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Novel 18β-glycyrrhetinic acid analogues as potent and selective inhibitors of 11β-hydroxysteroid dehydrogenases

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Abstract—Extensive structural modifications to the 18β-glycyrrhetinic acid template are described and their effects on the SAR of the 11β-hydroxysteroid dehydrogenase isozymes type 1 and 2 from the rat are investigated. Isoform selective inhibitors have been discovered and compound **7** *N*-(2-hydroxyethyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide is highlighted as a very potent selective inhibitor of 11β-hydroxysteroid dehydrogenase 2 with an $IC_{50} = 4$ pM.

1. Introduction

The short-chain dehydrogenases/reductases (SDR) are a large well-established family of functionally heterogeneous enzymes present in all forms of life.[1] The 11β-hydroxysteroid dehydrogenases (11β-HSDs) are members of this family and are microsomal enzymes catalyzing the conversion of active glucocorticoids to their 11-dehydro products and vice versa.[2] The 11β-hydroxysteroid dehydrogenase isozymes type 1 and 2 are responsible for the interconversion of cortisone (E) and cortisol (F) as shown in Figure 1.

The 11β-hydroxysteroid dehydrogenase type 1 (11β-HSD1) isoform converts cortisone to the active glucocorticoid cortisol and is present in liver, muscle and adipose tissue.[3] Cortisol has a central role in regulating carbohydrate metabolism and its main action in this respect is to oppose the action of insulin and 11β-HSD1 has been shown to mediate glucocorticoid action and insulin release in pancreatic islets.[4] In the liver, while insulin stimulates glucose uptake and inhibits gluconeogenesis, cortisol acts to inhibit glucose uptake and stimulate gluconeogenesis. Gluconeogenesis in this organ is reduced in knockout mice without the 11β-HSD1 gene resulting in lower blood sugar levels.[5] Recently, it has been shown that selective inhibition of 11β-HSD1 decreases blood glucose concentrations in hyperglycaemic mice.[6] Inhibition of 11β-HSD1 in subjects suffering from impaired glucose tolerance or diabetes mellitus could increase glucose uptake by the liver and inhibit gluconeogenesis. Thus, a selective inhibitor of 11β-HSD1 has considerable potential as an antidiabetic agent. The effects of the non-selective 11β-HSD inhibitor carbenoxolone (CBX **2**) on insulin sensitivity in non-obese men with type 2 diabetes has recently been shown to support this hypothesis.[7] The choice of lean patients for this study was an important consideration as these patients had no change in the 11β-HSD1 levels in adipose tissue.[7] Several groups have programmes targeted at the development of selective 11β-HSD1 inhibitors for the treatment of metabolic disorders such as insulin resistance, obesity, hyperlipidemia and arterial hypertension.[4,8–11] Although it has been known for some

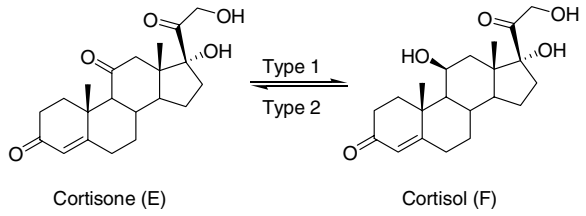

Figure 1. Interconversion of cortisone (E) and cortisol (F) by 11β-HSD type 1 and 2.

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time that 18β-glycyrrhetinic acid (18β-GA **1**), a principal active ingredient of liquorice root, and its hemisuccinate derivative carbenoxolone (CBX **2**) (Fig. 2) are potent non-selective inhibitors of both 11β-HSD1 and 11β-HSD2,[12] only recently have selective inhibitors of 11β-HSD1 with nanomolar potency been reported.[8]

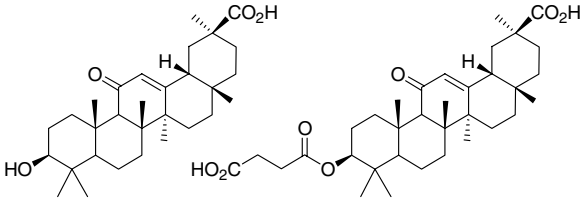
The 11β-HSD type 2 isoform inactivates cortisol to cortisone and is a unidirectional enzyme and exclusively acts as a NAD^+ dependent dehydrogenase of adrenal glucocorticoids. This isoform is found primarily in mineralocorticoid (MC) tissues such as the kidney, colon, salivary glands and the sodium-transporting epithelia of the lung a nonclassical MC target organ.[13] Inhibition of 11β-HSD2 could be used to potentiate the anti-inflammatory effects of glucocorticoids, leading to a reduction in the amount of glucocorticoid required for anti-inflammatory therapy and in the severity of very significant side effects that can result from this type of medication. Inhibition of 11β-HSD2 with liquorice derivatives results in cortisol-dependent mineralocorticoid excess with hypertension and hypokalemic alkalosis.[14,15] Disruption or mutations in the 11β-HSD2 gene result in sodium retention, hypokalemia and hypertension because of inappropriate glucocorticoid occupation of the MC receptor in the kidney, where 11β-HSD2 is principally expressed in the distal nephron.[5,16] An excellent recent review on the 11β-HSDs highlighted the link between 11β-HSD2 and cancer.[17] Adrenal cortical adenomas and carcinomas synthesize 11β-HSD2,[18] and 11β-HSD2 levels are high in pituitary tumours.[19,20] Ductal and lobular breast epithelial cells have also been shown to synthesize 11β-HSD2, with increased synthesis of 11β-HSD2 seen in invasive carcinomas.[21] Transfection experiments to study the role of 11β-HSDs showed that in stably transfected cells overexpressing *HSD11B2* cell proliferation was increased.[22] In addition, the observation that 11β-HSD2 potentiates the antiproliferative effects of glucocorticoids in endometrial, and some breast cancer cell lines highlights a putative role for 11β-HSD2 activity in tumourigenesis.[23] These observations highlight the need for selective inhibitors of 11β-HSD1 and 11β-HSD2 as therapeutic agents or tools for further mechanistic studies.

A number of natural products have been reported to inhibit the 11β-HSDs and these include xenobiotics, flavonoids, polyphenolic compounds from tea, gossypol and the constituents of Saiboku-To, a Chinese herbal remedy.[24,25] In general, these compounds are non-selective inhibitors of the 11β-HSDs and are much less potent than 18β-GA **1**. Some selectivity for 11β-HSD1 has been reported for weakly inhibiting synthetic steroids and chenodeoxycholic acid; the diuretic furosemide has also been reported as a non-selective inhibitor.[24,25]

As 18β-GA **1** and CBX **2** are potent inhibitors of 11β-HSD lacking selectivity a programme of work was initiated to evaluate the effects on SAR by modifying the 18β-GA template on 11β-HSD activity and selectivity. The use of a number of 18β-GA derivatives was the topic of a recent patent by our group.[26] Here we substantially extend the structural modifications of the 18β-GA template and report the effects of these novel compounds on the SAR of 11β-HSD1 and 11β-HSD2 isoforms from the rat.

2. Chemistry

The synthesis of compounds from the 18β-GA template **1** was targeted at three key areas of the molecule where functionality is present for further modification. The template was modified in the A, C and E rings at positions 3, 11 and 30, respectively, as indicated in Figure 3.



1 18β-Glycyrrhetinic acid (18β-GA) **2** Carbenoloxone (CBX)

Figure 2. Structures of 18β-glycyrrhetinic acid and carbenoxolone.

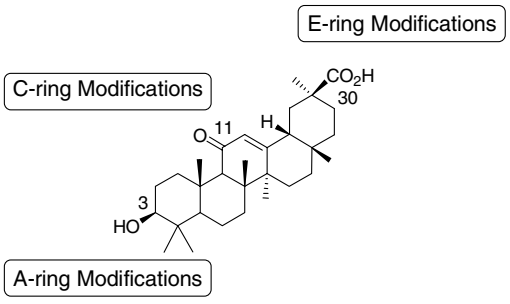
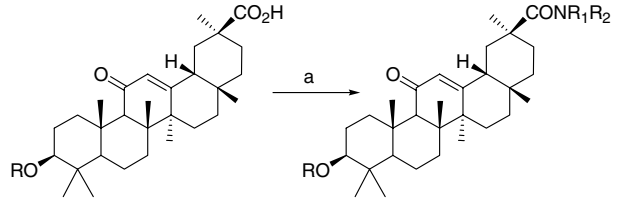


Figure 3. Structural modification of 18β-glycyrrhetinic acid template.

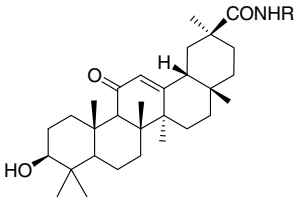
2.1. Modifications to the 30-position

2.1.1. Amides. A diverse set of amides **3**–**33** was synthesized by activation of the carboxylic acid moiety at the 30-position and reaction with a range of amines. Syntheses were performed classically and in parallel using the water soluble EDCI as the activating agent under a variety of conditions (Scheme 1).[27] The compounds listed in Tables 1 and 2 were synthesized by these methods.



Scheme 1. Synthesis of 18β-glycyrrhetinic acid amides. Reagents and conditions: (a) EDCI, R_1R_2NH, CH_2Cl_2 or $CHCl_3$, DMAP, HOBt (optional), rt.

Table 1. Secondary amide derivatives of 18β-GA (**1**) at the 30-position and their inhibition of 11β-HSD1 and 11β-HSD2



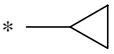
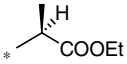
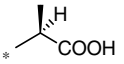
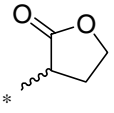
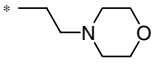
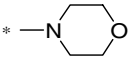
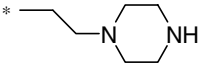
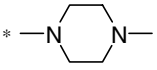
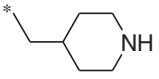
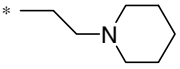
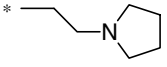
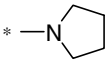
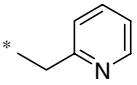
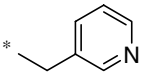
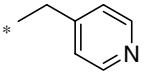
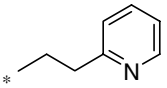
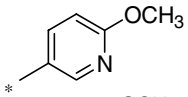
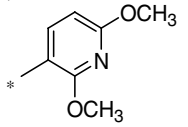
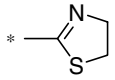
Compd	R	% Inhibition of 11β-HSD1 at 10 μM[a]	% Inhibition of 11β-HSD2 at 10 μM[a]
1		85	101
2		52	100
3	$CH_2CH_2CH_2CH_3$	13	100
4		90	103
5		25	35
6		58	39
7	CH_2CH_2OH	36	92
8	$CH_2(CH_2)_4OH$	88	98
9	$CH_2CH_2NHCH_3$	36	101
10		71	25
11	$CH(CH_2CH_2OH)CO_2H$	50	6
12		19	66
13		34	20
14		7	92
15		10	38
16		23	100
17		36	23
18		29	18
19		66	99
20	$CH_2C_6H_5$	85	74
21		35	96
22		21	44
23		52	77
24		18	99

Table 1 (*continued*)

Compd	R	% Inhibition of 11β-HSD1 at 10 μM[a]	% Inhibition of 11β-HSD2 at 10 μM[a]
25		38	15
26		58	93
27		55	94

*Indicates point of attachment.

[a] Mean of at least two measurements with typically ±5% variation.

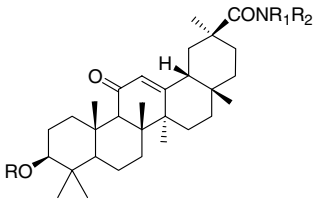
2.1.2. Ethers and esters. A number of chemical modifications to the 30-position of the 18β-GA template have been published. However, the effects of these structural changes on 11β-HSD activity and selectivity have not been reported.[26,28,29] Schemes 2 and 4 illustrate the introduction of alcohol and ether functionalities into the 18β-GA template. The C-30 esters were prepared from 18β-GA **1** using the standard methods with the requisite alkyl halides as previously described to give **35**–**38**.[26] Compound **34** had previously been prepared by the above method,[26] and also by treatment of 18β-GA **1** with diazomethane;[30] in this instance *p*-TSA in methanol was used.[31]

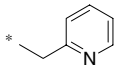
The C-30 hydroxymethyl analogue of 18β-GA **39** was prepared from 18β-GA **1** by reduction with LAH followed by oxidation of the allylic alcohol with manganese dioxide (Scheme 2). Esterification of the C-30 acid of 18β-GA **1** using MeOH/*p*-TSA followed by protection of the 3β-OH as its THP ether using THP/PPTS gave **45** as an intermediate for further modification. Etherification of the C-30 hydroxymethyl moiety using sodium hydride and the requisite alkyl halide under standard conditions followed by deprotection of the 3-position using PPTS gave the ether derivatives **40**–**43**. The tertiary *gem* dimethyl alcohol **44** was one of the minor products isolated by treatment of the C-30 methyl ester of 18β-GA **34** with methyl lithium (Scheme 4). Compounds synthesized in Schemes 2 and 4 and C-30 esters where the 11-position is unchanged are listed in Table 3.

2.2. Modifications to the C-3 position

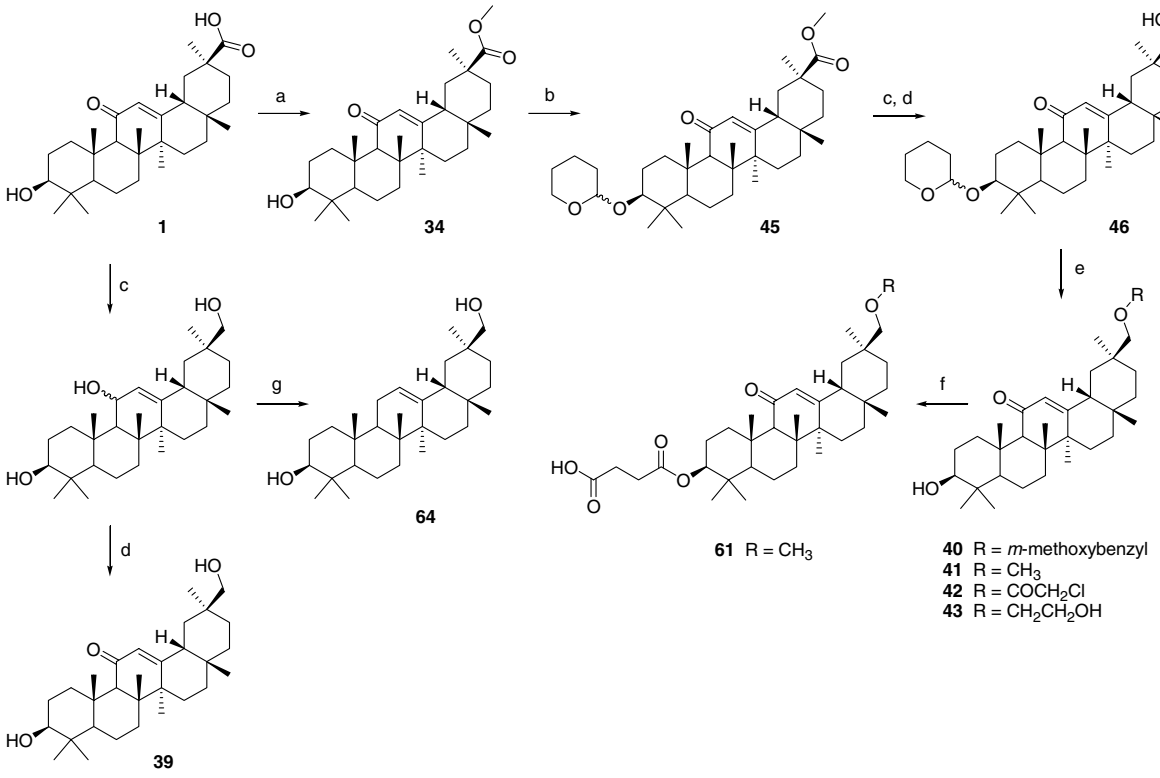
A number of modifications have been examined at the 3-position, these include the synthesis of ether and ester derivatives and oxidation of the C-3 hydroxyl group to give 3-oxocompounds. The C-3 acetate **58** was prepared as previously described,[31] and the C-3 ethers **47**–**57** were prepared as outlined in Scheme 3 using standard procedures these compounds are listed in Table 4.

Table 2. Tertiary and other amide modifications of (**1**) coupled with changes to the 3-position



Compd	R	R_1	R_2	% Inhibition of 11β-HSD1 at 10 μM[a]	% Inhibition of 11β-HSD2 at 10 μM[a]
28	$COCH_3$	H	$CH_2C_6H_5$	36	27
29	$COCH_3$	H	OH	32	89
30	$COCH_3$	H	$(CH_2)_2OH$	39	4
31	CH_3	H	$(CH_2)_2OH$	32	0
32	H	$R_1R_2 = -(CH_2)_5-$		59	23
33	$CO(CH_2)_2COOH$	H		40	23

*Indicates point of attachment.
[a] Mean of at least two measurements with typically ±5% variation.



Scheme 2. Modifications to the 30 and 11 positions of 18β-GA. Reagents and conditions: (a) CH_3OH, *p*-TSA, reflux; (b)THP, PPTS, DCM, rt; (c) $LiAlH_4$, THF, 60 °C; (d) MnO_2, $CHCl_3$, rt; (e) (i) NaH, RX or $ClCH_2CO_2C_2H_5$ for **42**, THF or toluene, 60 °C; (ii) PPTS, CH_3OH, 50 °C; (f) succinic anhydride, pyridine, DMAP, 90 °C; (g) PtO_2, H_2, C_2H_5OH–THF, rt.

2.3. 3-Oxo-compounds and carbenoxolone (CBX) analogues

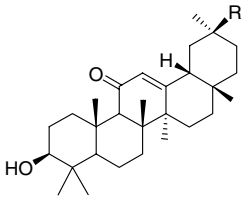
The 3-oxo analogues of 18β-GA **1** were prepared by oxidation of the 3-position of 18β-GA **1** and the corresponding C-30 methyl ester **34** using Jones reagent as previously described to give **59** and **60** (Scheme 3).[26,30]

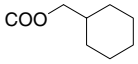
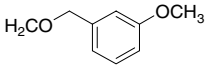
The succinate ester derivatives **33** and **61** related to CBX **2** were prepared from the corresponding 3β-hydroxy-GA compounds using succinic anhydride and DMAP in pyridine using standard methods.

2.4. Modifications to the 11-position of the C-ring

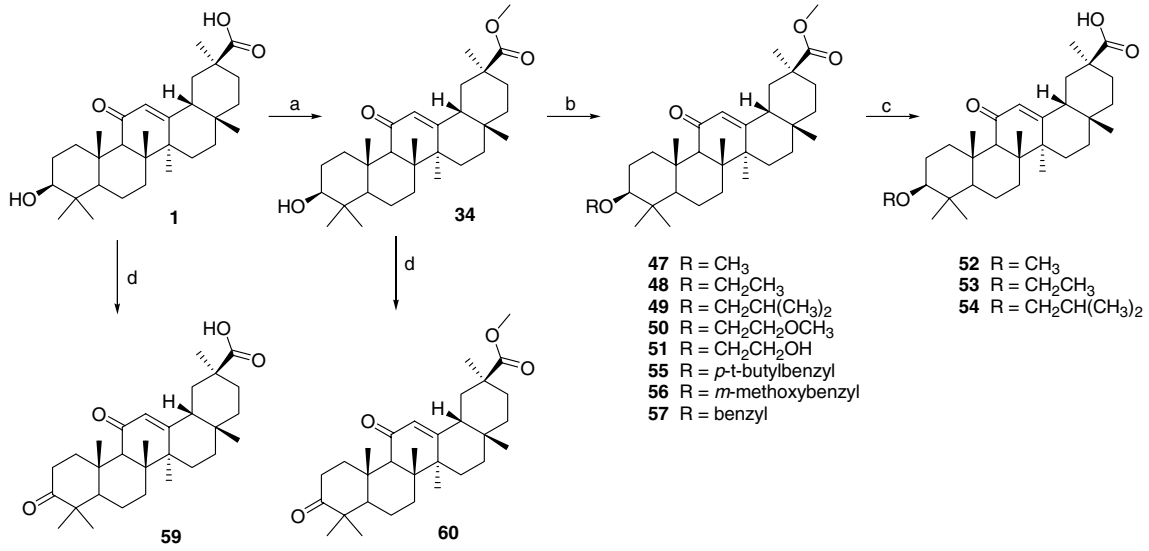
The reduced compound **64** was prepared by treatment of 18β-GA **1** with LAH followed by reduction of the allylic alcohol at the 11-position with hydrogen using PtO_2 as the catalyst (Scheme 2).[29] Reduction of 18β-GA **1** with hydrogen over PtO_2 gave the 11-deoxo-18β-GA ana-

Table 3. Ester, ether and alcohol modifications of the 30-position of 18β-GA (**1**)



Compd	R	% Inhibition of 11β-HSD1 at 10 μM[a]	% Inhibition of 11β-HSD2 at 10 μM[a]
34	$COOCH_3$	85	105
35	$COOCH_2CH_3$	81	98
36	$COOC(CH_3)_3$	51	23
37		38	34
38	$COOCH_2C_6H_5$	53	60
39	CH_2OH	90	100
40		6	14
41	CH_2OCH_3	43	8
42	CH_2OCOCH_2Cl	6	92
43	$CH_2OCH_2CH_2OH$	88	19
44	$C(CH_3)_2OH$	31	9

[a] Mean of at least two measurements with typically ±5% variation.



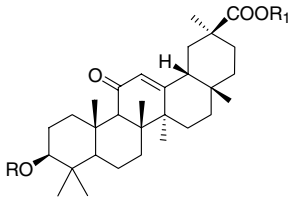
Scheme 3. Modifications to the 3-position of 18β-GA. Reagents and conditions: (a) CH_3OH, *p*-TSA, reflux; (b) NaH, RX, THF, reflux; (c) NaOH, CH_3OH–THF, reflux; (d) Jones reagent.[19]

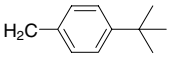
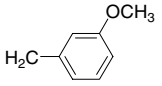
logue **62**, the corresponding C-30 methyl ester **63** was prepared in the same manner from 18β-GA methyl ester **34** formed from 18β-GA **1** by treatment with *p*-TSA in methanol (Scheme 4).[26,31] Treatment of 18β-GA methyl ester **34** with methyl lithium gave three products as indicated in Scheme 4 with the major products being the 1,2-addition product **65** and the *exo*-methylene derivative **66** resulting from the dehydration of **65**. The corresponding C-30 acid derivatives were formed by hydrolysis of the esters with potassium hydroxide to yield **67** and **68**. Alternatively, **68** was also synthesized in high yield from 18β-GA **1** by treatment with methyl lithium followed by dehydration under acidic conditions with hydrochloric acid during work up (Scheme 4, Table 5).

3. Results and discussion

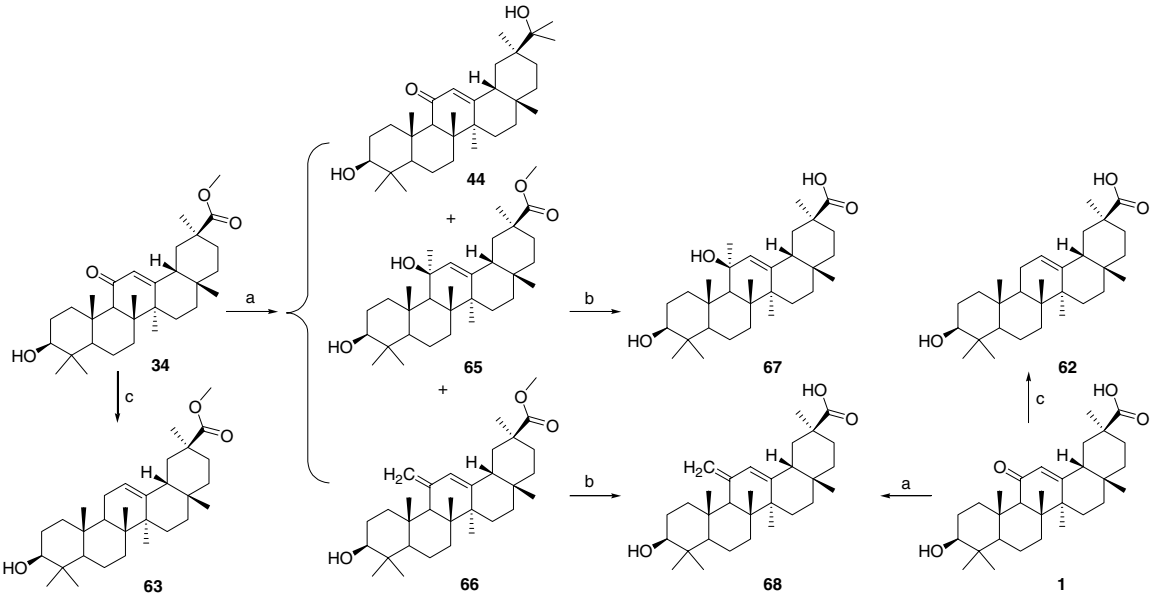
On the rat 11β-HSD type 1 and 2 isozymes 18β-GA **1** and CBX **2** show potent and non-selective inhibition at 10 μM. Both **1** and **2**, although being non-selective, inhibit the type 2 enzyme to a higher degree as evidenced by the greater inhibition of 11β-HSD2 over 11β-HSD1 at different concentrations.[26] As **1** and **2** show maximal

Table 4. 3-Ether and ester 18β-GA analogues and their inhibitions for 11β-HSD



Compd	R	R_1	% Inhibition of 11β-HSD1 at 10 μM[a]	% Inhibition of 11β-HSD2 at 10 μM[a]
47	CH_3	CH_3	8	6
48	CH_2CH_3	CH_3	32	18
49	$CH_2CH(CH_3)_2$	CH_3	33	19
50	$CH_2CH_2OCH_3$	CH_3	11	10
51	CH_2CH_2OH	CH_3	38	5
52	CH_3	H	28	99
53	CH_2CH_3	H	74	89
54	$CH_2CH(CH_3)_2$	H	61	43
55		CH_3	15	26
56		CH_3	2	4
57	$CH_2C_6H_5$	CH_3	18	17
58	$COCH_3$	H	24	99

[a] Mean of at least two measurements with typically ±5% variation.



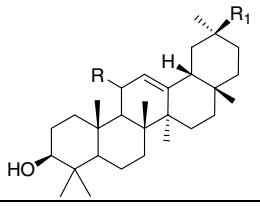
Scheme 4. Modifications to the 11 and 30 positions of 18β-GA. Reagents and conditions: (a) CH_3Li–ether, THF, −78 to 25 °C; (b) KOH, CH_3OH–THF–H_2O; (c) PtO_2, H_2, C_2H_5OH–THF, rt.

inhibition of 11β-HSD2 at 10 μM, compounds synthesized by template modifications were screened at 10 μM against both isozymes. Selected analogues were examined at lower concentrations and IC_{50} values determined for a number of highly potent compounds. In general terms compounds have been classed as showing some selectivity if there is greater than 2.5-fold difference in % inhibition, provided >50% inhibition is observed for one isozyme. For the more potent selective inhibitors highlighted the percentage inhibition for one isozyme is >90%.

3.1. Amide modifications

The secondary amide modifications at the 30-position (Table 1) gave a wide range of activities on both 11β-HSD1 and 11β-HSD2. In general, most compounds

Table 5. 11-Modified 18β-GA analogues and their inhibition for 11β-HSD1 and 11β-HSD2



Compd	R	R_1	% Inhibition of 11β-HSD1 at 10 μM[a]	% Inhibition of 11β-HSD2 at 10 μM[a]
62	H	COOH	93	109
63	H	$COOCH_3$	20	20
64	H	CH_2OH	13	60
65	β-OH-α-CH_3	$COOCH_3$	30	5
66	$=CH_2$	$COOCH_3$	40	20
67	β-OH-α-CH_3	COOH	88	14
68	$=CH_2$	COOH	57	22

[a] Mean of at least two measurements with typically ±5% variation.

showed a greater inhibition of 11β-HSD2 over 11β-HSD1 and were non-selective. A number of compounds showed >90% inhibition of 11β-HSD2 with >2.5-fold % inhibition over 11β-HSD1, indicating selectivity. These compounds included the neutral species **7** and **3** with hydroxyethyl and *n*-butyl side chains, respectively. Most compounds in this series that displayed the above criteria contained basic side chains. These derivatives included the 2-pyridinylethyl and 2-pyridinylmethyl analogues **24** and **21**, the 4-ethylpiperidinyl and piperazinylmethyl analogues **16** and **14**, and the ethylaminomethyl derivative **9**.

The 2-hydroxyethyl analogue **7** was designed to mimic the C-17 side chain of cortisol/cortisone and probe the hydrogen bonding characteristics in this region. Although being longer by two atoms than the side chain in cortisone the amide carbonyl in **7** is isosteric with the ketone at the 20-position of cortisone and the hydroxyl is in a similar spatial region to the C-21 hydroxyl in cortisone. This compound has an IC_{50} of 4 pM against 11β-HSD2 with only 36% inhibition against 11β-HSD1 at 10 μM, and is the most potent 11β-HSD2 inhibitor reported against the rat isozyme. The position of the hydroxyl group in **7** is important for selectivity as the 5-hydroxypentyl analogue **8** is potent on 11β-HSD1 and 11β-HSD2.

The *n*-butyl analogue **3** is a hydrophobic derivative with a linear alkyl chain. The other hydrophobic derivatives **4** and **20** with cyclopropyl and benzyl side chains did not show selectivity for 11β-HSD2. This observation indicates that the hydrophobic interactions in this region of 11β-HSD1 are more restricted than in 11β-HSD2 as **3**, with a hydrophobic side chain with more degrees of freedom, is poorly active against 11β-HSD1.

The active and selective basic amides indicate that the position of the basic moiety is important for activity and selectivity on 11β-HSD2. Both **16** and **14** have a secondary amine moiety in a ring on the basic side chain in a similar region of space, and as the *N*-ethylpiperidinyl, *N*-ethylpyrrolidinyl and *N*-ethylmorpholinyl analogues **17**–**18** and **12** are weakly active compared to **16** and **14** the importance of the basic interaction in this region is highlighted. As the 2-pyridinyl compounds **24** and **21** are both potent and selective the position of the basic nitrogen is further highlighted as both the 3-pyridinyl and 4-pyridinyl compounds **22** and **23** are less potent and non-selective. The ethylaminomethyl analogue **9** is potent and selective and has a secondary amine in the same region as the pyridyl nitrogen in **21**. As both pyridyl and secondary amine derivatives have been shown to be potent selective inhibitors of 11β-HSD2 this suggests that a hydrogen bond acceptor interaction may be important in this region. Although the position of the basic group in the side chain is important for activity and selectivity it is likely that different interactions are being picked up by the sets **16**, **14**, **9**, and **21**, **24** as the basic group in these sets occupies a different spatial region.

The 4-methoxypyridin-3-yl analogue **25** was weakly active on both isozymes, however the 2,4-dimethoxypyridin-3-yl compound **26**, the thiazol-2-yl analogue **27** and the pyrrolidinyl hydrazide **19**, although non-selective, were potent 11β-HSD2 inhibitors, highlighting the importance of electronic effects in this region.

A number of compounds in this series were weakly active and non-selective, these include the ethyl ester **5** and its corresponding carboxylic acid analogue **6**; the *N*-methylpiperazinyl, morpholinyl and derivatives **15**, and **13** also show low activity and poor selectivity. These results indicate that the steric and electronic effects of these groups in this region are not providing favourable interactions with either of the 11β-HSD isozymes.

The cyclic lactone **10**, although not potent, does show some selectivity for 11β-HSD1 as does the hydroxy acid **11**, which is the ring opened version of **10**. The possibility, although unlikely, that **10** is hydrolytically converted to **11** under the assay conditions cannot be ruled out.

Other secondary amide modifications (Table 2) include compounds with *O*-acetyl **28**, **30**, *O*-methyl **31** and succinate **33** groups at the 3-position. The 3-*O*-acetyl

benzyl amide **28** was weakly active and non-selective. The 3-acetyl hydroxamate analogue **29** showed selectivity for 11β-HSD2 similar to the close structural analogue **58**, 3-*O*-acetyl 18β-GA (Table 4). Interestingly, **30** the 3-*O*-acetyl analogue of the potent selective 11β-HSD2 inhibitor **7** (Table 1) was inactive on 11β-HSD2, indicating that the combination of these groups is not tolerated by the active site of the type 2 isozyme. This observation was also noted for the 3-*O*-methyl analogue **31**, which was also inactive on 11β-HSD2 (Table 2) compared to **52** the 3-*O*-methyl analogue of 18β-GA (Table 4), which was a potent inhibitor of 11β-HSD2. This indicates that changes to the 3 and 30 positions to give **50** were not additive and probably modifications at both ends of the template are resulting in unfavourable steric effects. The tertiary amide **32** was a weak non-selective inhibitor of both isozymes, possibly indicating that a tertiary amide in this region does not have the required electronic effect, but as the similar secondary amide analogues **17** and **18** discussed above were also weakly active, an unfavourable hydrophobic interaction in the region is also possible.

In summary, amide modifications at the 30-position are generally non-selective but show greater inhibition of 11β-HSD2 than 11β-HSD1. The position of the basic nitrogen in amide side chains is important for activity and selectivity on 11β-HSD2. The most potent compound in this series is the hydroxyethyl analogue **7** and elongation of the alkyl chain decreases activity.

3.2. Ester and ether modifications

Further modifications to the 30-position including esters, ethers and alcohols are listed in Table 3. Esters with small alkyl groups such as methyl and ethyl, **34** and **35**, are potent non-selective inhibitors of 11β-HSD1 and 11β-HSD2. The more bulky hydrophobic esters such as its *t*-butyl, cyclohexylmethyl and benzyl derivatives, **36**–**38** are less potent and non-selective, indicating that large hydrophobic groups in this region are not beneficial for activity.

The hydroxymethyl derivative **39** is potent on both 11β-HSD1 and 11β-HSD2 and has comparable activity to 18β-GA **1**. This indicates that a carbonyl group at the 30-position is not a requirement for activity. However, the more bulky *gem*-dimethyl derivative **44** shows weak activity, indicating the poor tolerance of steric bulk and the importance of an interaction in this region. Interestingly, the 2-hydroxyethyloxymethyl compound **43** is selective for 11β-HSD1 and this compound has the hydroxyl moiety in a similar region to **11** indicating an important interaction in this region for 11β-HSD1 activity.

The bulky ether **40** is inactive on both 11β-HSD1 and 11β-HSD2, indicating that the tolerance for steric bulk for activity has been exceeded. The smaller methoxymethyl ether **41** although weakly active, shows some selectivity for 11β-HSD1 and it is interesting to note this selectivity is also observed in **61** (Scheme 2), the corresponding carbenoxolone analogue (with 75% and 19% inhibition of 11β-HSD1 and 11β-HSD2, respectively at 10 μM, not shown in tables). Conversely, **42** is a potent and selective 11β-HSD2 inhibitor; clearly, interactions in this area of space are key to determine selectivity with unfavourable hydrophobic effects being limiting for both isozymes.

The 3-ether analogues of the 18β-GA template are listed in Table 4. The direct analogues of 18β-GA **1** itself show that the 3-methoxy ether **52** is potent and selective for 11β-HSD2. By increasing the steric bulk to ethyl and isopropyl selectivity for 11β-HSD2 is lost, although moderate activity, decreasing with hydrophobicity is maintained. The 3-ether analogues of the C-30 methyl ester of 18β-GA (**47**–**51**, **55**–**57**) are essentially inactive on both isozymes irrespective of the size and hydrophobicity of the ether. Clearly a combination of C-30 ester and C-3 ether moieties is sufficient to block key interactions on both 11β-HSD1 and 11β-HSD2.

The acetyl ester derivative of 18β-GA, **58** was a potent selective inhibitor of 11β-HSD2. The potency of **58** on 11β-HSD2 is similar to that of the succinate ester CBX **2**, however hydrolytic instability of ester groups anywhere on the GA template cannot be ruled out and **58** may be slowly converted to 18β-GA **1**.

The 3-oxo analogue of 18β-GA, **60** is a non-selective and potent inhibitor of 11β-HSD1 and 11β-HSD2 and the corresponding C-30 methyl ester **59**, although losing some potency, is also non-selective (activities not shown, Scheme 3).[26] This indicates that a hydrogen bond donor at the 3-position is not essential for activity and a hydrogen bond acceptor interaction may be taking place in this region. This hypothesis is in agreement with the results observed above for the 3-ethers **52**–**53** and acetyl analogue of 18β-GA **58** and also for CBX **2** where a hydrogen bond donor interaction close to C-3 may be important. The succinate ester side chain present in CBX **2** was incorporated into selected active compounds that had indicated selectivity for either 11β-HSD1 or 11β-HSD2; the synthetic ease of introduction of the succinate side chain was also taken into account when choosing the analogues. In the secondary amide series **21** was chosen as a selective 11β-HSD2 inhibitor and, although only moderately active, **41** with a methoxymethyl ether at C-30 was chosen as a selective 11β-HSD1 inhibitor. Activity and selectivity for 11β-HSD1 was retained with **61**; however, for **33** selectivity was lost and only weak activity observed indicating the combination of structural changes at C-3 and C-30 was not tolerated in this case (activities not shown).[26]

In summary, small alkyl esters such as methyl or ethyl at the 30-position are potent but not selective 11β-HSD inhibitors and larger groups result in loss of potency. At the 3-position the acetyl compound is a potent and selective 11β-HSD2 inhibitor however potency is lost with additional substitution at the 30-position. In the ether series the 3-methoxy compound is a potent and selective inhibitor of 11β-HSD2 and a loss of selectivity is observed with larger substituents.

3.3. Modification of the 11-position

A number of modifications were made at the 11-position of the 18β-GA **1** template, the region where the 11β-HSD isozymes invoke their catalysis. The 11-*exo*-methylene compounds **66** and **68** were weakly active and non-selective showing that this carbonyl isostere, although having a similar size to a carbonyl, does not have the electronic and hydrogen bonding properties in this region likely to be required for inhibition of 11β-HSD catalysis. The tertiary alcohol analogue **65** showed poor activity against both 11β-HSD1 and 11β-HSD2 although some selectivity for 11β-HSD1 was indicated. This observation was strengthened by the corresponding C-30 acid derivative **67** showing reasonable potency and selectivity for the type 1 isozyme. Removal of the carbonyl at the 11-position to give the desoxo analogues **62**–**64** showed that with this change only the C-30 acid derivative **62** retained potency but was non-selective. The ester analogue **63** was weakly active and non-selective. The C-30 hydroxymethyl derivative **64**, although weakly active, demonstrated selectivity for 11β-HSD2, an observation previously noted for small nonhindered C-30 side chain alcohols such as **7**. In summary, with hydrogen at the 11-position and the 30-position unsubstituted potency is maintained with lack of selectivity. Introduction of a methylene group at the 11-position gives weakly active non-selective compounds. Introduction of a tertiary alcohol giving **67** results in selectivity for 11β-HSD1.

As the 11β-HSD isozymes exert their catalytic action at the 11-position, it is not surprising to see dramatic changes in potency when this region of the molecule is modified.

From the extensive number of structural changes to the 18β-GA template discussed a number of potent and selective inhibitors of 11β-HSD2 have been identified and the IC_{50} values of a selection these compounds are shown in Table 6 with 18β-GA **1** included for comparison.

From the extensive modifications on the 18β-GA template **1** discussed a number of potent and selective inhibitors of 11β-HSD2 have been identified. A preliminary communication relating to some of this work has been published.[34] These compounds are currently being used in the construction of a pharmacophore for 11β-HSD2, which will not only be used in the design of further selective inhibitors of 11β-HSD2 but also in the identification of novel nonsteroidal templates as 11β-HSD inhibitors and as templates for further design.

Table 6. IC_{50} values for selective inhibitors of 11β-HSD2

Compd	IC_{50} (nM) on 11β-HSD2[a]
1	360[b]
7	0.004
42	164
52	184
58	0.02

[a] Mean of at least two measurements with typically ±5% variation.
[b] Reported value.[32]

4. Conclusions

Novel highly potent and selective inhibitors of rat 11β-HSD2 have been identified and the knowledge of the SAR of glycyrrhetinic acid analogues as inhibitors of the 11β-hydroxysteroid dehydrogenases has been greatly extended. The selective 11β-HSD2 described herein have potencies ranging from low picomolar to hundred nanomolar levels. Compound **7** is the most potent selective 11β-HSD2 inhibitor reported to date with an $IC_{50} = 4$ pM on the rat isozyme. Compounds such as **7** should prove useful as mechanistic tools for in vivo studies in rodent models to evaluate the biological effects of potent and selective 11β-HSD2 inhibitors. In addition, they will serve as templates for further design of selective nonsteroidal inhibitors and the recent publication of a homology model of 11β-HSD2 will be used in structure based drug design to accelerate this process.[35]

5. Experimental

5.1. General

All chemicals were either purchased from the Aldrich Chemical Co. (Gillingham, UK), Lancaster Synthesis (Morecambe, UK) or ACROS Organics (Loughborough, UK). All organic solvents of A.R. grade were supplied by Fisher Scientific (Loughborough, UK).

Rat livers and rat kidneys from normal Wistar rats were obtained from Harlan Olac, Bicester, Oxon, UK. The PBS–sucrose buffer assay medium, Dulbecco's Phosphate Buffered Saline, 1 tablet/100 mL with 0.25 M sucrose, pH 7.4 was purchased from BDH Laboratory supplies, UK. Ecoscint A scintillation fluid was obtained from National Diagnostics, US. Radioactive cortisol solutions, [1,2,6,7-^{3}H]-cortisol was obtained from American Radiolabelled Chemical Inc., (ARC) MD, USA with 2×10^{5} dpm and [4-^{14}C]-cortisol was obtained from Perkin Elmer, MS, USA with 10,000 dpm. Radiolabelled cortisone was obtained from American Radiolabelled Chemical Inc., (ARC) MD, USA with 2×10^{5} dpm and [4-^{14}C]-cortisone was bought from ARC (10,000 dpm). Cortisol, cortisone and cofactors NADPH and NADP were purchased from Sigma Chemical Co., Poole, UK.

Thin layer chromatography (TLC) was performed on pre-coated plates (Merck TLC aluminium sheets silica gel 60 F_{254}, Art. No 5554). Compounds were visualized by either viewing under UV light or treating with an ethanolic solution of phosphomolybdic acid (PMA) followed by heating. Flash chromatography was carried out using Sorbsil C60 silica gel or Isolute® pre-packed Flash Si columns from Argonaut Technologies. Parallel synthesis was performed on either Radleys Carousel reaction stations or Radleys GreenHouse parallel synthesizers. Solvent removal from parallel syntheses was

performed on a GeneVac DD4 evaporation system. NMR spectra were recorded with a JEOL GX-270 or Varian-Mercury-400 spectrometer, and chemical shifts are reported in parts per million (ppm, δ) relative to tetramethylsilane (TMS) as an internal standard. Only diagnostic proton signals are listed. Mass spectra were recorded at the Mass Spectrometry Service Centre, University of Bath. FAB-MS were carried out using *m*-nitrobenzyl alcohol (NBA) as the matrix. High performance liquid chromatography (HPLC) analysis was performed with a Waters Delta 600 liquid chromatograph with a Waters 996 photodiode Array Detector using a Waters Radialpack C18, 8×100 mm column. Melting points (mp) were measured with a Reichert-Jung ThermoGalen Kofler block or a Sanyo Gallenkamp melting point apparatus and are uncorrected.

Incubations were performed in a mechanically shaken water bath, SW 20, Germany. Evaporations were carried out using a Techne Driblock DB 3A, UK. Scintillation vials used were 20 mL polypropylene vials with caps, SARSTEDT, Germany, and scintillation countering was performed on a Beckman LS 6000 SC, Beckman Instruments Inc., USA.

5.2. Biology

Assays were performed essentially as described previously.[26] Kidneys and livers from normal Wistar rats were homogenized on ice in PBS–sucrose buffer (1 g/10 mL) using an Ultra-Turrax. After the livers and kidneys were homogenized the homogenate was centrifuged for 5 min at 4000 rpm. The supernatant obtained was removed and stored in glass vials at −20 °C. The amount of protein per μL of rat liver and kidney centrifuged supernatants was determined using the Bradford method.[33]

For the assay of 11β-HSD type 1 activity rat centrifuged supernatant (76 μg protein) was incubated for 90 min with [^{3}H] cortisone and adjusted to a final substrate concentration of 0.5 μM with cortisone. The assay was carried out in phosphate-buffered saline (PBS) with NADPH (1 mM) as the co-factor. At the end of the incubation period [4-^{14}C] cortisol was added to monitor procedural losses together with 50 μg of unlabelled cortisol to assist in the location of product steroid. Using this assay, conversion of cortisone to cortisol was linear with respect to time (0–120 min) and protein concentration (10–100 μg) (data not shown).

The assay for 11β-HSD type 2 activity employed rat kidney centrifuged supernatant (136 μg protein) and [^{3}H] cortisol adjusted to a final substrate concentration of 0.5 μM with cortisol. PBS–sucrose was used as the buffer with NADP (1 mM) as the co-factor. [4-^{14}C] Cortisone was added at the end of the incubation period (60 min) to monitor procedural losses with 50 μg unlabelled cortisone being added to assist product location,

At the end of the incubation period and addition of [4-^{14}C] and unlabelled product steroids, precursor and product steroids were extracted with diethyl ether (4 mL). The organic phase was removed and taken to dryness under air. The resulting residue was dissolved in diethyl ether (50–100 μL), transferred to a thin-layer chromatography plate, which contained a fluorescent dye, and developed using the system chloroform: methanol (9:1, v/v). Product steroids were visualized under UV light. In this system the R_f values for cortisol and cortisone were 0.5 and 0.8, respectively. The areas containing cortisol or cortisone were cut from the TLC plate and placed in a 20 mL scintillation vials. Steroids were eluted from the plate by the addition of methanol (0.5 mL) before the addition of scintillation fluid (10 mL) and determining the radioactivity using scintillation spectrometry. Enzyme activity was determined as the amount of product formed/mg protein/h after correction for procedural losses. Assays were carried out in the absence or presence of inhibitors. Initially, all compounds were tested at 10 μM with IC_{50} values being determined for compounds showing >90% inhibition when tested at this concentration.

5.3. Chemistry

5.3.1. General synthetic procedures

5.3.1.1. Method A: Synthesis of 18β-GA 30-amides (4, 5, 7, 8, 10, 12, 30–32). To a solution of 18β-GA (**1**) (0.5 mmol) in DCM (15 mL) were added the amine (1.0 mmol), HOBt (0.26 mmol), EDCI (0.55 mmol), DMAP (0.55 mmol) and triethylamine (0.55 mmol). The mixture was stirred under nitrogen at room temperature for 16–24 h. When TLC showed the completion of the reaction, the reaction mixture was poured into water and extracted with DCM. The organic phase was washed with 2% HCl and water, dried over $MgSO_4$. Evaporation of the solvent gave a residue that was purified by flash chromatography (SiO_2, ethyl acetate–hexane, gradient elution) to give the amide product.

5.3.1.2. Method B: Synthesis of 18β-GA 30-amides (20, 28). To a solution of 18β-GA (**1**) (0.2 mmol) in chloroform (5 mL) the requisite amine (0.4 mmol) and EDCI (0.4 mmol) were added. The mixture was stirred under nitrogen at room temperature for 6–16 h. When TLC showed the completion of the reaction, the reaction mixture was poured into water, extracted with DCM. The organic phase was washed with 2% HCl and water, dried over $MgSO_4$ and concentrated in vacuo to give a residue that was purified by flash chromatography (SiO_2, ethyl acetate–hexane, gradient elution) to give the amide products.

5.3.1.3. Method C: Parallel synthesis of 18β-GA 30-amides using Radleys GreenHouse Parallel Synthesizer (3, 9, 13–19, 22–27). To a suspension of 18β-GA (**1**) (50 mg, 0.106 mmol) in anhydrous DCM (4 mL, 10 mL tubes) under an argon atmosphere at room temperature, EDCI (1.1 M equiv), DMAP (cat.) were added followed by Et_3N (1.1 M equiv). The reaction mixture was stirred for 0.5 h at room temperature, added the amine (2 M equiv) and stirred overnight. The reactions were

monitored using TLC (DCM–MeOH, 95:5) and quenched by addition of water (1 mL). The resulting mixtures were stirred at rt for 10 min and the aqueous layer was separated. The organic phase was then washed subsequently with 1 M HCl (1 mL) and water (1 mL). The aqueous phase was removed and the bi-phasic mixture was evaporated using the *GeneVac*. The crude products were purified in a parallel manner using *Argonaut* prepacked columns (5 g) on the *Vacuum Flash Master* using a gradient elution with hexane–ethyl acetate–methanol mixtures to give the products as white solids.

5.3.1.4. Method D: Synthesis of 3-alkylated 18β-GA 30-methyl ester derivatives (47–51, 55–57). The intermediate methyl ester **34** was suspended in anhydrous THF under an argon atmosphere, NaH (60% dispersed in oil, 2 equiv) was added at rt over 5 min, followed by the requisite alkyl or aryl halide (2 equiv). The crude mixtures were heated at reflux under inert atmosphere. The reactions were monitored by TLC (EtOAc–hexane, 2:8). Once completed, the reactions were quenched by addition of water (dropwise) at rt. The crude mixtures were extracted with DCM, and the organic phase was washed with saturated NaCl solution. The organic extracts were dried ($MgSO_4$) and concentrated in vacuo to obtain the product as a solid. The crude product was then purified using flash chromatography (SiO_2, hexane–ethyl acetate, gradient elution) to obtain in general a colourless solid.

5.3.1.5. Method E: Synthesis of 3-alkylated 18β-GA derivatives (52–54). The starting ester was suspended in THF–water (3:1, 4 mL), LiOH (5 M equiv) were added, and the mixture heated at reflux for 24 h. The crude reaction was cooled to rt, acidified with 2 M HCl (pH = 2) and extracted with DCM. The organic phase was dried ($MgSO_4$) and concentrated to obtain the crude product as a pale yellow solid. The crude product was then purified using flash chromatography eluting with ethyl acetate–methanol or DCM–methanol.

5.3.1.6. Method F: Synthesis of 18β-GA 30-esters (35–38). A solution of **1** (1.0 g; 2.12 mmol) in anhydrous DMF (50 mL) containing anhydrous K_2CO_3 (2.9 g; 21.2 mmol) was stirred at rt under N_2 for 1 h. The requisite alkyl halide (11 equiv) was introduced to the reaction mixture followed by tetra-butyl ammonium iodide (200 mg). The mixture was stirred for 24 h at rt, poured into brine and extracted with ethyl acetate (3 × 200 mL). The organic phase was washed with water (3 × 100 mL), dried over MgSO4, filtered and evaporated in vacuo to give a white solid. Purification by flash chromatography (SiO2, EtOAc–Hexane gradient elution) and recrystallization from absolute ethanol gave the required product.

5.3.1.7. *N*-Cyclopropyl-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (4). 4 was synthesized with general method A. White crystalline solid (150 mg, 59%) was obtained. Mp 253–256 °C; HPLC purity 99% (t_R 3.9 min in 6% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.64 (s, 1H, 12-H), 3.23 (m, 1H, 3α-H), 2.80 (dt, J = 13.3, 3.4 Hz, 1H, 1β-H), 2.71 (m, 1H, –NH*CH*), 2.34 (s, 1H, 9α-H), 2.15 (t, J = 8.2 Hz, 1H, 18β-H), 1.37 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.11 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.82 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 510 (100, MH^+); FAB-HRMS calcd for $C_{33}H_{53}NO_3$ (MH^+) 510.3947, found 510.3956.

5.3.1.8. *N*-(3β-Hydroxy-11,30-dioxo-18β-olean-12-en-30-yl)-L-alanine ethyl ester (5). 5 was synthesized with general method A starting from **1** (1.0 mmol). White amorphous powder (430 mg, 75%) was obtained. HPLC purity 99% (t_R 4.2 min in 6% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.14 (d, J = 8 Hz, 1H, *NH*), 5.76 (s, 1H, 12-H), 4.60 (m, 1H, NH*CH*), 4.23 (q, J = 7.3 Hz, 2H, –O*CH*$_2$CH$_3$), 3.23 (m, 1H, 3α-H), 2.82 (dt, J = 13.3, 3.5 Hz, 1H, 1β-H), 2.34 (s, 1H, 9α-H), 2.28 (t, J = 8.5 Hz, 1H, 18β-H), 1.40 (d, J = 7 Hz, 3H, CH_3), 1.39 (s, 3H, CH_3), 1.30 (t, J = 7.3 Hz, 3H, CH_3), 1.15 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.82 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 570 (100, MH^+); FAB-HRMS calcd for $C_{35}H_{56}NO_5$ (MH^+) 570.4158, found 570.4150.

5.3.1.9. *N*-(3β-Hydroxy-11,30-dioxo-18β-olean-12-en-30-yl)-L-alanine (6). To a solution of **5** (300 mg, 0.53 mmol) in methanol–THF (8 mL:4 mL) was added 1 N NaOH solution (1 mL). The mixture was stirred under nitrogen at rt for 2 h, adjusted to pH 3 with 10% HCl and extracted with DCM. The organic phase was washed with water, dried over $MgSO_4$ and concentrated to give a residue, which was purified with flash chromatography and recrystallized from ethyl ether. White crystalline solid (180 mg, 63%) was obtained. Mp 272–275 °C; HPLC purity 97% (t_R 2.6 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.67 (d, J = 7.8 Hz, 1H, NH), 5.64 (s, 1H, 12-H), 4.65 (m, 1H, –NH*CH*–), 3.18 (m, 1H, 3α-H), 2.70 (dt, J = 13.3, 3.2 Hz, 1H, 1β-H), 2.27 (s, 1H, 9α-H), 1.33 (d, J = 7 Hz, 3H, CH_3), 1.28 (s, 3H, CH_3), 1.09 (s, 3H, CH_3), 1.05 (s, 3H, CH_3), 1.04 (s, 3H, CH_3), 0.94 (s, 3H, CH_3), 0.74 (s, 3H, CH_3), 0.73 (s, 3H, CH_3); FAB-MS m/z: 542 (100, MH^+); FAB-HRMS calcd for $C_{35}H_{52}NO_5$ (MH^+) 542.3845, found 542.3853.

5.3.1.10. *N*-(2-Hydroxyethyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (7). 7 was synthesized with general method A. White crystalline solid (110 mg, 43%) was obtained. Mp 160–163 °C; HPLC purity 96% (t_R 6.2 min in 55% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.06 (t, J = 5.9 Hz, 1H, NH), 5.61 (s, 1H, 12-H), 3.67 (t, J = 5.1 Hz, 2H, CH_2), 3.39 (m, 2H, –NH*CH*$_2$–), 3.16 (m, 1H, 3α-H), 2.72 (dt, J = 13.6, 3.6 Hz, 1H, 1β-H), 2.27 (s, 1H, 9α-H), 2.12 (t, J = 8.6 Hz, 1H, 18β-H), 1.30 (s, 3H, CH_3), 1.08 (s, 3H, CH_3), 1.06 (s, 3H, CH_3), 1.05 (s, 3H, CH_3), 0.94(s, 3H, CH_3), 0.75 (s, 3H, CH_3), 0.74 (s, 3H, CH_3); FAB-MS m/z: 542 (100, MH^+); FAB-HRMS calcd for $C_{35}H_{52}NO_5$ (MH^+) 542.3845, found 542.3853.

5.3.1.11. *N*-(5-Hydroxypentyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (8). 8 was synthesized with general method A. White crystalline solid

(165 mg, 59%) was obtained. Mp 136–139 °C; HPLC purity 98% (t_R 5.1 min in 8% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.67 (s, 1H, 12-H), 5.63 (m, 1H, NH), 3.68 (m, 2H, -CH_2OH), 3.42 (m, 1H, –NHCH–), 3.24 (m, 1H, –NHCH–), 3.23 (m, 1H, 3α-H), 2.80 (dt, $J = 13.6$, 3.5 Hz, 1H, 1β-H), 2.38 (s, 1H, 9α-H), 1.34 (s, 3H, CH_3), 1.14 (s, 6H, 2×CH_3), 1.13 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.82 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 556 (100, MH^+); FAB-HRMS calcd for $C_{35}H_{58}NO_4$ (MH^+) 556.4366, found 556.4376.

5.3.1.12. *N*-(2-Oxo-tetrahydrofuran-3-yl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (10). The diastereoisomers **10** were synthesized with general method A starting from **1** (0.75 mmol). White powder (305 mg, 74%) was obtained. HPLC purity 99% (as diastereoisomers, $t_R = 3.9$ min in 4% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.37 (d, $J = 6.2$ Hz, 1H, NH), 6.32 (d, $J = 6.2$ Hz, 1H, NH), 5.75 (s, 1H, 12-H), 5.66 (s, 1H, 12-H), 4.58 (m, 2H, 2×NHCH), 4.49 (m, 2H, –OCH_2), 4.30 (m, 2H, –OCH_2), 3.23 (m, 2H, 2×3α-H), 2.80 (m, 2H, 2×1β-H), 2.32 (s, 2H, 2×9α-H), 1.35 (s, 6H, 2×CH_3), 1.16 (s, 6H, 2×CH_3), 1.11 (s, 12H, 4×CH_3), 0.98 (s, 6H, 2×CH_3), 0.81 (s, 6H, 2×CH_3), 0.79 (s, 6H, 2×CH_3); FAB-MS m/z: 554 (100, MH^+); FAB-HRMS calcd for $C_{34}H_{52}NO_5$ (MH^+) 554.3845, found 554.3832.

5.3.1.13. *N*-(3β-Hydroxy-11,30-dioxo-18β-olean-12-en-30-yl)-2-amino-4-hydroxy-butyric acid (11). To a solution of **10** (110 mg, 0.20 mmol) in methanol (4 mL) was added 1N KOH solution (1 mL). The mixture was stirred under nitrogen at rt for 24 h, then adjusted to pH 2 with 10% HCl and extracted with DCM. The organic phase was washed with water, dried over $MgSO_4$ and concentrated to give a residue, which was purified with flash chromatography. White solid (65 mg, 57%) was obtained. Mp 220–229 °C; HPLC purity 95% (as diastereoisomers, t_R 2.0 min in 4% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.0 (m, 1H, NH), 5.75 (s, 1H, 12-H), 4.40 (m, 1H, –NHCH–), 3.65 (m, 2H, –OCH_2), 3.18 (m, 1H, 3α-H), 1.31 (s, 3H, CH_3), 1.19 (s, 3H, CH_3), 1.05 (s, 3H, CH_3), 1.02 (s, 3H, CH_3), 0.92 (s, 3H, CH_3), 0.75 (s, 6H, 2×CH_3); FAB-MS m/z: 570 (30, $M-H^+$); FAB-HRMS calcd for $C_{34}H_{52}NO_6$ ($M-H^+$) 570.3795, found 570.3797.

5.3.1.14. *N*-[2-(Morpholin-4-yl)ethyl]-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (12). 12 was synthesized with general method A. White crystalline solid (200 mg, 69%) was obtained. Mp 135–138 °C; HPLC purity 97% (t_R 3.9 min in 6% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) : δ 6.21 (m, 1H, NH), 5.71 (s, 1H, 12-H), 3.72 (m, 4H, –$(CH_2)_2$O of morpholine), 3.38 (m, 2H, –CONHCH_2), 3.23 (m, 1H, 3α-H), 2.82 (dt, $J = 13.5$, 3.2 Hz, 1H, 1β-H), 2.52 (t, $J = 5.9$ Hz, 2H, –CH_2N), 2.47 (m, 4H, –N($CH_2)_2$), 2.37 (s, 1H, 9-H), 1.40 (s, 3H, CH_3), 1.14 (s, 9H, 3×CH_3), 1.01 (s, 3H, CH_3), 0.82 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 583 (100, MH^+); FAB-HRMS calcd for $C_{36}H_{59}N_2O_4$ (MH^+) 583.4475, found 583.4492.

5.3.1.15. *N*-Benzyl-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (20). 20 was synthesized with general method B. Off-white crystalline powder (40 mg, 33%) was obtained. Mp 233–235 °C; HPLC purity 98% (t_R 2.6 min in 4% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.36 (m, 2H, aromatic protons), 7.25–7.30 (m, 3H, aromatic protons), 5.83 (broad, 1H, NH), 5.57 (s, 1H, 12-H), 4.47 (m, 2H, NHCH_2Ph), 3.21 (dd, $J = 10.5$, 6.2 Hz, 1H, 3α-H), 2.78 (dt, $J = 13.3$, 4.5 Hz, 1H, 1β-H), 2.31 (s, 1H, 9α-H), 2.18 (dd, $J = 9.8$, 3.5 Hz, 1H, 18β-H), 1.36 (s, 3H, CH_3), 1.16 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.12 (s, 3H, CH_3), 1.00 (s, 3H, CH_3), 0.81 (s, 3H, CH_3), 0.80 (s, 3H, CH_3); FAB-MS m/z: 560 (100, MH^+); FAB-HRMS calcd for $C_{37}H_{54}NO_3$ (MH^+) 560.4104, found 560.4090.

5.3.1.16. *N*-Benzyl-3β-acetyloxy-11-oxo-18β-olean-12-en-30-oic acid amide (28). 28 was synthesized with general method B starting from 3β-acetyloxy glycyrrhetinic acid (**58**).[31] White crystalline solid (55 mg, 48%) was obtained. Mp 150–152 °C; HPLC purity 97.7% (t_R 3.6 min in 4% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.37 (m, 2H, aromatic protons), 7.24–7.30 (m, 3H, aromatic protons), 5.83 (t, $J = 5.5$ Hz, 1H, *NH*), 5.56 (s, 1H, 12-H), 4.41–4.53 (m, 3H, 3α-H and NHCH_2Ph), 2.78 (dt, $J = 13.6$, 4.5 Hz, 1H, 1β-H), 2.33 (s, 1H, 9α-H), 2.16 (dd, $J = 9.7$, 3.2 Hz,1H, 18β-H), 2.05 (s, 3H, 3-CH_3CO–), 1.35 (s, 3H, CH_3), 1.16 (s, 6H, 2×CH_3), 1.15 (s, 3H, CH_3), 1.12 (s, 3H, CH_3), 0.88 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 602 (100, MH^+); FAB-HRMS calcd for $C_{39}H_{56}$ NO (MH^+) 602.4209, found 602.4211.

5.3.1.17. *N*-Hydroxy-3β-acetyloxy-11-oxo-18β-olean-12-en-30-oic acid amide (29). To a solution of **58** (235 mg, 0.45 mmol) in anhydrous THF (8 mL) was added DMAP (11 mg, 0.09 mmol), followed by carbonyldiimidazole (89 mg, 0.55 mmol). The mixture was stirred at rt under nitrogen for 18 h. A solution of hydroxylamine hydrochloride (64 mg, 0.92 mmol) in DMF (2 mL) was added. The mixture was stirred at 60 °C for 5 h, and poured into water, extracted with DCM. The organic phase was washed brine, dried over $MgSO_4$ and concentrated in vacuo to afford a residue that was purified with flash chromatography (EtOAc–hexane gradient elution). White crystalline solid (90 mg, 38%) was obtained. Mp 294–299 °C; HPLC purity 99% (t_R 7.2 min in 10% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.37 (s, 1H, NH), 5.69 (s, 1H, 12-H), 4.52 (dd, $J = 11.7$, 7.1 Hz, 1H, 3α-H), 2.81 (dt, $J = 13.6$, 3.5 Hz, 1H, 1β-H), 2.28 (s, 1H, 9α-H), 2.08 (s, 3H, CH_3CO–), 1.36 (s, 3H, CH_3), 1.20 (s, 3H, CH_3), 1.16 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 0.88 (s, 6H, 2×CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 528 (100, MH^+); FAB-HRMS calcd for $C_{32}H_{50}NO_5$ (MH^+) 528.3689, found 528.3698.

5.3.1.18. *N*-(2-Hydroxyethyl)-3β-acetyloxy-11-oxo-18β-olean-12-en-30-oic acid amide (30). 30 was synthesized with general method A starting from **58** (872 mg, 1.70 mmol). White crystalline solid (688 mg, 73%) was obtained. Mp 236–238 °C; HPLC purity 99% (t_R 2.2 min

in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.22 (t, $J = 5.5$ Hz, 1H, NH), 5.68 (s, 1H, 12-H), 4.51 (dd, $J = 12.7$, 5.1 Hz, 1H, 3α-H) 3.73 (m, 2H, –CH_2OH), 3.54 (m, 1H, –NH*CH*–), 3.39 (m, 1H, –NH*CH*–), 2.86 (broad, 1H, OH), 2.77 (dt, $J = 13.7$, 3.5 Hz, 1H, 1β-H), 2.36 (s, 1H, 9α-H), 2.18 (t, $J = 8.6$ Hz, 1H, 18β-H), 2.06 (s, 3H, CH_3CO–), 1.37 (s, 3H, CH_3), 1.15 (s, 6H, 2×CH_3), 1.12 (s, 3H, CH_3), 0.88 (s, 6H, 2×CH_3), 0.81 (s, 3H, CH_3); ^{13}C NMR (270 MHz, $CDCl_3$) δ 200.2, 176.9, 171.0, 169.5, 128.4, 80.6, 62.5, 61.7, 55.0, 48.2, 45.4, 43.7, 43.2, 42.0, 41.9, 38.8, 38.0, 37.4, 36.9, 32.7, 31.9, 31.5, 29.5, 28.5, 28.0, 26.4, 26.3, 23.5, 23.3, 21.3, 18.7, 17.3, 16.7, 16.4; FAB-MS m/z: 556 (100, MH^+); FAB-HRMS calcd for $C_{34}H_{54}NO_5$ (MH^+) 556.4002, found 556.3991.

5.3.1.19. *N*-(2-Hydroxyethyl)-3β-methoxy-11-oxo-18β-olean-12-en-30-oic acid amide (31). 31 was synthesized with general method A starting from **52** (500 mg, 1.03 mmol). White crystalline solid (396 mg, 75%) was obtained. Mp 146–148 °C; HPLC purity 99% (t_R 2.6 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.18 (t, $J = 5.4$ Hz, 1H, NH), 5.68 (s, 1H, 12-H), 3.74 (m, 2H, –CH_2OH), 3.38–3.48 (m, 2H, –NH*CH*$_2$–), 3.28 (s, 3H, CH_3O–), 2.80 (dt, $J = 13.7$, 3.5 Hz, 1H, 1β-H), 2.68 (dd, $J = 12.6$, 5.0 Hz, 1H, 3α-H), 2.33 (s, 1H, 9α-H), 2.17 (t, $J = 8.5$ Hz, 1H, 18β-H), 1.37 (s, 3H, CH_3), 1.15 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.12 (s, 3H, CH_3), 0.99 (s, 3H, CH_3), 0.82 (s, 3H, CH_3), 0.79 (s, 3H, CH_3); FAB-MS m/z: 528 (100, MH^+); FAB-HRMS calcd for $C_{33}H_{54}NO_4$ (MH^+) 528.4053, found 528.4041.

5.3.1.20. *N*-(3β-Hydroxy-11,30-dioxo-18β-olean-12-en-30-yl)-piperidine (32). 32 was synthesized with general method A. White crystalline solid (110 mg, 41%) was obtained. Mp 276–280 °C; HPLC purity 98% (t_R 4.8 min in 4% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.71 (s, 1H, 12-H), 3.55 (m, 4H, –N(CH_2)$_2$ of piperidine), 3.23 (m, 1H, 3α-H), 2.82 (dt, $J = 13.3$, 3.5 Hz, 1H, 1β-H), 2.35 (s, 1H, 9α-H), 2.30 (t, $J = 8.2$ Hz, 1H, 18β-H), 1.37 (s, 3H, CH_3), 1.22 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.82 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 538 (100, MH^+); FAB-HRMS calcd for $C_{35}H_{56}NO_3$ (MH^+) 538.4260, found 538.4239.

5.3.1.21. *N*-(Pyridin-2-yl-methyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide 3β-succinic semiester (33). To a solution of **21** (122 mg, 0.218 mmol) in pyridine (5 mL) were added succinic anhydride (304 mg, 3.04 mmol) and DMAP (106 mg, 0.88 mmol). The mixture was stirred at 90 °C for 72 h, and poured over 10% HCl solution, extracted with DCM. The organic phase was washed brine, dried over $MgSO_4$ and concentrated in vacuo to afford a residue, which was purified with flash chromatography. Yellow solid (65 mg, 45%) was obtained. Mp 152–154 °C; HPLC purity 99% (t_R 3.4 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 (dd, $J = 7.9$, 2.0 Hz 1H, Ar–H), 7.66 (dt, $J = 7.8$, 2.0 Hz, 1H, Ar–H), 7.53 (m, 1H, NH), 7.31 (d, $J = 7.8$, 1H, Ar–H), 7.15–7.23 (m. 1H, Ar–H), 5.71 (s, 1H, 12-H), 4.40–4.57 (m, 3H, 3α-H and –CH_2Py), 2.71 (dt, $J = 13.3$, 3.5 Hz, 1H, 1β-H), 2.58–2.64 (m, 4H, –$COCH_2CH_2CO$–), 2.34 (s, 1H, 9α-H), 1.34 (s, 3H, CH_3), 1.19 (s, 3H, CH_3), 1.04 (s, 6H, 2×CH_3), 0.82 (s, 3H, CH_3), 0.81 (s, 3H, CH_3), 0.66 (s, 3H, CH_3); FAB-MS m/z: 661 (60, MH^+); FAB-HRMS calcd for $C_{40}H_{57}N_2O_6$ (MH^+) 661.4217, found 661.4231.

The following amides (**3**, **9**, **13**–**19**, **21**–**27**) were synthesized with general method C.

5.3.1.22. *N*-Butyl-3β-hydroxy-18β-olean-12-en-11-one-30-oic acid amide (3). 3: HPLC purity 90% (t_R 2.38 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.69 (s, 1H, olefinic), 3.50–3.21 (m, 3H), 2.34 (s, 1H, CH), 1.64–1.43 (broad m, 4H), 1.37, 1.25, 1.23, 1.14, 1.01, 0.83 and 0.81 (7×s, 3H each, CH_3); APCI-MS m/z: 526 (50, MH^+), 567 (50, M+CH_3CN^+); FAB-HRMS calcd for $C_{35}H_{55}NO_3$ (MH^+) 526.4260, found 526.4267.

5.3.1.23. *N*-(2-Amino-*N*-methylethyl)-3β-hydroxy-18β-olean-12-en-11-one-30-oic acid amide (9). 9: mp 153–156 °C; HPLC purity 95% (t_R 2.38 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.70 (s, 1H, olefinic H), 3.25–3.21 (m, 2H), 3.13–2.78 (broad dt, 1H, 1β-CH), 2.18 (s, 3H N–CH_3), 1.37, 1.35, 1.12, 1.10, 1.00, 0.80 and 0.79 (7×s, 3H each, 7×CH_3); APCI-MS m/z: 526 (100, M^+); FAB-HRMS calcd for $C_{33}H_{54}N_2O_3$ (M^+) 526.4089, found 526.4049.

5.3.1.24. *N*-(Morpholin-4-amino)-3β-hydroxy-18β-olean-12-en-11-one-30-oic acid amide (13). 13: mp 183–186 °C; HPLC purity >99% (t_R 1.53 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 270 MHz) δ 6.30 (broad s, 1H, NH), 5.60 (s, 1H, olefinic), 3.82–3.78 (broad t, 4H, CH_2), 3.22–3.20 (broad m, 1H, CH), 2.80–2.77 (broad m, 5H, CH_2), 2.34 (s, 1H, CH), 1.37, 1.25, 1.10, 1.12, 1.01, 0.81 and 0.75 (7×s, 3H each, CH_3); APCI-MS m/z: 555 (40, MH^+), 577 (30, M+Na^+); FAB-HRMS calcd for $C_{37}H_{54}N_2O_4$ (MH^+) 555.4525, found 555.4512.

5.3.1.25. *N*-(1-Piperazinylethyl)-3β-hydroxy-18β-olean-12-en-11-one-30-oic acid amide (14). 14: HPLC purity >90% (t_R 2.45 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 270 MHz) δ 5.71 (s, 1H, olefinic), 3.64 (broad t, 4H, CH_2), 3.20–3.10 (broad m, CH), 2.81–2.71 (broad dt, 1H, 1β-CH), 2.38–2.32 (broad t, 4H, CH_2), 2.30 (s, 1H, CH), 1.35, 1.25, 1.13, 1.12, 1.00, 0.81 and 0.80 (7×s, 3H each, CH_3); APCI-MS m/z: 582 (100, MH^+), 553 (40, M−CH_3^+).

5.3.1.26. *N*-(4-Methylpiperazinyl-1-amino)-3β-hydroxy-18β-olean-12-en-11-one-30-oic acid amide (15). 15: mp 190–191 °C; HPLC purity >99% (t_R 2.45 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 270 MHz) δ 5.71 (s, 1H, olefinic), 3.64 (broad t, 4H, CH_2), 3.20–3.10 (broad m, CH), 2.81–2.71 (broad dt, 1H, 1β-CH), 2.38–2.32 (broad t, 4H, CH_2), 2.30 (s, 1H, CH), 1.35, 1.25, 1.13, 1.12, 1.00, 0.81 and 0.80 (7×s, 3H each, CH_3); APCI-MS m/z: 568 (30, MH^+), 553 (100, M−CH_3^+).

5.3.1.27. *N*-(4-Piperidinylmethyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (16). 16: mp 198–200 °C HPLC purity >99% (t_R 1.68 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.67 (s, 1H, olefinic), 3.47–3.16 (m, 3H), 2.80–2.72 (broad dt, 1H, 1β-CH), 2.32 (s, 1H, CH), 1.34, 1.20, 1.11, 1.10, 0.98, 0.81 and 0.78 (7×s, 3H each, CH_3); APCI-MS m/z: 547 (70, MH^+).

5.3.1.28. *N*-(Piperidinylethyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (17). 17: HPLC purity 90% (t_R 2.46 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.66 (s, 1H, olefinic H), 3.97–3.54 (m, 2H, CH_2), 3.30–3.20 (m, 3H), 2.84–2.73 (m, 1H, CH), 2.34 (s, 1H, CH), 1.39, 1.35, 1.13, 1.12, 1.00 (5×s, 3H each, 5×CH_3), 0.80 (s, 6H, 2×CH_3); APCI-MS m/z: 581 (85, MH^+); FAB-HRMS calcd for $C_{37}H_{60}N_2O_3$ (MH^+) 581.4682, found 581.4674.

5.3.1.29. *N*-(Pyrrolindinylethyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (18). 18: mp 156–159 °C; HPLC purity 95% (t_R 2.37 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) 5.67 (s, 1H, olefinic H), 3.31–3.28 (m, 2H, CH_2), 3.13–2.78 (broad s, 1H, β-CH), 2.77–2.73 (m, 1H, CH), 2.34–2.18 (m, 5H), 1.38, 1.21 1.12, 1.11 and 1.00 (5×s, 3H each, 5×CH_3), 0.80 (s, 6H, 2×CH_3); FAB-MS m/z: 567 (100, M^+); APCI-MS m/z: 567 (70, MH^+); FAB-HRMS calcd for $C_{36}H_{59}N_2O_3$ (MH^+) 567.4525, found 567.4533.

5.3.1.30. *N*-(Pyrrolidinyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (19). 19: mp 191–195 °C; HPLC purity >99% (t_R 1.79 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.68 (s, 1H, olefinic H), 3.25–3.21 (dd, $J = 10.5$, and 5.4 Hz, 1H, CH–OH), 2.94–2.81 (broad m, 4H), 2.26 (s, 1H, CH), 1.37, 1.23 1.14, 1.13, 1.01, 0.83 and 0.81 (7×s, 3H each, 7×CH_3); APCI-MS m/z: 539 (75, MH^+), 580 (100, $M+41^+$); FAB-HRMS calcd for $C_{37}H_{60}N_2O_3$ (MH^+) 539.4212, found 539.4209.

5.3.1.31. *N*-(Pyridin-2-yl-methyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (21). 21: mp 150–153 °C; HPLC purity >99% (t_R 1.48 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.66–8.67 (d, $J = 4.6$ Hz, 1H, aromatic), 7.69–7.65 (m, 1H, aromatic), 7.38 (broad t, 1H, NH), 7.25–7.22 (m, 2H, aromatic), 5.89 (s, 1H olefinic), 4.68–4.47 (m, $J = 16.7$, 5.0 Hz, 1H, benzylic CH), 4.48–4.43 (m, $J = 16.7$, 5.0 Hz, 1H, benzylic CH), 3.26–3.22 (dd, $J = 10.5$, 5.4 Hz, 1H, CH), 2.84–2.79 (dt, $J = 13.2$, 3.9 Hz, 1H, 1β-CH), 2.37 (s, 1H, CH), 1.41, 1.19, 1.14, 1.12, 0.88, 0.81 and 0.77 (7×s, 3H each, CH_3); APCI-MS m/z: 561 (MH^+); FAB-HRMS calcd for $C_{36}H_{52}N_2O_3$ (MH^+) 561.4056, found 561.4045.

5.3.1.32. *N*-(Pyridin-3-yl-methyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (22). 22: mp 236–237 °C; HPLC purity >99% (t_R 1.48 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.54–8.52 (m, 2H, aromatic), 7.63–7.61 (d, $J = 7.8$ Hz, 1H, aromatic), 7.29–7.28 (m, 1H, aromatic), 6.01 (broad t, 1H, NH), 5.59 (s, 1H,olefinic), 4.55–4.47 (m, 2H, benzylic CH_2), 3.23–3.22 (broad m, 1H, CH), 2.79–2.76 (dt, $J = 13.2$, 3.1 Hz, 1H, 1β-CH), 2.32 (s, 1H, CH), 1.36, 1.15, 1.13, 1.12 and 1.00 (5×s, 3H each, 5×CH_3), 0.80 (s, 6H, 2×CH_3); APCI-MS m/z: 561 (100, MH^+), 583 (50, $M+Na^+$); FAB-HRMS calcd for $C_{36}H_{52}N_2O_3$ (MH^+) 561.4056, found 561.4035.

5.3.1.33. *N*-(Pyridin-3-yl-methyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (23). 23: mp 250–251 °C; HPLC purity >99% (t_R 1.48 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.57–8.55 and 7.18–7.17 (2×d, $J = 5.8$ Hz each, 4H, aromatic); 6.03 (broad t, 1H, NH), 5.62 (s, 1H, olefinic), 4.50–4.46 (m, 2H, benzylic CH_2), 3.23 (broad m, 1H, CH), 2.80–2.70 (broad dt, 1H, 1β-CH), 2.33 (s, 1H, CH), 1.37, 1.19, 1.13, 1.00, 0.88, 0.82 and 0.81 (7×s, 3H each, 7×CH_3); APCI-MS m/z: 561 (100, MH^+), 583 (30, $M+Na^+$).

5.3.1.34. *N*-(Pyridin-2-yl-ethyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (24). 24: mp 150–153 °C; HPLC purity >99% (t_R 1.59 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.57–8.56 (m, 1H, aromatic), 7.65–7.61 (ddd, $J = 7.8$, 1.5 Hz, 1H, aromatic), 7.21–7.19 (m, 2H, aromatic), 7.05 (broad t, 1H, NH), 5.63 (s, 1H, oefinic), 3.67–3.73 (m, 2H, CH_2), 3.21–3.25 (dd, $J = 10.9$, 5.8 Hz, CH), 3.02–2.99 (t, $J = 11.7$ Hz, 2H, CH_2), 2.83–2.79 (dt, $J = 10.1$, 3.5 Hz, 1H, 1β-CH), 2.34 (s, 1H, CH), 1.37, 1.13, 1.10, 1.07, 1.01, 0.81 and 0.75 (7×s, 3H each, CH_3), APCI-MS m/z: 575 (100, MH^+); FAB-HRMS calcd for $C_{37}H_{54}N_2O_3$ (MH^+) 575.4167, found 575.4199.

5.3.1.35. *N*-(6-Methoxypyridin-3yl-methyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (25). 25: mp 180–183 °C; HPLC purity >99% (t_R 1.63 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.11–8.10 (s, 1H, aromatic), 7.88–7.85 (d, $J = 8.5$ Hz, 1H, aromatic), 7.24 (s, 1H, NH), 6.75–6.73 (d, $J = 8.5$ Hz, 1H, aromatic), 5.67 (s, 1H, olefinic), 3.91 (s, 3H, OCH_3), 3.24–3.04 (broad m, 1H, CH), 2.81–2.76 (dt, $J = 13.6$, 3.9 Hz, 1H, 1β-CH), 2.34 (s, 1H, CH), 1.61, 1.39, 1.26, 1.12, 1.01, 0.83 and 0.80 (7×s, 3H each, CH_3); APCI-MS m/z: 577 (40, $M-CH_3^+$); FAB-HRMS calcd for $C_{37}H_{54}N_2O_4$ (MH^+) 591.3627, found 591.3606.

5.3.1.36. *N*-(2,6-Dimethoxypyridin-3yl-methyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (26). 26: mp 210–215 °C; HPLC purity >99% (t_R 1.63 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.46–8.43 (d, $J = 8.5$ Hz, 1H, aromatic), 7.68 (broad s, 1H, NH), 6.33–6.32 (d, $J = 8.5$ Hz, 1H, aromatic), 5.78 (s, 1H, aromatic), 4.08–3.89 (s, 3H, OCH_3), 3.50–3.49 (s, 3H, OCH_3), 3.23–3.21 (broad m, 1H, CH), 2.80–2.37 (dt, $J = 13.6$, 3.5 Hz, 1H, 1β-CH), 2.32 (s, 1H, CH), 2.20–2.16 (dd, $J = 12.8$, 3.5 Hz, 1H, CH), 1.37, 1.26, 1.00, 0.86 and 0.81 (5×s, 3H each, CH_3), 1.13 (s, 6H, 2×CH_3); FAB-MS m/z: 607 (100, MH^+); FAB-HRMS calcd for $C_{37}H_{54}N_2O_5$ (MH^+) 607.4110, found 607.4090.

5.3.1.37. *N*-(2-Thiazolyl)-3β-hydroxy-11-oxo-18β-olean-12-en-30-oic acid amide (27). 27: mp 224–227 °C; HPLC purity >99% (t_R 1.91 min in 100% MeOH); ^{1}H

NMR ($CDCl_3$, 400 MHz) δ 9.24 (1H, s, NH), 7.36 (d, $J = 3.5$ Hz, 1H, aromatic), 6.91–6.90 (d, $J = 3.5$ Hz, 1H, aromatic), 5.67 (s, 1H, olefinic), 3.16–3.13 (broad m, 1H, CH), 2.72–2.69 (dt, $J = 13.6$, 3.9 Hz, 1H, 1β-CH), 2.26 (s, 1H, CH), 1.18, 1.06, 1.05, 1.04, 0.94, 0.74 and 0.73 (7×s, 3H each, CH_3); APCI-MS m/z 553 (25, MH^+), 594 (100, $M+CH_3CN^+$); FAB-HRMS calcd for $C_{33}H_{48}N_2O_3S$ (MH^+) 553.3430, found 553.3455.

5.3.1.38. 3β-Hydroxy-11-oxo-18β-olean-12-en-30-oic acid methyl ester (34). To a solution of **1** (15 g, 31.9 mmol) in methanol (200 mL) was added *p*-toluenesulfonic acid (2 g). The mixture was refluxed for 72 h, concentrated in vacuo, poured into water, extracted with DCM. The organic phase was washed with 5% sodium bicarbonate and brine, dried over magnesium sulfate and concentrated to yield white solid, which was recrystallized from methanol. White crystals (14 g, 91%) were obtained. Mp 254–258 °C (lit.[25] 248–256 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.67 (s, 1H, 12-H), 3.70 (s, 3H, $-OCH_3$), 3.23 (m, 1H, 3α-H), 2.80 (dt, $J = 13.6$, 4.5 Hz, 1H, 1β-H), 2.37 (s, 1H, 9α-H), 1.37 (s, 3H, CH_3), 1.15 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.81 (s, 6H, 2×CH_3); FAB-MS m/z: 485 (100, MH^+).

5.3.1.39. 3β-Hydroxy-11-oxo-18β-olean-12-en-30-oic acid ethyl ester (35). 35 was synthesized with general method F. Pale yellow crystals (592 mg; 56%) were obtained. Mp 93–94 °C; FAB-MS m/z: 499 (100, MH^+); FAB-HRMS calcd for $C_{32}H_{51}O_4$ (MH^+) 499.3787, found 499.3786.

5.3.1.40. 3β-Hydroxy-11-oxo-18β-olean-12-en-30-oic acid *t*-butyl ester (36). 36 was synthesized with general method F. Yellow crystals (201 mg; 18%) were obtained. Mp 171–174 °C; FAB-MS m/z: 527 (100, MH^+); FAB-HRMS calcd for $C_{34}H_{55}O_4$ (MH^+) 527.4100, found 527.4105.

5.3.1.41. 3β-Hydroxy-11-oxo-18β-olean-12-en-30-oic acid cyclohexylmethyl ester (37). 37 was synthesized with general method F. White crystals (703 mg; 59%) were obtained. Mp 98–99 °C; FAB-MS m/z: 567 (100, MH^+); FAB-HRMS calcd for $C_{37}H_{59}O_4$ (MH^+) 567.4413, found 567.4409.

5.3.1.42. 3β-Hydroxy-11-oxo-18β-olean-12-en-30-oic acid benzyl ester (38). 38 was synthesized with general method F. White solid (680 mg; 57%) were obtained. Mp 125–126 °C; FAB-MS m/z: 561 (100, MH^+); FAB-HRMS calcd for $C_{37}H_{53}O_4$ (MH^+) 561.3944, found. 561.3933.

5.3.1.43. 11-Oxo-18β-olean-12-ene-3β,30-diol (39). 39 was synthesized by the literature[28] method. Mp 275–277 °C (lit.[28] 274–277 °C); HPLC purity 99% (t_R 7.6 min in 15% water–methanol).

5.3.1.44. 3β-Tetrahydropyran-2-yloxy-11-oxo-18β-olean-12-en-30-oic acid methyl ester (45). To a solution of **34** (900 mg, 1.86 mmol) in DCM (10 mL) was added 3,4-dihydro-2*H*-pyran (250 μL, 2.74 mmol), followed by *p*-toluenesulfonic acid (0.1 g). The mixture was stirred at rt for 6.5 h, poured into 5% sodium bicarbonate, extracted with DCM. The organic phase was washed with brine, dried over magnesium sulfate and concentrated to afford white solid (1.0 g, 95%). HPLC showed the purity of diastereoisomers 51% and 48%, respectively (t_R 23 and 24 min in 10% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.66 (s, 2H, 2×12-H), 4.73 (broad t, 1H, 2′-H of tetrahydropyranyl), 4.58 (dd, $J = 4.7$, 3.5 Hz, 1H, 2′-H of tetrahydropyranyl), 3.95 (m, 2H, 6′-H of tetrahydropyranyl), 3.68 (s, 3H, $-OCH_3$), 3.47 (m, 2H, 6′-H of tetrahydropyranyl), 3.25 (dd, $J = 11.7$, 4.7 Hz, 1H, 3α-H), 3.06 (m, 1H, 3α-H), 2.78 (m, 2H, 1β-H), 2.33 (s, 2H, 9α-H), 1.36 (s, 3H, CH_3), 1.35 (s, 3H, CH_3), 1.15 (s, 12H, 4×CH_3), 1.12 (s, 6H, 2×CH_3), 1.06 (s, 3H, CH_3), 0.92 (s, 3H, CH_3), 0.83 (s, 3H, CH_3), 0.82 (s, 3H, CH_3), 0.80 (s, 6H, 2×CH_3); FAB-MS m/z: 569 (80, MH^+); FAB-HRMS calcd for $C_{36}H_{57}O_5$ (MH^+) 569.4206, found 569.4215.

5.3.1.45. 3β-Tetrahydropyran-2-yloxy-11-oxo-18β-olean-12-en-30-ol (46). To a solution of **45** (900 mg, 1.58 mmol) in THF (50 mL) was added $LiAlH_4$ (500 mg, 13 mmol) in portions. The mixture was stirred at 60 °C for 20 h, quenched with saturated NH_4Cl solution and extracted with DCM. The organic phase was washed with brine, dried over magnesium sulfate and concentrated to afford an oily residue, which was dissolved in $CHCl_3$ (100 mL). MnO_2 (8 g, 92 mmol) was added. The suspension was stirred at rt for 8 h, filtered. Evaporation of the solvent in vacuo gave a brown residue that was purified with flash chromatography (EtOAc–hexane gradient). White crystalline solid (500 mg, 58%) was obtained. HPLC purity 99% (as diastereoisomers, t_R 7.7 min in 4% water–methanol); ^{1}HNMR showed the diastereoisomers in 2:1 ratio (400 MHz, $CDCl_3$) δ 5.58 (s, 2H, 2×12-H), 4.73 and 4.58 (m, 2H, 2′-H of tetrahydropyranyl), 3.95 and 3.45 (m, 4H, 6′-H of tetrahydropyranyl), 3.50 (m, 4H, $-OCH_2-$), 3.22 and 3.05 (m, 2H, 3α-H), 2.78 (m, 2H, 1β-H), 2.35 (s, 2H, 9α-H), 1.36 and 1.35 (s, 6H, 2×CH_3), 1.15 (s, 6H, 2×CH_3), 1.13 (s, 3H, CH_3), 1.06 (s, 3H, CH_3), 0.93 (s, 12H, 4×CH_3), 0.92 (s, 6H, 2×CH_3), 0.83 and 0.82 (s, 6H, 2×CH_3); FAB-MS m/z: 541 (100, MH^+); FAB-HRMS calcd for $C_{35}H_{57}O_4$ (MH^+) 541.4257, found 541.4279.

5.3.1.46. 3β,30-Dihydroxy-18β-olean-12-en-11-one 30-*m*-methoxybenzyl ether (40). To a solution of **46** (60 mg, 0.11 mmol) in THF (5 mL) was added 3-methoxybenzyl chloride (87 mg, 0.56 mmol), followed by NaH (60% dispersion, 22 mg, 0.56 mmol). The mixture was stirred at 60 °C under nitrogen for 3 h, quenched with water and extracted with DCM. The organic phase was washed with brine, dried over magnesium sulfate and concentrated to afford white solid, which was dissolved in CH_3OH (6 mL). Pyridium *p*-toluenesulfonate (50 mg) was added. The mixture was stirred at 50 °C for 7 h, concentrated in vacuo gave white solid that was purified with flash chromatography (EtOAc–hexane gradient). White powder (28 mg, 44%) was obtained; HPLC purity 99% (t_R 8.1 min in 4% water–methanol);

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.92 (broad, 1H, Ar–H), 6.91 (broad, 1H, Ar–H), 6.89 (broad, 1H, Ar–H), 6.82 (dd, $J = 7.5$, 2.8 Hz, 1H, Ar–H), 5.56 (s, 1H, 12-H), 4.49 (s, 2H, –CH_2Ph), 3.82 (s, 3H, –OCH_3), 3.28(AB, $J = 25$ Hz, 2H, 30-OCH_2–), 3.23 (m, 1H, 3α-H), 2.79 (dt, $J = 13.6$, 3.6 Hz, 1H, 1β-H), 2.34 (s, 1H, 9α-H), 1.37 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.12 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.97 (s, 3H, CH_3), 0.81 (s, 6H, 2×CH_3); FAB-MS m/z: 577 (85, MH^+); FAB-HRMS calcd for $C_{38}H_{57}O_4$ (MH^+) 577.4257, found 577.4275.

5.3.1.47. 3β,30-Dihydroxy-18β-olean-12-en-11-one 30-methyl ether (41). Starting from **46** (95 mg, 0.18 mmol) and CH_3I (50 μL, 0.80 mmol), **41** was synthesized as described for **40**. White crystalline solid (65 mg, 78%) was obtained. Mp 224–227 °C; HPLC purity 99% (t_R 4.3 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.59 (s, 1H, 12-H), 3.34 (s, 3H, –OCH_3), 3.23 (m, 1H, 3α-H), 3.20 (AB, $J = 25$ Hz, 2H, 30-OCH_2–), 2.79 (dt, $J = 13.7$, 3.5 Hz, 1H, 1β-H), 2.34 (s, 1H, 9α-H), 1.37 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.92 (s, 3H, CH_3), 0.86 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 471 (100, MH^+); FAB-HRMS calcd for $C_{31}H_{51}O_3$ (MH^+) 471.3838, found 471.3826.

5.3.1.48. 3β,30-Dihydroxy-18β-olean-12-en-11-one 30-chloroacetyl ester (42). Starting from **46** (60 mg, 0.11 mmol) and chloroacetic acid ethyl ester (60 μL, 0.56 mmol), **42** was synthesized as described for **40**. White solid (30 mg, 52%) was obtained. Mp 178–179 °C; HPLC purity 99% (t_R 5.2 min in 4% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) 5.58 (s, 1H, 12-H), 4.12 (s, 2H, –CH_2O–), 4.08 (s, 2H, –CH_2Cl–), 3.23 (m, 1H, 3α-H), 2.79 (dt, $J = 13.2$, 3.4 Hz, 1H, 1β-H), 2.33 (s, 1H, 9α-H), 1.38 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.96 (s, 3H, CH_3), 0.88 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 533 (100, MH^+); FAB-HRMS calcd for $C_{32}H_{50}ClO_4$ (MH^+) 533.3398, found 533.3389.

5.3.1.49. 3β,30-Dihydroxy-18β-olean-12-en-11-one 30-(2-hydroxyethyl) ether (43). To a solution of **46** (100 mg, 0.19 mmol) in toluene (6 mL) was added NaH (60% dispersion, 42 mg, 1.05 mmol). After stirring at 50 °C for 10 min, 2-(2-bromoethoxy)-tetrahydro-pyran (200 μL, 1.32 mmol) was added. The mixture was stirred at 90 °C under nitrogen for 8 h. More NaH (30 mg, 0.75 mmol) and 2-(2-bromo-ethoxy)-tetrahydro-pyran (100 μL, 0.66 mmol) were added. The solution was stirred at 100 °C for 24 h, quenched with water and extracted with DCM. The organic phase was washed with brine, dried over magnesium sulfate and concentrated in vacuo to afford an oily residue that was dissolved in CH_3OH (10 mL). Pyridium *p*-toluenesulfonate (50 mg) was added to the solution. The mixture was stirred at 50 °C for 7 h, diluted with 5% $NaHCO_3$ solution, extracted with DCM. The organic phase was washed with brine, dried and concentrated in vacuo gave a yellow residue that was purified with flash chromatography. Off-white solid (37 mg, 39%) was obtained. Mp 208–211 °C; HPLC purity 98% (t_R 3.5 min in 4% water–methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.57 (s, 1H, 12-H), 3.73 (m, 2H, –OCH_2–), 3.56 (m, 2H, –CH_2O–), 3.40 (m, 2H, 30-OCH_2–), 3.23 (m, 1H, 3α-H), 2.79 (dt, $J = 13.6$, 3.5 Hz, 1H, 1β-H), 2.34 (s, 1H, 9α-H), 1.38 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.13 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 0.95 (s, 3H, CH_3), 0.87 (s, 3H, CH_3), 0.81 (s, 3H, CH_3); FAB-MS m/z: 471 (100, MH^+); FAB-HRMS calcd for $C_{32}H_{53}O_4$ (MH^+) 501.3944, found 501.3928.

The following compounds (**47**–**51**, **55**–**57**) were synthesized with general method D.

5.3.1.50. 3β-Methoxy-18β-olean-12-en-11-one-30-oic acid methyl ester (47). 47: mp ⩾ 300 °C; HPLC purity >95% (t_R 5.63 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.67 (s, 1H, olefinic), 3.69 (s, 3H, CH_3), 3.36 (s, 3H, CH_3), 2.95–2.81 (dt, $J = 13.2$, 3.1 Hz, 1H, 1β-CH), 2.70–2.66 (dd, $J = 11.7$, 4.6 Hz, 1H, CH), 2.33 (s, 1H, CH), 2.09–1.66 (m, 6H), 1.36, 1.15, 1.14, 1.12, 0.99, 0.81 and 0.79 (7×s, 3H each, CH_3); FAB-MS m/z: 499 (100, MH^+); FAB-HRMS calcd for $C_{32}H_{50}O_2$ (MH^+) 499.3787, found 499.3801.

5.3.1.51. 3β-Ethoxy-18β-olean-12-en-11-one-30-oic acid methyl ester (48). 48: HPLC purity >90% (t_R 2.59 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.66 (s, 1H, olefinic), 4.47–4.17 (m, 2H, CH_2), 3.68 (s, 3H, CH_3), 2.84–2.81 (dt, $J = 13.6$, 3.5 Hz, 1H, 1β-CH), 2.35 (s, 1H, CH), 2.09–2.01 (m, 1H, 18β-CH), 1.36, 1.157, 1.150 and 1.12, 0.95, 0.90 and 0.80 (7×s, 3H each, CH_3); FAB-MS m/z: 513 (30, MH^+), 557 (80, $M+CH_3CN)^+$; FAB-HRMS calcd for $C_{33}H_{52}O_4$ (MH^+) 513.3943, found 513.3941.

5.3.1.52. 3β-Isobutyloxy-18β-olean-12-en-11-one-30-oic acid methyl ester (49). 49: mp 298–300 °C; HPLC purity >99% (t_R 4.97 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.59 (s, 1H, olefinic), 3.61 (s, 3H, CH_3), 3.35–3.32 (dd, $J = 8.9$, 6.2 Hz, CH), 2.90–2.86 (dd, $J = 8.9$, 6.2 Hz, CH), 2.75–2.69 (dt, $J = 13.2$, 3.5 Hz, 1H, 1β-CH), 2.68–2.64 (dd, $J = 12.1$, 4.6 Hz, 1H, CH), 2.25 (s, 1H, CH), 1.48 (s, 6H, 2×CH_3), 1.29, 1.071, 1.05,0.91 (4×s, 3H each, CH_3), 0.86–0.84 (d, $J = 5.8$ Hz, 3H, CH_3), 0.82–0.80 (d, $J = 6.6$ Hz, 3H, CH_3), 0.73 (s, 6H, 2×CH_3); FAB-MS m/z: 527 (100, MH^+); FAB-HRMS calcd for $C_{37}H_{52}O_4$ (MH^+) 527.3736, found 527.3734.

5.3.1.53. 3β-(2-Methoxyethoxy)-18β-olean-12-en-11-one-30-oic acid methyl ester (50). 50: HPLC purity >90% (t_R 4.82 min in 100% MeOH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.66 (s, 1H, olefinic), 4.23–4.09 (m, 1H, CH), 3.78–3.73 (m, 1H, CH), 3.69 (s, 3H, OCH_3), 3.58–3.44 (m, 2H, CH_2), 3.38 (s, 3H, OCH_3), 2.83–2.78 (m, 2H, 2×CH), 2.33 (s, 1H, CH), 1.36, 1.15, 1.14, 1.12, 1.00, 0.81 and 0.80 (7×s, 3H each, CH_3); FAB-MS m/z: 543 (90, MH^+); FAB-HRMS calcd for $C_{34}H_{54}O_5$ (MH^+) 543.4049, found 543.4035.

5.3.1.54. 3β-(2-Hydroxyethoxy)-18β-olean-12-en-11-one-30-oic acid methyl ester (51). 51: mp ⩾ 300 °C; HPLC purity >99% (t_R 4.82 min in 100% MeOH); ^{1}H

NMR ($CDCl_3$, 400 MHz) δ 5.66 (s, 1H, olefinic), 3.74–3.70 (broad m, 2H, CH_2), 3.69 (s, 3H, OCH_3), 3.43–3.38 (m, 2H, CH_2), 2.87–2.80 (m, 2H, 2×CH), 2.33 (s, 3H, CH), 1.61, 1.36, 1.15, 1.12, 1.00, 0.81 and 0.80 (7×s, 3H each, CH_3); FAB-MS m/z: 529 (55, MH^+), 467 (30, [M-61$^+$]); FAB-HRMS calcd for $C_{33}H_{52}O_5$ (MH^+) 529.3893, found 529.3873.

5.3.1.55. 3β-(4-*t*-Butylbenzyloxy)-18β-olean-12-en-11-one-30-oic acid methyl ester (55). 55: mp 234–236 °C; HPLC purity >95% (t_R 4.97 min in 100% MeOH); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.41–7.28 (2×d, $J = 8.5$ Hz each), 5.66 (s, 1H, olefinic), 4.66–4.63 (d, 1H, $J = 11.7$ Hz, benzylic CH), 4.40–4.37 (d, 1H, $J = 11.7$ Hz, benzylic CH) 3.69 (s, 3H, CH_3), 2.96–2.92 (dd, $J = 11.3$, 4.2 Hz, 1H, CH), 2.84–2.80 (dt, $J = 13.2$, 3.5 Hz, 1H, 1β-CH), 2.33 (s, 1H, CH), 2.09–2.08 (m, 18-βCH,), 1.315 (s, 9H, *tert*-butyl), 1.360, 1.154, 1.150, 1.12, 1.01, 0.86 and 0.80 (7×s, 3H each, CH_3); FAB-MS m/z: 631 (40, MH^+); FAB-HRMS calcd for $C_{42}H_{62}O_4$ (MH^+) 632.4759, found 632.4771.

5.3.1.56. 3β-(3-Methoxybenzyloxy)-18β-olean-12-en-11-one-30-oic acid methyl ester (56). 56: mp $\geqslant$ 300 °C; HPLC purity >99% (t_R 5.03 min in 100% MeOH); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.24–7.22 (m, 1H, aromatic), 6.94 (appd, 1H, aromatic), 6.92 (s, 1H, aromatic), 6.82–6.80 (m, 1H, aromatic), 5.66 (s, 1H, olefinic), 4.68–4.65 (d, $J = 12.1$ Hz, 1H, benzylic CH), 4.42–4.39 (d, $J = 12.1$, 1H, benzylic CH), 3.81 (s, 3H, CH_3), 3.69 (s, 3H, CH_3), 2.96–2.92 (dd, $J = 11.7$, 4.2 Hz, 1H, CH), 2.84–2.80 (dt, $J = 13.2$, 3.1 Hz, 1H, 1β-CH), 2.33 (s, 1H, CH), 1.36, 1.16, 1.15, 1.13, 1.01, 0.87 and 0.81 (7×s, 3H each, CH_3), FAB-MS m/z: 605 (100, MH^+); FAB-HRMS calcd for $C_{39}H_{56}O_5$ (MH^+) 605.4222, found 605.4206.

5.3.1.57. 3β-Benzyloxy-18β-olean-12-en 11-one 30-oic acid methyl ester (57). 57: mp 302–304 °C; HPLC purity >95% (t_R 4.97 min in 100% MeOH); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.36–7.30 (m, 5H, aromatic), 5.66 (s, 1H, olefinic), 4.70–4.67 (d, $J = 12.1$ Hz, 1H, benzylic CH), 4.42–4.39 (d, $J = 11.7$ Hz, 1H, benzylic CH), 3.69 (s, 3H, CH_3), 2.95–2.91 (dd, $J = 11.7$, 4.2 Hz, 1H, CH), 2.84–2.80 (dt, $J = 13.6$, 3.5 Hz, 1H, 1β-CH), 2.32 (s, 1H, CH), 2.09–1.66 (m, 6H), 1.35, 1.15, 1.14, 1.12, 1.00, 0.86 and 0.80 (7×s, 3H each, CH_3); FAB-MS m/z: 575 (30, MH^+); FAB-HRMS calcd for $C_{37}H_{52}O_4$ (MH^+) 575.4055, found 575.4106.

The following compounds (**52**–**53**) were synthesized with general method E.

5.3.1.58. 3β-Methyloxy-18β-olean-12-en 11-one 30-oic acid (52). 52: mp $\geqslant$ 300 °C; HPLC purity >95% (t_R 5.63 min in 100% MeOH); ^1H NMR ($CDCl_3$, 400 MHz) δ 5.62 (s, 1H, olefinic), 3.29 (s, 3H, CH_3), 2.95–2.81 (dt, $J = 13.2$, 3.5 Hz, 1H, 1β-CH), 2.70–2.66 (dd, $J = 11.7$, 4.2 Hz, 1H, CH), 2.26 (s, 1H, CH), 2.09–1.66 (m, 6H), 1.29, 1.15, 1.07, 1.05, 0.91, 0.76 and 0.71 (7×s, 3H each, CH_3), FAB-MS 485 (100, MH^+).

5.3.1.59. 3β-Ethyloxy-18β-olean-12-en 11-one 30-oic acid (53). 53: mp 284 °C (dec.); HPLC purity >95% (t_R 2.59 min in 100% MeOH); ^1H NMR ($CDCl_3$) δ 5.70 (s, 1H, olefinic), 3.70–3.64 (m, 1H, CH), 3.38–3.31 (m, 1H, CH), 2.82–2.75 (m, 2H, 2×CH), 2.34 (s, 1H, CH), 2.19–2.03 (m, 1H, 18β-CH), 1.37, 1.23, 1.14, 1.13, 0.98, 0.84 and 0.80 (7×s, 3H each, CH_3), 1.19–1.65 (t, $J = 13.6$, 3H, CH_3); FAB-MS m/z: 499 (80, MH^+), 453 (40, M-45)$^+$, FAB-HRMS calcd for $C_{32}H_{50}O_4$ (MH^+) 499.3787, found 499.3772.

5.3.1.60. 3β-Isobutyloxy-18β-olean-12-en-11-one-30-oic acid (54). 54: mp 238 °C (dec.); HPLC purity >95% (t_R 5.14 min in 100% MeOH); ^1H NMR ($CDCl_3$, 400 MHz) δ 5.70 (s, 1H, olefinic), 3.43–3.39 (dd, $J = 8.9$, 6.2 Hz, 1H, CH), 2.98–2.94 (dd, $J = 8.9$, 7.4 Hz, 1H), 2.81–2.75 (dt, $J = 13.7$, 3.4 Hz, 1H, 1β-CH), 2.75–2.71 (dd, $J = 12.1$, 4.6 Hz, 1H, CH), 2.33 (s, 1H, CH), 1.37, 1.23, 1.14, 1.13, 0.99, 0.83, 0.81 (7×s, 3H each, CH_3), 0.93–0.88 (2×d, $J = 6.6$ Hz each, 2×CH_3); FAB-MS m/z: 527 (100, MH^+); FAB-HRMS calcd for $C_{34}H_{54}O_4$ [MH^+] 527.4100, found 527.4090.

5.3.1.61. 3,11-Dioxo-18β-olean-12-en-30-oic acid (59). Jones reagent (1 mL) was added to a solution of **1** (100 mg; 0.21 mmol) in acetone (5 mL). The reaction mixture was stirred for 0.5 h at 0 °C, poured into ice-water and extracted with $CHCl_3$ (50 mL). The organic phase was washed with water (3×50 mL), dried ($MgSO_4$) and evaporated to get a white solid (108 mg). The crude product was purified by recrystallization from hot absolute ethanol to give **59** as white crystals (82 mg; 82%). Mp 302–303 °C (lit.[23] mp 298–302 °C); FAB-MS m/z: 469 (100, MH^+); FAB-HRMS calcd for $C_{30}H_{45}O_4$ (MH^+) 469.3318, found 469.3322.

5.3.1.62. 3,11-Dioxo-18β-olean-12-en-30-oic acid methyl ester (60). Starting from **34**, **60** was synthesized as described for the preparation of **59**. White crystals (59 mg; 59%) was obtained. Mp 249–250 °C (lit.[30] mp 254–256 °C); FAB-MS m/z: 483 (100, MH^+); FAB-HRMS calcd for $C_{31}H_{47}O_4$ (MH^+) 483.3474, found 483.3472.

5.3.1.63. 3β,30-Dihydroxy-18β-olean-12-en-11-one 30-methyl ether 3β-succinic semiester (61). Starting from **41** (25 mg, 0.05 mmol) and succinic anhydride (27 mg, 0.27 mmol), **61** was synthesized as described for **33**. Off-white solid (17 mg, 60%) was obtained. Mp 237–239 °C; HPLC purity 99% (t_R 2.5 min in 2% water–methanol); ^1H NMR (400 MHz, $CDCl_3$) δ 5.58 (s, 1H, 12-H), 4.55 (dd, $J = 11.7$, 4.7 Hz, 1H, 3α-H), 3.33 (s, 3H, –OCH_3), 3.22 (AB, $J = 25$ Hz, 2H, 30-OCH_2–), 2.78 (dt, $J = 13.3$, 3.5 Hz, 1H, 1β-H), 2.62–2.72 (m, 4H, –$COCH_2CH_2CO$–), 2.35 (s, 1H, 9α-H), 1.36 (s, 3H, CH_3), 1.16 (s, 3H, CH_3), 1.13 (s, 6H, 2×CH_3), 0.92 (s, 3H, CH_3), 0.88 (s, 6H, 2×CH_3), 0.86 (s, 3H, CH_3); FAB-MS m/z: 571 (100, MH^+); FAB-HRMS calcd for $C_{35}H_{55}O_6$ (MH^+) 571.3999, found 571.3999.

5.3.1.64. 18β-Olean-12-ene-3β,30-diol (64). 64 was synthesized with literature[29] method. Mp 245–247

°C (lit.[29] 250–251 °C, lit.[28] 246–250 °C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.18 (t, 1H,, $J = 3.9$ Hz, 12-H), 3.52 (m, 2H, 30-CH_2–), 3.22 (dd, $J = 11.3$, 5.9 Hz, 1H, 3α-H), 1.15 (s, 3H, CH_3), 1.00 (s, 3H, CH_3), 0.96 (s, 3H, CH_3), 0.94 (s, 3H, CH_3), 0.90 (s, 3H, CH_3), 0.83 (s, 3H, CH_3), 0.81 (s, 3H, CH_3).

5.3.1.65. 3β,30-Dihydroxy-30,30-dimethyl-18β-olean-12-en-11-one (44), 3β, 11β-dihydroxy-11α-methyl-18β-olean-12-en-30-oic acid methyl ester (65), 3β-hydroxy-11-methylene-18β-olean-12-en-30-oic acid methyl ester (66). To a solution of **34** (2.37 g, 4.90 mmol) in THF (25 mL) was added CH_3Li–ether solution (1.6 M, 6.2 mL, 9.92 mmol) dropwise at −78 °C under nitrogen. The mixture was stirred at −78 °C for 30 min, and then brought to rt gradually. After stirring at rt for 1 h, the reaction was quenched with 1% HCl and extracted with DCM. The organic phase was washed with 5% $NaHCO_3$ solution, brine, dried over magnesium sulfate and concentrated to give a white solid that was subjected to flash chromatography (EtOAc–hexane gradient elution). Starting material **34** (820 mg) was recovered. **44** was obtained as white crystals (130 mg, 8%). Mp 241–246 °C; HPLC purity 99% (t_R 2.4 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.59 (s, 1H, 12-H), 3.23 (m, 1H, 3α-H), 2.70 (dt, $J = 13.7$, 3.5 Hz, 1H, 1β-H), 2.27 (s, 1H, 9α-H), 1.35 (s, 3H, CH_3), 1.22 (s, 3H, CH_3), 1.21 (s, 3H, CH_3), 1.20 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.00 (s, 3H, CH_3), 0.95 (s, 3H, CH_3), 0.81 (s, 3H, CH_3), 0.68 (s, H, CH_3); FAB-MS m/z: 500 (15, M^+), 483 (MH^+-H_2O, 100); FAB-HRMS calcd for $C_{32}H_{53}O_3$ (MH^+) 485.3955, found 485.4000.

65 was obtained as white crystals (455 mg, 28%). Mp 251–257 °C; HPLC purity 91% (t_R 2.6 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.07 (s, 1H, 12-H), 3.70 (s, 3H, –OCH_3), 3.25 (broad, 1H, 3α-H), 2.20 (dt, $J = 12.5$, 3.5 Hz, 1H, 1β-H), 1.44 (s, 3H, CH_3), 1.35 (s, 3H, CH_3), 1.16 (s, 3H, CH_3), 1.14 (s, 3H, CH_3), 1.06 (s, 3H, CH_3), 1.00 (s, 3H, CH_3), 0.82 (s, 6H, $2\times CH_3$); FAB-MS m/z: 500 (15, M^+), 483 (MH^+-H_2O, 100); FAB-HRMS calcd for $C_{32}H_{53}O_4$ (MH^+) 501.3944, found 501.3905.

66 was obtained as white crystals (350 mg, 22%). Mp 168–170 °C; HPLC purity 99% (t_R 4.2 min in methanol); ^{1}H NMR (270 MHz, $CDCl_3$) δ 5.67 (s, 1H, 12-H), 5.03 and 4.95 (s, 2H, 11-CH_2), 3.68 (s, 3H, –OCH_3), 3.24 (m, 1H, 3α-H), 2.45 (dt, $J = 13.3$, 3.5 Hz, 1H, 1β-H), 2.35 (s, 1H, 9α-H), 1.18 (s, 3H, CH_3), 1.17 (s, 3H, CH_3), 1.11 (s, 3H, CH_3), 0.99 (s, 3H, CH_3), 0.92 (s, 3H, CH_3), 0.80 (s, 3H, CH_3), 0.75 (s, 3H, CH_3); FAB-MS m/z: 483 (100, MH^+); FAB-HRMS calcd for $C_{32}H_{51}O_3$ (MH^+) 483.3838, found 483.3838.

5.3.1.66. 3β, 11β-Dihydroxy-11α-methyl-18β-olean-12-en-30-oic acid (67). To a solution of **65** (100 mg, 0.2 mmol) in methanol–THF–water (5:2:1 mL) was added KOH (88 mg, 1.56 mmol). The mixture was stirred under nitrogen at 70 °C for 48 h, poured into 2% HCl, extracted with DCM. The organic phase was washed with brine, dried over magnesium sulfate and concentrated in vacuo to give a white solid that was recrystallized from CH_3OH–DCM. White solid (80 mg, 82%) was obtained. Mp 287–290 °C; HPLC purity 95% (t_R 2.6 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.10 (s, 1H, 12-H), 3.23 (m, 1H, 3α-H), 2.20 (dt, $J = 12.5$, 3.5 Hz, 1H, 1β-H), 1.43 (s, 3H, CH_3), 1.35 (s, 3H, CH_3), 1.22 (s, 3H, CH_3), 1.16 (s, 3H, CH_3), 1.07 (s, 3H, CH_3), 1.00 (s, 3H, CH_3), 0.86 (s, 3H, CH_3), 0.83 (s, 3H, CH_3); FAB-MS m/z: 486 (10, M^+), 469 (MH^+-H_2O, 100); FAB-HRMS calcd for $C_{31}H_{51}O_4$ (MH^+) 487.3787, found 487.3730.

5.3.1.67. 3β-Hydroxy-11-methylene-18β-olean-12-en-30-oic acid (68). Method 1: Starting from **66** (150 mg, 0.31 mmol), **68** was synthesized as described for the preparation of **67**. White crystals (122 mg, 84%) were obtained. Mp 295–296 °C; HPLC purity 99% (t_R 3.1 min in methanol); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.72 (s, 1H, 12-H), 5.06 and 4.98 (s, 2H, 11-CH_2), 3.27 (m, 1H, 3α-H), 2.50 (dt, $J = 13.7$, 3.5 Hz, 1H, 1β-H), 2.31 (s, 1H, 9α-H), 1.23 (s, 3H, CH_3), 1.22 (s, 3H, CH_3), 1.21 (s, 3H, CH_3), 1.02 (s, 3H, CH_3), 0.96 (s, 3H, CH_3), 0.83 (s, 3H, CH_3), 0.82 (s, 3H, CH_3); FAB-MS m/z: 469 (100, MH^+); FAB-HRMS calcd for $C_{31}H_{49}O_3$ (MH^+) 469.3682, found 469.3629.

Method 2: To a solution of **1** (0.8 g, 1.7 mmol) in THF (50 mL) was added CH_3Li–ether solution (1.6 M, 6.2 mL, 9.92 mmol) dropwise at rt under nitrogen. The mixture was stirred at rt for 1 h, and then quenched with 1% HCl and extracted with ethyl acetate. The organic phase was washed with 5% $NaHCO_3$, brine, dried over magnesium sulfate and concentrated to give a white solid that was re-crystallized from CH_3OH–DCM. White crystals (760 mg, 95%) were obtained. Mp 293–296 °C; ^{1}H NMR was identical with the compound from method 1.

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References and notes

1. Jörnvall, H.; Persson, B.; Krook, M.; Atrian, S.; Gonzalez-Duarte, R.; Jeffery, J.; Ghosh, D. *Biochemistry* **1995**, *34*, 6003–6013.
2. Edwards, C. R.; Stewart, P. M.; Burt, D.; Brett, L.; McIntyre, M. A.; Sutano, W. S. *Lancet* **1988**, *2*, 986–989.
3. Seckl, J. R.; Walker, B. R. *Endocrinology* **2001**, *142*, 1371–1376.
4. Davani, B.; Kahn, A.; Måartensson, E.; Efendic, S.; Jörnvall, H.; Oppermann, U. C. T. *J. Biol. Chem.* **2000**, *275*, 34841–34844.
5. Kotelevtsev, Y. V.; Brown, R. W.; Fleming, S.; Kenyon, C.; Edwards, C. R. W.; Seckl, J. R.; Mullins, J. J. *J. Clin. Invest.* **1999**, *103*, 683–689.
6. Alberts, P.; Engblom, L.; Edling, N.; Forsgren, M.; Kilngström, G.; Larsson, C.; Rönquist-Nii, Y.; Öhman, B.; Abrahmsén, L. *Diabetalogica* **2002**, *45*, 1528–1532.
7. Andrews, R. C.; Rooyackers, O.; Walker, B. R. *J. Clin. Endocrinol. Metab.* **2003**, *88*, 285–291.

8. Barf, T.; Vallgårda, J.; Emond, R.; Häggstrom, G. K.; Nygren, A.; Larwood, V.; Mosialou, E.; Axelsson, K.; Olsson, R.; Engblom, L.; Edling, N.; Rönquist-Nii, Y.; Öhman, B.; Alberts, P.; Abrahmsén, L. *J. Med. Chem.* **2002**, *45*, 3813–3815.
9. Sandeep, T. C.; Walker, B. R. *Trends Endocrinol. Metab.* **2001**, *12*, 446–453.
10. Kotelevtsev, Y. V.; Holmes, M. C.; Burchell, A.; Houston, P. M.; Schmoll, D.; Jamieson, P.; Best, R.; Brown, R.; Edwards, C. R. W.; Seckl, J. R.; Mullins, J. J. *Proc. Natl. Acad. Sci. U.S.A.* **1997**, *94*, 14924–14929.
11. Masusaki, H.; Paterson, J.; Shinyama, H.; Morton, N. M.; Mullins, J. J.; Seckl, J. R.; Flier, J. S. *Science* **2001**, *294*, 2166–2170.
12. Monder, C.; Stewart, P. M.; Laksmi, V.; Valentino, R.; Burt, D.; Edwards, C. R. W. *Endocrinology* **1989**, *125*, 1046–1053.
13. Diederich, S.; Grossmann, C.; Hanke, B.; Quinkler, M.; Herrmann, M.; Bähr, V.; Oelkers, W. *Eur. J. Endocrinol.* **2000**, *142*, 200–207.
14. Stewart, P. M.; Valentino, R.; Wallace, A. M.; Burt, D.; Shackleton, C. H. L.; Edwards, C. R. W. *Lancet* **1987**, *2*, 281–284.
15. Stewart, P. M.; Wallace, A. M.; Atherton, S. M.; Shearing, C. H.; Edwards, C. R. W. *Clin. Sci.* **1990**, *78*, 49–54.
16. Dave-Sharma, S.; Wilson, R. C.; Harbison, M. D.; Newfield, R.; Azar, M. R.; Krozowski, M. R.; Funder, J. W.; Shackleton, C. L.; Bradlow, H. L.; Wei, J.-Q.; Hertecant, J.; Moran, A.; Neiberger, R. E.; Balfe, J. W.; Fattah, A.; Daneman, D.; Akkurt, H. I.; de Santis, C. *J. Clin. Endocrinol. Metab.* **1998**, *83*, 2244–2254.
17. Walker, E. A.; Stewart, P. M. *Trends Endocrinol. Metab.* **2003**, *14*, 334–339.
18. Coulter, C. L.; Smith, R. E.; Stowaser, M.; Sasano, H.; Krozowski, Z. S.; Gordon, R. D. *Endocr. Res.* **1998**, *24*, 875–876.
19. Korbonits, M.; Bujalska, I.; Shimojo, M.; Nobes, J.; Kordan, S.; Grossman, A. B.; Stewart, P. M. *J. Clin. Endocrinol. Metab.* **2001**, *86*, 2728–2733.
20. Rabbitt, E. H.; Ayuk, J.; Boelaert, K.; Sheppard, M. C.; Hewison, M.; Stewart, P. M.; Gittoes, N. J. L. *Oncogene* **2003**, *22*, 1663–1667.
21. Sasano, H.; Frost, A. R.; Saitoh, R.; Matsunaga, G.; Nagura, H.; Krozowski, Z. S.; Silverberg, S. G. *Anticancer Res.* **1997**, *17*, 2001–2007.
22. Rabbitt, E. H.; Lavery, G. C.; Walker, E. A.; Cooper, M. S.; Stewart, P. M.; Hewison, M. *FASEB J.* **2002**, *16*, 36–44.
23. Rabbitt, E. H.; Gittoes, N. J. L.; Stewart, P. M.; Hewison, M. *J. Steroid. Mol. Biol.* **2003**, *85*, 415–421.
24. Hult, M.; Jörnvall, H.; Oppermann, U. C. T. *FEBS Lett.* **1998**, *441*, 25–28.
25. Guo, J.; Reidenberg, M. M. *J. Lab. Clin. Med.* **1998**, *132*, 32–38.
26. Potter, B. V. L.; Purohit, A.; Reed, M. J.; Vicker, N. WO 02072084, 2002.
27. Sheehan, J. C.; Ledis, S. L. *J. Am. Chem. Soc.* **1973**, *95*, 875–879.
28. Terasawa, T.; Okada, T.; Nishino, H. *Eur. J. Med. Chem.* **1992**, *27*, 689–692.
29. Shibata, S.; Takahashi, K.; Yano, S.; Harada, M.; Saito, H.; Tamura, Y.; Kumagai, A.; Hirabayashi, K.; Yamamoto, M.; Nagata, N. *Chem. Pharm. Bull.* **1987**, *35*, 1910–1918.
30. Terasawa, T.; Okada, T.; Hara, T.; Itoh, I. *Eur. J. Med. Chem.* **1992**, *27*, 351–354.
31. Sakano, K.; Ohshima, M. *Agric. Biol. Chem.* **1986**, *50*, 763–766.
32. Shimoyama, Y.; Hirabayashi, K.; Matsumoto, H.; Sato, T.; Shibata, S.; Inoue, H. *J. Pharm. Pharmacol.* **2003**, *55*, 811–817.
33. Bradford, M. M. *Anal. Biochem.* **1976**, *72*, 248–254.
34. Vicker, N.; Su, X.; Lawrence, H.; Cruttenden, A.; Purohit, A.; Reed, M. J.; Potter, B. V. L. *Bioorg. Med. Chem. Lett.*, **2004**, *14*, 3263–3267.
35. Arnold, P.; Tam, S.; Yan, L.; Baker, M. E.; Frey, J. F.; Odermatt, A. *Mol. Cell. Endocrinol.* **2003**, *201*, 177–187.