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Entropically-driven Ring-opening Metathesis Polymerization (ED-ROMP) of Macrocyclic Olefins Prepared from Deoxycholic Acid to give Functionalized Polymers

Philip Hodge* and Abdel Chakiri

Dedicated to Dave Sherrington, a good friend and colleague for more than 40 years

Three new families of macrocyclic olefins were prepared from deoxycholic acid. Two of these have a novel structure in that the bile acid unit is linked to a C20 fatty acid unit via the 3α- and 12α-positions, thus creating macrocycles with rings with a repeat unit of 29 ring atoms. Entropically-driven Ring-opening Methathesis Polymerizations (ED-ROMPs) of the macrocycles gives polymers with free hydroxyl groups, or free methyl or *t*-butyl carboxylic ester groups. The latter could be converted into carboxylic acid groups by treatment with trifluoroacetic acid. The polymers form transparent hole-free films that are potentially useful for supporting cell growth.

Keywords: *macrocycles; ring:chain equilibria; polymer films*

Introduction

Entropically-driven ring-opening polymerizations (ED-ROP) are a relatively new type of polymer synthesis.[1,2] They are usually based on ring:chain equilibria (RCE), i.e. the

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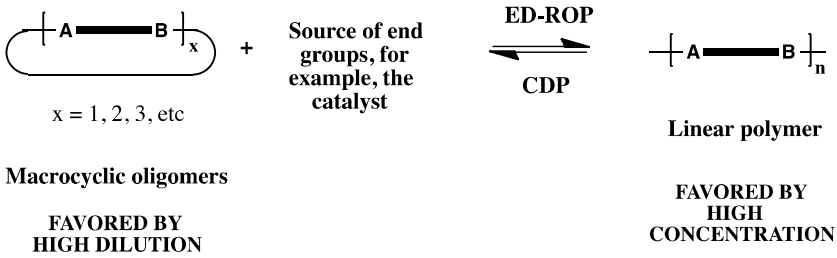
well-known equilibria that can exist, under appropriate reaction conditions, between a condensation polymer and the corresponding *family* of macrocyclic oligomers (MCOs): see Scheme 1.[1-3] The position of the RCE is very dependent on the concentration of the reactants and if *MCOs are taken at high concentration and the RCE established, polymer is formed in high yield*. Such polymerizations have several attractive features.[1,2] For example, (i) they are essentially thermally neutral; (ii) they proceed without the formation of any byproducts; (iii) they extend the range of application of ROPs to large *strainless* macrocycles such as 84-membered rings;[4,5] and (iv) if few end groups are present in the reaction system, high molecular weight polymers may be obtained.[6,7] Essentially ED-ROPs are a green method of polymer synthesis.

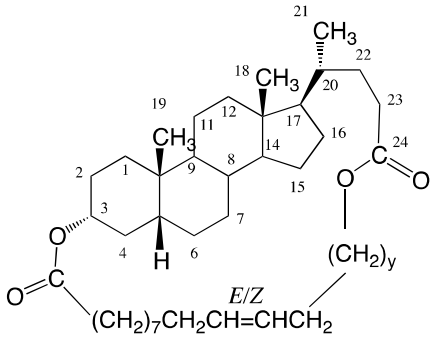


Scheme 1: Scheme for a generalized Ring:Chain Equilibrium (RCE).

Biocompatible and biodegradable polymeric materials have many potential applications, such as bone screws, stents, tissue engineering scaffolds, or drug delivery systems.[8,9] The polymers are of particular interest if the organism can eventually metabolize them to molecules that are harmless and/or can be excreted easily. Recently, in this context, Zhu *et al.* have studied polymers prepared from bile acid derivatives,[7,10-13] often in combination with fatty acid derivatives.[7,12,13] Simple hydrocarbon chains are very flexible, but the bile acid moieties introduce a degree of

stiffness and this potentially gives more useful materials, e.g. materials with T_gs greater than body temperature.

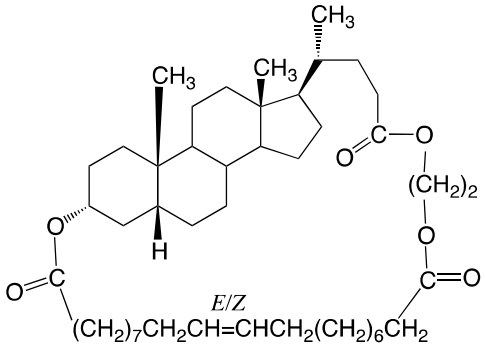
Zhu *et al.* prepared pure macrocycle **1** (35 ring atoms), pure macrocycle **2** (38 ring atoms) and several closely related macrocycles by ring-closing metathesis (RCM).[7,12] The macrocycles were then subjected to ED-ROPs, or more correctly in the present context ED-ROMPs.[7,12] These were catalyzed by Grubbs Second Generation olefin metathesis catalyst (**3**, G2).[7,12,14] This afforded high molecular weight polymers such as **4** and **5**.[7,12] The work has since been extended by Hodge *et al*. to ED-ROPs of MCOs **1** and **6**, and a variety of other MCOs, proceeding via transesterifications catalyzed by polymer-supported *Candida antarctica* lipase B (PS-CALB).[5] Very recently the lipase catalyzed ED-ROP of pure macrocycle **7** (38 ring atoms), prepared from cholic acid (**8**), has been reported.[15]



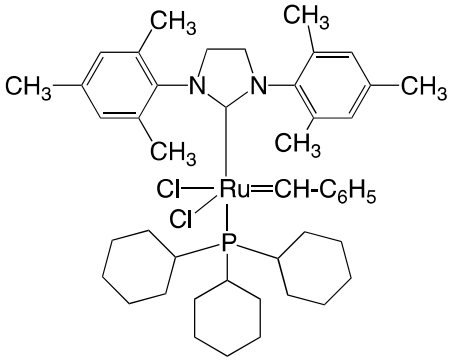
The lower face is α; the upper β.

(**1**): y = 8

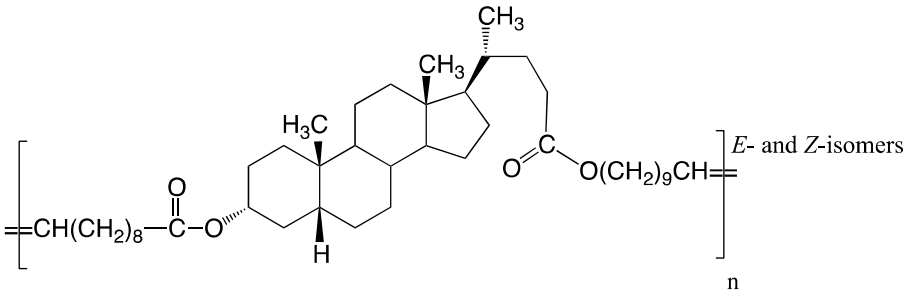
(**6**): y = 2



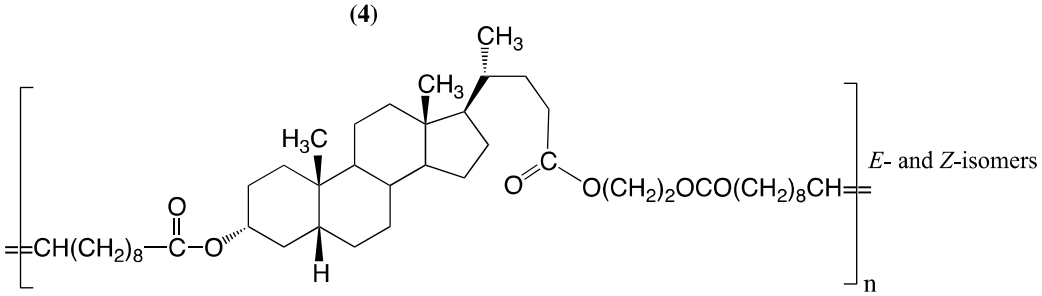
(**2**)



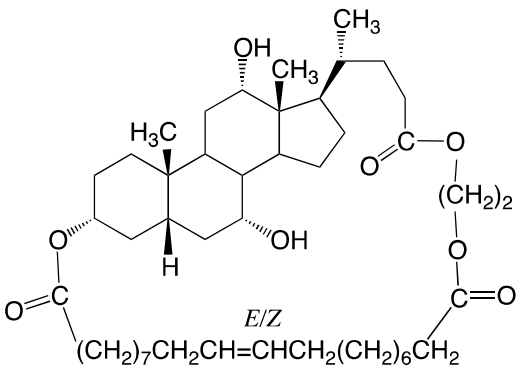
(**3**)



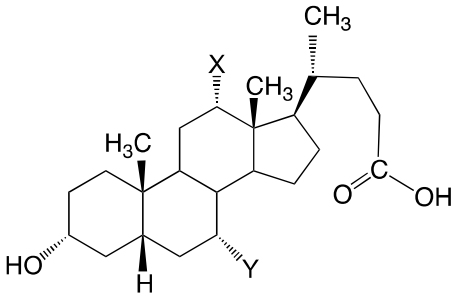
(**4**)



(**5**)



(**7**)

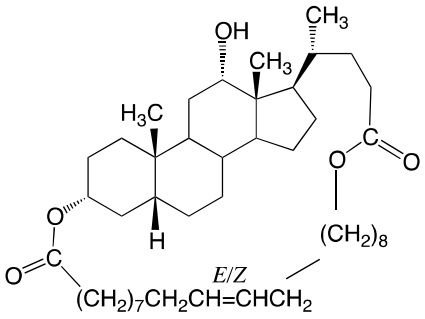


(**8**): X = Y = OH; cholic acid

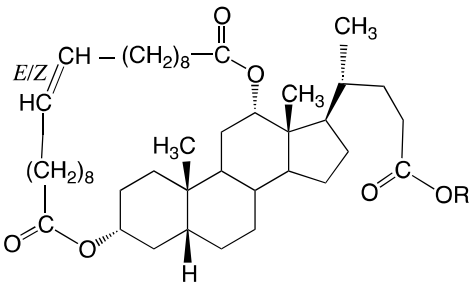
(**12**): X = OH, Y = H; deoxycholic acid

(**13**): X = Y = H; lithocholic acid

In connection with a programme aimed at providing novel functionalized polymeric films to support cell growth, we wished to prepare appropriate polymers using the above concepts. In this paper we report the preparation MCOs **9** – **11**, see Chart 1, from deoxycholic acid (**12**), and their ED-ROMPs. MCOs **10** and **11** are a novel type of macrocycle (29 ring atoms per repeat unit) in that the C20 chain is linked via the 3α- and 12α-positions instead of the more usual 3α- and 24-positions.[5,7,12] Since **12** has three functional groups and only two are required to create macrocycles, and thence polymer chains, the polymeric products obtained using such macrocycles have a free functional group on each repeat unit. Thus, the polymeric products prepared using MCOs **9** have a free 12α-hydroxyl group on each repeat unit, whilst those prepared from MCOs **10** and **11** have a free methyl or *t*-butyl carboxylic ester group. The latter can potentially be deprotected to give a carboxylic acid group on that unit.



(9)



(**10**) : R = CH_3

(**11**) : R = *t*-C_4H_9

Chart 1: New familes of MCOs discussed. For simplicity only the cyclic monomers are shown. Cyclic oligomers are also present in smaller amounts. The repeat units of the cyclic oligomers start at the centre of the olefinic bonds in the macrocycles shown, continue round the ring and back to the centre of the olefinic bonds. Since the repeat units are unsymmetrical, unlike with the cyclic monomer, each size of cyclic oligomer is expected to consist of regioisomers.

Results and discussion

Macrocycle **1** was prepared as described previously.[7] Thus, lithocholic acid (**13**) was esterified with undec-10-enol and the product acylated using undec-10-enoyl chloride. The α,ω-bisolefin produced was then subjected to RCM using Grubbs First Generation Metathesis catalyst. Macrocycle **9** was prepared analogously starting with deoxycholic acid (**12**) and exploiting the greater reactivity of the equatorial 3α-hydroxyl group over the axial 12α-hydroxyl group.[16] Macrocycles **10** and **11** were synthesized in three steps. First, the known methyl and *t*-butyl esters were prepared,[17,18] then these were bisacylated using undec-10-enoyl chloride and pyridine. Finally, the bisolefins produced were subjected to RCM.

All the macrocycles were characterized by FT-IR and ^{1}H NMR spectroscopy, MALDI-ToF MS and size-exclusion chromatography (SEC). This showed that in general the products were mixtures of cyclic oligomers. Typically, MCOs **10** consisted of cyclic monomer (*ca.* 85%), dimer (*ca.* 13%) and trimer (*ca.* 2%). Given that each olefinic linkage is present as a mixture of *E*- and *Z*-isomers (*ca.* 80:20), each macrocyclic monomer is present as a mixture. Moreover, because the repeat units are unsymmetrical, the cyclic *oligomers* exist as a mixture of regioisomers. For example, the cyclic dimers can have the repeat units linked either Head-to-Head and Tail-to-Tail, or both units linked Head-to-Tail, and each type of dimer is a mixture of three geometric isomers (*EE, EZ* and *ZZ*). Not surprisingly, in the event only macrocycle **1** was crystalline; the others were oils or gums. This is not a problem for ED-ROMP as *all* the components, because they all have the same repeat unit, react to give the same polymer. Indeed, the fact that such mixtures can be used not only increases the overall yields, it also simplifies the preparation and required purification of the starting

materials.[1] Furthermore, mixtures of MCOs are generally more soluble and this can help in obtaining the high concentrations needed for the ED-ROMPs.[1]

ED-ROMPs were carried out by stirring concentrated solutions of macrocycle **1** or MCOs **9** - **11** in dichloromethane under reflux with G2 for 2 h.[7] Copolymers were prepared using equimolar mixtures of macrocycle **1** and MCOs **9**, and of MCOs **10** and **11**. In each case at the end of the reaction period the metathesis reaction was quenched by the addition of a few drops of ethyl vinyl ether, then the reaction mixture was evaporated to dryness. The crude product was dissolved in ether, passed through a plug of alumina to remove ruthenium residues, and precipitated into hexane-methanol. The reprecipitated products were obtained in high yields and were characterized by FT-IR and ^{1}H NMR spectroscopy and by SEC. The results are summarized in Table 1. The structures of the products are shown in formulae **4** and **14** – **18**. As the yields of copolymers **15** and **18** were high it is clear that in each case both types of MCO were incorporated efficiently. The ^{1}H NMR spectra were consistent with this. The molecular weights are generally modest though it is known that for the ED-ROMP of macrocycles **1** and **2** the molecular weights obtained depend significantly on the reaction conditions used.[7] In part the modest molecular weights may be due to the fact the polymerizations were carried out on a small scale, and the possible presence of trace impurities from the RCM, i.e. the presence of 'vinyl end groups'. As expected dispersities,[19] were close to 2.0.[1]

It should be noted that since all the repeat units are unsymmetrical, the polymers can have them in Head-to-Head, Head-to-Tail, Tail-to-Head and Tail-to-Tail arrangements. As the olefinic groups are separated from the steroid nucleus by more than eight methylenes in each direction, it is expected that all these arrangements are equally probable. In the case of the copolymers **15** and **18**, the two types of repeat unit

Table 1: ED-ROMPs of MCOs **1** and **9** – **11**[a]

Entry	MCO(s)	Polymer produced	Yield (%)	Molecular weights[b] M_n	M_w	$Đ$ [c]
1	**1**	**4**	95	45,400	82,200	1.81
2	**9**	**14**	92	24,000	46,500	1.94
3	**1** + **9**[d]	**15**	94	37,000	71,000	1.92
4	**10**	**16**	90	13,200	24,200	1.83
5	**11**	**17**	97	21,400	42,100	2.01
6	**10** + **11**[d]	**18**	90	14,100	28,300	2.00

[a] See Experimental for standard procedure.

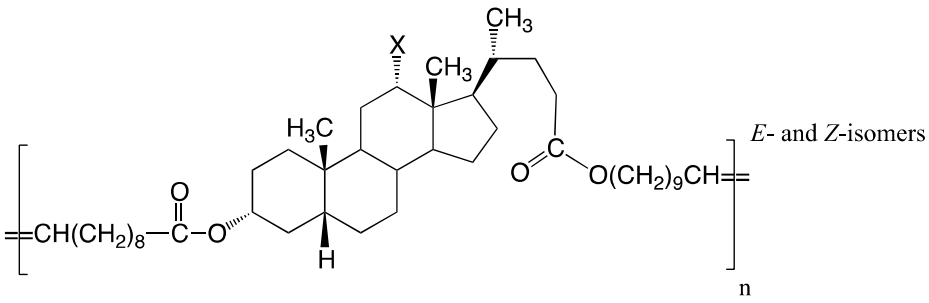
[b] By SEC.

[c] $Đ$ = dispersity. See reference 19 for IUPAC's recent recommendations on dispersity, previously called polydispersity.

[d] An equimolar mixture of the two MCOs was used. By ^{1}H NMR spectroscopy of the polymeric products the two MCOs were incorporated equally.

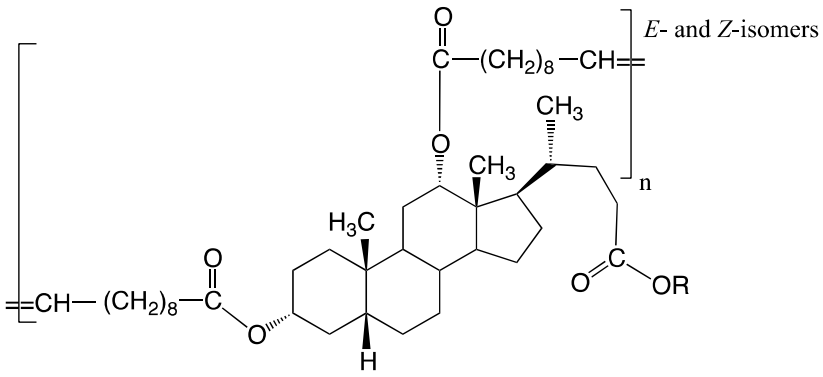
are expected to be distributed randomly. Also each arrangement will be present as *E*- and *Z*-isomers.

Polymer **14** had a 12α-hydroxyl group on every repeat unit. Copolymer **15** had a hydroxyl on half the units. The use of **9** to introduce hydroxyl groups is less complex than the use of **7** as the former has only one free hydroxyl group.[15]



(**14**) : X = OH

(**15**) : X = 50 % H and 50 % OH



(**16**) : R = CH_3

(**17**) : R = *t*-C_4H_9

(**18**) : R = 50 % CH_3 and 50% *t*-C_4H_9

(**19**) : R = H

(**20**) : R = 50 % CH_3 and 50 % H

For polymers **17** and **18** the conversion of the *t*-butyl ester groups into carboxylic acid groups was investigated using trifluoroacetic acid (TFA) in dry dichloromethane.[20] First, polymer **17** in a mixture of dry dichloromethane and TFA was allowed to react under reflux for 4 h. ^{1}H NMR analysis of the polymeric product indicated that the sharp singlet due to the *t*-butyl group at δ 1.44 ppm had disappeared. Thus, the product had structure **19**. Treating copolymer **18** similarly gave polymer **20** in which half the repeat units had a CO_2CH_3 group and half had a CO_2H group. The molecular

weights of polymers **19** (M_n 18,100 and M_w 36,000) and **20** (M_n 13,900 and M_w 26,000) were not significantly different from the starting polymers, indicating that, as expected,[20] the TFA reagent is specific to the *t*-butyl esters.

With all the polymers **14** - **20** thin films were cast from ether solutions onto microscope slides. The films were transparent and hole free. As noted above, by choice, the films can have free hydroxyl or carboxylic acid moieites and these can potentially be chemically modified in various ways.

Conclusions

Several new macrocycles have been prepared from deoxycholic acid (**12**). These include the novel type of macrocycles **10** and **11**, where the bile acid unit is linked to the C20 fatty acid unit via the 3α- and 12α-positions. The various macrocycles were subjected to ED-ROMP using G2 as a catalyst to give polymers **4**, **14**, **16** and **17**. Copolymers **15** and **18** were also prepared. Deprotection of the *t*-butyl ester groups in polymers **17** and **18** allows the preparation of polymers **19** and **20** with a free carboxylic acid group on the repeat units derived from MCOs **11**. The use of macrocycles **9** results in a 12α-hydroxyl group on each repeat unit. Films of polymers **14** – **20** will be investigated for their suitability to support cell growth.[21]

EXPERIMENTAL

Materials and methods

These are as given in an earlier publication.[5]

Preparation of macrocycles

(a) Macrocycle 1. This was prepared as described by Gautrot and Zhu.[7] Column chromatography of the crude reaction product gave cyclic monomer **1** (*E*- and *Z*-

isomers) as white crystals (80%); m.p. 123 – 128 ^{o}C (lit.,[7] 119.6 ^{o}C by DSC); FT-IR (KBr) ν_{max} 1733 cm^{-1} (C=O); ^{1}H NMR (500 MHz, $CDCl_3$, δ, ppm) 5.38 (m, 2 H, CH=), 4.72 (m, 1 H, 3β-CH), 4.08 (m, 2 H, CH_2OCO), 2.40 – 2.11 (m, 4 H, 23CH_2 and CH_2CO), 2.0 – 0.9 (m, 56 H, various CH), 0.92 (s, 3 H, C19), 0.90 (d, *J* = 10 Hz, 3 H, C21 methyl), 0.64 (s, 3 H, C18); MS MALDI ToF 690, $C_{44}H_{74}O_4Na^+$ requires 689.6. Another column fraction was, by MALDI ToF, mainly C1 (690) with much smaller amounts of C2 (1357) and (C3) 2028.

(b) MCOs 9. These were prepared similarly to macrocycle **1**. Details for the preparation of the undec-10-enyl undec-10-enoyldeoxycholate and the RCM of this bisolefin are given in the ESI. Column chromatography of the crude product gave MCOs **9** as a pale fawn glass (78 %); FT-IR (KBr) ν_{max} 3100 br. (OH), 1731 cm^{-1} (C=O); ^{1}H NMR (400 MHz, $CDCl_3$, δ, ppm) 5.33 (m, 2 H, CH=, *E*- and *Z*-isomers), 4.70 (m, 1 H, 3β-CH), 4.00 (m, 2 H, CH_2OCO), 3.90 (m, 1 H, 12β-H), 2.35 – 2.10 (m, 4 H, 2 x CH_2CO), 2.0 – 1.0 (m, 55 H, various CH), 0.92 (d, *J* = 10 Hz, 3 H, C21 methyl), 0.90 (s, 3 H, C19), 0.64 (s, 3 H, C18); MS MALDI ToF 707, $C_{44}H_{74}O_5Na^+$ requires 706.0. Also peaks due to C2 (1390) and C3 (2072). SEC: C1, 85%, C2, 13%, and C3, 2%. $C_{44}H_{74}O_5$ requires C, 77.37; H, 10.92 %. Found: C, 77.09; H, 10.68 %.

(c) MCOs 10. Methyl deoxycholate was prepared as described by Gangwal *et al.*[18a] It had m.p. 112 - 118 ^{o}C (lit.,[18a] 120 ^{o}C). Details for the preparation of the methyl bisundec-10-enoyldeoxycholate are given in the ESI. RCM was carried out using the general procedure.[7] Column chromatography of the crude product gave the desired MCOs **10** as a colourless gum (67 %); FT-IR (ATR) ν_{max} 1728 cm^{-1} (ester carbonyl); ^{1}H NMR (500 MHz, $CDCl_3$, δ, ppm) 5.38 (m, 2 H, CH=, *E*- and *Z*-isomers), 5.13 (m, 1 H, 12β-CH), 4.74 (m, 1 H, 3β-CH), 3.70 (s, 3 H, OCH_3), 2.45 – 2.15 (m, 6 H,

CH_2CO), 2.1 – 1.0 (m, 52 H, various CH), 0.93 (s, 3 H, C19), 0.84 (d, J = 10 Hz, 3 H, C21 methyl), 0.76 (s, 3 H, C18); MS MALDI ToF 734 and 750, $C_{45}H_{74}O_6Na^+$ requires 734.1, $C_{45}H_{74}O_6K^+$ requires 750.2. SEC: C1, 79% and C2, 21%. $C_{45}H_{74}O_6$ requires C, 76.01; H, 10.49 %. Found: C, 76.22; H, 10.60 %

(d) MCOs 11. *t*-Butyl deoxycholate was prepared as described by Alexander *et al*.[18b] It had m.p. 74 - 77 °C from water/ethanol (lit.,[18b] 72-76 °C). Details for the preparation of the methyl bisundec-10-enoyldeoxycholate and the subsequent RCM are given in the ESI. By ^{1}H NMR spectroscopy, based on signals in the vinyl region, the crude product was estimated to contain *ca.* 8% of starting material and/or linear oligomers. Accordingly, starting with this product the entire RCM procedure was repeated. Column chromatography of the crude product gave the desired product as a clear oil (85 %); FT-IR (ATR) ν_{max} 1738 cm^{-1} (ester carbonyl); ^{1}H NMR (500 MHz, $CDCl_3$, δ, ppm) 5.34 (m, 2 H, CH=, *E*- and *Z*-isomers), 5.08 (m, 1 H, 12β-CH), 4.71 (m, 1 H, 3β-CH), 2.40 – 2.30 (m, 6 H, CH_2CO), 2.1 – 1.0 (m, 52 H, various CH), 1.44 (s, 9 H, *t*-butyl), 0.91 (s, 3 H, C19), 0.80 (d, J = 10 Hz, 3 H, C21 methyl), 0.72 (s, 3 H, C18). SEC: C1, 60% and C2, 40%. $C_{48}H_{80}O_6$ requires C, 76.54; H, 10.71 %. Found: C, 76.22; H, 10.60 %.

ED-ROMPs of MCOs

General procedure.[7] The procedure is similar to that described in the literature for the ED-ROMP of macrocycles **1** and **2**.[7] A solution of macrocycle(s) (500 mg, *ca.* 0.7 mmol of repeat units depending on the substrate) and G2 [0.1 mL of a solution of the catalyst (15 mg) in dichloromethane (1.0 mL), i.e. 1.8 μmol of G2] in dichloromethane (2.0 mL) was stirred under nitrogen at 20 °C for 2 h. Two or three drops of ethyl vinyl ether were then added to quench the metathesis reaction and

stirring was continued for a further 1 h. The solution was then diluted with dichloromethane (5.0 mL) and added to hexane-methanol (30 mL of 2 vol: 1vol). The precipitate was collected and reprecipitated from dichloromethane into hexane-methanol. The product was collected and dried under vacuum. FT-IR and ^{1}H NMR spectra were recorded and an SEC was run. The results are summarized in Table 1.

Entry 1. Polymer **3** was obtained as a brittle glass (95%); FT-IR (KBr) ν_{max} 1738 cm^{-1} (C=O); ^{1}H NMR (300 MHz, $CDCl_3$, δ, ppm ν_{max} 1736 cm^{-1} (C=O); ^{1}H NMR (500 MHz, $CDCl_3$, δ, ppm) 5.36 (m, 2 H, CH=), 4.72 (m, 1 H, 3β-CH), 4.06 (m, 2 H, CH_2OCO), 2.41 – 2.11 (m, 4 H, 23CH_2 and CH_2CO), 2.05 – 0.95 (m, 56 H, various CH), 0.92 (s, 3 H, C19), 0.90 (d, *J* = 10 Hz, 3 H, C21 methyl), 0.65 (s, 3 H, C18); SEC M_n 45,400; M_w 82,200; *Đ* 1.81.

Entry 2. Polymer **14** was obtained as a light brown gum (92%); FT-IR (KBr) ν_{max} 1738 cm^{-1} (C=O); ^{1}H NMR (300 MHz, $CDCl_3$, δ, ppm) 5.30 (m, 2 H, CH=, *E*- and *Z*-isomers), 4.70 (m, 1 H, 3β-CH), 4.00 (m, 2 H, CH_2OCO), 3.90 (m, 1 H, 12β-H), 2.35 – 2.10 (m, 4 H, 23CH_2 and CH_2CO), 2.0 – 1.0 (m, 55 H, various CH), 0.92 (d, *J* = 10 Hz, 3 H, C21 methyl), 0.90 (s, 3 H, C19), 0.64 (s, 3 H, C18). SEC Mn 24,000; Mw 46,500; *Đ* 1.94.

Entry 3. Copolymer **15** was obtained as a clear gum (94%). The FT-IR (KBr) and ^{1}H NMR (300 MHz, $CDCl_3$) spectra were consistent with the product being a 50:50 combination of repeat units in polymers **3** and **14**. SEC M_n 37,000; M_w 71,000; *Đ* 1.92.

Entry 4. Polymer **16** was obtained as a gum (90%) with FT-IR (KBr) ν_{max} 1735 cm^{-1} (C=O); ^{1}H NMR (500 MHz, $CDCl_3$, δ, ppm) 5.37 (m, 2 H, CH=, *E*- and *Z*-isomers),

5.08 (m, 1 H, 12β-CH), 4.70 (m, 1 H, 3β-CH), 3.65 (s, 3 H, OCH_3), 2.40 – 2.15 (m, 6 H, CH_2CO), 2.1 – 1.0 (m, 52 H, various CH), 0.90 (s, 3 H, C19), 0.80 (d, *J* = 10 Hz, 3 H, C21 methyl), 0.72 (s, 3 H, C18). SEC M_n 13,200; M_w 24,200; *Đ* 1.83.

Entry 5. Polymer **17** was obtained as a brittle glass (97 %) with FT-IR (KBr) ν_{max} 1738 cm^{-1} (C=O); ^1H NMR (300 MHz, $CDCl_3$, δ, ppm) 5.30 (m, 2 H, CH=, *E*- and *Z*-isomers), 5.04 (m, 1 H, 12β-CH), 4.62 (m, 1 H, 3β-CH), 2.30 – 2.10 (m, 6 H, CH_2CO), 2.1 – 1.0 (m, 52 H, various CH), 1.35 (s, 9 H, O-*t*-butyl), 0.93 (s, 3 H, C19), 0.75 (d, *J* = 10 Hz, 3 H, C21 methyl), 0.70 (s, 3 H, C18). SEC Mn 21,400; Mw 42,100; *Đ* 1.96.

Entry 6. Copolymer **18** was obtained as a clear gum (90%). The FT-IR (KBr) and ^1H NMR (400 MHz, $CDCl_3$) spectra were consistent with the product being a 50:50 combination of repeat units in polymers **16** and **17**. SEC M_n 14,100; M_w 28,300; *Đ* 2.00.

Preparation of polymers 19 and 20.

(i) Polymer 19. A solution of polymer **17** (1.30 g) in dichloromethane (30 mL) was treated with trifluoroacetic acid (7.0 mL) and then heated at 42 ^oC for 4 h.[20] The reaction mixture was then evaporated to dryness and the residue dissolved in ether (100 mL). The solution was washed repeatedly with water. Evaporation of the dried solution gave **19** as a clear gum (1.26 g). It was purified by passing a solution in dichloromethane through a short column of alumina. The product **19** (92% yield) was obtained as a white solid. It had FT-IR (ATR) ν_{max} 1738 (ester carbonyl) and 1724 cm^{-1} (carboxylic acid); ^1H NMR (500 MHz, $CDCl_3$, δ, ppm) 5.35 (m, 2 H, CH=, *E*- and *Z*-isomers), 5.09 (m, 1 H, 12β-CH), 4.71 (m, 1 H, 3β-CH), 2.30 – 2.10 (m, 6 H,

CH_2CO), 2.1 – 1.0 (m, 52 H, various C-H); 0.91 (s, 3 H, C19), 0.83 (d, J = 10 Hz, 3 H, C21 methyl), 0.74 (s, 3 H, C18). By SEC it had M_n 18,100, M_w 36,000.

(ii) Polymer 20: This was prepared from polymer **18** using a similar procedure to that given immediately above. The polymer was obtained as an off-white solid. It had FT-IR (ATR) ν_{max} 1735 (ester carbonyl) and 1720 cm^{-1} (carboxylic acid); ^1H NMR (500 MHz, $CDCl_3$, δ, ppm)) 5.32 (m, 2 H, CH=, *E*- and *Z*-isomers), 5.08 (m, 1 H, 12β-CH), 4.71 (m, 1 H, 3β-CH), 3.65 (s, 1.5 H, OCH_3), 2.35 – 2.10 (m, 4 H, $^{23}CH_2$ and CH_2CO), 2.1 – 1.0 (m, 55 H, various CH), 0.95 (s, 3 H, C19), 0.82 (d, J = 10 Hz, 3 H, C21 methyl), 0.75 (s, 3 H, C18). By SEC it had M_n 13,900, M_w 26,000.

Preparation of polymer films

Solutions of polymers **14** - **20** in diethyl ether (30 mg of polymer per mL) were separately prepared. In each case a small amount of the solution (300 μL per 20 mm^2) was cast onto a microscope slide and the solvent was allowed to evaporate slowly. The final films were transparent and hole free.

Electronic Supplementary Information (ESI)

ESI is available that describes the synthesis of macrocycles **1** and **9** – **11**.

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References

1. P. Hodge, *Chem. Rev*. 2014, **114**, 2278-2312.

2. (a) P. Hodge, H. M. Colquhoun, D. J. Williams, *Chem. Ind. (London)* 1998, 162-167. (b) A. J. Hall, P. Hodge, *React. Funct. Polym*., 1999, **41**, 133-139. (c) P. Hodge, *React. Funct. Polym*. 2001, **48**, 15-23. (d) P. Hodge, H. M. Colquhoun, *Polym. Adv. Tech*., 2005, **6**, 84-94. (e) D. J. Brunelle, *J. Polym. Sci., Part A: Polym. Chem*. 2008, **46**, 1151-1164. (f) Z. Xue, M. F. Mayer, *Soft Matter* 2009, **5**, 4600-4611. (g) A. Ben-Haida, L. Conzatti, P. Hodge, B. Manzini, P. Stagnaro, *Macromol. Symp*. 2010, **297**, 6-17. (h) S. Strandman, J. E. Gautrot, X. X. Zhu, *Polym. Chem.,* 2011, **2**, 791-799.

3. (a) H. Jacobson, W. H. Stockmayer, *J. Chem. Phys.,* 1950, **18**, 1600-1606, and H. Jacobson, C. O. Beckmann, W. H. Stockmayer, *J. Chem. Phys.,* 1950, **18**, 1607-1612. (b) J. A. Semlyen, *Adv. Polym. Sci.* 1976, **21**, 41-75. (c) P. Maravigna, M. Montaudo, in *Comprehensive Polymer Science*; G. Allen, J. C. Bevington, Eds.; Pergamon Press: Oxford, U.K., 1989; Vol. 5, p 63-90. (d) U. W. Suter in *Comprehensive Polymer Science*; G. Allen, J. C. Bevington, Eds.; Pergamon Press: Oxford, U.K., 1989; Vol. 5, p 91-96. (e) E. Thorn-Csanàyi, K. Ruhland, *Macromol. Chem. Phys.*1999, **200**, 1662-1671. (f) A. Hejl, O. A. Scherman, R. H. Grubbs, *Macromolecules* 2005, **38**, 7214-7218. (g) E. A. Ofstead, N. Calderon, *Makromol. Chem.* 1972, **154**, 21-34. (h) H. Höcker, W. Reimann, L. Reif, K. Riebel, *J. Mol. Catal.* 1980, **8**, 191-202. (i) G. Ercolani, L. Mandolini, P. Mencareli, S. Roelens, *J. Am. Chem. Soc.* 1993, **115**, 3901-3908. (j) G. Ercolani, L. Mandolini, P. Mencareli, *J. Chem. Soc., Perkin Trans. 2,* **1990**, 747-752. (k) A. Dalla Cort, G. Ercolani, L. Mandolini, P. Mencareli, J., *Chem. Soc. Chem. Commun*. 1993, 538-540.

4. (a) P. Hodge, S. D. Kamau, *Angew. Chem. Int. Ed.* 2003, **42**, 2412-2414. (b) S. D.

Kamau, P. Hodge, A. J. Hall, S. Dad, A. Ben-Haida, *Polymer*, 2007, **48**, 6808-6822.

5. B. Manzini, P. Hodge, A. Ben-Haida, *Polym. Chem.*, 2010, **1**, 339-346.

6 C. L. Ruddick, P. Hodge, Yang Zhuo, R. L. Beddoes, M. Helliwell , *J. Mater. Chem.,* 1999, **9**, 2399-2405.

7. J. E. Gautrot, X. X. Zhu, *Angew. Chem. Int. Ed.* 2006, **45**, 6872-6874.

8. (a) A. C Albertsson, I. K. Varma, *Biomacromolecules* 2003, **4**, 1466-1486. (b) A. C Albertsson, I. K. Varma, *Adv. Polym. Sci.* 2002, **157**, 1-40.

9. (a) X. X. Zhu, M. Nichifor, *Acc. Chem. Res*. 2002, **35**, 539-546. (b) J. E. Gautrot, X. X. Zhu, *J. Biomater. Sci. Polymer Ed.* 2006, **17**, 1123-1139.

10. S. Ivanysenko, S. Strandman, X. X. Zhu, *Polym. Chem.,* 2012, **3**, 1962-1965.

11. J. E. Gautrot, X. X. Zhu, *J. Mat. Chem*. 2009, **19**, 5705-5716.

12. J. E. Gautrot, X. X. Zhu, *Macromolecules*, 2009, **42**, 7324-7331.

13. J. E. Gautrot, X. X. Zhu, *Chem. Commun.,* 2008, 1674-1676.

14. See, for example, T. M. Trnka, R. H. Grubbs, *Acc. Chem. Res.,* 2001, **34**, 18-29.

15. S. Strandman, I.-H. Tsai, R. Lortie, X. X. Zhu, *Polym. Chem*. 2013, **4**, 4312-4316.

16. (a) H. J. E. Loewenthal, *Tetrahedron*, 1959, **6**, 269-303. (b) *Steroid Reaction Mechanisms*, D. N. Kirk, M. P. Hartshorn, Elsevier, Amsterdam, London and New York, 1968, Chapter 2.

17. T. Reichstein, M. Sorkin, *Helv. Chim. Acta.* 1942, **25**, 797-805.

18. (a) J. T. Gangwal, M. G. Kulkarni, *J. Appl. Poly. Sci.* 2011, **122**, 220-232. (b) C. Alexander, C. R. Smith, M. J. Whitcombe, E. V. Vulfson, *J. Am. Chem.*

Soc., 1999, **121**, 6640-6651.

19. R. G. Gilbert, M. Hess, A. D. Jenkins, R. G. Jones, P. Kratochvil, R. F. T. Stepto, *Pure Appl. Chem*. 2009, **81**, 351-353.

20. (a) P. A. Wender, J. M. Schaus, A. W. White, *J. Am. Chem. Soc*., 1980, **102**, 6157-6159. (b) D. B. Bryan, R. F. Hall, K. G. Holden, W. F. Huffman, J. G. Gleason, *J. Am. Chem. Soc*., 1977, **99**, 2353-2355.

21 See for example, P. R. Patel, R. C. Kiser, Y. Y. Lu, E. Fong, W. C. Ho, D. A. Tirrell, R. H. Grubbs, *Biomacromolecules*, 2012, **13**, 2546-2553.

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Graphical Abstract

The following macrocycles, where R = methyl or *t*-butyl, and related cyclic oligomers, were prepared. They were polymerized and copolymerized by ROMP using Grubbs Second Generation Catalyst. The former type of macrocycle gave polymers with free hydroxyl groups. Treatment of the polymers with R = *t*-butyl with trifluoroacetic acid gave polymers with free carboxylic acid groups.