was epoxides. It is reasonable to assume that for each of the olefins in the study, the fraction of epoxide is more or less the same, meaning that the product selectivity mirrors the substrate selectivity. This was experimentally verified in one case, for **4a** : **5a** (entries 1 and 2 in Table 1), where the selectivity calculated based on both substrate consumption and product formation[3d] was the same as when calculated based on only substrate consumption. However, we can only with absolute certainty report selectivity as substrate selectivity for the other cases.
§ The strapping of the receptor part has so far failed in our hands.
¶ Pyridine *N*-oxides coordinate to the Mn ion and promotes the Jacobsen–Katsuki epoxidation of olefins, see ref. 23.
‖ In model **A** + **B** ⇌ **AB**, increasing [**B**] will result in an increase of [**AB**].
** All attempts to synthesize the unknown *Z*-isomer failed in our hands.

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