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A Covalent and Modular Synthesis of Homo- and Hetero[*n*]rotaxanes

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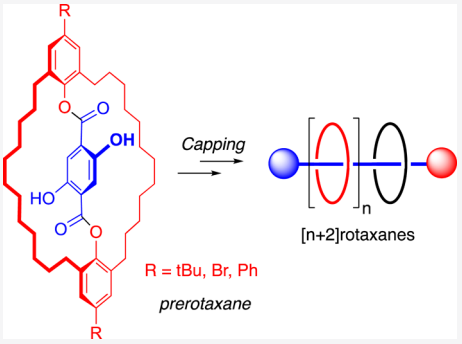
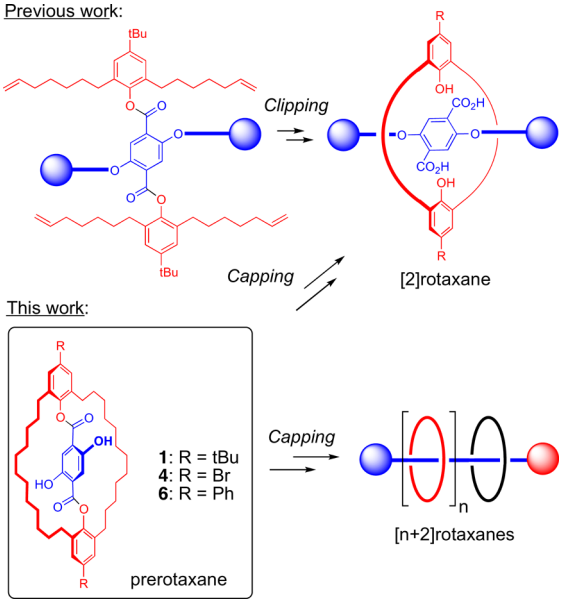
ABSTRACT: Incorporation of 2,5-dihydroxyterephthalate as a covalent scaffold in the axis of a 30-membered all-carbon macrocycle provides access to a modular series of rotaxanes. Installment of tethered alkynes or azides onto the terephthalic phenolic hydroxyl functionalities, which are situated at opposite sides of the macrocycle, gives versatile prerotaxane building blocks. The corresponding [2]rotaxanes are obtained by introduction of bulky stoppering ("capping") units at the tethers and subsequent cleavage of the covalent ring/thread ester linkages. Extension of this strategy via coupling of two prerotaxanes bearing complementary linker functionalities (i.e., azide and alkyne) and follow-up attachment of stopper groups provide efficient access to [*n*]rotaxanes. The applicability and modular nature of this novel approach were demonstrated by the synthesis of a series of [2]-, [3]-, and [4]rotaxanes. Furthermore, it is shown that the prerotaxanes allow late-stage functionalization of the ring fragment introducing further structural diversity.



INTRODUCTION

Mechanically interlocked molecules (MiMs) such as rotaxanes or catenanes attract attention because of their fascinating structural features and aesthetic architecture[1,2] as well as their application as molecular switches or as components of molecular machines.[3] Over the last three decades, several robust methodologies for the synthesis of MiMs have been developed.[4] In the case of rotaxanes, the vast majority of these approaches relies on noncovalent preorganization of the ring and thread fragments. The key mechanical bond is made by (i) slipping of the macrocycle over the thread fragment followed by introduction of stoppering groups at the thread end or (ii) clipping of the ring precursor over the thread and subsequent macrocyclization. By using covalent approaches, the synthesis of so-called "impossible" rotaxanes, which lack the supramolecular elements required to preorganize the ring and thread fragments, has also been established. Ironically, in the first two decades after the first synthesis of a [2]catenane by Schill et al.[5] back in 1964 and a [2]rotaxane by Harrison et al.[6] in 1967, the field was solely based on covalent and statistical approaches. Over the last years, covalent approaches reappeared on the scene, widening the structural diversity of MiMs.[7−13] In a recent letter, we described the covalent synthesis of a [2]rotaxane using a terephthalic acid-centered thread on which the ring-precursor fragments were esterified followed by clipping-type macrocyclization around the end-stoppered thread to give a prerotaxane (Scheme 1).[14] Saponification of the terephthalic esters liberated the [2]-

Scheme 1. Outline of the Work Described in the Previous Letter and in This Work



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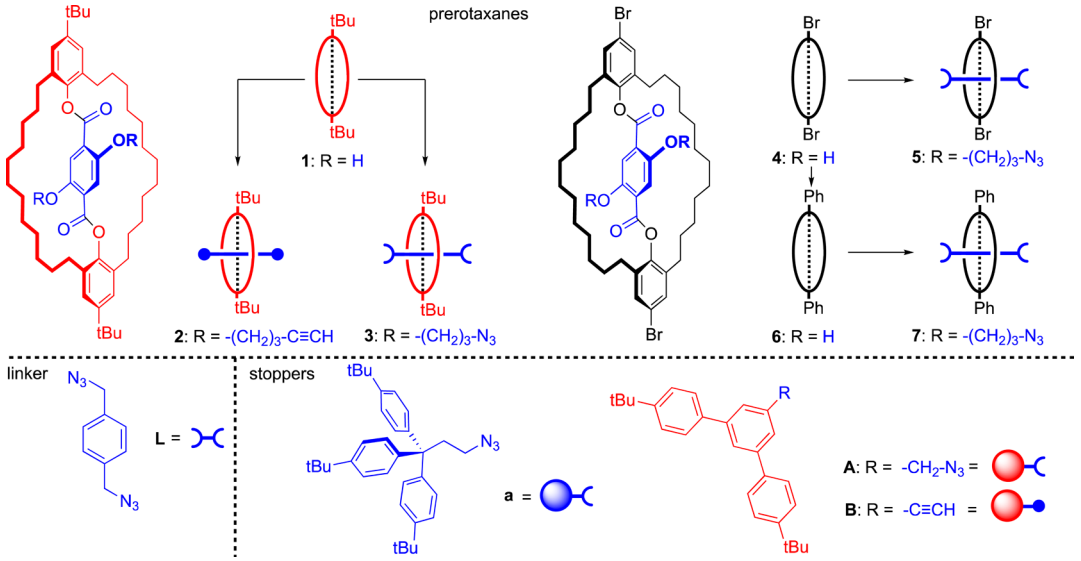

Figure 1. Ring, thread, and stopper building blocks for modular [*n*]rotaxane synthesis.

rotaxane featuring an all-carbon ring fragment that would be inaccessible using the common supramolecular approaches.

We have now shortened our previous clipping-type covalent route to obtain similar "impossible" MiMs, starting from the common prerotaxane synthons **1**, **4**, and **6**, differing in the substitution pattern at the ring phenyl *para*-positions (Scheme 1). This capping-type methodology provides facile access to a series of homo- and hetero[*n*]rotaxanes featuring a combination of different rings, thread fragments, and stoppers. Both homo- and hetero[*n*]rotaxanes have been made before using supramolecular methodology.[15] Especially, hetero[*n*]rotaxanes pose a challenge that has been solved by using several orthogonal host–guest systems[16,17] or with an iterative active-metal template approach.[18] In these approaches, the former methodology is limited by the number of available orthogonal noncovalent recognition elements and the latter by the necessity of stoppering units in between the rings to avoid dethreading during building of the [*n*]rotaxane sequence. Our capping-type synthesis from covalently linked prerotaxane building blocks overcomes these drawbacks. In addition, we have deliberately chosen 4-bromo phenyl groups in the ring fragment of prerotaxane **4** to demonstrate the possibility for late-stage installation of functional stations via versatile cross-coupling chemistry for future application as molecular switches or motors.

As outlined in Figure 1, the phenolic hydroxyl groups at the terephthalic ester template are located at opposite sides of the macrocycle and thus ideally placed for introduction of thread fragments. Installation of tethered alkynes or azides at **1**, **4**, and **6** gives prerotaxanes **2**, **3**, **5**, and **7** from which, in combination with the three stoppers **a**,[14] **A**, and **B** and a linking fragment **L**,[19] a diverse series of nine homo-, and hetero[2]-, [3]-, and [4]rotaxanes were obtained. Connection of the different fragments is carried out via a Lego-like building approach relying on the Cu(I)-catalyzed azide-alkyne cycloaddition (CuAAC) reaction without the need for protecting groups.

RESULTS AND DISCUSSION

The synthesis of the ring fragment of prerotaxanes **1** and **4** commences with a Grignard reaction of hex-5-en-1-ylmagnesium bromide and 5-(*tert*-butyl)-2-hydroxyisophthalaldehyde **8a** or 5-bromo-2-hydroxyisophthalaldehyde **8b**. The latter two were conveniently made by a double Duff reaction from 4-(*tert*-butyl)phenol or 4-bromophenol.[20] The Grignard reaction was followed by Et_3SiH-mediated reductive removal of the resulting benzylic hydroxyl groups to give macrocycle precursors **9a** or **9b** in 84 and 56% overall yields, respectively (Scheme 2).

The central terephthalic templates, which are also part of the thread fragment, were prepared by double allylation or methylation of dimethyl 2,5-dihydroxyterephthalate (**10**) followed by saponification to give the diacids. These were subsequently converted into the bis-acid chlorides and further transformed into the shelf-stable and crystalline bispentafluorophenyl esters **11** and **12** in 33% and 45% yields over the four steps, respectively. Transesterification of pentafluorophenol ester **11** with phenol **9a** by stirring in acetonitrile in the presence of Cs_2CO_3 as the base went smoothly with a follow-up Pd(0)-catalyzed removal of the allyl protective groups leading to the macrocyclic ring precursor **13a** in a 72% isolated yield. It should be noted here that all attempts to couple the sterically hindered phenol **9a** directly to either the diacid chloride derivative of phthalic acid of **11** or through the use of carboxylic-acid activating reagents gave significantly lower yields. Similarly, activated ester **12** and phenol **9b** gave ring-closing metathesis (RCM) precursor **13b** in an 86% isolated yield. A double RCM macrocycloolefination of **13a** and **13b**, using the second-generation Grubbs catalyst, gave the macrocyles as a mixture of *E*/*Z* isomers.[21] Subsequent catalytic hydrogenation led to the key prerotaxanes **1** and **14** in yields of 93 and 50%, respectively, over the two steps.

These results demonstrate the optimal preorganization of the terminal olefins for the anticipated macrocyclization reaction by the phthalate template. Both the ^1H and ^{13}C NMR spectra of prerotaxanes **1** and **14** showed sharp signals, pointing to a rigid and symmetric conformation. Although we were able to grow single crystals of prerotaxane **1**, their quality proved to be insufficient for full refinement by X-ray crystallographic analysis. However, the obtained connectivity plot unequivocally demonstrates that the phthalate template prevents collapsing of the macrocycle but also effectively positions the two phenolic hydroxyl groups at opposite sides of

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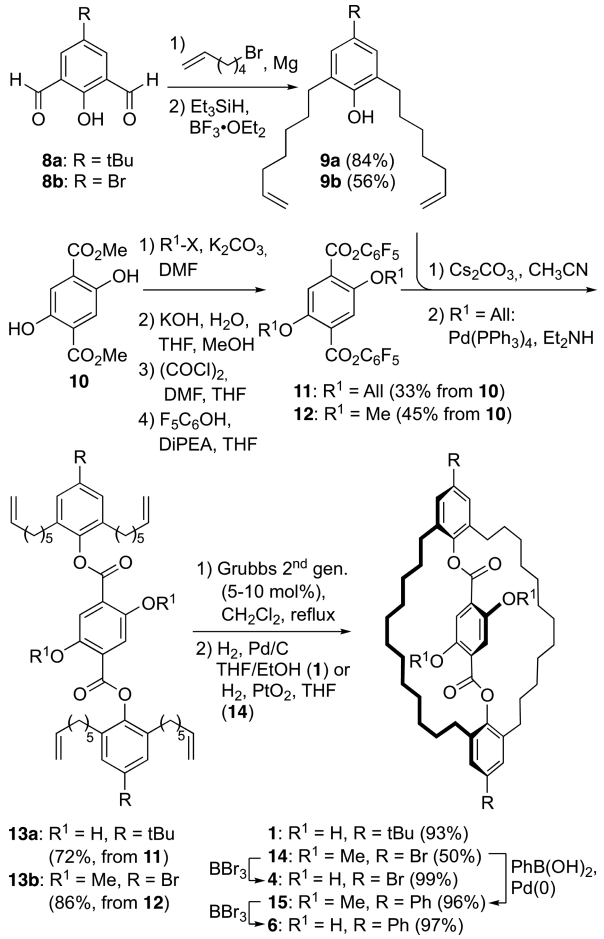
Scheme 2. Synthesis of the Prerotaxanes



the macrocycle (see Figure 2a). This is a prerequisite for arriving at a mechanically interlocked structure through further capping-type installation of additional functional thread elements and stoppers.

As proof to show the feasibility of this approach for the future synthesis of functional rotaxanes, the bromides in prerotaxane **14** were substituted by phenyl groups using the Pd-mediated Suzuki-Miyaura coupling reaction giving **15** in a 96% yield. BBr_3-mediated cleavage of the aryl methyl ethers in **14** and **15** went smoothly and gave bisphenols **4** and **6** in yields of 99 and 97%, respectively. It is noteworthy that, in comparison to prerotaxane **1** carrying two *t*Bu groups, prerotaxanes **4** and **6** show considerably lower solubility in the common solvents.

To allow for installation of stopper units via the CuAAC reaction, prerotaxanes **1**, **4**, and **6** were functionalized with tethered alkynes or azides. Introduction of alkynes was conducted by Williamson-type alkylation of the phenolic hydroxyl groups in **1** using pent-4-yn-1-yl methanesulfonate as the electrophile and K_2CO_3 as the base (Scheme 3). Most probably due to steric hindrance encountered at the axis within the macrocycle wheel, elevated temperature was required to obtain prerotaxane **2**. Complementary azide groups were installed into prerotaxanes **1**, **4**, and **6** using the same protocols, starting from 3-azidopropyl methanesulfonate as the electrophile, to give **3**, **5**, and **7** in yields of 92, 100, and 71%, respectively.

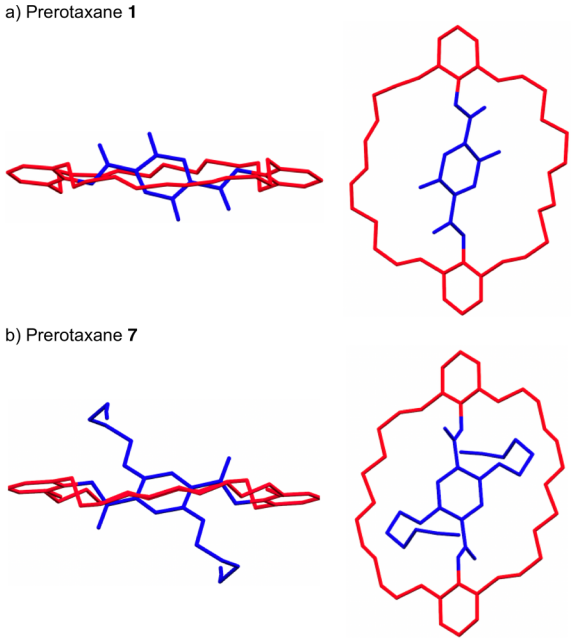
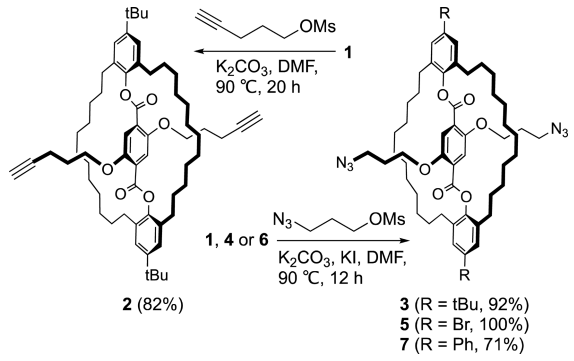


Figure 2. Connectivity plots as determined by X-ray crystallography of prerotaxanes (a) **1** and (b) **7**. The macrocycle respective *para t*-butyl or phenyl substituents in **1** or **7** have been omitted for clarity.

Scheme 3. Attachment of the Tethered Alkyne and Azide Thread Components To Give the Four Prerotaxane Building Blocks



Gratifyingly, single crystals of prerotaxane **7** featuring the propyl tethered azides could be obtained. Similarly as encountered for prerotaxane **1**, full refinement of the X-ray crystallographic data of **7** was not possible due to weak diffraction. However, the connectivity plot resembled the conformation of the phthalic ester within the macrocyle of prerotaxane **1**, thus positioning the tethered azides at opposite sides of the ring (see Figure 2b).

Functionalization of the terephthalic template with the tethered azides and alkynes affected the ^{1}H NMR spectra of compounds **2** and **3**, now showing broad signals as a result of different interconverting conformations of the ring and positioning of the template within the macrocycle. To clarify these spectral features, ^{1}H NMR spectra were recorded at elevated temperatures in deuterated toluene (see the Supporting Information). At higher temperatures, the increased conformational freedom results in coalescence of the different peaks of the template thread protons and a less complex spectrum. In prerotaxane **2**, the hydrogens on the terminal alkynes appeared as a beacon in the complex room-

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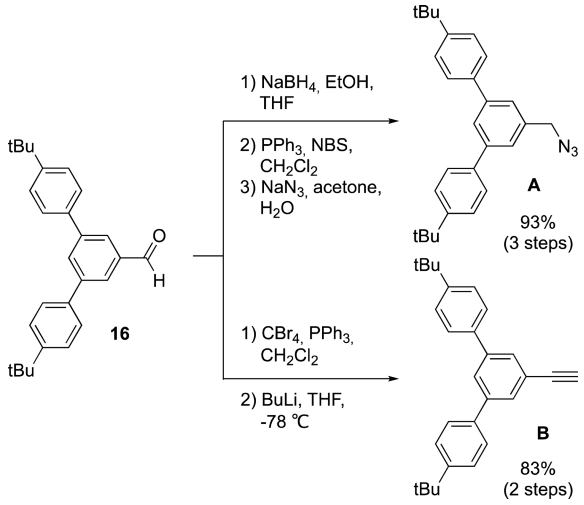
temperature ^{1}H NMR spectra. The corresponding isolated terminal alkyne-CH singlet around 1.95 ppm proved to be useful for identification of the mono- and di-stoppered prerotaxanes resulting from CuAAC reactions (vide infra).

As a last task, the stoppers had to be prepared. Besides bulky stopper **a**, which has been previously described by us,[14] new stoppers **A** and **B** were successfully prepared via a short route from the known common terphenylaldehyde **16**[22] (Scheme 4).

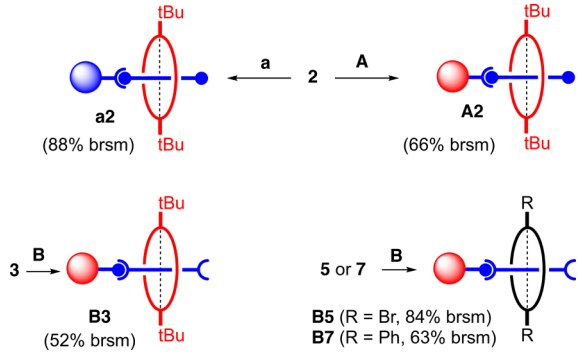
Scheme 4. Synthesis of the Azide and Alkyne Stoppers A and B



After subsequent $NaBH_4$ reduction, an Appel reaction, and nucleophilic substitution, azide-functionalized stopper **A** was obtained in a 93% overall yield. Using the reliable two-step Corey–Fuchs protocol, the same aldehyde **16** was transformed into the terminal alkyne-functionalized stopper **B** in a 83% yield (over the two steps).

With the four prerotaxanes **2**, **3**, **5**, and **7**, the three stoppers **a**, **A**, and **B**, and the reported 1,4-bis(azidomethyl)benzene **L** as a linking connector in hand, we were ready for the Lego-type construction of a series of nine [*n*]rotaxanes. The synthesis of hetero[*n*]rotaxanes employing different stoppers or rings required the availability of the respective mono-stoppered prerotaxanes (Scheme 5). After optimization, it was found that the reaction of 0.4 equiv of the stopper with respect

Scheme 5. Synthesis of the Half-Stoppered Prerotaxanes[a]



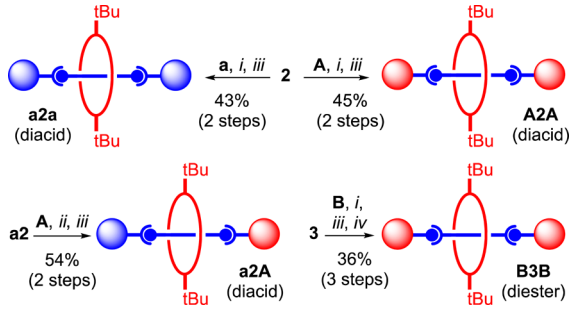
[a]Reaction conditions: prerotaxane **2**, **3**, **5**, or **7** (1 equiv), stopper **A** or **B** (0.4 equiv), TBTA (0.2 equiv), $Cu(CH_3CN)_4BF_4$ (0.2 equiv), CH_2Cl_2, rt, overnight.

to the prerotaxane prevented the formation of the bis-stoppered prerotaxanes, selectively providing the mono-stoppered prerotaxanes **a2** and **A2**.

The CuAAC reaction of bis-alkyne functionalized prerotaxane **2** with 0.4 equiv of stopper **a** or **A** gave the mono-stoppered prerotaxanes **a2** and **A2** in 88 and 66% yields based on the recovered starting material (brsm). The azide-functionalized mono-stoppered prerotaxane **B3** was obtained after the CuAAC reaction of the bis-azide-threaded prerotaxane **3** with 0.4 equiv of stopper **B** in a 52% yield (brsm). To allow the synthesis of a hetero[*n*]rotaxane featuring different ring substitutions, the mono-stoppered prerotaxanes **B5** and **B7** were made in a similar way. By reaction of prerotaxane **5** and **7** with 0.4 equiv of stopper **B**, mono-stoppered prerotaxanes **B5** and **B7** were obtained in 84 and 63% yields (brsm) in their pure form.

First, the capping-type synthesis of [2]rotaxanes was undertaken (Scheme 6). CuAAC-type coupling of alkyne-

Scheme 6. Synthesis of Homo- and Hetero[2]rotaxanes[a]



[a]Reaction conditions: (i) prerotaxane **2** or **3**, stopper **a**, **A** or **B** (2.2 equiv), TBTA (0.2 equiv), $Cu(CH_3CN)_4BF_4$ (0.2 equiv), rt, 5-14 h. (ii) prerotaxane **a2**, stopper **A** (1.2 equiv), TBTA (0.2 equiv), $Cu(CH_3CN)_4BF_4$ (0.2 equiv), rt, overnight. (iii) Tesser's base (1,4-dioxane/MeOH/2M NaOH, 3:1:0.1), 50 °C, overnight. (iv) MeOH, HCl, 40 °C, 5 h.

tether functionalized prerotaxane **2** with 2.2 equiv of azide stoppers **a** or **A** gave the homo[2]prerotaxanes of **a2a** or **A2A** in yields of 56 and 51%, respectively. Saponification of the temporal linking terephthalate ester linkages liberated the [2]rotaxanes **a2a** or **A2A** in 77 and 88% yields, respectively. Although accurate mass determination unequivocally confirms the integrity of the [2]rotaxane architecture of **a2a**, for comparison reasons, we have also made the separate ring and thread fragments (see the Supporting Information). Simple TLC analysis of the ring and thread fragments and the [2]rotaxane clearly established their different physical properties. While the apolar macrocycle runs high on TLC using EtOAc/hexanes as the eluent, the thread component shows the lowest polarity due to the presence of the two carboxylic acid and triazole moieties. Comparison of the ^{1}H NMR spectra of [2]rotaxane **a2a**, the loose thread, and the corresponding ring fragment as well as an equimolar mixture of the latter two compounds shows subtle but significant differences (see the Supporting Information). In [2]rotaxane **a2a**, almost all protons in the thread fragment, including the triazole CH, show a slight upfield shift. This is also the case for the aliphatic protons on the ring fragment. Remarkably, the singlet of the two protons at the phthalate phenyl ring did not shift although they are located in the center of the ring of the rotaxane skeleton. These results show that the terephthalate template

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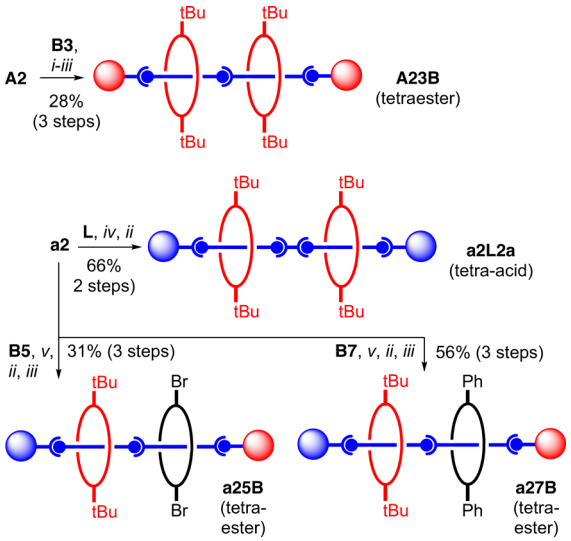
not only allows for the clipping approach that was previously published by us but also enables a more convergent capping strategy to arrive at mechanically interlocked structures. Similarly, from prerotaxane **a2**, hetero[2]rotaxane **a2A** was readily obtained in a 54% overall yield, now after CuAAc-coupling with stopper **A** followed by saponification. After having confirmed the feasibility of this new synthetic pathway, homo[2]rotaxane **B3B** was made by coupling prerotaxane **3** and stopper **B** via the same two-step sequence. To facilitate chromatographic purification, the crude carboxylic acids were converted into their methyl esters by heating in methanol using HCl as the catalyst to give **B3B** as the diester in an overall yield of 36% over the three steps.

Next, the covalent approach to MiMs was expanded to the [3]rotaxane series (Scheme 7). A [3]rotaxane could be made

Scheme 7. Synthesis of Homo- and Hetero[3]rotaxanes[a]

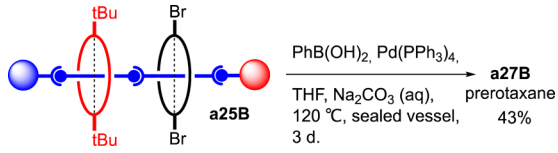


[a]Reaction conditions: (i) prerotaxane **A2** (1 equiv), prerotaxane **B3** (2 equiv), TBTA (0.68 equiv), $Cu(CH_3CN)_4BF_4$ (0.2 equiv), rt, overnight. (ii) Tesser's base (1,4-dioxane/MeOH/2M NaOH, 3:1:0.1), 50 °C, overnight. (iii) MeOH, HCl, 40 °C, 5 h. (iv) prerotaxane **a2** (2.2 equiv), linker **L** (1 equiv), TBTA (0.68 equiv), $Cu(CH_3CN)_4BF_4$ (0.2 equiv), rt, overnight. (v) prerotaxane **a2** (1 equiv), prerotaxane **B5** or **B7** (1−1.1 equiv), TBTA (0.2 equiv), $Cu(CH_3CN)_4BF_4$ (0.2 equiv), rt, overnight.

by directly connecting two half-stoppered [2]rotaxanes. Coupling/saponification/esterification of the half-stoppered [2]prerotaxanes **A2** and **B3** went uneventfully and gave homo[3]rotaxane **A23B** (28% yield over 3 steps). Alternatively, connecting two half-stoppered alkyne-functionalized prerotaxanes **a2** via diazide-functionalized linker **L** followed by saponification gave homo[3]rotaxane **a2L2a** in a 66% overall yield. By coupling of prerotaxane **a2** with the two different prerotaxanes **B5** or **B7** followed by saponification and esterification, the two hetero[3]rotaxanes **a25B** and **a27B** were obtained as the tetramethylesters in overall yields of 31 and 56%.

To show the applicability of our covalent approach toward the synthesis of functional hetero[*n*]rotaxanes via late-stage decoration, prerotaxane **a25B** was transformed to prerotaxane **a27B** by the robust Suzuki-Miyaura reaction (Scheme 8). Reaction of **a25B** with phenyl boronic acid under classical Suzuki conditions in a sealed vessel at 120 °C for three days

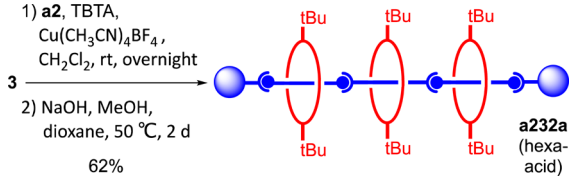
Scheme 8. Late-Stage Ring Decoration via the Suzuki-Miyaura Reaction



followed by purification gave prerotaxane **a27B** in an isolated yield of 43%.

As a final effort, homo[4]rotaxane **a232a** was conveniently prepared in a 62% overall yield just by clicking the alkyne-functionalized half-stoppered [2]rotaxanes **a2** and the bisazide-equipped [2]prerotaxane **3** together followed by saponification (Scheme 9).

Scheme 9. Synthesis of a [4]Rotaxane.



CONCLUSIONS

With nine homo- and hetero[*n*]rotaxanes in hand, we have shown that, although covalent routes per definition require more synthetic steps than a supramolecular route (i.e., making and breaking the covalent connection between the ring/thread fragments), this approach may be a viable and complementary alternative, particularly to arrive at hetero[*n*]rotaxanes with different stoppers, rings, and thread components. Both the covalent and supramolecular approaches require specific functional groups for preorganization of the ring/thread fragments, making them complementary. We have presented here a modular approach to hetero[*n*]rotaxanes that is amenable for further installation of functional stations in both the thread and ring fragments. These stations may also be introduced at a late stage of the synthesis as was shown by installation of two phenyl groups at the rim of the ring fragment by a Suzuki-Miyaura coupling reaction. The synthesis of functional MiMs using this methodology is currently undertaken by us.

EXPERIMENTAL SECTION

General Methods and Materials. Reactions were carried out under air and without additional measures such as drying unless stated otherwise. Heating and stirring was performed using an oil bath and standard thermostatized stirring plates and teflon stirring beans. Thin-layer chromatography (TLC) was performed on Merck TLC plates (0.25 mm) precoated with silica gel 60 F254. Flask column chromatography was performed using SilaFlash P60 (40−63 μm) under a compressed air flow. Starting materials and reagents were used as supplied by commercial vendors. Anhydrous CH_2Cl_2 and CH_3CN were freshly distilled from CaH_2. Dried THF was obtained through distillation with sodium, and dried solvents were stored under a N_2 atmosphere. Bruker DRX-300, 400, and 500 MHz instruments were used to record NMR spectra. Chemical shifts (δ) are reported in ppm relative to residual undeuterated solvent peaks. Data of the recorded ^1H NMR spectra are described as follows: chemical shift (multiplicity, coupling constant when applicable, number of H). The following abbreviations are used to report the multiplicities: s

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(singlet), d (doublet), t (triplet), q (quartet), quint (quintet), dd (doublet of doublet), m (multiplet), br m (broad multiplet). All reflection intensities were measured with a Bruker D8 Quest Eco diffractometer equipped with a Triumph monochromator (λ = 0.71073 Å) and a CMOS Photon 50 detector at 150(2) K. Intensity data were integrated with the Bruker APEX2. High-resolution mass spectra (HRMS) were recorded on an AccuTOF GC v 4g, JMS-T100GCV mass spectrometer (JEOL, Japan) and HR-ToF Bruker Daltonik GmbH (Bremen, Germany) Impact II, an ESI-ToF MS capable of resolution of at least 40,000 FWHM. The FD/FI probe was equipped with an FD Emitter, Carbotec, FD = 10 μm. Current rate = 51.2 mA/min over 1.2 min using field desorption (FD) as an ionization method.

4-(*tert*-Butyl)-2,6-di(hept-6-en-1-yl)phenol (9a). This compound has been made previously by us but the procedure has been optimized.[14] Magnesium turnings (1.51 g, 62.1 mmol, 4.5 equiv) were suspended in dry THF (60 mL) in an oven-dried flask. 6-Bromo-1-hexene (8.3 mL, 61.9 mmol, 4.5 equiv) was added dropwise to the stirred solution and heated under reflux for 3 h. The mixture was then cooled to room temperature and added dropwise to a solution of **8a**[20] (2.84 g, 13.7 mmol, 1.0 equiv) in dry THF (60 mL) at 0 °C under a N_2 atmosphere. The reaction mixture was stirred and heated under reflux overnight and subsequently quenched with H_2O (5 mL). The mixture was diluted with Et_2O (100 mL) and 1 M HCl (100 mL), and after which, the aqueous layer was extracted with 2× 20 mL of Et_2O. The combined organic layer was washed with brine, dried over Na_2SO_4, and concentrated in vacuo to give a yellow oil. The residue (2.22 g, 5.93 mmol, 1 equiv) was dissolved in dry CH_2Cl_2 (50 mL) under a N_2 atmosphere and cooled to −78 °C, and Et_3SiH (3.78 mL, 23.7 mmol, 4.0 equiv) was added. $BF_3{\cdot}Et_2O$ (2.93 mL, 23.7 mmol, 4.0 equiv) was added slowly over the course of 1 h to the stirred reaction mixture, and after which, the dry-ice bath was removed. After the solution had returned to room temperature, it was quenched with water then the organic layer was separated, dried over Na_2SO_4, and concentrated in vacuo. The crude product was purified by Kugelrohr distillation (180−190 °C, 0.04 mbar) to give **9a** (1.71 g, 5.00 mmol, 84%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.99 (s, 2H), 5.84 (quint, J = 17.0, 10.1, 6.7 Hz, 2H), 5.11−4.86 (m, 4H), 4.53 (s, 1H), 2.72−2.46 (m, 4H), 2.08 (q, J = 7.1, 6.6 Hz, 4H), 1.68−1.61 (m, 4H), 1.52−1.34 (m, 8H), 1.31 (s, 9H). For further spectral data, see ref 14.

4-(Bromo)-2,6-di(hept-6-en-1-yl)phenol (9b). A solution of 6-bromo-1-hexene (9.97 g, 61 mmol, 3.5 equiv) in dry THF (20 mL) was added dropwise to magnesium turnings (1.70 g, 70 mmol, 4 equiv) at a rate to maintain reflux. Then, more dry THF (15 mL) was added, and the reaction was heated to reflux for 2.5 h. The mixture was then cooled to room temperature and added dropwise to a solution of **8b**[22] (4.00 g, 17.5 mmol, 1 equiv) in dry THF (50 mL) at 0 °C under a N_2 atmosphere. The reaction mixture was stirred for 1 h then warmed to room temperature and stirred for an additional 3.5 h. The reaction mixture was subsequently quenched with H_2O (5 mL) and diluted with Et_2O (50 mL) and 1 M HCl (50 mL), and after which, the aqueous layer was extracted with 2× 50 mL of Et_2O. The combined organic phases were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. The mixture was purified by column chromatography (PE/EtOAc 19:1 → 9:1 → 8:2) to give the diol as a yellow oil (5.87 g, 14.7 mmol, 84%). This diol (4.21 g, 10.6 mmol, 1 equiv) was dissolved in dry CH_2Cl_2 (100 mL) under a N_2 atmosphere and cooled to 0 °C, and Et_3SiH (51 mL, 317 mmol, 30 equiv) was added. $BF_3{\cdot}Et_2O$ (3.9 mL, 31.8 mmol, 3 equiv) was added dropwise, and after which, the reaction mixture was stirred for 5 h at 0 °C. The reaction mixture was then quenched by dropwise addition of H_2O (20 mL) and warmed to room temperature. Additional H_2O (80 mL) was then added, and the mixture was extracted with 3× 50 mL of CH_2Cl_2. The reunited organic phases were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was dissolved in THF (40 mL), and MeOH (40 mL) was added followed by NH_4F (3.53 g, 95.4 mmol, 9 equiv), and the mixture was stirred for 45 min. The mixture was then concentrated and subsequently diluted in EtOAc (100 mL) and H_2O (100 mL). The aqueous layer was extracted with 2× 50 mL of EtOAc, and the reunited organic phases were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Column chromatography (PE/Et_2O 80:1 → 40:1) afforded **9b** (2.60 g, 7.10 mmol, 67%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10 (s, 2H), 5.83 (m, 2H), 5.02 (dd, 2H), 4.97 (d, 2H), 4.60 (s, 1H), 2.56 (t, 4H), 2.08 (td, 4H), 1.62 (m, 4H), 1.52−1.34 (m, 8H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 150.5, 138.9, 130.2, 130.0, 114.4, 112.4, 33.6, 29.9, 29.3, 28.9, 28.7. IR (cm^{-1}): 3582, 3075, 2975, 2926, 2855, 1640, 1459, 1184, 993, 910, 864. HRMS (FD$^+$) m/z calcd for $C_{20}H_{29}Br_1O_1$ (M^+) 364.1396, found 364.1396.

Bis(perfluorophenyl) 2,5-Bis(allyloxy)terephthalate (11). Dimethyl 2,5-dihydroxyterephthalate (**10**)[14] (10.04 g, 44.4 mmol, 1 equiv), allyl bromide (13.4 g, 111.0 mmol, 2.5 equiv), and K_2CO_3 (15.3 g, 111.0 mmol, 2.5 equiv) were dissolved in 90 mL of DMF, and the solution was stirred at 100 °C overnight. Then, the solution was diluted with 300 mL of EtOAc and 300 mL of water. The aqueous layer was washed with 2× 200 mL of EtOAc, and the organic layers were combined and evaporated in vacuo. The crude product was precipitated with 25 mL of EtOAc and 40 mL of PE to yield dimethyl 2,5-bis(allyloxy)terephthalate as a white solid (8.14 g, 26.58 mmol, 61%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.42 (s, 2H), 6.07 (ddt, J = 17.2, 10.2, 4.9 Hz, 2H), 5.64−5.39 (m, 2H), 5.38−5.27 (m, 2H), 4.69−4.57 (m, 4H), 3.93 (s, 6H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 166.1, 151.7, 132.8, 124.8, 117.7, 117.5, 70.6, 52.5.

For saponification of the methyl esters, dimethyl 2,5-bis(allyloxy)-terephthalate (8.14 g, 26.6 mmol, 1 equiv) and KOH (5.96 g, 106 mmol, 4 equiv) were dissolved in 130 mL of THF:MeOH:H_2O (2:1:1), and the solution was stirred overnight at room temperature. Subsequently, the solution was acidified with 15 mL of HCl (37%) then concentrated in vacuo and then diluted again with 200 mL of water and was extracted with 2× 200 mL of EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, filtered, and evaporated in vacuo to give 2,5-bisallyloxyterephthalic acid as a white solid (5.25 g, 18.9 mmol, 71%). ^{1}H NMR (300 MHz, CD_3OD) δ 7.49 (s, 2H), 6.09 (ddt, J = 17.2, 10.3, 5.0 Hz, 2H), 5.61−5.40 (m, 2H), 5.39−5.16 (m, 2H), 4.74−4.61 (m, 4H). ^{13}C {^{1}H} NMR (75 MHz, CD_3OD) δ 168.6, 152.6, 134.2, 126.4, 118.2, 118.0, 71.6.

The synthesis of the bis acid chloride and subsequent transformation into the bis pentafluorophenol ester was conducted by dissolving 2,5-bisallyloxyterephthalic acid (5.25 g, 18.9 mmol, 1 equiv) in 100 mL of dry THF and oxalyl chloride (6.5 mL), and subsequently, a droplet of DMF was added to the solution. The solution was stirred at room temperature overnight. The solution was then concentrated in vacuo, and after which, it was dissolved again in 20 mL of dry THF. The resulting solution was added dropwise to a solution of pentafluorophenol (7.94 g, 56.7 mmol, 3 equiv) and DIPEA (7.90 mL, 45.4 mmol, 2.4 equiv) in 90 mL of dry THF. The solution was stirred at 0 °C for 1 h and at room temperature for 3 h. Subsequently, the solution was concentrated in vacuo and then dissolved in EtOAc and extracted with HCl (1 M), water, saturated $NHCO_3$ solution, and then brine. The organic layer was washed with $MgSO_4$, filtered, and evaporated in vacuo to yield terephthalic ester template **11** as a white solid (8.71 g, 14.3 mmol, 76%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.69 (s, 2H), 6.08 (ddt, J = 17.2, 10.3, 5.0 Hz, 2H), 5.62−5.45 (m, 2H), 5.41−5.27 (m, 2H), 4.82−4.65 (m, 4H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 160.8, 152.7, 132.1, 122.6, 118.4, 118.0, 70.8.

Bis(perfluorophenyl) 2,5-Bis(methoxy)terephthalate (12). Dimethyl 2,5-dihydroxyterephthalate (**10**) (5.40 g, 23.9 mmol, 1 equiv) and K_2CO_3 (9.91 g, 71.7 mmol, 3 equiv) were dissolved in DMF (24 mL), and MeI (6.0 mL, 95.6 mmol, 4 equiv) was added dropwise. The solution was then stirred overnight at room temperature and subsequently diluted with saturated NH_4Cl in H_2O (40 mL) and extracted with 4× 25 mL of CH_2Cl_2. The reunited organic phases were then washed with 3× 75 mL of H_2O and brine, dried over $MgSO_4$, and concentrated in vacuo to give dimethyl 2,5-dimethoxyterephthalate (5.91 g, 23.3 mmol, 97%), which was used without further purification. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (s, 2H), 3.95 (s, 6H), 3.92 (s, 6H). No additional spectral data were acquired (known compound).[14]

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Dimethyl 2,5-dimethoxyterephthalate (5.91 g, 23.3 mmol, 1 equiv) and KOH (5.22 g, 93 mmol, 4 equiv) were dissolved in 180 mL of THF:MeOH:H_2O (4:3:2), and the solution was stirred overnight at room temperature. Subsequently, the solution was acidified to pH 1 with HCl (37%), diluted with 250 mL of ice-cold H_2O, and filtered, and the filtrate was extracted with 3× 150 mL of EtOAc. The reunited organic phases were washed with brine, dried over $MgSO_4$, and concentrated in vacuo, and the residue was triturated with Et_2O to give 2,5-dimethoxyterephthalic acid (3.54 g, 15.6 mmol, 67%). ^{1}H NMR (400 MHz, CD_3OD) δ 7.53 (s, 2H), 3.92 (s, 6H). No additional spectral data were acquired (known compound).[2,3]

2,5-Dimethoxyterephthalic acid (3.54 g, 15.6 mmol, 1 equiv) was suspended in dry THF (200 mL), and DIPEA (11 mL, 62 mmol, 4 equiv), pentafluorophenol (7.18 g, 39.0 mmol, 2.5 equiv), and HBTU (17.8 g, 46.9 mmol, 3 equiv) were added. The resulting mixture was stirred at room temperature overnight then dry-loaded on SiO_2 and purified by column chromatography (Et_2O → Et_2O/EtOAc 5:1). Traces of pentafluorophenol were removed from the final product by trituration with PE, giving terephthalic ester template **12** as a yellow solid (6.00 g, 10.8 mmol, 69%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.69 (s, 2H), 4.01 (s, 6H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 160.6, 153.5, 122.0, 116.3, 56.9. IR (cm^{-1}): 1761, 1729, 1516, 1505, 1468, 1445, 1386, 1328, 1308, 1238, 1201, 1183, 1153, 1090, 1029, 1009, 993, 886, 861, 792, 770, 712, 652, 628, 592, 576, 451. HRMS (FD$^+$) m/z calcd for $C_{22}H_8F_{10}O_6$ (M^+) 558.0156, found 558.0145. mp: 169.6−170.8 °C.

Bis(4-(*tert*-butyl)-2,6-di(hept-6-en-1-yl)phenyl) 2,5-Bis-(hydroxy)terephthalate (13a). Compound **9a** (0.57 g, 1.65 mmol, 2.2 equiv), Cs_2CO_3 (0.73 g, 2.23 mmol, 3.0 equiv), and bis(perfluorophenyl) 2,5-bis(allyloxy)terephthalate **11** (0.45 g, 0.74 mmol, 1.0 equiv) were dissolved in dry CH_3CN (9 mL), and the reaction was stirred overnight at 50 °C under a N_2 atmosphere. The reaction mixture was concentrated in vacuo and purified by column chromatography (PE/CH_2Cl_2 5:1 → 3:1 → 1:1 → 1:2) to give the bisaryl ester (0.616 g, 0.66 mmol, 89%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (s, 2H), 7.12 (s, 4H), 6.08−5.98 (m, 2H), 5.80−5.70 (m, 4H), 5.46 (dd, J = 17.3, 1.7 Hz, 2H), 5.26 (dd, J = 10.6, 1.6 Hz, 2H), 4.97−4.86 (m, 8H), 4.68−4.66 (m, 4H), 2.54 (t, J = 7.9 Hz, 8H), 2.00 (q, J = 6.8 Hz, 8H), 1.62 (q, J = 7.6 Hz, 8H), 1.33 (s, 34H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 164.1, 152.0, 148.7, 145.2, 139.0, 133.9, 132.6, 124.9, 124.6, 118.1, 117.5, 114.4, 70.6, 34.5, 33.8, 32.7, 31.6, 30.9, 30.1, 29.2, 28.8, 27.9, 27.7, 25.3.

The thus-obtained bis arylester (391 mg, 0.422 mmol) was dissolved in dry 1,4-dioxane (4 mL) under a N_2 atmosphere. Et_2NH (0.18 mL, 1.69 mmol, 4.0 equiv) and $Pd(PPh_3)_4$ (24 mg, 0.021 mmol, 0.05 equiv) were added, and the reaction was stirred overnight at room temperature. The mixture was diluted with EtOAc (20 mL) and 1 M HCl (10 mL), and after which, the organic layer was washed with brine (10 mL), dried over $MgSO_4$, concentrated in vacuo, and purified by column chromatography (PE/CH_2Cl_2 7:1 → 5:1) to give **13a** (345 mg, 0.407 mmol, 97%) as a yellow crystalline solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.07 (s, 2H), 7.83 (s, 2H), 7.17 (s, 4H), 5.83−5.73 (m, 4H), 5.01−4.89 (m, 8H), 2.50 (t, J = 7.8 Hz, 8H), 2.03 (q, J = 6.9 Hz, 8H), 1.61 (t, J = 7.7 Hz, 8H), 1.44−1.30 (m, 34H). mp 88.2−92.8 °C. ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 168.1, 153.9, 149.5, 144.5, 138.9, 133.7, 125.1, 118.4, 118.3, 114.4, 34.6, 33.7, 32.7, 31.6, 30.8, 30.1, 29.0, 28.7, 25.3. HRMS (FD$^+$) m/z calcd for $C_{56}H_{78}O_6$ (M^+) 846.5793, found 846.5814.

Bis(4-bromo-2,6-di(hept-6-en-1-yl)phenyl) 2,5-Bis-(methoxy)terephthalate (13b). Compound **9b** (2.60 g, 7.10 mmol, 2 equiv), Cs_2CO_3 (4.63 g, 14.2 mmol, 4 equiv), bis-(perfluorophenyl) 2,5-dimethoxyterephthalate **12** (1.98 g, 3.55 mmol, 1 equiv), and 4 Å molecular sieves (3.5 g) were suspended in dry CH_3CN (70 mL), and the reaction was stirred overnight at 50 °C under a N_2 atmosphere. The reaction mixture was then filtered over celite, concentrated in vacuo, and purified by column chromatography (PE/EtOAc 25:1 → 20:1) to give the bisaryl ester **13b** (2.81 g, 3.06 mmol, 86%) as a colorless oil, which slowly crystallized in the fridge. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.61 (s, 2H), 7.30 (s, 4H), 5.78 (m, 4H), 4.97 (dd, 4H), 4.92 (d, 4H), 3.97 (s, 6H), 2.55 (t, 8H), 2.04 (td, 8H), 1.63 (m, 8H), 1.48−1.27(m, 16H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 163.8, 152.8, 146.5, 138.8, 137.1, 130.5, 123.7, 119.4, 115.6, 114.4, 56.7, 33.6, 30.3, 29.6, 29.0, 28.7. IR (cm^{-1}): 3075, 2926, 2855, 1750, 1720, 1640, 1600, 1572, 1502, 1459, 1394, 1229, 1206, 1151, 1079, 1032, 908, 865. HRMS (FD$^+$) m/z calcd for $C_{50}H_{64}{}^{79}Br^{81}BrO_6$ (M^+) 920.3044, found 920.3057.

Prerotaxane 1. Compound **13a** (1.16 g, 1.37 mmol, 1.0 equiv) was dissolved in dry CH_2Cl_2 (270 mL), and the solution was degassed with five vacuum/N_2 cycles. A Grubbs second-generation catalyst (116 mg, 0.137 mmol, 0.10 equiv) was then added, and the mixture was stirred overnight at 40 °C under a N_2 atmosphere. The ^{1}H NMR spectrum of the crude reaction mixture revealed that approximately 15% terminal alkene was still present. The solution was again degassed with five vacuum/N_2 cycles, 58 mg of Grubbs II was added, and the reaction was stirred overnight at 40 °C under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/CH_2Cl_2 1:1). A colorless oil of 1.06 g was obtained, which was dissolved in dry THF (50 mL), and Pd(C) (400 mg, 10 wt % Pd) was added. H_2 was bubbled through the mixture for 5 min, and the reaction was subsequently stirred overnight at 50 °C under a H_2 atmosphere (balloon). The mixture was filtered and concentrated in vacuo. The residue was triturated in MeOH to give **1** (1.01 g, 1.27 mmol, 93%) as a yellow crystalline solid. Slow evaporation of a saturated solution in MeOH gave crystals that were suitable for X-ray crystallographic analysis. ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.14 (s, 2H), 7.87 (s, 2H), 7.17 (s, 4H), 2.56−2.42 (m, 8H), 1.69−1.64 (m, 4H), 1.35−1.28 (m, 32H), 1.15 (s, 14H), 1.02 (s, 8H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 168.0, 153.6, 149.6, 144.1, 134.2, 125.3, 118.3, 118.0, 34.4, 31.4, 30.4, 30.4, 29.6, 29.2, 28.9, 28.1. HRMS (FD$^+$) m/z calcd for $C_{52}H_{74}O_6$ (M^+) 794.5480, found 794.5497.

Prerotaxane 14. Compound **13b** (2.81 g, 3.06 mmol, 1 equiv) was dissolved in dry CH_2Cl_2 (1500 mL), and the solution was purged with N_2 for 1 h. A Grubbs second-generation catalyst (130 mg, 0.150 mmol, 5 mol %) was then added, and the mixture was purged with N_2 for 15 min before being warmed to 40 °C and stirred for two days. Then, more of the Grubbs second-generation catalyst (65 mg, 0.075 mmol, 2.5 mol %) was added, and the resulting mixture stirred overnight. The reaction mixture was concentrated, and the residue was suspended in boiling EtOAc (10 mL), cooled, and then filtered, affording the macrocyclic prerotaxane tetradehydro **14** (1.42 g, 1.64 mmol, 54%) as a gray powder. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (s, 2H), 7.30 (s, 4H), 5.18 (m, 2H), 5.11 (m, 2H), 3.99 (s, 6H), 2.70−2.36 (m, 8H), 1.95−1.76 (m, 8H), 1.74−1.49 (m, 8H), 1.46−1.15 (m, 16H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 163.3, 153.3, 153.1, 146.5, 137.6, 137.6, 131.0, 130.9, 129.9, 129.7, 123.1, 123.0, 119.4, 116.4, 116.2, 56.6, 32.5, 32.3, 30.1, 28.9, 28.7, 28.4, 28.3. IR (cm^{-1}): 2926, 2853, 1750, 1720, 1572, 1502, 1459, 1395, 1304, 1231, 1207, 1156, 1081. HRMS (FD$^+$) m/z calcd for $C_{46}H_{56}{}^{79}Br^{81}BrO_6$ (M^+) 864.2424, found 864.2385.

Prerotaxane tetradehydro **14** (1.42 g, 1.64 mmol, 1 equiv) was dissolved in dry THF (400 mL) under a N_2 atmosphere, and PtO_2 (56.0 mg, 0.247 mmol, 15 mol %) was added to the resulting solution. The reaction mixture was purged with H_2 for 30 min and stirred for three days at room temperature under a H_2 atmosphere (balloon). Then, further PtO_2 (37.3 mg, 0.165 mmol, 10 mol %) was added, and the reaction was stirred overnight. The mixture was filtered over celite and concentrated in vacuo. The residue was triturated in a 1:1 EtOAc/PE mixture (6 mL) to give prerotaxane **14** (1.31 g, , 92%) as a white solid. mp: 256.6−258.8 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.78 (s, 2H), 7.29 (s, 4H), 4.01 (s, 6H), 2.69−2.35 (m, 8H), 1.72−1.47 (m, 8H), 1.42−1.26 (m, 8H), 1.25−0.90 (m, 24H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 163.2, 153.4, 153.2, 146.6, 137.7, 130.9, 123.3, 123.2, 119.4, 116.6, 116.4, 56.7, 30.0, 29.9, 29.8, 29.4, 29.4, 29.0, 28.9, 28.1. IR (cm^{-1}): 2923, 2852, 1718, 1572, 1502, 1461, 1395, 1302, 1230, 1207, 1154, 1033, 732. HRMS (FD$^+$) m/z calcd for $C_{46}H_{60}{}^{79}Br^{81}BrO_6$ (M^+) 868.2731, found 868.2771.

Prerotaxane 4. Compound **15** (434 mg, 0.500 mmol, 1 equiv) was dissolved in dry CH_2Cl_2 (125 mL) and subsequently cooled to 0 °C. Then, a 1 M BBr_3 solution in CH_2Cl_2 (4.0 mL, 4.0 mmol, 8

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equiv) was added dropwise. Once addition was complete, the mixture was allowed to warm to room temperature and stirred overnight. The mixture was then cooled in an ice/salt bath, and MeOH (25 mL) was added dropwise followed by dilution in MeOH (100 mL) and concentration in vacuo. The residue was reconcentrated from MeOH (125 mL) two more times, giving prerotaxane **4** (416 mg, 0.495 mmol, 99%) as a yellow powder. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.95 (s, 2H), 7.86 (s, 2H), 7.32 (s, 4H), 2.56−2.35 (m, 8H), 1.72−1.46 (m, 8H), 1.41−1.21 (m, 8H), 1.20−0.82 (m, 24H). ^{13}C {^{1}H} NMR spectroscopy of the same sample failed due to the insolubility in $CDCl_3$ leading to a too low concentration. IR (cm^{-1}): 3282, 2920, 2850, 1691, 1572, 1497, 1457, 1358, 1324, 1184, 1149, 1082, 1067, 857, 829, 811, 786, 636, 422. HRMS (FD$^+$) m/z calcd for $C_{44}H_{56}{}^{79}Br^{81}BrO_6$ (M^{+}) 840.2418, found 840.2480.

Prerotaxane 15. Aryl bromide **14** (217 mg, 0.250 mmol, 1 equiv) and phenylboronic acid (122 mg, 1.00 mmol, 4 equiv) were dissolved in THF (10 mL), and the resulting solution was purged with N_2 for 30 min. Then, a degassed 2 M solution of Na_2CO_3 in H_2O (1.9 mL, 3.75 mmol, 15 equiv) was added followed by $Pd(PPh_3)_4$ (28.9 mg, 0.025 mmol, 10 mol %), and the mixture was heated at reflux overnight under a N_2 atmosphere. The mixture was concentrated in vacuo and diluted in CH_2Cl_2 (30 mL), the organic layer was washed with brine, dried over $MgSO_4$, and concentrated in vacuo. The solid residue was triturated with EtOAc/PE (1:1) to give compound prerotaxane **15** (207 mg, 0.239 mmol, 96%) as a brown powder. mp: 285.9−288.2 °C (decomposition). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.85 (s, 2H), 7.63 (d, 4H), 7.47 (t, 4H), 7.41−7.33 (m, 6H), 4.05 (s, 6H), 2.80−2.49 (m, 8H), 1.79−1.56 (m, 8H), 1.46−0.94 (m, 32H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 163.6, 153.4, 153.3, 147.0, 140.9, 139.4, 135.7, 128.7, 127.2, 127.1, 127.03, 127.0, 123.5, 116.6, 116.5, 56.8, 30.3, 30.0, 29.8, 29.7, 29.5, 29.4, 29.2, 29.1, 28.2. IR (cm^{-1}): 2923, 2852, 1712, 1577, 1496, 1462, 1396, 1297, 1229, 1205, 1148, 1105, 1031, 905, 882, 804, 781, 761, 732, 696, 641. HRMS (FD$^+$) m/z calcd for $C_{58}H_{70}O_6$ (M^{+}) 862.5167, found 862.5156.

Prerotaxane 6. Compound **15** (207 mg, 0.239 mmol, 1 equiv) was dissolved in dry CH_2Cl_2 (40 mL) and subsequently cooled to 0 °C. Then, a 1 M BBr_3 solution in CH_2Cl_2 (1.9 mL, 1.9 mmol, 8 equiv) was added dropwise. Once addition was complete, the mixture was allowed to warm to room temperature and stirred overnight. The mixture was then cooled in an ice/salt bath, and MeOH (8 mL) was added dropwise followed by dilution in MeOH (32 mL) and concentration in vacuo. The residue was reconcentrated from MeOH (50 mL) two more times, giving **6** (195 mg, 0.233 mmol, 97%) as a yellow powder. ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.10 (s, 2H), 7.93 (s, 2H), 7.62 (d, 4H), 7.47 (t, 4H), 7.42−7.35 (m, 6H), 2.70−2.46 (m, 8H), 1.80−1.52 (m, 8H), 1.44−1.32 (m, 8H), 1.18 (s, 16H), 1.04 (s, 8H). Due to low solubility, the ^{13}C {^{1}H} NMR spectrum was not obtained. IR (cm^{-1}): 3261, 2921, 2851, 1687, 1497, 1460, 1360, 1324, 1219, 1183, 1146, 1080, 1028, 887, 874, 810, 786, 762, 723, 698, 642, 601, 583, 541, 597. HRMS (FD$^+$) m/z calcd for $C_{56}H_{66}O_6$ (M^{+}) 834.4854, found 834.4887.

Prerotaxane 2. Diol **1** (180 mg, 0.226 mmol, 1.0 equiv), K_2CO_3 (166 mg, 1.20 mmol, 5.3 equiv), and pent-4-yn-1-ylmethanesulfonate (0.133 g, 0.70 mmol, 2.6 equiv) were dissolved in dry DMF (2 mL), and the reaction was stirred for 20 h at 90 °C. The mixture was cooled to room temperature and diluted with Et_2O (60 mL) and H_2O (60 mL). The aqueous layer was extracted twice with Et_2O (20 mL), and the combined organic layers were washed with saturated NH_4Cl (40 mL), twice with H_2O (20 mL), and brine (20 mL). The organic layer was dried over Na_2SO_4 and concentrated in vacuo. The residue was triturated with MeOH to give **2** (173 mg, 0.187 mmol, 82%) as a solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (d, J = 9.4 Hz, 1H), 7.78 (d, J = 8.8 Hz, 1H), 7.16 (s, 4H), 4.31−4.23 (m, 4H), 2.73−2.42 (m, 12H), 2.09 (br m, 4H), 1.96 (s, 2H), 1.65 (br m, 6H), 1.36 (br m, 30H), 1.19 (br m, 16H), 1.04 (br m, 6H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 165.5, 161.7, 148.9, 148.6, 145.3, 134.4, 134.1, 125.2, 123.7, 118.3, 116.9, 83.5, 83.1, 69.1, 68.8, 67.9, 67.7, 34.3, 31.4, 30.5, 30.1, 29.8, 29.5, 29.3, 29.2, 29.0, 28.2, 28.0, 15.1. HRMS (FD$^+$) m/z calcd for $C_{55}H_{90}O_{11}$ (M^{+}) 926.6478, found 926.6470.

Prerotaxane 3. Dry DMF (20 mL) was added to diol **1** (400 mg, 0.503 mmol, 1.0 equiv), 3-azidopropyl methanesulfonate (450 mg, 1.76 mmol, 3.5 equiv), KI (8.4 mg, 0.0506 mmol, 0.10 equiv), and K_2CO_3 (173 mg, 1.25 mmol, 2.5 equiv), and the reaction mixture was stirred overnight at 100 °C. The mixture was cooled to room temperature and diluted with Et_2O (70 mL) and H_2O (70 mL). The aqueous layer was extracted twice with Et_2O (20 mL), and the combined organic layers were washed with saturated NH_4Cl (40 mL), twice with H_2O (20 mL), and with brine (20 mL). The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was triturated in MeOH to give **3** (443 mg, 0.461 mmol, 92%) as a white crystalline solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 (s, 1H), 7.75 (d, J = 7.1 Hz, 1H), 7.16 (s, 4H), 4.32−4.11 (m, 4H), 3.71−3.46 (m, 4H), 2.72−2.35 (m, 8H), 2.12 (br m, 4H), 1.63 (br m, 6H), 1.35 (br m, 30H), 1.19 (br m, 16H), 1.02 (br m, 6H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 165.4, 161.8, 153.4, 153.1, 152.1, 151.8, 149.1, 148.9, 145.3, 144.7, 144.7, 134.5, 134.2, 134.1, 125.4, 125.2, 124.0, 123.6, 118.4, 118.2, 117.0, 116.6, 66.2, 48.1, 48.0, 34.5, 31.6, 30.6, 30.3, 29.9, 29.6, 29.5, 29.5, 29.1, 29.0, 28.9, 28.2. HRMS (FD$^+$) m/z calcd for $C_{58}H_{84}N_6O_6$ (M^{+}) 960.6447, found 960.6400.

Prerotaxane 5. Dry DMF (12.5 mL) was added to diol **4** (210 mg, 0.250 mmol, 1 equiv), 3-azidopropyl methanesulfonate (179 mg, 1.00 mmol, 4 equiv), and K_2CO_3 (345 mg, 2.50 mmol, 10 equiv), and the reaction mixture was stirred overnight at 90 °C. The mixture was cooled to room temperature and diluted with H_2O (25 mL) and EtOAc (25 mL). The aqueous layer was extracted twice with EtOAc (25 mL), and the reunited organic phases were washed with 3× 25 mL of H_2O and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. Purification by column chromatography (PE/EtOAc 19:1 → 9:1) afforded prerotaxane **5** (252 mg, 0.250 mmol, 100%) as a white solid. mp: 171.2−174.5 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 (s, 1H), 7.77 (s, 1H), 7.31 (s, 4H), 4.24 (m, 4H), 3.64 (m, 2H), 3.54 (m, 2H), 2.73−2.32 (m, 8H), 2.12 (m, 4H), 1.71−1.49 (m, 8H), 1.44−0.83 (m, 32H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 164.9, 161.2, 153.5, 153.2, 152.1, 151.8, 146.6, 146.1, 137.7, 137.5, 131.0, 123.6, 123.4, 123.2, 123.0, 119.6, 118.5, 118.2, 116.9, 116.4, 66.1, 47.9, 30.2, 29.9, 29.9, 29.8, 29.7, 29.6, 29.4, 29.0, 28.8, 28.8, 28.7, 28.3, 28.2, 28.0. IR (cm^{-1}): 2922, 2851, 2096, 1745, 1718, 1601, 1572, 1502, 1459, 1411, 1385, 1301, 1264, 1227, 1192, 1048, 730. HRMS (FD$^+$) m/z calcd for $C_{50}H_{66}{}^{79}Br^{81}BrN_6O_6$ (M^{+}) 1006.3385, found 1006.3425.

Prerotaxane 7. Dry DMF (5 mL) was added to diol **6** (195 mg, 0.233 mmol, 1 equiv), 3-azidopropyl methanesulfonate (167 mg, 0.932 mmol, 4 equiv), and K_2CO_3 (322 mg, 2.33 mmol, 10 equiv), and the reaction mixture was stirred overnight at 90 °C. The mixture was cooled to room temperature and diluted with H_2O (25 mL) and CH_2Cl_2 (25 mL). The aqueous layer was extracted twice with CH_2Cl_2 (25 mL), and the reunited organic phases were washed with 3× 25 mL of H_2O and brine. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was triturated with PE/EtOAc (2:1) to give prerotaxane **7** (152 mg, 0.152 mmol, 71%) as a yellow solid. To obtain crystals that were suitable for X-ray diffraction, a concentrated solution of **7** in CH_2Cl_2 was transferred into an NMR tube. A layer of petroleum ether was carefully added on top of this solution. The crystals were grown after slow diffusion of petroleum ether into the CH_2Cl_2 layer. mp: 212.0−214.8 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.94 (s, 1H), 7.84 (s, 0.5H), 7.82 (s, 0.5H), 7.64 (d, 4H), 7.51−7.35 (m, 10H), 4.36−4.23 (m, 4H), 3.73−3.54 (m, 4H), 2.85−2.45 (m, 8H), 2.25−2.06 (m, 4H), 1.80−1.57 (m, 8H), 1.49−0.87 (m, 32H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 165.3, 161.7, 153.5, 153.2, 152.2, 151.9, 147.1, 146.5, 140.8, 139.6, 139.5, 135.7, 135.5, 135.4, 128.7, 127.2, 127.1, 123.8, 123.7, 123.5, 123.3, 118.5, 118.25, 117.0, 116.6, 66.4, 66.3, 66.2, 48.0, 30.5, 30.4, 30.1, 30.0, 29.6, 29.5, 29.2, 29.0, 28.9, 28.4, 28.3, 28.1. IR (cm^{-1}): 2922, 2851, 2095, 1741, 1715, 1598, 1576, 1501, 1461, 1410, 1384, 1346, 1300, 1261, 1222, 1188, 1142, 1106, 1083, 1047, 1007, 971, 908, 883, 830, 781, 762, 729, 697, 669, 648. HRMS (FD$^+$) m/z calcd for $C_{62}H_{76}N_6O_6$ (M^{+}) 1000.5821, found 1000.5802.

5′-(Azidomethyl)-4,4″-di-*tert*-butyl-1,1′:3′,1″-terphenyl A. Carbaldehyde **16**[22] (1.85 g, 5.00 mmol, 1 equiv) was dissolved in

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absolute ethanol (30 mL) and dry THF (30 mL), and the solution was cooled to 0 °C. $NaBH_4$ (378 mg, 10.0 mmol, 2 equiv) was added, and after which, the solution was stirred for 1 h. The reaction mixture was then concentrated in vacuo and partitioned between Et_2O (40 mL) and H_2O (40 mL). The aqueous layer was extracted with Et_2O (20 mL), and after which, the combined organic layers were washed with brine (20 mL), dried over $MgSO_4$, and concentrated in vacuo to give a colorless film. The residue was dissolved in CH_2Cl_2 (30 mL), and the mixture was purged with N_2 for 30 min and cooled to 0 °C. Subsequently, PPh_3 (1.57 g, 6.00 mmol, 1.2 equiv) was added followed by NBS (1.07 g, 6.00 mmol, 1.2 equiv). The reaction mixture was stirred at 0 °C for 30 min then at room temperature for 30 min and concentrated in vacuo. The crude mixture was dry-loaded on silica and purified by column chromatography (PE/EtOAc 200:1 → 100:1) to give the bromide (2.05 g, 4.70 mmol, 94%) as a colorless foam. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.80−7.72 (m, 1H), 7.66−7.56 (m, 6H), 7.52 (d, J = 8.4 Hz, 4H), 4.64 (s, 2H), 1.41 (s, 18H).

The bromide (871 mg, 2.00 mmol, 1 equiv) was dissolved in acetone (16 mL), and after which, a solution of NaN_3 (195 mg, 3.00 mmol, 1.5 equiv) in H_2O (4 mL) was added. The reaction mixture was stirred overnight at room temperature and subsequently diluted with Et_2O (40 mL) and H_2O (40 mL). The aqueous layer was extracted with Et_2O (10 mL), and after which, the combined organic layers were washed with brine (20 mL), dried over $MgSO_4$, and concentrated in vacuo to give **A** (784 mg, 1.97 mmol, 99%) as a thick colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87−7.77 (m, 1H), 7.64 (d, J = 7.1 Hz, 4H), 7.59−7.45 (m, 6H), 4.50 (s, 2H), 1.43 (s, 18H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 150.7, 142.3, 137.8, 136.3, 127.0, 125.9, 125.5, 55.0, 34.6, 31.4. HRMS (FD$^+$) m/z calcd for $C_{27}H_{31}N_3$ ($M^{\cdot+}$) 397.2513, found 397.2525.

4,4″-Di-*tert*-butyl-5′-ethynyl-1,1′:3′,1″-terphenyl B. A solution of CBr_4 (1.51 g, 4.56 mmol, 2 equiv) and PPh_3 (2.39 g, 9.12 mmol, 4 equiv) in dry CH_2Cl_2 (25 mL) under a nitrogen atmosphere was cooled to 0 °C and stirred for 15 min. Carbaldehyde **16** (846 mg, 2.28 mmol, 1 equiv) was added to the yellow solution then the mixture was stirred cooled at 0 °C for 1 h and concentrated in vacuo. The crude mixture was dry-loaded on silica and purified by column chromatography (PE/EtOAc 100:1 → 99:1) to give the dibromovinyl (1.10 g, 2.09 mmol, 92%). The residue was dissolved in dry THF (20 mL) and cooled to −78 °C under a nitrogen atmosphere. Then, BuLi (2.5 M, 2.1 mL, 5.23 mmol, 2.5 equiv) was added slowly to the cooled solution, which was subsequently stirred for 1 h at −78 °C and 1 h at room temperature. The reaction was quenched with H_2O (5 mL), and the aqueous layer was extracted with Et_2O (5 mL). The combined organic layers were washed with H_2O (10 mL) and brine (10 mL), dried over $MgSO_4$, and concentrated in vacuo. The crude mixture was purified by column chromatography (PE/EtOAc 100:0 → 99:1) to give **B** (712 mg, 1.88 mmol, 90%) as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.83 (s, 1H), 7.73 (s, 2H), 7.61 (d, J = 8.5 Hz, 4H), 7.53 (d, J = 8.4 Hz, 4H), 3.16 (s, 1H), 1.42 (s, 18H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 151.0, 141.9, 137.5, 129.4, 127.0, 126.6, 126.0, 122.9, 83.9, 34.7, 31.5. HRMS (FD$^+$) m/z calcd for $C_{28}H_{30}$ ($M^{\cdot+}$) 366.2342, found 366.2354.

Half-Stoppered Prerotaxane a2. Diyne **2** (200 mg, 0.216 mmol, 1.0 equiv), stopper 4,4′,4″-(3-azidopropane-1,1,1-triyl)tris(*tert*-butylbenzene) **a**[14] (42 mg, 0.087 mmol, 0.40 equiv), and TBTA (23 mg, 0.043 mmol, 0.20 equiv) were dissolved in dry CH_2Cl_2 (23 mL), and the solution was degassed with five vacuum/N_2 cycles. $Cu(CH_3CN)_4BF_4$ (14 mg, 0.045 mmol, 0.21 equiv) was added, and the reaction was stirred overnight at room temperature under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/EtOAC 14:1 → 12:1 → 10:1) to give **a2** (57 mg, 0.0405 mmol, 19%) as a white foam. Also, 140 mg of **2** (0.151 mol, 70%) was retrieved (yield brsm 63%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88−7.84 (m, 1H), 7.80−7.69 (m, 1H), 7.31 (d, J = 8.2 Hz, 6H), 7.23 (d, J = 8.4 Hz, 6H), 7.14 (s, 4H), 6.94 (d, J = 9.0 Hz, 1H), 4.22 (t, J = 20.1 Hz, 4H), 4.05 (br m, 2H), 3.20−3.08 (m, 2H), 2.96−2.91 (m, 2H), 2.67 (br m 2H), 2.57−2.43 (m, 8H), 2.27 (br m, 2H), 2.07 (br m, 2H), 1.95 (s, 1H), 1.55 (br m, 4H), 1.33 (br m, 47H), 1.16 (br m, 16H), 1.00 (br m, 6H), 0.88 (br m, 12H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 148.7, 143.1, 134.4, 128.4, 124.9, 54.1, 47.8, 34.3, 34.3, 31.5, 31.3, 30.5, 30.1, 29.8, 29.0, 28.2, 15.1. HRMS (FD$^+$) m/z calcd for $C_{95}H_{129}N_3O_6$ ($M^{\cdot+}$) 1407.9876, found 1407.9941.

Half-Stoppered Prerotaxane A2. Diyne **2** (130 mg, 0.140 mmol, 1.0 equiv), 5′-(azidomethyl)-4,4″-di-*tert*-butyl-1,1′:3′,1″-terphenyl (22 mg, 0.055 mmol, 0.39 equiv), and TBTA (15 mg, 0.028 mmol, 0.20 equiv) were dissolved in dry CH_2Cl_2 (3 mL), and the solution was degassed with five vacuum/N_2 cycles. $Cu(CH_3CN)_4BF_4$ (13 mg, 0.041 mmol, 0.29 equiv) was added, and the reaction was stirred for 18 h at room temperature under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/EtOAc 10:1 → 4:1 → 2:1) to give **A2** (60 mg, 0.0453 mmol, 32%) as a white solid. Also, 66 mg of prerotaxane **2** (0.0712 mmol, 51%) was retrieved (yield brsm **A2** 66%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94−7.66 (m, 3H), 7.54 (d, J = 8.1 Hz, 4H), 7.49 (d, J = 8.3 Hz, 4H), 7.39 (d, J = 15.1 Hz, 2H), 7.20−7.06 (m, 4H), 7.00−6.96 (m, 1H), 5.63−5.49 (m, 2H), 4.22−4.18 (m, 4H), 2.95 (d, J = 21.4 Hz, 2H), 2.49 (br m, 8H), 2.07 (br m, 2H), 1.94 (s, 1H), 1.38 (s, 18H), 1.28 (br m, 40H), 0.91 (br m, 32H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 176.3, 126.8, 126.0, 125.7, 125.2, 125.0, 77.2, 77.1, 76.9, 76.6, 70.4, 69.2, 68.7, 62.9, 47.1, 34.5, 34.3, 31.6, 31.4, 31.2, 30.4, 29.7, 29.6, 29.5, 25.4, 22.5, 13.9, 11.7. HRMS (ESI$^+$) m/z calcd for $C_{89}H_{118}N_3O_6$ [M+H]$^+$ 1324.9015, found 1324.8976.

Half-Stoppered Prerotaxane B3. Diazide **3** (117 mg, 0.127 mmol, 1 equiv), stopper **B** (24.5 mg, 0.051 mmol, 0.4 equiv), and TBTA (13.5 mg, 0.025 mmol, 0.2 equiv) were dissolved in dry CH_2Cl_2 (10 mL), and the solution was purged with N_2 for 30 min. Then, $Cu(CH_3CN)_4BF_4$ (8.0 mg, 0.025 mmol, 0.2 equiv) was added, and the mixture was purged with N_2 for an additional 10 min and stirred overnight at room temperature under a N_2 atmosphere. The crude mixture was dry-loaded on silica (ca. 600 mg) and purified by column chromatography (EtOAc/PE 1:14 → 1:10) to give starting material **3** (68.7 mg, 0.074 mmol, 58%) and mono-stoppered product **B3** (54.4 mg, 0.039 mmol, 30%) as a colorless film. The procedure was repeated on the recovered starting material to afford again **B3** (33.1 mg, 0.023 mmol, 32%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.98−7.67 (m, 2H), 7.36−7.20 (m, 12.5H), 7.20−7.10 (s, 4H), 7.01−6.90 (m, 0.5H), 4.34−3.98 (m, 6H), 3.22−3.09 (m, 2H), 3.04−2.87 (m, 2H), 2.78−2.35 (m, 10H), 2.35−2.21 (m, 2H), 2.15−2.02 (m, 2H), 1.95 (s, 1H), 1.75−1.50 (m, 8H), 1.47−0.82 (m, 77H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 165.6, 165.4, 162.0, 153.2, 152.1, 149.0, 148.8, 146.8, 145.6, 145.4, 144.7, 143.2, 140.6, 134.5, 134.3, 133.9, 128.8, 128.5, 125.5, 125.3, 125.0, 123.9, 123.6, 123.4, 121.1, 120.7, 118.4, 118.2, 116.7, 83.6, 83.2, 69.1, 68.9, 68.7, 68.0, 54.2, 47.9, 40.8, 40.1, 34.6, 34.5, 34.4, 34.4, 32.7, 31.8, 31.7, 31.6, 31.4, 30.6, 30.2, 29.9, 29.7, 29.7, 29.6, 29.3, 29.1, 28.7, 28.3, 25.2, 22.7, 22.1, 15.2, 14.1. IR (cm^{-1}): 3312, 3032, 2955, 2924, 2854, 2098, 1745, 1718, 1599, 1504, 1463, 1410, 1384, 1363, 1303, 1269, 1228, 1199, 1165, 1116, 1088, 1051, 1015, 958, 910, 880, 824, 782, 732, 701, 646, 588, 541. HRMS (FD$^+$) m/z calcd for $C_{95}H_{129}N_3O_6$ ($M^{\cdot+}$) 1407.9876, found 1407.9951.

Half-Stoppered Prerotaxane B5. Diazide **5** (252 mg, 0.250 mmol, 1 equiv), stopper **B** (36.6 mg, 0.100 mmol, 0.4 equiv), and TBTA (26.5 mg, 0.050 mmol, 0.2 equiv) were dissolved in dry CH_2Cl_2 (20 mL), and the solution was purged with N_2 for 30 min. Then, $Cu(CH_3CN)_4BF_4$ (15.7 mg, 0.050 mmol, 0.2 equiv) was added, and the mixture was purged with N_2 for an additional 10 min and stirred overnight at room temperature under a N_2 atmosphere. The crude mixture was dry-loaded on silica (ca. 700 mg) and purified by column chromatography (CH_2Cl_2/PE 1:1 → 7:3 → 8:2 → 9:1 → CH_2Cl_2) to give starting material **5** (152 mg, 0.151 mmol, 60%) and half-stoppered prerotaxane **B5** (82.6 mg, 0.060 mmol, 24%) as a colorless film. The procedure was repeated on the recovered starting material to afford an additional portion of **B5** (64.5 mg, 0.047 mmol, 31%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.03−7.95 (m, 2H), 7.87−7.72 (m, 3H), 7.69−7.50 (m, 9H), 7.34−7.28 (m, 4H), 4.83−4.60 (m, 2H), 4.35−4.14 (m, 4H), 3.69−3.49 (m, 2H), 2.78−2.32 (m, 10H), 2.19−2.06 (m, 2H), 1.75−0.81 (m, 58H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 165.1, 164.8, 162.6, 161.6, 161.1, 154.4, 153.4, 153.1, 152.8,

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152.7, 152.3, 152.0, 151.8, 151.5, 150.6, 147.9, 147.4, 146.6, 146.0, 142.3, 142.1, 138.0, 138.0, 137.7, 137.5, 137.4, 137.0, 131.5, 131.1, 131.0, 130.7, 130.5, 127.0, 125.8, 125.6, 125.4, 123.8, 123.3, 123.2, 122.7, 121.3, 121.2, 120.0, 119.8, 119.6, 119.4, 118.7, 118.4, 118.2, 117.0, 116.9, 116.7, 116. 5, 69.9, 66.3, 65.6, 62.5, 62.2, 48.4, 48.2, 48.0, 47.9, 47.0, 46.6, 34.6, 31.4, 30.2, 30.1, 29.9, 29.8, 29.7, 29.6, 29.4, 29.3, 29.1, 29.1, 28.9, 28.8, 28.3, 28.2, 28.0. IR (cm^{-1}): 2924, 2853, 2098, 1743, 1720, 1599, 1572, 1502, 1460, 1411, 1386, 1302, 1270, 1228, 1195, 1154, 1051, 909, 832, 781, 732. HRMS (FD^+) m/z calcd for $C_{78}H_{96}Br_2N_6O_6$ (M^{+}) 1370.5753, found 1370.5797.

Half-Stoppered Prerotaxane B7. Diazide **7** (152 mg, 152 μmol, 1 equiv), stopper **B** (22.2 mg, 60.6 μmol, 0.4 equiv), and TBTA (16.1 mg, 30.4 μmol, 0.2 equiv) were dissolved in dry CH_2Cl_2 (10 mL), and the solution was purged with N_2 for 30 min. Then, $Cu(CH_3CN)_4BF_4$ (9.6 mg, 30.4 μmol, 0.2 equiv) was added, and the mixture was purged with N_2 for an additional 10 min and stirred overnight at room temperature under a N_2 atmosphere. The crude mixture was dry-loaded on silica (ca. 500 mg) and purified by column chromatography (CH_2Cl_2/PE 8:2 → 9:1 → CH_2Cl_2) to give starting material **7** (76.0 mg, 76.0 μmol, 50%) and mono-stoppered product **B7** (26.9 mg, 20.0 μmol, 13%) as a colorless film. The procedure was repeated on the recovered starting material to afford again **7** (49.1 mg, 49.1 μmol, 65%) and **B7** (32.3 mg, 23.6 μmol, 31%). ^1H NMR (300 MHz, $CDCl_3$) δ 8.07−7.88 (m, 4H), 7.85−7.76 (m, 2H), 7.68−7.59 (m, 8H), 7.58−7.33 (m, 14H), 4.87−4.66 (m, 2H), 4.37−4.19 (m, 4H), 3.71−3.54 (m, 2H), 2.91−2.44 (m, 10H), 2.23−2.08 (m, 2H), 1.81−1.56 (m, 8H), 1.48−0.85 (m, 50H). ^{13}C {^1H} NMR (75 MHz, $CDCl_3$) δ 165.1, 162.1, 161.6, 153.4, 152.7, 150.5, 147.4, 147.1, 146.9, 146.4, 142.1, 140.8, 140.7, 139.8, 139.6, 139.5, 138.0, 135.7, 135.4, 131.5, 128.7, 128.7, 127.2, 127.1, 126.9, 125.7, 125.6, 123.6, 123.2, 117.1, 66.3, 65.5, 48.0, 46.7, 34.6, 31.4, 30.5, 30.4, 30.0, 29.9, 29.7, 29.7, 29.0, 28.9, 28.3, 28.1. IR (cm^{-1}): 2923, 2852, 2097, 1741, 1718, 1597, 1501, 1462, 1410, 1385, 1302, 1268, 1223, 1191, 1145, 1106, 1084, 1051, 968, 883, 831, 803, 782, 762, 735, 699. HRMS (FD^+) m/z calcd for $C_{90}H_{106}N_6O_6$ (M^{+}) 1366.8169, found 1366.8131.

Prerotaxane a2a. Diyne **2** (46 mg, 0.050 mmol), stopper **a** (53 mg, 0.110 mmol, 2.2 equiv), and TBTA (6 mg, 0.010 mmol, 0.20 equiv) were dissolved in dry CH_2Cl_2 (45 mL), and the solution was degassed with five vacuum/N_2 cycles. $Cu(CH_3CN)_4BF_4$ (3 mg, 0.010 mmol, 0.20 equiv) was added, and the reaction was stirred overnight at room temperature under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/EtOAC 14:1 → 12:1 → 10:1) to give **a2a** (53 mg, 0.028 mmol, 56%) as a colorless foam. Spectral data of **a2a** matched those reported in the literature.[14]

[2]Rotaxane a2a (Diacid). Prerotaxane **a2a** (190 mg, 0.100 mmol) was dissolved in 8 mL of Tesser's base (1,4-dioxane/MeOH/2 M NaOH, 3:1:0.1), and the reaction was stirred overnight at 50 °C. The mixture was subsequently diluted with EtOAc (15 mL) and a saturated $KHSO_4$ solution (15 mL). The organic layer was washed with brine (10 mL), dried over $MgSO_4$, and concentrated in vacuo to give [2]rotaxane **a2a** (149 mg, 0.0773 mmol, 77%) as a colorless film. ^1H NMR (400 MHz, $CDCl_3$) δ 7.72 (s, 2H), 7.31 (d, J = 7.9 Hz, 12H), 7.23 (d, J = 8.3 Hz, 12H), 7.15 (s, 2H), 6.98 (s, 4H), 4.21 (t, J = 6.3 Hz, 4H), 4.15−4.02 (m, 4H), 3.22−3.09 (m, 4H), 2.88 (t, J = 7.4 Hz, 4H), 2.61 (t, J = 8.1 Hz, 8H), 2.23 (quint, J = 6.9 Hz, 4H), 1.59−1.48 (m, 8H), 1.30 (br m, 78H), 1.09 (br m, 26H). ^{13}C {^1H} NMR (100 MHz, $CDCl_3$) δ 165.0, 151.3, 149.5, 148.8, 148.8, 145.7, 143.0, 142.6, 129.0, 128.4, 124.9, 124.4, 123.4, 121.2, 117.0, 69.3, 67.0, 54.0, 53.3, 48.1, 40.7, 34.3, 33.9, 31.6, 31.6, 31.3, 31.1, 30.8, 30.5, 29.6, 29.6, 29.3, 29.2, 29.1, 28.5, 21.4. MS (FD^+) m/z calcd for $C_{128}H_{176}N_6O_8$ (M^{+}) 1925.4, found 1925.4.

Prerotaxane A2A. Diyne **2** (50 mg, 0.0539 mmol, 1.0 equiv), stopper **A** (47 mg, 0.118 mmol, 2.2 equiv), and TBTA (6 mg, 0.011 mmol, 0.20 equiv) were dissolved in dry CH_2Cl_2 (10 mL), and the solution was degassed with five vacuum/N_2 cycles. $Cu(CH_3CN)_4BF_4$ (4 mg, 0.013 mmol, 0.24 equiv) was added, and the reaction was stirred overnight at room temperature under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/EtOAC 5:1 → 4:1 → 3:1→ 1:1) to give **A2A** (47 mg, 0.273 mmol, 51%) as a yellow solid. ^1H NMR (400 MHz, $CDCl_3$) δ 7.84−7.66 (m, 4H), 7.55 (d, J = 8.2 Hz, 8H), 7.50 (d, J = 8.2 Hz, 8H), 7.40 (d, J = 14.9 Hz, 4H), 7.11 (d, J = 15.2 Hz, 4H), 6.98 (d, J = 15.7 Hz, 2H), 5.63−5.46 (m, 4H), 4.30−4.16 (m, 4H), 3.06−2.85 (m, 4H), 2.68−2.23 (m, 12H), 1.39 (s, 36H), 1.29 (br m, 34H), 1.12 (br m, 12H), 0.93 (br m, 12H). ^{13}C {^1H} NMR (100 MHz, $CDCl_3$) δ 176.3, 153.2, 152.9, 152.0, 151.8, 150.8, 150.7, 148.9, 148.7, 147.7, 147.5, 145.3, 144.6, 144.6, 142.4, 137.4, 137.4, 135.7, 135.7, 134.4, 134.2, 134.1, 126.8, 126.0, 125.7, 125.2, 125.2, 125.0, 79.4, 69.8, 68.9, 68.8, 68.6, 68.4, 34.7, 34.5, 34.3, 34.0, 33.7, 31.9, 31.7, 31.6, 31.4, 31.3, 31.1, 30.4, 30.3, 30.0, 29.7, 29.6, 29.6, 29.6, 29.5, 29.4, 29.4, 29.3, 29.1, 29.0, 28.9, 28.8, 28.4, 28.4, 28.2, 28.1, 28.0, 27.9, 25.4, 23.8, 23.1, 22.6, 22.3, 22.2, 22.1, 22.0, 14.6, 14.1. HRMS (FD^+) m/z calcd for $C_{116}H_{148}N_6O_6$ (M^{+}) 1721.1455, found 1721.1524.

[2]Rotaxane A2A (Diacid). Prerotaxane **A2A** (71 mg, 0.0412 mmol) was dissolved in 4 mL of Tesser's base (1,4-dioxane/MeOH/2 M NaOH, 3:1:0.1), and the reaction was stirred overnight at 50 °C. The mixture was subsequently diluted with EtOAc (10 mL) and a saturated $KHSO_4$ solution (10 mL). The organic layer was washed with brine (10 mL), dried over $MgSO_4$, and concentrated in vacuo to give [2]rotaxane **A2A** (64 mg, 0.0364 mmol, 88%) as a yellow solid. ^1H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, J = 6.8 Hz, 2H), 7.69 (d, J = 12.2 Hz, 2H), 7.62−7.30 (m, 26H), 7.01 (s, 4H), 5.63−5.53 (m, 4H), 4.35−4.20 (m, 6H), 2.95−2.87 (m, 4H), 2.65−2.57 (m, 8H), 2.37−2.23 (m, 4H), 1.74−1.43 (m, 12H), 1.43−1.10 (m, 54H), 1.09−0.76 (m, 24H). ^{13}C {^1H} NMR (125 MHz, $CDCl_3$) δ 176.4, 165.0, 151.4, 151.4, 151.0, 150.9, 149.6, 146.5, 146.4, 142.7, 142.6, 142.6, 137.4, 135.4, 128.9, 127.4, 126.9, 126.9, 126.2, 126.1, 125.9, 125.9, 125.6, 125.5, 124.7, 124.5, 123.4, 123.4, 121.5, 121.3, 117.2, 117.1, 70.6, 69.6, 69.5, 69.4, 63.1, 54.4, 54.3, 47.2, 34.6, 34.5, 34.0, 32.0, 31.7, 31.7, 31.7, 31.6, 31.4, 31.1, 30.8, 30.7, 30.6, 30.4, 30.0, 29.7, 29.7, 29.6, 29.6, 29.5, 29.4, 29.3, 29.2, 29.1, 29.1, 29.0, 28.4, 28.3, 25.5, 25.3, 22.7, 22.7, 22.1, 21.7, 14.2, 14.0, 11.8. HRMS (ESI^+) m/z calcd for $C_{116}H_{154}N_6O_8$ $[M + 2H]^{2+}$ 879.5909, found 879.5972.

Prerotaxane B3B. Diazide **3** (75 mg, 0.0759 mmol, 1.0 equiv), stopper **B** (73 mg, 0.20 mmol, 2.6 equiv), and TBTA (15 mg, 0.028 mmol, 0.37 equiv) were dissolved in dry CH_2Cl_2 (3 mL), and the solution was degassed with five vacuum/N_2 cycles. $Cu(CH_3CN)_4BF_4$ (13 mg, 0.041 mmol, 0.54 equiv) was added, and the reaction was stirred overnight at room temperature under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/EtOAC 5:1 → 4:1 → 3:1→ 1:1) to give **B3B** (91.3 mg, 0.0531 mmol, 70%) as glass. ^1H NMR (400 MHz, $CDCl_3$) δ 8.09−7.93 (m, 5H), 7.93−7.72 (m, 4H), 7.65 (d, J = 6.9 Hz, 8H), 7.54 (d, J = 7.2 Hz, 8H), 7.18 (s, 4H), 4.88−4.63 (m, 4H), 4.39−4.13 (m, 4H), 2.81−2.39 (m, 12H), 1.61 (br m, 11H), 1.43 (s, 35H), 1.38 (s, 14H), 1.31 (br m, 11H), 0.95 (br m, 23H). ^{13}C {^1H} NMR (100 MHz, $CDCl_3$) δ 162.1, 152.7, 150.5, 149.3, 147.4, 145.1, 144.5, 142.3, 142.1, 138.1, 134.4, 131.6, 127.0, 125.8, 125.6, 125.4, 123.7, 123.2, 121.4, 116.9, 65.3, 46.7, 34.6, 34.5, 31.6, 31.4, 30.5, 29.7, 29.6, 29.0, 28.3. HRMS (ESI^+) m/z calcd for $C_{114}H_{144}KN_6O_6$ $[M+K]^+$ 1732.0779, found 1732.0799.

[2]Rotaxane B3B (Tetramethylester). Prerotaxane **B3B** (72.0 mg, 0.0419 mmol) was dissolved in a mixture of dioxane (4 ml) and methanol (1 ml), a solution of NaOH (40 mg) in water (0.5 ml) was added, and the reaction was stirred at 50 °C for 72 h. The mixture was subsequently diluted with EtOAc (10 mL) and a saturated $KHSO_4$ solution (10 mL). The organic layer was washed with brine (10 mL), dried over $MgSO_4$, and concentrated in vacuo to give the diacid, which was immediately converted to a diester. A solution of HCl in MeOH (prepared from 8 mL of MeOH and 1.5 mL of acetyl chloride at 50 °C) was added, and the solution was stirred at 50 °C for 5 h. The reaction mixture was concentrated in vacuo, and the residue was co-evaporated with MeOH (3× 5 ml) and purified by flash chromatography (PE/EtOAc 3:1 and 2:1) to give **B3B** (37.2 mg, 0.0211 mmol, 51%) as glass. ^1H NMR (400 MHz, $CDCl_3$) δ 8.24 (s, 2H), 8.03 (s, 4H), 7.75 (s, 2H), 7.51 (d, J = 8.1 Hz, 8H), 7.46−7.33 (m, 10H), 7.16 (s, 2H), 7.04 (s, 4H), 4.78 (t, J = 6.7 Hz, 4H), 4.06 (t, J = 5.6 Hz, 4H), 3.86 (s, 6H), 2.63 (t, J = 8.2 Hz, 8H), 2.55 (t, J = 6.1

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Hz, 4H), 1.59−1.44 (m, 9H), 1.38 (s, 34H), 1.35 (s, 18H), 1.15 (t, J = 7.4 Hz, 8H), 1.00−0.77 (m, 25H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 165.4, 151.8, 150.4, 149.8, 147.6, 142.6, 142.2, 138.0, 131.1, 129.3, 127.0, 125.8, 125.7, 124.5, 124.2, 123.3, 121.3, 116.6, 65.6, 52.5, 46.9, 34.6, 34.0, 31.8, 31.4, 31.3, 30.7, 29.8, 29.5, 29.4, 29.0, 29.0. HRMS (ESI$^+$) m/z calcd for $C_{116}H_{153}N_6O_8$ $[M+H]^+$ 1758.1744, found 1758.1764.

Prerotaxane a2A. Half-stoppered prerotaxane **a2** (54.9 mg, 0.0390 mmol, 1 equiv), stopper **A** (0.0186 g, 0.0468 mmol, 1.2 equiv), and TBTA (4.13 mg, 0.00779 mmol, 0.2 equiv) were dissolved in 5 mL of dry DCM, and then $Cu(CH_3CN)_4BF_4$ (2.45 mg, 0.00779 mmol, 0.2 equiv) was added. The solution was stirred at room temperature under a N_2 atmosphere overnight. The solution was concentrated in vacuo, and the crude product was purified by column chromatography (PE/EtOAc 9:1 → 7:1 → 5:1) to yield prerotaxane **a2A** as a colorless film (0.039 g, 0.0216 mmol, 56%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92−7.65 (m, 4H), 7.56 (d, J = 8.3 Hz, 4H), 7.50 (d, J = 8.1 Hz, 4H), 7.40 (d, J = 15.3 Hz, 2H), 7.31 (d, J = 8.2 Hz, 6H), 7.24 (d, J = 8.2 Hz, 6H), 7.19−7.06 (m, 4H), 7.05−6.88 (m, 1H), 5.55−5.44 (m, 2H), 4.34−4.12 (m, 4H), 4.12−3.97 (m, 2H), 3.15 (t, J = 8.4 Hz, 2H), 3.06−2.82 (m, 4H), 2.79−2.17 (m, 12H), 1.60 (br m, 12H), 1.34 (m, 68H), 1.08 (br m, 24H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 148.7, 143.1, 142.4, 137.4, 128.3, 126.8, 126.0, 125.7, 125.2, 124.8, 54.0, 47.8, 34.5, 34.3, 34.2, 31.4, 31.2, 30.4, 30.0, 29.6, 29.5, 29.0, 28.0. HRMS (FD$^+$) m/z calcd for $C_{122}H_{160}N_6O_6$ ($M^{\cdot+}$) 1805.2394, found 1805.2477.

[2]Rotaxane a2A (Diacid). Prerotaxane **a2A** (39 mg, 0.216 mmol) was dissolved in 2 mL of Tesser's base (1,4-dioxane/MeOH/2 M NaOH, 3:1:0.1), and the reaction was stirred overnight at 50 °C. The mixture was subsequently diluted with EtOAc (10 mL) and a saturated $KHSO_4$ solution (10 mL). The organic layer was washed with brine (5 mL), dried over $MgSO_4$, and concentrated in vacuo to give [2]rotaxane **a2A** (38 mg, 0.0206 mmol, 96%) as a colorless film. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81−7.79 (m, 2H), 7.72 (m, 2H), 7.61−7.41 (m, 11H), 7.31 (d, J = 8.0 Hz, 6H), 7.23 (d, J = 8.2 Hz, 6H), 6.99 (s, 4H), 5.63 (s, 2H), 5.54−5.43 (m, 2H), 4.30−4.15 (m, 4H), 4.14−4.03 (m, 2H), 3.23−3.10 (m, 2H), 2.99−2.78 (m, 4H), 2.65−2.53 (m, 6H), 2.23 (s, 4H), 1.58−1.42 (m, 6H), 1.42−1.14 (m, 75H), 1.14−0.65 (m, 24H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$ δ 164.9, 164.7, 151.3, 151.3, 150.9, 150.8, 149.5, 149.4, 149.3, 148.8, 143.0, 142.6, 142.5, 142.4, 137.3, 128.8, 128.3, 126.8, 125.8, 125.7, 125.5, 124.9, 124.4, 124.4, 121.1, 117.0, 117.0, 69.6, 69.3, 67.0, 64.3, 54.2, 54.1, 54.0, 53.3, 48.1, 40.7, 34.5, 34.2, 33.9, 31.6, 31.2, 31.0, 30.4, 29.6, 29.3, 29.1, 29.0, 29.0, 24.7, 22.6. MS (FD$^+$) m/z calcd for $C_{122}H_{164}N_6O_8$ ($M^{\cdot+}$) 1841.3, found 1841.3.

Prerotaxane A23B. Compound **A2** (54.5 mg, 0.0411 mmol, 1.0 equiv), **B3** (110 mg, 2 equiv), and TBTA (15 mg, 0.028 mmol, 0.68 equiv) were dissolved in dry CH_2Cl_2 (3 mL), and the solution was degassed with five vacuum/N_2 cycles. $Cu(CH_3CN)_4BF_4$ (13 mg, 0.041 mmol, 1.0 equiv) was added, and the reaction was stirred for 18 h at room temperature under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/EtOAc 8:1 → 5:1 → 2:1) to give **A23B** (60.5 mg, 0.0228 mmol, 55%) as glass. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02−7.31 (m, 26H), 7.24−7.18 (m, 2H), 7.18−7.06 (m, 8H), 7.04−6.89 (m, 1H), 5.54−5.49 (m, J = 2H), 4.88−4.69 (m, 2H), 4.64−4.44 (m, 2H), 4.27 (t, J = 4.9 Hz, 12H), 4.18 (br m, 6H), 2.91 (br m, 4H), 2.53 (br m, 18H), 1.49 (br m, 8H), 1.39 (br m, 18H), 1.29 (br m, 72H), 1.12 (br m, 18H), 0.91 (br m, 32H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 176.4, 142.5, 138.0, 134.4, 128.4, 127.9, 126.9, 126.1, 125.8, 125.7, 125.2, 125.1, 123.2, 79.5, 70.6, 69.8, 69.4, 63.0, 47.2, 46.8, 34.6, 34.4, 34.1, 31.9, 31.7, 31.5, 31.4, 31.4, 31.4, 30.5, 30.2, 29.7, 29.7, 29.6, 29.4, 29.1, 28.3, 25.5, 23.1, 22.7, 22.6, 21.7, 21.4, 19.3, 19.2, 19.0, 19.0, 17.8, 14.1, 14.0, 11.8. HRMS (ESI$^+$) m/z calcd for $C_{175}H_{233}N_9O_{12}$ $[M + 2H)]^{2+}$ 1326.8961, found 1326.8928.

[3]Rotaxane A23B (Tetramethylester). Prerotaxane **A23B** (30 mg, 0.0113 mmol) was dissolved in a mixture of dioxane (4 mL) and methanol (1 mL), a solution of NaOH (40 mg) in water (0.5 ml) was added, and the reaction was stirred at 50 °C during 72 h. The mixture was subsequently diluted with EtOAc (10 mL) and a saturated $KHSO_4$ solution (10 mL). The organic layer was washed with brine (5 mL), dried over Na_2SO_4, and concentrated in vacuo to give the diacid, which was immediately converted to the diester. A solution of HCl in MeOH (prepared from 8 mL of MeOH and 1.5 mL of acetyl chloride at 50 °C) was added, and the solution was stirred at 50 °C for 5 h. The reaction mixture was concentrated in vacuo, and the residue was co-evaporated with MeOH (3× 5 mL) and purified by flash chromatography (PE/EtOAc 3:1 and 2:1) to give [3]rotaxane **A23B** (16.1 mg, 0.00579 mmol, 51%) as glass.^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 (s, 1H), 8.06−7.96 (m, 2H), 7.77 (s, 1H), 7.73 (s, 1H), 7.51 (d, J = 8.3 Hz, 4H), 7.49−7.44 (m, 7H), 7.44−7.41 (m, 2H), 7.41−7.30 (m, 10H), 7.11 (s, 2H), 7.01 (s, 4H), 6.99 (s, 4H), 5.45 (s, 2H), 4.77 (t, J = 6.8 Hz, 2H), 4.53 (t, J = 6.8 Hz, 2H), 4.17−3.94 (m, 8H), 3.84 (s, 3H), 3.82 (s, 3H), 3.74 (s, 3H), 3.73 (s, 3H), 2.98−2.85 (m, 4H), 2.78−2.48 (m, 18H), 2.41−2.31 (m, 2H), 2.27−2.11 (m, 4H), 1.62−1.46 (m, 20H), 1.38 (s, 18H), 1.36 (s, 18H), 1.32 (s, 18H), 1.30 (s, 20H), 1.27−1.13 (m, 16H), 1.13−0.82 (m, 42H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 165.8, 165.7, 165.3, 165.1, 151.8, 151.7, 150.7, 150.2, 149.8, 149.7, 147.5, 147.4, 146.9, 142.5, 142.3, 142.0, 137.8, 137.4, 135.6, 130.8, 129.1, 128.9, 126.8, 125.9, 125.7, 125.6, 125.4, 124.3, 124.2, 124.1, 124.0, 123.2, 121.7, 121.3, 121.1, 116.7, 116.6, 77.2, 77.1, 76.9, 76.6, 68.8, 66.0, 65.6, 54.0, 52.4, 52.2, 52.1, 46.9, 46.7, 34.5, 34.4, 33.9, 33.8, 31.8, 31.6, 31.3, 31.2, 31.1, 30.5, 30.4, 29.8, 29.7, 29.6, 29.5, 29.4, 29.3, 29.2, 29.0, 28.9, 22.6, 22.0, 21.9, 14.0. HRMS (ESI$^+$) m/z calcd for $C_{179}H_{247}N_9O_{16}$ ($M^{\cdot+}$) 2779.8819, found 2779.8762.

Prerotaxane a2L2a. Prerotaxane **1** (110 mg, 0.0779 mmol, 2.2 equiv), linker **L** (6.67 mg, 0.0354 mmol, 1 eq), and TBTA (3.76 mg, 0.00708 mmol, 0.2 equiv) were dissolved in 10 mL of dry DCM, and then $Cu(CH_3CN)_4BF_4$ (2.23 mg, 0.00708 mmol, 0.2 equiv) was added to the solution. The solution was stirred at room temperature under a N_2 atmosphere overnight. Subsequently, the solution was concentrated in vacuo, and the crude product was purified by column chromatography to yield prerotaxane **a2L2a** as a white film (0.0790 g, 0.0263 mmol, 74%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91−7.79 (m, 2H), 7.77−7.63 (m, 2H), 7.31 (d, J = 8.3 Hz, 12H), 7.24 (d, J = 8.5 Hz, 12H), 7.21−6.89 (m, 16H), 5.47−5.27 (m, 4H), 4.32−4.12 (m, 8H), 4.12−3.93 (m, 4H), 3.16 (t, J = 8.3 Hz, 4H), 3.05−2.82 (m, 8H), 2.79−2.12 (m, 24H), 1.59 (br m, 16H), 1.34 (m, 110H), 1.06 (br m, 44H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 148.7, 143.1, 134.4, 128.3, 124.8, 68.6, 54.0, 53.3, 47.8, 40.7, 34.3, 34.2, 31.4, 31.2, 30.5, 30.1, 29.8, 29.6, 29.4, 28.9, 28.2, 28.0, 23.8, 22.0. HRMS (ESI$^+$) m/z calcd for $C_{198}H_{266}N_{12}O_{12}Na$ $[M + Na]^+$ 3027.0465, found 3027.0744.

[3]Rotaxane a2L2a (Tetraacid). Prerotaxane **a2L2a** (71 mg, 0.0236 mmol) was dissolved in 7 mL of Tesser's base (1,4-dioxane/MeOH/2 M NaOH, 3:1:0.1), and the reaction was stirred overnight at 50 °C. The mixture was subsequently diluted with EtOAc (10 mL) and a saturated $KHSO_4$ solution (10 mL). The organic layer was washed with brine (5 mL), dried over $MgSO_4$, and concentrated in vacuo to give **20** (65 mg, 0.0211 mmol, 89%) as an off-white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (s, 2H), 7.67 (s, 2H), 7.62 (s, 1H), 7.34−7.29 (m, 11H), 7.22 (d, J = 8.2 Hz, 14H), 7.19−7.11 (m, 6H), 6.98 (s, 8H), 5.46−5.32 (m, 4H), 4.30−4.14 (m, 8H), 4.13−4.01 (m, 4H), 3.22−3.03 (m, 4H), 2.99−2.82 (m, 8H), 2.64−2.56 (m, 12H), 2.30−2.19 (m, 8H), 2.02−1.54 (m, 12H), 1.52−1.37 (m, 12H), 1.37−1.19 (m, 106H), 1.19−0.83 (m, 44H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 165.1, 164.9, 151.3, 151.3, 149.4, 148.8, 146.4, 145.6, 143.0, 142.6, 142.6, 135.1, 128.9, 128.8, 128.6, 128.3, 124.9, 124.4, 69.4, 69.2, 67.0, 54.0, 53.4, 48.1, 40.7, 34.2, 33.9, 31.6, 31.5, 31.2, 31.0, 30.5, 29.6, 29.3, 29.2, 29.1, 29.0, 21.5, 21.4. MS (ESI$^+$) m/z calcd for $C_{198}H_{278}N_{12}O_{16}$ $[M + 2H]^{2+}$ 1540.1, found 1540.1

Prerotaxane a25B. The half-stoppered prerotaxanes **B5** (85.3 mg, 62.1 μmol, 1 equiv), **a2** (87.5 mg, 62.1 μmol, 1 equiv), and TBTA (6.6 mg, 12.4 μmol, 0.2 equiv) were dissolved in dry CH_2Cl_2 (15 mL), and the solution was purged with N_2 for 30 min. Then, $Cu(CH_3CN)_4BF_4$ was added, and the mixture was purged with N_2 for an additional 10 min and stirred overnight at room temperature under a N_2 atmosphere. The crude mixture was dry-loaded on silica and purified by column chromatography (CH_2Cl_2/PE/Et_2O 6.7:3.3:0.5 →

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5:5:0.5) to give **a25B** (126 mg, 45.3 μmol, 73%) as a colorless film. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.03−7.95 (m, 3H), 7.91−7.50 (m, 13.5H), 7.42−7.07 (m, 21H), 6.98−6.92 (m, 0.5H), 4.83−4.71 (m, 1H), 4.70−4.40 (m, 3H), 4.33−4.00 (m, 10H), 3.22−3.11 (m, 2H), 3.04−2.83 (m, 4H), 2.78−2.15 (m, 24H), 1.72−1.50 (m, 16H), 1.46−0.81 (m, 127H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 164.6, 161.6, 161.3, 153.1, 152.9, 152.1, 150.6, 148.8, 147.4, 147.09, 146.5, 145.9, 145.4, 143.2, 142.3, 142.2, 138.0, 137.6, 137.4, 134.5, 134.3, 131.5, 131.1, 131.1, 128.5, 126.9, 125.8, 125.6, 125.3, 125.0, 123.7, 123.5, 123.2, 121.3, 121.1, 119.8, 119.7, 118.0, 118.3, 117.0, 116.5, 85.3, 84.9, 82.7, 68.8, 66.4, 65.6, 54.2, 47.9, 46.6, 40.9, 40.8, 37.1, 36.7, 34.6, 34.4, 34.4, 31.6, 31.4, 31.4, 30.6, 30.1, 29.9, 29.7, 29.6, 29.5, 29.4, 29.1, 28.8, 28.7, 28.2, 25.2, 23.9, 22.7, 22.7, 22.1, 20.9, 20.6, 17.5, 17.3, 14.7, 14.2, 14.1, 8.0. IR (cm^{-1}): 2954, 2923, 2853, 1742, 1720, 1599, 1572, 1503, 1461, 1410, 1385, 1363, 1303, 1270, 1226, 1197, 1161, 1114, 1086, 1052, 954, 909, 881, 831, 803, 781, 732. HRMS (ESI$^+$) *m*/*z* calcd for $C_{172}{}^{13}CH_{225}Br_2N_9O_{12}$ ($M^{\cdot+}$) 2780.5661, found 2780.5746.

[3]Rotaxane a25B (Tetraester). Prerotaxane **a25B** (21.6 mg, 7.76 μmol, 1 equiv) was dissolved in a mixture of dioxane (3.1 mL) and methanol (1.1 mL), a 4 M solution of NaOH in water (194 μL, 0.780 mmol, 100 equiv) was added, and the reaction was stirred at room temperature overnight. The mixture was subsequently diluted with EtOAc (10 mL) and a 1 M $KHSO_4$ solution (10 mL). The aqueous layer was extracted twice with EtOAc (10 mL), and the reunited organic phases were washed with brine, dried over $MgSO_4$, and concentrated in vacuo to give the tetraacid, which was immediately converted to the tetramethylester. A solution of HCl in MeOH (prepared from 8 mL of MeOH and 1.5 mL of acetyl chloride) was added, and the solution was stirred at 50 °C during 4 h. The reaction mixture was concentrated in vacuo, and the residue was co-evaporated with MeOH (3× 5 mL) and purified by column chromatography (CH_2Cl_2/Et_2O 19:1 → 9:1 → 8:2) to give [3]rotaxane **a25B** (9.6 mg, 3.30 μmol, 43%) as a colorless film. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.33 (s, 1H), 7.90 (s, 2H), 7.73 (s, 2H), 7.43−7.25 (m, 17H), 7.25−7.15 (m, 7H), 7.16−7.09 (m, 5H), 6.97 (s, 4H), 4.80 (t, 2H), 4.54 (s, 2H), 4.18−3.93 (m, 10H), 3.90−3.67 (m, 12H), 3.13 (s, 2H), 2.92 (s, 4H), 2.80−2.53 (m, 14H), 2.52−2.11 (m, 10H), 1.50−1.47 (m, 8H), 1.38 (s, 18H), 1.31 (s, 27H), 1.28 (s, 18H), 1.22−0.80 (m, 64H). IR (cm^{-1}): 2924, 2853, 1719, 1505, 1461, 1437, 1408, 1386, 1363, 1307, 1237, 1203, 1103, 1040, 975, 909, 877, 831, 791, 732, 649, 588. HRMS (FD$^+$) *m*/*z* calcd for $C_{177}H_{242}{}^{81}Br{}^{81}BrN_9O_{16}$ [M+H]$^+$ 2911.68, found 2911.59. Only two digits are given because the peak chosen consists of several isotopic components.

Prerotaxane a27B. Synthesis by late-stage Suzuki cross coupling: aryl bromide **a25B** (27.6 mg, 9.91 μmol, 1 equiv) and phenylboronic acid (9.7 mg, 79.3 μmol, 8 equiv) were dissolved in THF (3 mL), and the resulting solution was purged with N_2 for 30 min. Then, a degassed 2 M solution of Na_2CO_3 in H_2O (79 μL, 159 μmol, 16 equiv) was added followed by $Pd(PPh_3)_4$ (2.3 mg, 1.98 μmol, 20 mol %), and the mixture was heated at 120 °C in a sealed pressure vessel for three days. The mixture was concentrated in vacuo and diluted in CH_2Cl_2 (10 mL) and H_2O (10 mL), the aqueous layer was extracted with 2× 10 mL of CH_2Cl_2, and the reunited organic phases were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Purification by column chromatography (CH_2Cl_2/PE/Et_2O 6.7:3.3:0.5 → 5:5:0.5 → 5:5:1) to give **a27B** (11.7 mg, 4.21 μmol, 43%) as a film. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.09−7.97 (m, 3H), 7.95−7.72 (m, 5H), 7.70−7.60 (m, 8H), 7.60−7.23 (m, 28H), 7.20−7.11 (m, 4.5H), 7.00−6.94 (m, 0.5H), 4.88−4.44 (m, 4H), 4.39−4.01 (m, 10H), 3.23−3.14 (m, 2H), 3.04−1.98 (m, 28H), 1.75−1.52 (m, 16H), 1.48−0.83 (m, 127H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 165.6, 165.0, 162.1, 161.7, 153.4, 153.1, 152.9, 152.0, 150.6, 148.9, 147.5, 147.1, 146.9, 146.4, 145.5, 144.7, 143.2, 142.2, 140.7, 139.8, 139.7, 138.0, 135.7, 135.4, 134.5, 134.3, 131.6, 131.3, 128.7, 128.5, 127.2, 127.2, 127.0, 125.8, 125.0, 123.8, 123.2, 121.4, 121.1, 118.7, 118.4, 117.0, 116.6, 85.2, 84.8, 82.6, 68.8, 66.3, 65.5, 54.2, 47.9, 46.7, 41.0, 40.8, 34.6, 34.4, 34.4, 31.6, 31.4, 31.4, 30.6, 30.5, 30.3, 29.9, 29.8, 29.8, 29.7, 29.0, 28.4, 28.1, 24.0, 22.8, 22.7, 22.2, 20.9, 17.6, 17.3, 14.7, 14.2, 14.1, 8.0. IR (cm^{-1}): 2953, 2923, 2853, 1741, 1719, 1598, 1550, 1503, 1462, 1410, 1384, 1363, 1303, 1269, 1225, 1196, 1164, 1147, 1114, 1086, 1052, 954, 909, 882, 832, 803, 782, 763, 732. HRMS (ESI$^+$) *m*/*z* calcd for $C_{189}H_{251}N_9O_{16}Na$ [M+Na]$^+$ 2925.9002, found 2925.8881.

Synthesis by coupling of prerotaxanes **a2** and **B7**: the half-stoppered prerotaxanes **B7** (59.2 mg, 43.3 μmol, 1 equiv), **a2** (65.5 mg, 46.5 μmol, 1.07 equiv), and TBTA (4.6 mg, 8.67 μmol, 0.2 equiv) were dissolved in dry CH_2Cl_2 (10 mL), and the solution was purged with N_2 for 30 min. Then, $Cu(CH_3CN)_4BF_4$ (2.7 mg, 8.67 μmol, 0.2 equiv) was added, and the mixture was purged with N_2 for an additional 10 min and stirred overnight at room temperature under a N_2 atmosphere. The crude mixture was dry-loaded on silica (ca. 400 mg) and purified by column chromatography (CH_2Cl_2/PE/Et_2O 6.7:3.3:0.5 → 5:5:0.5 → 5:5:1) to give **a27B** (110 mg, 39.8 μmol, 92%) as a colorless film.

[3]Rotaxane a27B (Tetramethylester). Prerotaxane **a27B** (49.4 mg, 17.8 μmol, 1 equiv) was dissolved in a mixture of dioxane (3.1 mL) and methanol (1.1 mL), a 4 M solution of NaOH in water (220 μL, 0.890 mmol, 50 equiv) was added, and the reaction was stirred at room temperature overnight. The mixture was subsequently diluted with EtOAc (10 mL) and a 1 M $KHSO_4$ solution (10 mL). The aqueous layer was extracted twice with EtOAc (10 mL), and the reunited organic phases were washed with brine, dried over $MgSO_4$, and concentrated in vacuo to give the tetraacid, which was immediately converted to the tetramethylester. A solution of HCl in MeOH (prepared from 8 mL of MeOH and 1.5 mL of acetyl chloride) was added, and the solution was stirred at 50 °C during 4 h. The reaction mixture was concentrated in vacuo, and the residue was co-evaporated with MeOH (3× 5 mL) and purified by column chromatography (CH_2Cl_2/PE/Et_2O 6.7:3.3:1 → 8:2:1 → 8:2:2) to give **a27B** (32.7 mg, 11.3 μmol, 63%) as a faint yellow film. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.30 (s, 0.75H), 8.13 (s, 0.25H), 7.97 (s, 2H), 7.74 (s, 1H), 7.62 (d, 4H), 7.45−7.37 (m, 10H), 7.34−7.11 (m, 26H), 6.98 (s, 4H), 4.79 (t, 2H), 4.49 (t, 2H), 4.13−4.00 (m, 8H), 3.94 (t, 2H), 3.88 (s, 3H), 3.85 (s, 3H), 3.80−3.73 (m, 6H), 3.18−3.09 (m, 2H), 3.01−2.77 (m, 8H), 2.70−2.53 (m, 14H), 2.35−2.13 (m, 6H), 1.58 (m, 16H), 1.37−0.86 (m, 127H). ^{13}C {^{1}H} NMR (75 MHz, $CDCl_3$) δ 165.8, 165.7, 165.2, 152.1, 152.0, 151.9, 151.8, 150.4, 150.0, 148.8, 147.6, 147.0, 143.2, 142.4, 142.2, 141.4, 137.8, 133.0, 130.8, 130.5, 129.5, 129.2, 128.7, 128.5, 126.9, 126.7, 126.4, 126.3, 125.8, 125.0, 124.4, 124.4, 124.1, 124.1, 123.9, 123.2, 121.8, 121.3, 116.7, 116.4, 68.9, 66.1, 65.6, 54.1, 52.6, 52.4, 52.3, 52.2, 48.1, 47.2, 46.8, 40.8, 38.9, 34.4, 34.4, 34.0, 32.0, 31.7, 31.6, 31.4, 31.3, 30.9, 30.6, 30.4, 30.0, 29.7, 29.5, 29.4, 29.2, 29.2, 29.1, 29.0, 29.0, 24.0, 23.0, 22.7, 22.1, 14.2, 14.1. IR (cm^{-1}): 2924, 2853, 1719, 1599, 1505, 1465, 1437, 1408, 1386, 1363, 1301, 1268, 1236, 1205, 1103, 1040, 976, 910, 879, 831, 791, 762, 736, 699, 655. HRMS (ESI$^+$) *m*/*z* calcd for $C_{189}H_{251}N_9O_{16}Na$ [M+Na]$^+$ 2925.8996, found 2925.8881.

Prerotaxane a232a. Diazide **3** (40 mg, 0.0416 mmol, 1.0 equiv), mono-stoppered prerotaxane **a2** (171 mg, 0.121 mmol, 2.9 equiv), and TBTA (5 mg, 0.0094 mmol, 0.23 equiv) were dissolved in dry CH_2Cl_2 (13 mL), and the solution was degassed with five vacuum/N_2 cycles. $Cu(CH_3CN)_4BF_4$ (3 mg, 0.0095 mmol, 0.23 equiv) was added, and the reaction was stirred overnight at room temperature under a N_2 atmosphere. The mixture was concentrated in vacuo and purified by column chromatography (PE/CH_2Cl_2 4:1 → 2:1 → 1:1) to give **a232a** (99 mg, 0.0262 mmol, 63%) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (s, 3H), 7.72 (s, 3H), 7.55−7.37 (m, 1H), 7.32 (d, *J* = 8.3 Hz, 12H), 7.24 (d, *J* = 8.7 Hz, 12H), 7.20−7.10 (m, 12H), 7.10−6.76 (m, 3H), 4.55 (br m, 4H), 4.21 (br m, 16H), 3.23−3.10 (m, 4H), 3.51 (br m, 42H), 1.55 (br m, 12H), 1.34 (br m, 136H), 1.16 (br m, 49H), 0.96 (br m, 34H). ^{13}C {^{1}H} NMR (100 MHz, $CDCl_3$) δ 176.3, 165.0, 152.1, 151.8, 149.0, 148.9, 148.7, 147.0, 146.7, 145.3, 145.0, 144.6, 144.4, 143.1, 131.7, 130.5, 128.6, 128.3, 128.0, 127.8, 124.9, 124.5, 123.7, 123.5, 123.3, 69.7, 69.0, 68.8, 68.6, 66.1, 53.7, 53.3, 47.8, 46.6, 38.8, 34.8, 34.4, 34.3, 34.2, 34.1, 33.7, 31.8, 31.5, 31.4, 31.3, 31.2, 31.1, 30.5, 30.1, 29.8, 29.5, 29.2, 28.8, 28.3, 28.2, 28.1, 15.1, 14.6, 14.1, 14.0. HRMS (ESI$^+$) *m*/*z* calcd for $C_{248}H_{345}N_{12}O_{18}$ [M + 3H]$^{3+}$ 1260.5500, found 1260.5468.

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[4]Rotaxane a232a (Hexaacid). Prerotaxane **a232a** (99 mg, 0.0262 mmol) was dissolved in 7 mL of Tesser's base (1,4-dioxane/MeOH/4 M NaOH, 3:1:0.1), and the reaction was stirred over the weekend at 50 °C. The mixture was subsequently diluted with EtOAc (10 mL) and a saturated $KHSO_4$ solution (10 mL). The organic layer was washed with brine (10 mL), dried over $MgSO_4$, and concentrated in vacuo to give [4]rotaxane **a232a** (101 mg, 0.0260 mmol, 99%) as a yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83−7.39 (m, 10H), 7.40−7.29 (m, 12H), 7.26−7.15 (m, 16H), 7.11−6.86 (m, 12H), 4.55 (br s, 4H), 4.30−4.26 (m, 4H), 4.26−4.14 (m, 8H), 3.21−3.09 (m, 4H), 3.03−2.83 (m, 8H), 2.68−2.53 (m, 20H), 2.47−2.18 (m, 16H), 1.71−1.59 (m, 16H), 1.54−1.44 (m, 16H), 1.44−1.21 (m, 136H), 1.21−0.98 (m, 46H), 0.97−0.79 (m, 20H). ^{13}C {^{1}H} NMR (125 MHz, $CDCl_3$) δ 176.4, 151.6, 149.4, 149.1, 148.9, 143.1, 129.2, 128.4, 127.5, 126.9, 125.0, 124.7, 124.5, 121.4, 117.2, 70.6, 69.4, 63.1, 54.1, 48.3, 47.2, 47.0, 40.8, 34.4, 34.0, 31.7, 31.5, 31.4, 31.1, 30.7, 30.6, 30.0, 29.7, 29.6, 29.4, 29.3, 29.2, 29.1, 28.4, 25.5, 25.3, 22.7, 21.6, 15.2, 14.2, 14.0, 11.8. HRMS (ESI$^+$) m/z calcd for $C_{248}H_{356}N_{12}O_{24}$ $[M + 2H]^{2+}$ 1944.3531, found 1944.3499.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.joc.9b03030.

1H and 13C NMR spectra of all new products and intermediates (PDF)

X-ray crystallographic structure of prerotaxane 1 (CIF)

X-ray crystallographic structure of prerotaxane 7 (CIF)

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Notes

The authors declare no competing financial interest.

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