Enantiospecific Syntheses of (+)-Goniofufurone, (+)-7-*epi*-Goniofufurone, (+)-Goniobutenolide A, (−)-Goniobutenolide B, (+)-Goniopypyrone, (+)-Altholactone, (+)-Goniotriol, and (+)-7-Acetylgoniotriol

Tony K. M. Shing,* Hon-Chung Tsui,[1] and Zhao-Hui Zhou

Department of Chemistry, The Chinese University of Hong Kong, Shatin, Hong Kong

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Practical and efficient syntheses of a number of styryl lactones with various structural complexities were accomplished from commercially available and inexpensive D-*glycero*-D-*gulo*-heptono-γ-lactone (D-glucoheptonic γ-lactone) (**11**). Lactone **11** was converted by four sequential reactions (acetonation, selective deacetonation, glycol cleavage oxidation, and Grignard reaction) into key intermediates 3,5-*O*-isopropylidene-1,1,6-tri-*C*-phenyl-D-*glycero*-D-*gulo*-hexitol (**15**) and 3,5-*O*-isopropylidene-1,1,6-tri-*C*-phenyl-L-*glycero*-D-*gulo*-hexitol (**16**). The alcohol **15** was transformed via a glycol cleavage oxidation and a *Z*-selective Wittig reaction into enoate *Z*-**9** which underwent hydrolysis and an intramolecular Michael-type cyclization to give (+)-goniofufurone (**1**). Likewise, reaction of **16** afforded 7-*epi*-goniofufurone (**2**). Acylation and subsequent deacylation of 7-*C*-phenyl-D-*gluco*-hept-2-enono-γ-lactone (**20**) readily gave (+)-goniobutenolide A (**3**) and (−)-goniobutenolide B (**4**), whereas treatment of (*Z*)-methyl 4,6-*O*-isopropylidene-7-*C*-phenyl-L-*ido*-hept-2-enonate (*Z*-**22**) with DBU followed by acid hydrolysis and intramolecular Michael reaction provided (+)-goniopypyrone (**5**). Mesylation of 4,6-*O*-isopropylidene-7-*C*-phenyl-L-*ido*-hept-2-enono-δ-lactone (**27**) followed by acid hydrolysis furnished (+)-altholactone (**6**). (+)-Goniotriol (**7**) and (+)-7-acetylgoniotriol (**8**) were readily obtained from the enoate *Z*-**9**. This work also provides a viable synthetic route for the construction of the enantiomers of the above styryl lactones for biological evaluation from the same starting material **11**. Suggestions about the possible biosynthetic pathway of the styryl lactones are given.

1. Introduction

The chemotherapeutic potential of the Asian trees of the genus *Goniothalamus* was recognized early; in that, the extracts of the seeds of *Goniothalamus amuyon* (Blanco) Merr. (Annonaceae) from the coastal regions of Taiwan have been used for the treatment of edema and rheumatism.[2] The leaves of *Goniothalamus sesquipedalis* Wall (Annonaceae) growing abundantly in the hilly regions of Manipur, when dried and powdered, have been used by local women during labor pain, and the burning leaves have been used as a mosquito repellant.[3] The leaves of *Goniothalamus macrophyllus* (Bl.) Hook f., Thomas (Annonaceae) were used as an abortifacient in rural areas of North Malaysia.[4] Recent bioactivity-directed studies[5] by McLaughlin's group on the constituents of these plants led to the discovery, isolation, and characterization of a number of novel styryl lactones which were found to possess marginal to significant cytotoxicities against several human tumors.[6-10] (+)-Goniofufurone (**1**),[6] (+)-7-*epi*-goniofufurone (**2**),[7] (+)-goniobutenolide A (**3**)[8] and (−)-goniobutenolide B (**4**),[8] (+)-goniopypyrone (**5**),[6] (+)-altholactone (**6**) (goniothalenol),[9] (+)-goniotriol (**7**),[10] and (+)-7-acetylgoniotriol (**8**)[6] (Chart 1) have been isolated from the ethanolic extracts of the stem bark of *Goniothalamus giganteus* Hook f., Thomas (Annonaceae), obtainable in Thailand. The structures and the relative configurations of these cytotoxic styryl lactones were determined by X-ray crystallographic and/or NMR spectral analysis. All of these styryl lactones except for **6** have first been successfully synthesized by us. Subsequently, other research groups have also reported on the syntheses of some of these styryl lactones (vide infra). As part of our continuing effort[11] in the fabrication of heavily oxygenated lactones as potential antitumor agents from sugars, we now describe in detail total syntheses of (+)-goniofufurone (**1**), (+)-7-*epi*-goniofufurone (**2**), (+)-goniobutenolide A (**3**) and (−)-goniobutenolide B (**4**), (+)-goniopypyrone (**5**), (+)-altholactone (**6**), (+)-goniotriol (**7**), and (+)-7-acetylgoniotriol (**8**) from commercially available and inexpensive D-*glycero*-D-*gulo*-heptono-γ-lactone (D-glucoheptonic γ-lactone), thereby corroborating their absolute stereochemistries as illustrated. Preliminary accounts of the syntheses of **1**,[12] **3**,[13] **4**,[13] and **5**[14] have appeared.

[⊗] Abstract published in *Advance ACS Abstracts,* May 1, 1995.

(1) Taken from: Tsui, H.-C. M.S. Thesis, The Chinese University of Hong Kong, Shatin, Hong Kong, 1993.

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(6) Fang, X.-P.; Anderson, J. E.; Chang, C.-J.; Fanwick, P. E.; McLaughlin, J. L. *J. Chem. Soc., Perkin Trans. 1* **1990**, 1655.

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(11) Examples of our previous efforts. (a) Synthesis of (+)-altholactone from D-gulonolactone, see: Guilhouley, J. G.; Shing, T. K. M. *J. Chem. Soc., Chem. Commun.* **1988**, 976. (b) Synthesis of the (6*R*,7*S*)-diastereoisomer of asperlin from D-glucose, see: Shing, T. K. M.; Aloui, M. *J. Chem. Soc., Chem. Commun.* **1988**, 1526. *Idem. Can. J. Chem.* **1990**, *68*, 1035.

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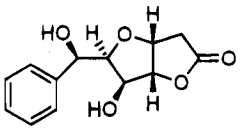
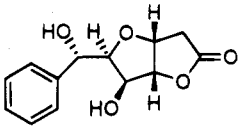
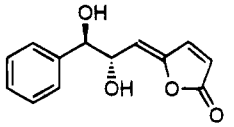
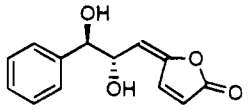
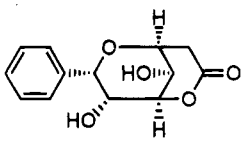
Chart 1

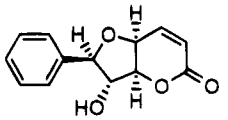

(+)-Goniofufurone **1**

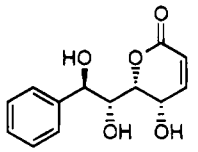

(+)-7-*epi*-Goniofufurone **2**

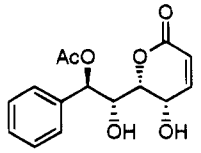

(+)-Goniobutenolide A **3**


(−)-Goniobutenolide B **4**


(+)-Goniopypyrone **5**


(+)-Altholactone **6**

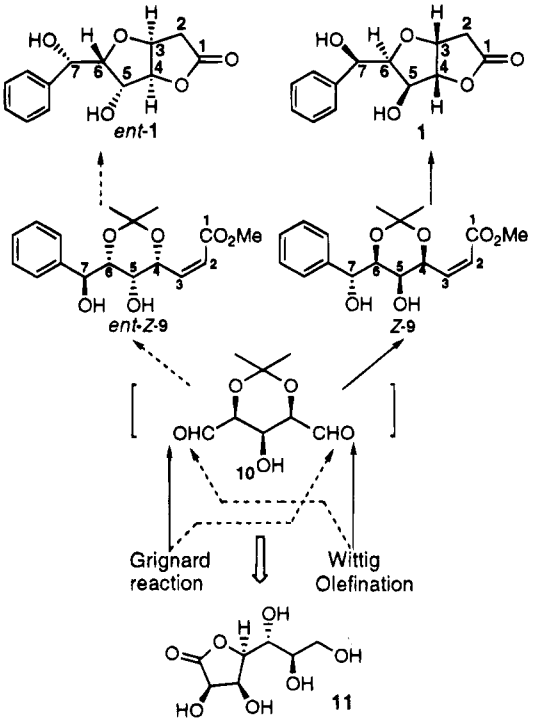

(+)-Goniotriol **7**


(+)-7-Acetylgoniotriol **8**

2. Results and Discussion

1. Synthesis of (+)-Goniofufurone (1)[12] and (+)-7-*epi*-Goniofufurone (2). The absolute stereochemistries of **1** and **2** were recently established by us on the basis of unambiguous total syntheses of their (−)-enantiomers from D-*glycero*-D-*gulo*-heptono-γ-lactone.[15,16] We had arbitrarily selected *ent*-(−)-**1** as our initial target molecule because only the relative stereochemistry of goniofufurone was known at the time.[6] Gracza and Jäger[17] also completed a synthesis of *ent*-(−)-goniofufurone and *ent*-7-*epi*-(−)-goniofufurone, starting from D-glucose and using a palladium(II)-catalyzed oxycarbonylation as the key step. Retrosynthetic analysis of (+)-**1** using the same intramolecular Michael strategy[18a] for the construction[15,16] of *ent*-(−)-**1** provides the intermediate enoate ***Z*-9** which was the mirror image of ***ent*-*Z*-9**. Close inspection of ***Z*-9** reveals that the three stereogenic centers (C-4, C-5, and C-6) are symmetrically disposed along the carbon skeleton, and thus, ***Z*-9** could be obtained using the same sequence of Grignard and *Z*-selective Wittig reactions as in the synthesis of *ent*-(−)-**1** but at opposite ends of the aldehyde intermediate **10** depicted in Scheme 1. The aldehydes could be generated at different stages from the same starting material, D-*glycero*-D-*gulo*-heptono-γ-lactone (**11**).[19]

Scheme 1. Retrosynthesis of (+)-Goniofufurone (1)



The 3,5:6,7-diacetonide **12**,[18] readily available from **11** by thermodynamically controlled acetonation, underwent selective hydrolysis at the terminal isopropylidene group to give the triol **13**[20] in good yields (Scheme 2). The selectivity was evident from the ^{13}C NMR spectral analysis. The quaternary carbons of the dioxane ring and the dioxolane ring in **12** showed different resonances[21] at δ 99.8 and 110.6, respectively. Removal of the terminal acetonide was indicated by the absence of the resonance at δ 110.6 and the continued existence of the dioxane ring ketal carbon at δ 99.7 in the ^{13}C spectrum of **13**.

Glycol cleavage oxidation[22] of the vicinal diol in **13** gave the aldehyde **14** which, without purification, reacted with an excess of phenylmagnesium bromide at 0 °C to provide the diastereoisomeric alcohols **15** and **16** in a ratio of 1 to 2. We chose these experimental conditions because both alcohols were required for the syntheses of different target molecules. Nevertheless, our earlier work[18a] on their enantiomers indicated that the preparation of either alcohol with high stereoselectivity should be feasible. The alcohols proved difficult to separate by chromatography

(12) Shing, T. K. M.; Tsui, H.-C.; Zhou, Z.-H. *J. Chem. Soc., Chem. Commun.* **1992**, 810.
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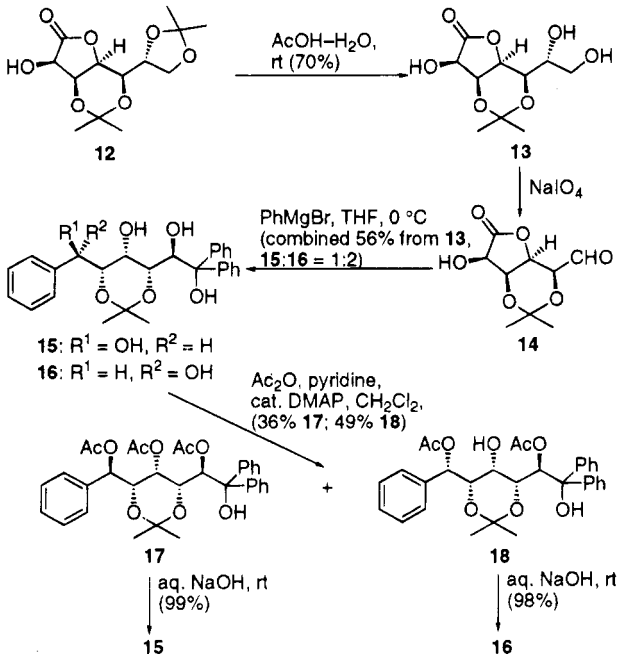
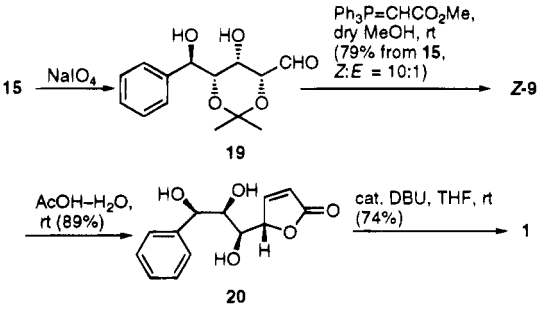
(16) Shing, T. K. M.; Tsui, H.-C.; Zhou, Z.-H. *Tetrahedron* **1992**, *48*, 8659.
(17) Gracza, T.; Jäger, V. *Synlett* **1992**, 191.
(18) (a) Shing, T. K. M.; Tsui, H.-C.; Zhou, Z.-H.; Mak, T. C. W. *J. Chem. Soc., Perkin Trans. 1* **1992**, 887. (b) Brimacombe, J. S.; Tucker, L. C. N. *Carbohydr. Res.* **1966**, *2*, 341.
(19) D-*glycero*-D-*gulo*-Heptono-γ-lactone has been used in the synthesis of $PGF_{2\alpha}$: Stork, G.; Takahashi, T.; Kawamoto, I.; Suzuki, T. *J. Am. Chem. Soc.* **1978**, *100*, 8272.
(20) The 3,5-*O*-isopropylidene substitution pattern in **13** is valuable in our present synthesis of (+)-goniopypyrone (**5**), (+)-altholactone (**6**), (+)-goniotriol (**7**), and (+)-7-acetylgoniotriol (**8**). Formation of six-membered acetonides (dioxanes) are not common in carbohydrate chemistry.
(21) Aslani-Shotorbani, G.; Buchanan, J. G.; Edgar, A. R.; Henderson, D.; Shahidi, P. *Tetrahedron Lett.* **1980**, *21*, 1791. Buchanan, J. G.; Chacon-Fuertes, M. E.; Edgar, A. R.; Moorhouse, S. J.; Rawson, D. I.; Wightman, R. H. *Tetrahedron Lett.* **1980**, *21*, 1793.
(22) For a recent review, see: Shing, T. K. M. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: Oxford, 1991; Vol. 7, p 703.

Scheme 2



Scheme 3. Synthesis of (+)-Goniofufurone (1)



at this stage and were derivatized to their corresponding acetates. Thus, the mixture of alcohols **15** and **16** was acetylated to give the crystalline triacetate **17** and diacetate **18**, readily separable by chromatography. Pure alcohols **15** and **16** were then regenerated from the respective acetates by alkaline hydrolysis in excellent yields. The alcohol **15** was used for the synthesis of **1**, and **16** was the intermediate for the construction of **2**.

The stereochemistries of the new stereogenic centers at the benzylic positions of **15** and **16** were confirmed later by converting **15** into *Z*-**9** as shown in Scheme 3. Oxidative cleavage of the vicinal diol in **15** using sodium metaperiodate gave the aldehyde **19** which reacted with $Ph_3P{=}CHCO_2Me$ in dry methanol at room temperature to give *Z*-**9** stereoselectively[23–25] as colorless needles in 79% yield (*Z*:*E* = 10:1). Alkene *Z*-**9** with mp 135–136 °C and $[\alpha]^{24}_D$ +71 (*c* 0.4, ethanol) showed all spectroscopic data in accord with those of *ent*-*Z*-**9** [lit.[16] mp = 135–136 °C and $[\alpha]^{24}_D$ −65 (*c* 0.9, ethanol)], except for the sign of the optical rotation. Therefore, *Z*-**9** was enantiomeric with *ent*-*Z*-**9**. To support the assignment of the geometry of the alkene, the *E*-isomer was deliberately prepared in larger quantity by employing toluene as the solvent in

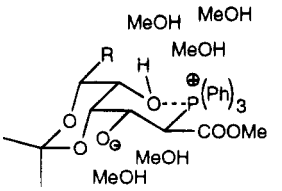
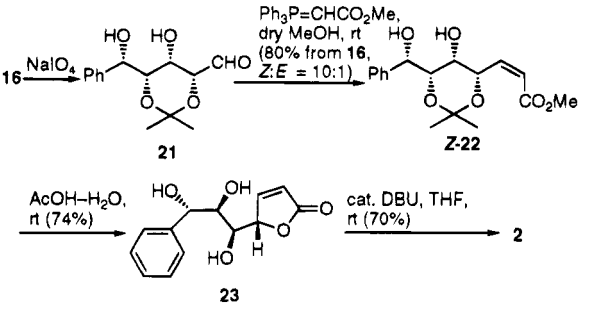


Figure 1. Proposed model that led to the high *Z*-selectivity.

Scheme 4. Synthesis of (+)-7-epi-Goniofufurone (2)



which the respective ratio of *Z*-**9** ($J_{2,3}$ = 12.0 Hz) to *E*-**9** ($J_{2,3}$ = 15.7 Hz) was 1 to 2.

The strong preference for the formation of *Z*-**9** in the Wittig reaction with the stabilized ylide $Ph_3P{=}CHCO_2Me$ in anhydrous methanol was rationalized using the model ("*anti*" betaine) depicted in Figure 1. The requirement for high *Z*-selectivity depended on both the solvent and the structure of the aldehyde; absolute methanol was the best solvent, and an alkoxy group at the carbon β to the aldehyde was required.[24]

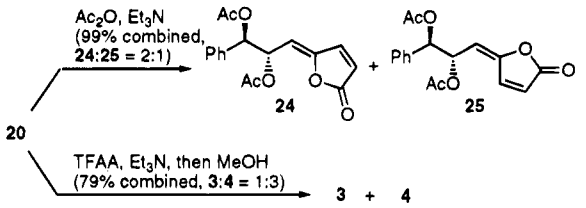
With *Z*-**9** in hand, the same sequence of reactions as described[16] previously for *ent*-*Z*-**9** was performed to obtain natural (+)-goniofufurone (**1**). Thus, hydrolysis of the remaining isopropylidene in *Z*-**9** proceeded with concomitant lactonization to give the crystalline trihydroxybutenolide **20** which underwent an intramolecular Michael-type cyclization induced by 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) to form natural (+)-goniofufurone (**1**) in 74% yield as colorless plates. Synthetic **1** showed all spectroscopic data in accord with the reported values,[6] including the sign of the optical rotation. In conclusion, natural (+)-goniofufurone (**1**) was synthesized from D-*glycero*-D-*gulo*-heptono-γ-lactone (**11**) in 10 steps with an overall 4.4% yield. Since the appearance of the preliminary account[12] of this work, five syntheses of **1** from other research groups have been reported.[26]

The versatility of the above synthetic route has been demonstrated by the facile construction of (+)-7-*epi*-goniofufurone (**2**) for the first time from the alcohol **16** in a similar fashion as shown in Scheme 4. Since the spectroscopic data and optical rotation of **2** were in good agreement with those reported,[7] the absolute configuration of natural (+)-7-*epi*-goniofufurone was corroborated as **2**. It is noteworthy that, whereas **1** showed significant cytotoxic activitites toward several human tumor cell lines, **2** was only weakly bioactive.[6,7]

2. Syntheses of (+)-Goniobutenolide A (3)[13] and (−)-Goniobutenolide B (4).[13] At first glance, **3** and **4** could be regarded as the dehydrated analogs of the

(23) We have previously employed this *Z*-selective Wittig reaction in a synthesis of (+)-altholactone; see ref 11a.
(24) Valverde, S.; Lomas, M. M.; Herradon, B.; Ochoa, S. G. *Tetrahedron* **1987**, *43*, 1895. Tronchet, J. M. J.; Gentile, B. *Helv. Chim. Acta* **1979**, *62*, 2091.
(25) Maryanoff, B. E.; Reitz, A. B. *Chem. Rev.* **1989**, *89*, 863.
(26) (a) Murphy, P. J.; Dennison, S. T. *Tetrahedron* **1993**, *49*, 6695. (b) Prakash, K. R. C.; Rao, S. P. *Tetrahedron* **1993**, *49*, 1505. (c) Tsubuki, M.; Kanai, K.; Honda, T. *Synlett* **1993**, 653. (d) Mukai, C.; Kim, I. J.; Hanaoka, M. *Tetrahedron Lett.* **1993**, *34*, 6081. (e) Ye, J.; Bhatt, R. K.; Falck, J. R. *Tetrahedron Lett.* **1993**, *34*, 8007.

Scheme 5. Synthesis of 3 and 4



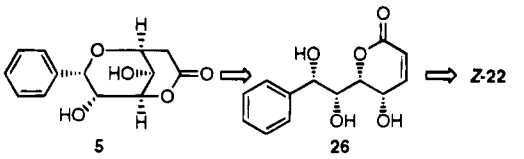
trihydroxybutenolide **20** and their fabrications[13] seem possible because the hydroxy group at C-5 may be easily eliminated under the acetylation conditions presumably via the E1-cb mechanism.[27] However, the generation of compounds **3** and **4** via the respective *anti*-E2 and the *syn*-E2 mechanism could not be ruled out.[27] Hence, as shown in Scheme 5, treatment of butenolide **20** with acetic anhydride–triethylamine in dry dichloromethane gave **24** and **25** which showed all spectroscopic data in accord with (+)-diacetylgoniobutenolide A[8] and (−)-diacetylgoniobutenolide B,[8] respectively. At this stage, syntheses of **3** and **4** were obvious and should be completed simply by deacetylation. However, attempts to remove the acetates from **24** and **25** via alkaline hydrolysis proved detrimental because of the highly reactive α,β- and γ,δ-unsaturated lactone moiety in both compounds.

Fortunately, the syntheses of **3** and **4** were finally realized from **20** by the fact that trifluoroacetyl ester could be easily hydrolyzed under mild conditions.[28] Thus, the trihydroxybutenolide **20** reacted with trifluoroacetic anhydride–triethylamine (dehydration) and then underwent in situ methanol hydrolysis to remove the esters, affording the target molecules **3** and **4** as shown in Scheme 5. Both synthetic **3** and **4** showed all spectroscopic data in accord with those of the natural compounds, including the sign of the optical rotation.[8] Therefore, the absolute configurations of the natural (+)-goniobutenolide A and (−)-goniobutenolide B must be **3** and **4**, respectively. These results have recently been corroborated independently by Xu and Sharpless.[29] Interestingly, using trifluoroacetic anhydride to mediate the dehydration gave **3** and **4** in a ratio of 1 to 3, whereas using acetic anhydride produced the diacetates **24** and **25** in a ratio of 2 to 1. This observation was in contrast to our expectation that trifluoroacetyl ester could be easily eliminated through the *anti*-E2 mechanism which would have given the (+)-goniobutenolide A (**3**) as the major product. Therefore, elimination via the E1-cb or *syn*-E2 mechanism was possible with trifluoroacetic anhydride.[27] In conclusion, both (+)-goniobutenolide A (**3**) and (−)-goniobutenolide B (**4**) were readily synthesized from the D-*glycero*-D-*gulo*-heptono-γ-lactone (**11**) in 10 steps with an overall yield of 1.2 and 3.6%, respectively.

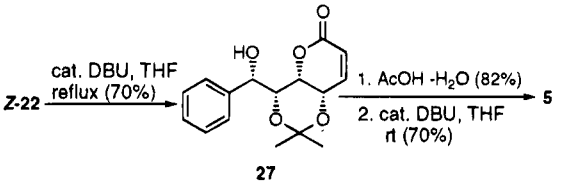
3. Synthesis of (+)-Goniopypyrone (5).[14] Among the styryl lactones, (+)-goniopypyrone (**5**) is the most bioactive, exhibiting nonselective ED_{50} values of ca. 6.7 $\times 10^{-1}$ mg/mL in several human tumor cell lines; its novel skeleton is also the most intriguing and presents a formidable synthetic challenge.[6]

On the basis of the aforedescribed synthetic work and assuming all the stryl lactones have the same biosynthetic origin, the absolute stereochemistry of (+)-goniopypyrone had been tentatively assigned as **5**. Retrosynthetic analysis[18a] of **5** using the same intramolecular Michael strategy for the goniofufurone synthesis gives the trihydroxypyrone **26** (Scheme 6). The mode of biogenetic formation of **5**, by Michael-type cyclization of the respective triol, was independently addressed by Gracza and Jäger.[17] The trihydroxypyrone **26** (7-*epi*-goniotriol) could be derived from the enoate *Z*-**22** through δ-lactonization which was facilitated by the substitution pattern[20] of the isopropylidene protecting group.

Scheme 6. Retrosynthesis of (+)-Goniopypyrone (5)



Scheme 7. Synthesis of (+)-Goniopypyrone (5)



Thus, lactonization of *Z*-**22** induced by DBU in dry THF under reflux smoothly gave the pyrone **27** as colorless needles in 70% yield (Scheme 7). As said earlier,[20] the dioxane acetal derived from **13** nicely blocked the O-4,6 in *Z*-**22** and thus allowed for facile formation of the δ-lactone **27** without incident. Attempted base-induced intramolecular Michael-type cyclization of **27** to give the acetonated goniopypyrone proved unrewarding. Decomposition was observed using LDA in THF, and no cyclized products were isolable. The failure of the cyclization was thought to be attributable to the large ring strain in the cyclized product. Therefore, the isopropylidene group in **27** was removed first. Hydrolysis of the acetonide in **27** by aqueous acetic acid under reflux then generated the trihydroxypyrone **26** in 82% yield as colorless needles. The pyrone moiety in **26** did not rearrange to the thermodynamic butenolide structure and was evident from the ^{1}H NMR spectral data. The continued existence of the two resonances at δ 6.02 and 7.06 (J = 9.7 Hz) for the two vinylic protons is characteristic of the pyrone structure.[30] Intramolecular Michael addition of **26** catalyzed by DBU in dry THF at room temperature then gave goniopypyrone **5**. The participation of the OH-6 of **26** in the intramolecular Michael reaction to form the corresponding furanoid ring was thought to be unfavorable, being attributable to severe steric interation between the lactone ring and the benzyl moiety as shown in Figure 2. Synthetic **5** showed all spectroscopic data in accord with those of the natural compound, including the sign of the optical rotation. Therefore, the structure and the absolute stereochemistry of natural (+)-goniopypyrone must be **5**. Thus, (+)-goniopypyrone (**5**) was effectively synthesized from **11** in 11 steps with an overall 3.7% yield. Since the publication of the preliminary account[14] of this work, two syntheses

(27) Pine, S. H.; Hendrickson, J. B.; Cram, D. J.; Hammond, G. S. *Organic Chemistry*, 4th ed.; McGraw-Hill: New York, 1980; pp 449–459.

(28) Greene, T. W. *Protective Groups in Organic Synthesis*, 1st ed.; John Wiley & Sons: New York, 1981; p 56.

(29) Xu, D.; Sharpless, K. B. *Tetrahedron Lett.* **1994**, *35*, 4658.

(30) Silverstein, R. M.; Bassler, G. C.; Morrill, T. C. *Spectrometric Identification of Organic Compounds*, 4th ed.; John Wiley & Sons: New York, 1981; Chapters 4 and 5.

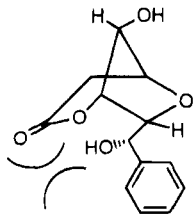
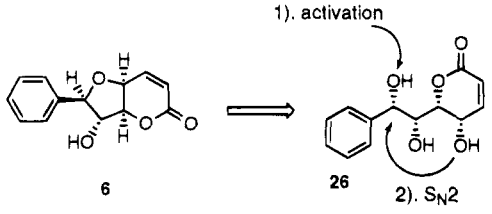
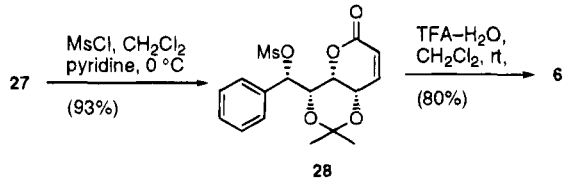


Figure 2. Intramolecular Michael addition by OH-6 of **26**.

Scheme 8. Retrosynthesis of (+)-Altholactone (6)



Scheme 9. Synthesis of (+)-Altholactone (6)



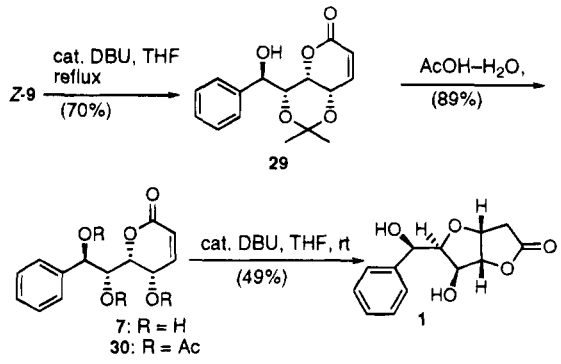
of **5** involving our intramolecular Michael protocol as the key step have appeared.[26c,31]

4. Synthesis of (+)-Altholactone (6). (+)-Altholactone (**6**) was first isolated from an unknown *Polyalthea* species in 1977 by Loder and Nearn.[32] Recently, McLaughlin's group isolated the same compound from the stem bark of *G. giganteus* (Annonaceae).[9] (+)-Altholactone was screened to display 9KB cytotoxicity at $ED_{50} = 2\ \mu g/mL$ and P388 toxicity at 45 mg/kg.[9] The absolute stereochemistry of **6** had first been corroborated by an unambiguous total synthesis by Gesson et al. from D-glucose.[33] Subsequently, several reports, including the one from us,[11a] on the synthesis of **6** also appeared.[26c,34]

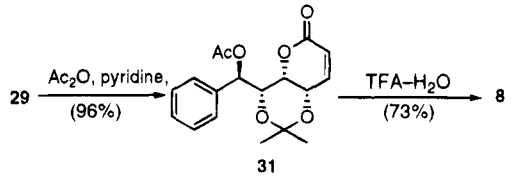
(+)-Altholactone (**6**) had been proposed[33,35] as an anhydro analog of the corresponding triol. Retrosynthetic analysis of **6** using this idea gives the pyrone **26** as the key intermediate (Scheme 8). Therefore, activating the hydroxy group at C-7 as a mesylate by treating pyrone **27** with methanesulfonyl chloride in pyridine–dichloromethane at 0 °C gave the unstable mesylate **28** (Scheme 9). Gratifyingly, acid hydrolysis of the isopropylidene group in **28** at room temperature occurred with concomitant S_N2 ring closure to give **6** in 80% yield. Synthetic **6** showed all spectroscopic data in accord with those[9] of the natural compound. In conclusion, this work constitutes a new synthesis of (+)-altholactone from **11** in 11 steps with an overall 4.8% yield.

5. Synthesis of (+)-Goniotriol (7) and (+)-7-Acetylgoniotriol (8). The absolute stereochemistries of (+)-goniotriol and (+)-7-acetylgoniotriol had already

Scheme 10



Scheme 11. Synthesis of (+)-7-Acetylgoniotriol (8)



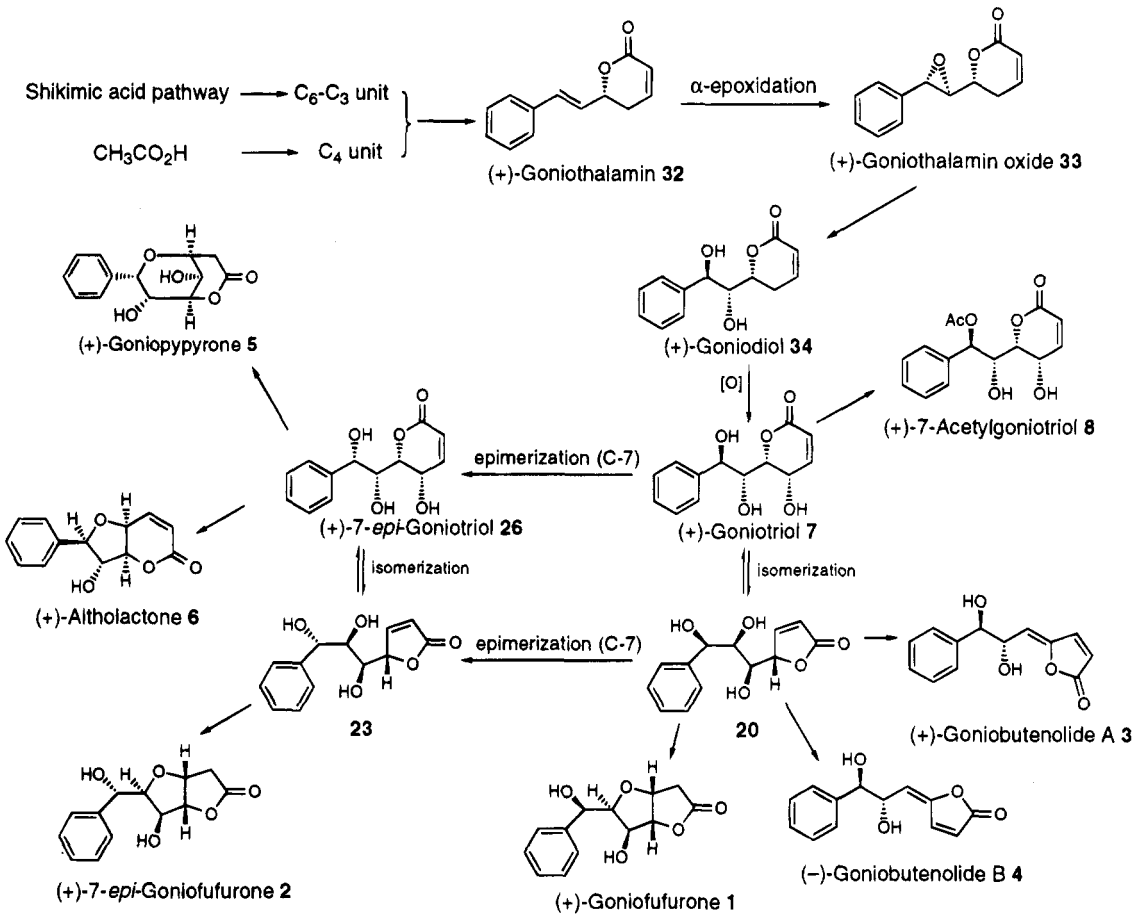
been established by us via syntheses of their enantiomers from D-*glycero*-D-*gulo*-heptono-γ-lactone (**11**).[36] Therefore, **7** and **8** could be easily obtained from the enoate *Z*-**9**, following the same reaction sequence[36] for their enantiomers. As shown in Scheme 10, lactonization of the 1,3-dioxane[20] *Z*-**9** induced by DBU in refluxing THF gave the pyrone **29** smoothly in 81% yield as colorless needles. The chemical shifts at δ 6.25 and 6.89 with a 9.6 Hz coupling constant for the two vinylic protons in the ^1H NMR spectrum of **29** were in accord with the pyrone structure as discussed before. Hydrolysis of the isopropylidene group in **29** using aqueous acetic acid at reflux temperature gave **7** as colorless needles with mp = 178–180 °C and $[\alpha]^{24}_D = +118$ (*c* 0.9, MeOH) [lit.[10] mp = 170 °C and $[\alpha]^{30}_D = +121$ (MeOH)]. The (+)-goniotriol (**7**) was further characterized by converting it into the corresponding triacetate **30** as a white solid with mp = 95–97 °C and $[\alpha]^{24}_D = +121$ (*c* 0.8, MeOH) [lit.[6] mp = 90–93 °C]. (+)-Goniotriol (**7**)[10] as well as its triacetyl derivative **30**[6] showed all spectroscopic data in accord with those reported.

For the synthesis of (+)-7-acetylgoniotriol (**8**), acetylation of the pyrone **29** nicely introduced the acetyl function onto the benzylic hydroxy group to give the 7-acetylpyrone **31** (Scheme 11). Hydrolysis of **31** with aqueous TFA in dichloromethane afforded (+)-7-acetylgoniotriol (**8**) as colorless needles with mp = 159–160 °C and $[\alpha]^{24}_D = +38$ (*c* 0.9, ethanol) [lit.[6] mp = 158–159 °C and $[\alpha]^{22}_D = +30$ (*c* 0.4, ethanol)]. Synthetic (+)-7-acetylgoniotriol (**8**) showed all spectroscopic data in accord with those[6] of the natural compound, including the sign of the optical rotation. In conclusion, (+)-goniotriol (**7**) and (+)-7-acetylgoniotriol (**8**) were synthesized from **11** in 10 and 11 steps with an overall yield of 4.3 and 3.2%, respectively. After the completion of this work, a report describing the syntheses of **7** and **8** has appeared.[26c]

It is noteworthy that, as shown in Scheme 10, when (+)-goniotriol (**7**) was treated with DBU in THF at room temperature, (+)-goniofufurone (**1**) was isolated together

(31) Zhou, W.-S.; Yang, Z.-C. *Tetrahedron Lett.* **1993**, *34*, 7075.
(32) Loder, J. W.; Nearn, R. M. *Heterocycles* **1977**, *7*, 113.
(33) Gesson, J. P.; Jacquesy, J. C.; Mondon, M. *Tetrahedron* **1989**, *45*, 2627.
(34) (a) Ueno, Y.; Tadano, K.; Ogawa, S.; MacLaughlin, J. L.; Alkofahi, A. *Bull. Chem. Soc. Jpn.* **1989**, *62*, 2328. (b) Kang, S. H.; Kim, W. J. *Tetrahedron Lett.* **1989**, *30*, 5915.
(35) (a) Sam, T. W.; Yeu, C. S.; Matsjeh, S.; Gan, E. K.; Razak, D.; Mohamed, A. L. *Tetrahedron Lett.* **1987**, *28*, 2541. (b) Gillhouley, J. G. M.S. Thesis, University of Manchester, Manchester, U.K., 1987.
(36) (a) Shing, T. K. M.; Zhou, Z.-H.; Mak, T. C. W. *J. Chem. Soc., Perkin Trans. I* **1992**, 1907. (b) Shing, T. K. M.; Zhou, Z.-H. *Tetrahedron Lett.* **1992**, *33*, 3333.

Scheme 12. Proposed Biosynthetic Pathways for Styryl lactones



with some unreacted starting material **7**. Rearrangement of the pyrone moiety in **7** to the butenolide structure **20** followed by the intramolecular Michael-type cyclization was the feasible explanation. The goniofufurone obtained by this rearrangement was identical in all respects with (+)-goniofufurone (**1**) prepared previously.

3. Conclusions

From the above results, we have devised effective and practical syntheses of a number of styryl lactones with various structural complexities from inexpensive and commerically available D-*glycero*-D-*gulo*-heptono-γ-lactone (**11**). The absolute stereochemistries of (+)-goniofufurone (**1**), (+)-7-*epi*-goniofufurone (**2**), (+)-goniobutenolide A (**3**) and (−)-goniobutenolide B (**4**), (+)-goniopypyrone (**5**), (+)-altholactone (**6**), (+)-goniotriol (**7**), and (+)-7-acetylgoniotriol (**8**) have been corroborated. Moreover, the unnatural enantiomers of these styryl lactones can also be prepared from the same starting material **11** for biological evaluation.

This work has given some hints about the possible biosynthetic pathway of the styryl lactones (Scheme 12). The biosynthesis of the styryl lactones was predicted to be of mixed origin.[35b] The C-6−C-3 unit comes from the shikimic acid pathway, and the C4 unit comes from two acetyl-Coenzyme A. Coupling of the two units followed by lactonization gives the (+)-goniothalamin (**32**) as the key intermediate. α-Epoxidation of the double bond in **32** gives the (+)-goniothalamin oxide (**33**).[37] *Trans*-opening of the epoxide at the benzylic carbon in **33** gives (+)-goniodiol (**34**). Allylic hydroxylation of **34** gives (+)-goniotriol (**7**). Esterification at the benzylic hydroxy group gives (+)-7-acetylgoniotriol (**8**).

The rearrangement of pyrone **7** to **20** under basic conditions in this work hints at the fact that the pyrone intermediates may be the biosynthetic precursors for γ-lactones **1**, **2**, **3**, and **4**. Thus, (+)-goniofufurone (**1**) may be derived from the rearrangement of (+)-goniotriol (**7**) to butenolide **20**, followed by an intramolecular Michael-type ring closure. Both (+)-goniobutenolide A (**3**) and (−)-goniobutenolide B (**4**) may be generated by the elimination of OH-5 in **20**.

Some styrylpyrones have the opposite stereochemistry at the benzylic carbon, and this stereochemistry is expected to derive from epimerization. Thus, (+)-goniopypyrone (**5**) may be produced from (+)-goniotriol (**7**) via epimerization at the benzylic carbon to (+)-7-*epi*-goniotriol (**26**), followed by an intramolecular Michael addition. (+)-Altholactone (**6**) can be regarded as the anhydro analog of the (+)-7-*epi*-goniotriol (**26**) and can be obtained via an intramolecular ring closure of **26** with inversion at the benzylic carbon. (+)-7-*epi*-Goniofufurone (**2**) can be derived through two possible pathways. The first pathway involves the epimerization of (+)-goniotriol (**7**) to (+)-7-*epi*-goniotriol (**26**) which isomerizes to the butenolide **23**, and a subsequent intramolecular Michael-type cyclization affords (+)-7-*epi*-goniofufurone (**2**). The second pathway toward **2** involves the epimerization of butenolide **20** at C-7 and then an intramolecular Michael reaction. We propose that butenolide **20** may be the immediate precursor for the biosyntheses of (+)-gonio-

(37) The absolute stereochemistry of **33** has not been confirmed by synthesis.

fufurone (**1**), (+)-goniobutenolide A (**3**), and (−)-goniobutenolide B (**4**), whereas butenolide **23** may be the immediate biosynthetic precursor for (+)-7-*epi*-goniofufurone (**2**), although both **20** and **23** have not been isolated or reported.

The proposed biosynthetic pathways are not totally speculative. The facile conversions of **20** → **1**, **23** → **2**, and **26** → **5** involving free precursors (with no hydroxy group protections) provide evidence that the intramolecular Michael-type cyclizations mimic the actual biosynthetic transformations. In contrast, the attempted Michael-type cyclization of **27** (with hydroxy protection) to give the acetonated **5** was unsuccessful. We believe that these syntheses may be biomimetic.

4. Experimental Section

Melting points are reported in degrees Celsius and are uncorrected. Optical rotations were measured at 589 nm. Infrared (IR) spectra were recorded as thin films on NaCl disks. Unless stated to the contrary, nuclear magnetic resonance (NMR) spectra were measured in solutions of $CDCl_3$ at 250 MHz (^1H) or at 62.9 MHz (^{13}C) . Spin−spin coupling constants (J) were measured directly from the spectra. Carbon and hydrogen elemental analyses were carried out at either the Shanghai Institute of Organic Chemistry, The Chinese Academy of Sciences, China, or the MEDAC Ltd, Department of Chemistry, Brunel University, Uxbridge. All reactions were monitored by analytical thin-layer chromatography (TLC) on aluminum precoated with silica gel $60F_{254}$ (E. Merck), and compounds were visualized with a spray of either 5% w/v dodecamolybdophosphoric acid in ethanol or 5% v/v concentrated sulfuric acid in ethanol and subsequent heating. All columns were packed wet using E. Merck silica gel 60 (230−400 mesh) as the stationary phase and eluted using the flash[38] chromatographic technique. Pyridine was distilled over barium oxide and stored in the presence of potassium hydroxide pellets. Absolute methanol was distilled over magnesium and stored in the presence of 4 Å molecular sieves. THF was distilled from sodium benzophenone ketyl under a nitrogen atmosphere. CH_2Cl_2 was distilled over phosphorous pentoxide and stored in the presence of 4 Å molecular sieves.

(+)-Goniofufurone (1). A solution of the unsaturated lactone **20** (213 mg, 0.85 mmol) in dry THF (20 mL) containing 0.05% (v/v) DBU was stirred at rt for 24 h. The solution was then filtered through a bed of silica gel topped with Celite. Removal of solvent from the filtrate under reduced pressure gave a white solid which was flash chromatographed (EtOAc−hexane, 2:1) to give **1** (158 mg, 74%), recrystallized from EtOAc−hexane as colorless plates: mp 152−154 °C (lit.[6] mp 152−154 °C); R_f 0.55 (EtOAc); $[\alpha]^{24}_D$ +10 (*c* 1.1, EtOH) {lit.[6] $[\alpha]^{22}_D$ +9 (*c* 0.5, EtOH)}; IR 1786 (γ-lactone), 3410 cm^{-1} (OH); ^1H NMR δ ($CDCl_3$ + D_2O) 2.68 (1H, dd, J = 1.5, 18.8 Hz), 2.81 (1H, dd, J = 5.4, 18.8 Hz), 4.10 (1H, dd, J = 2.9, 4.7 Hz), 4.39 (1H, d, J = 2.9 Hz), 4.87 (1H, d, J = 4.2 Hz), 5.12 (1H, ddd, J = 1.5, 4.2, 5.4 Hz), 5.20 (1H, d, J = 4.7 Hz), 7.33−7.45 (5H, m); ^{13}C NMR δ 36.42, 71.94, 74.49, 77.91, 84.82, 88.63, 127.61, 128.07, 128.73, 143.31, 176.61; MS m/z (relative intensity) (EI) 107 (PhCHOH, 100), 126 (M^+ − PhCHOH − OH, 50.9), 233 (MH^+ − H_2O, 12.3), 251 (MH^+, 1.7). Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.4; H, 5.6. Found: C, 62.35; H, 5.4.

(+)-Goniofufurone (1) Prepared from (+)-Goniotriol (7). A solution of (+)-goniotriol (**7**) (470 mg, 1.88 mmol) in dry THF (30 mL) containing a catalytic amount of DBU was stirred at rt for 48 h. The solution was then filtered through a bed of silica gel topped with Celite. Removal of solvents from the filtrate under reduced pressure gave a white solid. Purification by flash chromatography (Et_2O) afforded **1** (177 mg, 49% based on recovery of triol **7**) as colorless crystals and the starting triol **7** (111 mg, 24%). Recrystallization of **1** from EtOAc−hexane gave colorless plates, mp 152−154 °C. Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.4; H, 5.6. Found: C, 62.5; H, 5.55.

(38) Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

(+)-7-*epi*-Goniofufurone (2). A solution of the γ-lactone **23** (100 mg, 0.40 mmol) in THF (25 mL) containing 0.05% (v/v) DBU was stirred at rt for 12 h. The reaction mixture was then passed through a pad of silica gel and the filtrate concentrated under reduced pressure. The residue was recrystallized from EtOAc−hexane to give **2** (70 mg, 70%) as transparent tetragonal plates: mp 208−209 °C, sinters at 190 °C (lit.[7] mp 190−192 °C); $[\alpha]^{24}_D$ +103 (*c* 1.0, EtOH) {lit.[7] $[\alpha]^{22}_D$ +108 (*c* 0.2, EtOH)}; R_f 0.29 (Et_2O); IR (film) 1758 (γ-lactone), 3402 cm^{-1} (OH); ^1H NMR δ ($CDCl_3$ + D_2O) 2.65 (1H, dd, J = 0.8, 18.8 Hz), 2.71 (1H, dd, J = 5.0, 18.8 Hz), 4.24 (1H, dd, J = 4.2, 4.5 Hz), 4.42 (1H, dd, J = 4.5, 3.9 Hz), 4.90 (1H, t, J = 4.2 Hz), 5.08 (1H, d, J = 3.9 Hz), 5.10 (1H, ddd, J = 0.8, 4.2, 5.0 Hz), 7.35−7.41 (m, 5H); MS m/z (relative intensity) (EI) 232 (M^+ − H_2O, 1.8), 233 (MH^+ − H_2O, 2.5). Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.4; H, 5.6. Found: C, 62.5; H, 5.5.

(+)-Goniobutenolide A (3) and (−)-Goniobutenolide B (4). A solution of the triol **20** (599 mg, 2.4 mmol) in dry CH_2Cl_2 (20 mL) was stirred at rt, and triethylamine (1.7 mL) and trifluoroacetic anhydride (1.7 mL) were added. After the solution was stirred at rt for 2 h, MeOH (20 mL) was added. The solution was stirred at rt for a further 5 h and filtered through a bed of silica gel topped with Celite. Concentration of the filtrate followed by flash chromatography (Et_2O−hexane, 4:1) gave a mixture of **3** and **4** (437 mg, 79%) as a yellow solid. The ratio of **3**:**4** (ca. 1:3) was determined by ^1H NMR spectral analysis. Pure compounds were obtained by repeated chromatography. The more polar (+)-goniobutenolide A (**3**) was obtained as a yellowish oil: R_f 0.28 (Et_2O−hexane, 4:1); $[\alpha]^{27}_D$ +187 (*c* 0.4, $CHCl_3$) {lit.[8] $[\alpha]^{24}_D$ +82 (*c* 0.3, $CHCl_3$)}; IR 1678 (C=C), 1748, 1777 (C=O), 3426 cm^{-1} (OH); ^1H NMR δ 4.92−4.99 (2H, m), 5.30 (1H, d, J = 8.3 Hz), 6.13 (1H, d, J = 5.4 Hz), 7.24−7.33 (6H, m); ^{13}C NMR δ 70.77, 76.11, 112.99, 120.41, 126.50, 128.06, 128.35, 139.26, 143.51, 150.57, 169.00; MS m/z (relative intensity) (EI) 77 (29.19), 79 (28.86), 91 (3.38), 97 (8.37), 107 (23.86), 126 (47.17). The less polar **4** was obtained as colorless needles: mp 148−149 °C; R_f 0.31 (Et_2O−hexane, 4:1); $[\alpha]^{27}_D$ −112 (*c* 0.2, $CHCl_3$) {lit.[8] $[\alpha]^{24}_D$ −37 (*c* 0.2, $CHCl_3$)}; IR 1670 (C=C), 1742 (C=O), 3404 cm^{-1} (OH); ^1H NMR δ 2.35 (1H, d, J = 4.9 Hz), 2.42 (1H, d, J = 3.3 Hz), 4.65 (1H, ddd, J = 4.6, 4.9, 7.8 Hz), 4.89 (1H, dd, J = 3.3, 4.6 Hz), 5.79 (1H, ddd, J = 0.7, 1.8, 7.8 Hz), 6.14 (1H, dd, J = 1.8, 5.7 Hz), 7.28−7.37 (5H, m), 7.51 (1H, d, J = 0.7, 5.7 Hz); MS m/z (relative intensity) (EI) 77 (38), 79 (44.4), 97 (14.3), 107 (43.2), 126 (100). Anal. Calcd for $C_{13}H_{12}O_4$: C, 67.2; H, 5.2. Found: C, 67.1; H, 5.2.

(+)-Goniopypyrone (5). A solution of the triol **26** (108 mg, 0.43 mmol) in dry THF (20 mL) containing a catalytic amount of DBU was stirred at rt for 4 h. The solution was then filtered through a bed of silica gel topped with Celite. Removal of solvents under reduced pressure gave a white solid. Purification by flash chromatography (EtOAc−hexane, 1:1) afforded **5** (76 mg, 70%) as white crystals. Recrystallization from EtOAc−hexane gave colorless needles: mp 178−179 °C (lit.[6] mp 182−184 °C); R_f 0.37 (EtOAc−hexane, 1:1); $[\alpha]^{22}_D$ +53 (*c* 0.6, EtOH) {lit.[6] $[\alpha]^{22}_D$ +54 (*c* 0.4, EtOH)}; IR 1746 (lactone), 3330 cm^{-1} (OH); ^1H NMR δ [$(CD_3)_2C$=O] 2.97 (1H, dd, J = 1.5, 19.4 Hz), 3.16 (1H, dd, J = 5.2, 19.4 Hz), 4.04 (1H, m), 4.22 (1H, m), 4.42 (1H, m), 4.65 (1H, m), 4.74 (1H, br s), 4.97 (1H, br s), 5.18 (1H, br s), 7.22−7.48 (5H, m); ^{13}C NMR δ (acetone-d_6) 35.58, 64.89, 70.47, 71.40, 71.61, 74.32, 127.61, 128.06, 128.62, 139.29, 169.23; MS m/z (relative intensity) (EI) 107 ($PhCHOH^+$, 100), 126 (MH^+ − PhCHOH − H_2O, 10.7), 144 (MH^+ − PhCHOH, 9.6), 250 (M^+, 7.7). Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.4; H, 5.6. Found: C, 62.4; H, 5.6.

(+)-Altholactone (6). A solution of the mesylate **28** (215 mg, 0.58 mmol) in trifluoroacetic acid and water (10 mL, 9:1) was stirred at rt for 1 h. The solvent was then removed under reduced pressure to give a yellow oil. Purification by flash chromatography (EtOAc−hexane, 1:1) afforded **6** as a colorless oil (108 mg, 80%): R_f 0.47 (EtOAc−hexane, 1:1); $[\alpha]^{23}_D$ +177 (*c* 1.5, EtOH) {lit.[9] $[\alpha]^{25}_D$ +187 (EtOH)}; IR 1717, 1733 (α,β-unsaturated δ-lactone), 3400 cm^{-1} (OH); ^1H NMR δ 3.48 (1H, d, J = 4.1 Hz), 4.44 (1H, m), 4.62 (1H, t, J = 5.1 Hz), 4.73 (1H, d, J = 5.6 Hz), 4.92 (1H, dd, J = 2.2, 5.2 Hz), 6.22 (1H, d, J = 9.9 Hz), 7.00 (1H, dd, J = 5.0, 9.9 Hz), 7.29−7.35 (5H,

m); ^{13}C NMR δ 68.15, 83.44, 86.05, 86.53, 123.46, 126.04, 128.17, 128.52, 138.29, 140.52, 161.52; MS *m/z* (relative intensity) (EI) 97 (100), 91 (43.4), 107 (PhCHOH$^+$ or M$^+$ − PhCHOH − H_2O, 84.6), 232 (M$^+$, 27.1).

(+)-Goniotriol (7). A solution of the unsaturated lactone **29** (261 mg, 0.90 mmol) in acetic acid (8 mL) and water (2 mL) was stirred at 90−100 °C for 2 h. The solvents were removed under reduced pressure to give a white solid. Purification by flash chromatography (EtOAc) afforded **7** (200 mg, 89%) which was recrystallized from EtOAc−hexane as colorless needles: mp 178−180 °C (lit.[10] mp 170 °C); R_f 0.41 (EtOAc); $[\alpha]^{24}_D$ +118 (*c* 0.8, MeOH) {lit.[10] $[\alpha]_D$ +121 (MeOH)}; IR 1719 (α,β-unsaturated δ-lactone), 3400 cm^{-1} (OH); ^1H NMR δ [$(CD_3)_2C$=O] 4.15 (1H, ddd, *J* = 3.1, 4.1, 8.0 Hz), 4.35 (1H, d, *J* = 4.2 Hz), 4.55 (1H, m), 4.71−4.81 (3H, m), 5.10 (1H, d, *J* = 4.9 Hz), 6.05 (1H, d, J = 9.7 Hz), 7.05 (1H, dd, *J* = 5.8, 9.7 Hz), 7.25−7.49 (5H, m); MS *m/z* (relative intensity) (EI) 107 (PhCHOH$^+$, 100), 126 (M$^+$ − PhCHOH, 33.4), 144 (MH$^+$ − PhCHOH, 25.5). Anal. Calcd for $C_{13}O_5H_{14}$: C, 62.4; H, 5.6. Found: C, 62.5; H, 5.7.

(+)-7-Acetylgoniotriol (8). A solution of the acetate **31** (357 mg, 1.07 mmol) in CH_2Cl_2 (20 mL) was stirred at rt, and trifluoroacetic acid (10 mL) and water (10 mL) were added. After the solution was stirred at rt for 16 h, the solvents were then removed under reduced pressure to give a yellow oil. Purification by flash chromatography (Et_2O) afforded **8** (222 mg, 71%) as a white solid which was recrystallized from EtOAc−hexane to give colorless needles: mp 159−160 °C (lit.[6] 158−159 °C); R_f 0.26 (Et_2O); $[\alpha]^{23}_D$ +38 (*c* 0.91, EtOH) {lit.[6] $[\alpha]^{22}_D$ +30 (*c* 0.4, ethanol)}; IR 1725 (ester and α,β-unsaturated δ-lactone), 3400 cm^{-1} (OH); ^1H NMR δ 1.89 (3H, s), 4.31−4.81 (4H, m), 5.01 (1H, dd, *J* = 1.1, 5.6 Hz), 5.75 (1H, d, *J* = 7.3 Hz), 5.89 (1H, d, *J* = 9.7 Hz), 6.90 (1H, dd, *J* = 5.6, 9.7 Hz), 7.16−7.39 (5H, m); MS *m/z* (relative intensity) (EI) 143 (M$^+$ − PhCHOAc, 17.4), 144 (MH$^+$ − PhCHOAc, 7), 149 (PhCHOAc$^+$, 8.5), 215 (M$^+$ − Ph, 0.2), 233 (MH$^+$ − HOAc, 0.4). Anal. Calcd for $C_{15}H_{16}O_6$: C, 61.6; H, 5.4. Found: C, 61.65; H, 5.4.

(*Z*)- and (*E*)-Methyl 4,6-*O*-Isopropylidene-7-*C*-phenyl-D-*gluco*-hept-2-enonate (*Z*-9 and *E*-9). Method A. $(Ph)_3P$=$CHCO_2Me$ (843 mg, 2.52 mmol) was added in one portion to a stirred solution of the aldehyde **19** in anhydrous MeOH (50 mL) at rt. After being stirred at rt for a further 2 h, the solution was concentrated under reduced pressure. The ratio of *Z*-**9**:*E*-**9** (ca. 10:1) was determined by ^1H NMR spectral analysis. Fractionation of the residue by flash chromatography (Et_2O−hexane, 2:3) gave *Z*-**9** (531 mg, 79%) as a white solid. Recrystallization from Et_2O−hexane gave colorless needles: mp 135−136 °C; R_f 0.25 (Et_2O−hexane, 3:2); $[\alpha]^{24}_D$ +71 (*c* 0.4, EtOAc); IR 1658, 1722 (α,β-unsaturated ester), 3400 cm^{-1} (OH); ^1H NMR δ 1.44 (3H, s), 1.46 (3H, s), 2.83 (1H, d, *J* = 4.5 Hz), 3.09 (1H, d, *J* = 9.4 Hz), 3.69 (3H, s), 3.85 (1H, br d, *J* = 9.4 Hz), 4.00 (1H, d, *J* = 6.3 Hz), 4.88 (1H, dd, *J* = 4.5, 6.3 Hz), 5.48 (1H, br d, *J* = 7.2 Hz), 5.92 (1H, dd, *J* = 1.4, 12 Hz), 6.32 (1H, dd, *J* = 7.2, 12 Hz), 7.13−7.30 (5H, m); MS *m/z* (relative intensity) (EI) 59 (CO_2Me^+, 65.9), 77 (Ph$^+$, 59), 307 (M$^+$ − Me, 2). Anal. Calcd for $C_{17}H_{22}O_6$: C, 63.3; H, 6.9. Found: C, 63.1; H, 6.8.

Method B. $(Ph)_3P$=$CHCO_2Me$ (625 mg, 1.87 mmol) was added in one portion to a stirred solution of the aldehyde **19** in toluene (25 mL) at rt. After being stirred at rt for a further 16 h, the solution was concentrated under reduced pressure. Fractionation of the residue by flash chromatography (Et_2O−hexane, 1:1) gave first the less polar *Z*-**9** (142 mg, 28%) as a white solid. The more polar compound *E*-**9** (284 mg, 57%) was obtained as a white solid. Recrystallization from Et_2O−hexane gave *E*-**9** as colorless needles: mp 114−115 °C; R_f 0.15 (Et_2O−hexane, 1:1); $[\alpha]^{25}_D$ +22 (*c* 1.3, EtOH); IR 1727 (α,β-unsaturated ester), 3438 cm^{-1} (OH); ^1H NMR δ 1.40 (3H, s), 1.48 (3H, s), 2.97 (1H, br s), 3.16 (1H, br s), 3.73 (4H, m), 3.91, (1H, dd, *J* = 1.1, 6.1 Hz), 4.48 (1H, m), 4.91 (1H, br d, *J* = 6.0 Hz), 6.13 (1H, dd, *J* = 1.9, 15.7 Hz), 6.87 (1H, dd, *J* = 3.9, 15.7 Hz), 7.28−7.42 (5H, m); MS *m/z* (relative intensity) (EI) 307 (M$^+$ − Me, 8). Anal. Calcd for $C_{17}H_{22}O_6$: C, 63.3; H, 6.9. Found: C, 63.5; H, 6.7. The ratio of *Z*-**9**:*E*-**9** (ca. 1:2) was determined by the isolated yields.

3,5-*O*-Isopropylidene-D-*glycero*-D-*gulo*-heptono-γ-lactone (13). A solution of 3,5:6,7-di-*O*-isopropylidene-D-*glycero*-D-*gulo*-heptono-γ-lactone (**12**)[18] (5.0 g, 17.4 mmol) was stirred to dissolve in acetic acid (50 mL) at rt. Water (50 mL) was then added, and the solution was stirred at rt for a further 48 h. Solvents were removed under reduced pressure to give a white residue which was recrystallized from MeOH−Et_2O to give **13** (3.0 g, 70%) as colorless prisms: mp 160−161 °C (lit.[18b] mp 158 °C); R_f 0.39 (MeOH−$CHCl_3$, 1:4); $[\alpha]^{24}_D$ −77 (*c* 2.4, ethanol) {lit.[18b] $[\alpha]_D$ −75 (*c* 1.0, ethanol)}; IR 1779 (γ-lactone), 3450 cm^{-1} (OH); ^1H NMR δ (methanol-d_4) 1.37 (3H, s), 1.51 (3H, s), 3.58 (1H, dd, *J* = 4.8, 11.4 Hz), 3.70−3.82 (2H, m), 4.05 (1H, dd, *J* = 1.5, 9.0 Hz), 4.44 (1H, br t, 1.5 Hz), 4.61−4.66 (2H, m); ^{13}C NMR δ (methanol-d_4) 18.34, 29.39, 63.90, 69.16, 70.56, 70.63, 72.64, 99.73, 177.84; MS *m/z* (relative intensity) (EI) 233 (M$^+$ − Me, 16.6), 249 (MH$^+$, 1.2).

Aldehyde 14. Sodium periodate (1.0 g, 4.8 mmol) was added in one portion to a stirred solution of the triol **13** (1.0 g, 4.0 mmol) in MeOH (50 mL) and water (4 mL) at rt. After being stirred at rt for 30 min, the mixture was filtered through a bed of silica gel topped with Celite. Evaporation of the filtrate gave the crude aldehyde **14** which was dried by concentrating with toluene (5 × 10 mL) under reduced pressure. This compound was used in the following step without further purification.

3,5-*O*-Isopropylidene-1,1,6-tri-*C*-phenyl-D-*glycero*-D-*gulo*-hexitol (15) and 3,5-*O*-Isopropylidene-1,1,6-tri-*C*-phenyl-L-*glycero*-D-*gulo*-hexitol (16). A solution of the aldehyde **14** in dry THF (20 mL) was stirred at 0 °C under nitrogen while a solution of PhMgBr (prepared from 0.73 g of magnesium and 3.2 mL of bromobenzene in 30 mL dry THF) was added dropwise at 0 °C. The mixture was stirred at 0 °C for a further 2 h and quenched with an ice−water mixture (50 mL) and $CHCl_3$ (50 mL). The mixture was then filtered through Celite. The filtrate was washed with saturated NH_4Cl (50 mL). The aqueous layer was extracted with $CHCl_3$ (2 × 50 mL). The combined organic extracts were dried ($MgSO_4$) and filtered. Solvent removal gave a yellow syrup. Fractionation of the syrup by flash chromatography (EtOAc−hexane, 1:1) yielded a mixture of alcohols **15** and **16** (1.0 g, 56%) as a white solid. The ratio of **15**:**16** (ca. 1:2) was estimated by ^1H NMR spectral analysis.

3,5-*O*-Isopropylidene-1,1,6-tri-*C*-phenyl-D-*glycero*-D-*gulo*-hexitol (15). A solution of the triacetate **17** (583 mg, 1.01 mmol) in $CHCl_3$ (5 mL) and MeOH (10 mL) was stirred at rt. Aqueous sodium hydroxide (1.0 M, 5 mL) was added, and the mixture was stirred at rt for a further 1 h. The solution was diluted with $CHCl_3$ (50 mL) and washed with saturated NH_4Cl (10 mL). The aqueous layer was further extracted with $CHCl_3$ (2 × 10 mL). The combined organic extracts were dried ($MgSO_4$) and filtered. Concentration of the filtrate followed by flash chromatography (Et_2O−hexane, 2:1) afforded **15** (450 mg, 99%) as a white solid: mp 202−205 °C; R_f 0.28 (chloroform−methanol, 98:2); $[\alpha]^{24}_D$ +110 (*c* 1.8, EtOAc); IR 3450 cm^{-1} (OH); ^1H NMR δ 0.67 (3H, s), 1.25 (3H, s), 2.28 (1H, d, *J* = 3.4 Hz), 3.39 (1H, d, *J* = 4.1 Hz), 3.47 (1H, d, *J* = 8.2 Hz), 3.66 (1H, d, *J* = 6.9 Hz), 3.84 (1H, d, *J* = 8.0 Hz), 3.95 (1H, d, *J* = 8.2 Hz), 4.19 (1H, s), 4.47 (1H, dd, *J* = 4.1, 8.0 Hz), 4.68 (1H, dd, *J* = 3.4, 6.9 Hz), 7.02−7.78 (15H, m); MS *m/z* (relative intensity) (EI) 77 (Ph$^+$, 54.2), 105 (PhCO$^+$, 89.6), 183 (Ph_2COH^+, 100), 249 (M$^+$ − Ph_2COH − H_2O, 5.3), 435 (M$^+$ − Me, 0.3). Anal. Calcd for $C_{27}H_{30}O_6$: C, 72.0; H, 6.7. Found: C, 71.6; H, 6.4.

3,5-*O*-Isopropylidene-1,1,6-tri-*C*-phenyl-L-*glycero*-D-*gulo*-hexitol (16). A solution of the diacetate **18** (2.4 g, 4.5 mmol) in $CHCl_3$ (10 mL) and MeOH (30 mL) was stirred at rt. Aqueous sodium hydroxide (1.0 M, 10 mL) was added, and the mixture was stirred at rt for a further 5 h. The solution was diluted with $CHCl_3$ (100 mL) and washed with saturated NH_4Cl (10 mL). The aqueous layer was extracted with $CHCl_3$ (2 × 50 mL). The combined organic extracts were dried with $MgSO_4$ and filtered. Concentration of the filtrate followed by flash chromatography (Et_2O−hexane 2:1) afforded **16** (2.0 g, 98%) as a white solid: mp 166−168 °C; R_f 0.34 (chloroform−methanol, 98:2); $[\alpha]^{24}_D$ +122 (*c* 1.3, EtOAc); IR 3420 cm^{-1} (OH); ^1H NMR δ 0.84 (3H, s), 1.36 (3H, s), 2.57 (1H, d, *J* = 11.5 Hz),

2.62 (1H, d, J = 3.8 Hz), 2.73 (1H, d, J = 1.2 Hz), 3.32 (1H, d, J = 11.5 Hz), 3.60 (1H, d, J = 8.6 Hz), 3.75 (1H, d, J = 7.7 Hz), 3.93 (1H, s), 4.45 (1H, dd, J = 3.8, 7.7 Hz), 4.83 (1H, br d, J = 8.6 Hz), 7.11–7.70 (15H, m); MS m/z (relative intensity) (EI) 77 (Ph^+, 30.4), 105 ($PhCO^+$, 55.7), 183 (Ph_2COH^+, 100), 249 ($M^+ - Ph_2COH - H_2O$). Anal. Calcd for $C_{27}H_{30}O_6$: C, 72.0; H, 6.7. Found: C, 71.7; H, 6.5.

2,4,6-Tri-*O*-acetyl-3,5-*O*-isopropylidene-1,1,6-tri-*C*-phenyl-D-*glycero*-D-*gulo*-hexitol (17) and 2,6-di-*O*-acetyl-3,5-*O*-isopropylidene-1,1,6-tri-*C*-phenyl-L-*glycero*-D-*gulo*-hexitol (18). A solution of alcohols **15** and **16** (1.70 g, 3.8 mmol) in dry CH_2Cl_2 (40 mL) was stirred at rt. Pyridine (8.9 mL, 0.09 mol), acetic anhydride (7.6 mL, 0.09 mmol), and a catalytic amount of DMAP were added. After being stirred at rt for 48 h, the mixture was washed with water (10 mL) and then with saturated NH_4Cl (10 mL). The organic layer was dried ($MgSO_4$) and filtered. Concentration of the filtrate under reduced pressure followed by flash chromatography (EtOAc–hexane, 1:3) first afforded the less polar triacetate **17** (788 mg, 36%) as a white solid. Recrystallization from EtOAc–hexane gave colorless needles: mp 237–239 °C; R_f 0.55 (EtOAc–hexane, 1:2); $[\alpha]^{24}_D$+77 (c 0.9, EtOAc); IR 1750 cm^{-1} (C=O ester); ^1H NMR δ 0.54 (3H, s), 1.19 (3H, s), 1.85 (3H, s), 1.91 (3H, s), 2.03 (3H, s), 4.03 (1H, dd, J = 1.4, 9.5 Hz), 4.27 (1H, dd, J = 1.4, 9.2 Hz), 4.38 (1H, s), 5.13 (1H, br s), 5.45 (2H, t, J = 9.2 Hz), 7.13–7.75 (15H, m); MS m/z (relative intensity) (EI) 77 (Ph^+, 16.1), 105 ($PhCO^+$, 44.3), 183 (Ph_2COH^+, 89.4), 561 (M^+ – Me, 0.7). Anal. Calcd for $C_{33}H_{36}O_9$: C, 68.7; H, 6.3. Found: C, 68.7; H, 6.3.

The more polar diacetate **18** (981 mg, 49%) was also obtained as a white solid. Recrystallization from EtOAc–hexane gave white crystals: mp 183–185 °C; R_f 0.45 (EtOAc–hexane, 1:2); $[\alpha]^{24}_D$ +114 (c 0.8, EtOAc); IR 1750 (C=O ester), 3500 cm^{-1} (OH); ^1H NMR δ ($CDCl_3$ + D_2O) 0.78 (3H, s), 1.41 (3H, s), 2.00 (3H, s), 2.04 (3H, s), 2.67 (1H, br s), 3.76 (1H, d, J = 9.0 Hz), 3.79 (1H, d, J = 9.4 Hz), 5.62 (1H, d, J = 9.4 Hz), 5.97 (1H, d, J = 9.0 Hz), 7.18–7.77 (15H, m); MS m/z (relative intensity) (EI) 77 (Ph^+, 19.9%,), 105 ($PhCO^+$. 54.2), 183 (Ph_2COH^+, 100,), 233 ($M^+ - Ph_2COH - 2 \times OAc$, 1.5), 339 ($M^+ - Ph - 2 \times OAc$, 1.0). Anal. Calcd for $C_{31}H_{34}O_8$: C, 69.7; H, 6.2. Found: C, 69.8; H, 6.2.

2,4-*O*-Isopropylidene-5-*C*-phenyl-D-*gluco*-pentose (19). Sodium metaperiodate (539 mg, 2.52 mmol) was added in one portion to a stirred solution of tetraol **15** (945 mg, 2.10 mmol) in MeOH (40 mL) and water (10 mL) at rt. After being stirred at rt for 30 min, the mixture was filtered through a bed of silica gel topped with Celite. Removal of solvent from the filtrate under reduced pressure gave **19** as a colorless syrup which was dried by concentration with toluene several times. This compound was used in the next step without further purification.

7-*C*-Phenyl-D-*gluco*-hept-2-enono-γ-lactone (20). A solution of the enoate *Z*-**9** (307 mg, 0.95 mmol) in acetic acid (25 mL) and water (25 mL) was stirred at rt for 24 h. Solvent removal followed by flash chromatography (Et_2O–hexane, 1:1) afforded **20** (213 mg, 89%) as a white solid. Recrystallization from Et_2O–hexane gave colorless needles: mp 109–111 °C; R_f 0.42 (EtOAc); $[\alpha]^{24}_D$ –68 (c 0.6, EtOAc); IR 1750, 1778 (α,β-unsaturated γ-lactone), 3400 cm^{-1} (OH); ^1H NMR [$(CD_3)_2C$=O + D_2O] 3.70 (1H, dd, J = 2.1, 7.9 Hz), 4.09 (1H, dd, J = 2.1, 5.7 Hz), 4.78 (1H, d, J = 7.9 Hz), 5.27 (1H, ddd, J = 1.5, 2.1, 5.7 Hz), 6.15 (1H, dd, J = 2.1, 5.8 Hz), 7.24–7.45 (5H, m), 7.82 (1H, dd, J = 1.5, 5.8 Hz); MS m/z (relative intensity) (EI) 83 ($C_4O_2H_3^+$, 23.8), 107 ($PhCHOH^+$, 100), 126 (M^+ – PhCHOH – OH, 22.2), 232 ($M^+ - H_2O$, 0.3). Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.4; H, 5.6. Found: C, 62.4; H, 5.8.

2,4-*O*-Isopropylidene-5-*C*-phenyl-L-*ido*-pentose (21). Sodium metaperiodate (1.40 g, 6.50 mmol) was added in one portion to a stirred solution of the tetrol **16** (1.95 g, 4.33 mmol) in MeOH (150 mL) and water (20 mL) at rt. After being stirred at rt for 30 min, the mixture was filtered through a bed of silica gel topped with Celite. The filtrate was then concentrated under reduced pressure to give **21** as a colorless syrup. The aldehyde was dried by evaporation with toluene several times. This compound was used in the following step without further purification.

(*Z*)-Methyl 4,6-*O*-Isopropylidene-7-*C*-phenyl-L-*ido*-hept-2-enonate (*Z*-22). $(Ph)_3P$=$CHCO_2Me$ (1.74 g, 5.20 mmol) was added in one portion to a stirred solution of the aldehyde **21** in anhydrous MeOH (30 mL) at rt. After being stirred at rt for 3 h, the solution was concentrated under reduced pressure. Fractionation of the residue by flash chromatography (Et_2O–hexane, 2:3) gave *Z*-**22** (1.12 g, 80%) as a colorless oil: R_f 0.46 (EtOAc–hexane, 2:1); $[\alpha]^{22}_D$ +121 (c 0.8, EtOAc); IR 1657, 1724 (α,β-unsaturated ester), 3476 cm^{-1} (OH); ^1H NMR δ 1.54 (3H, s), 1.56 (3H, s), 2.64 (1H, d, J = 11.8 Hz), 2.84 (1H, d, J = 1.5 Hz), 3.25 (1H, dt, J = 1.3, 11.8 Hz), 3.61 (3H, s), 3.89 (1H, dd, J = 1.0, 8.1 Hz), 4.88 (1H, dd, J = 1.4, 8.1 Hz), 5.40 (1H, dt, J = 1.4, 7.3 Hz), 5.78 (1H, dd, J = 1.4, 11.7 Hz), 6.25 (1H, dd, J = 7.3, 11.7 Hz), 7.30–7.48 (5H, m); MS m/z (relative intensity) (EI) 307 (M^+ – Me, 15.5), 323 (MH^+, 2.7). The ratio of *Z*:*E* isomers (ca. 10:1) was determined by ^1H NMR spectral analysis.

7-*C*-Phenyl-L-*ido*-hept-2-enono-γ-lactone (23). A solution of the alkene *Z*-**22** (200 mg, 0.62 mmol) in aqueous acetic acid (10 mL, 75% v/v) was stirred at rt for 12 h. The reaction mixture was concentrated and the residue recrystallized from MeOH–ether to give **23** (140 mg, 90%) as a white solid: mp 143–145 °C; $[\alpha]^{21}_D$ –85 (c 0.3, MeOH); R_f 0.25 (Et_2O); IR (film) 1749 cm^{-1} (γ-lactone); ^1H NMR [$(CD_3)_2C$=O + D_2O] δ 3.41 (1H, dd, J = 2.9, 5.1 Hz), 3.58 (1H, dd, J = 2.9, 5.9 Hz), 4.77 (1H, d, J = 5.1 Hz), 5.10 (1H, ddd, J = 1.5, 2.1, 5.9 Hz), 5.96 (1H, dd, J = 2.1, 5.8 Hz), 7.29–7.39 (5H, m, 5H), 7.64 (1H, dd, J = 1.5, 5.8 Hz); MS m/z (relative intensity) (EI) 251 (MH^+, 0.7). Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.4; H, 5.6. Found: C, 62.5; H, 5.8.

Diacetylgoniobutenolide A (24) and Diacetylgoniobutenolide B (25). A solution of the triol **20** (201 mg, 0.80 mmol) in dry CH_2Cl_2 (20 mL) was stirred at rt. Triethylamine (0.6 mL), acetic anhydride (0.4 mL), and a catalytic amount of DMAP were added to the solution. The solution was stirred at rt for 21 h and then filtered through a bed of silica gel topped with Celite. Evaporation of the filtrate under reduced pressure gave a yellow oil. Purification by flash chromatography (Et_2O–hexane, 1:1) gave **24** and **25** as yellow oils (253 mg, 99%). The ratio of **24**:**25** (ca. 2:1) was determined by ^1H NMR spectral analysis. Separation by flash chromatography gave first the butenolide **25** as a yellow oil: R_f 0.28 (Et_2O–hexane, 1:1); $[\alpha]^{24}_D$ –63 (c 0.7, $CHCl_3$); IR 1744 (ester), 1790 cm^{-1} (conjugated α,β- and γ,δ-unsaturated γ-lactone); ^1H NMR δ 2.02 (3H, s), 2.12 (3H, s), 5.66 (1H, dd, J = 1.5, 9.9 Hz), 5.83 (1H, dd, J = 4.3, 9.9 Hz), 6.05 (1H, d, J = 4.3 Hz), 6.18 (1H, dd, J = 1.7, 5.7 Hz), 7.22–7.41 (5H, m), 7.47 (1H, d, J = 5.7 Hz); ^{13}C NMR δ 20.66, 20.71, 70.65, 75.56, 107.00, 122.02, 126.99, 128.49, 128.66, 135.40, 139.81, 153.22, 168.45, 169.39, 169.55; MS m/z (relative intensity) (CI, isobutane) 257 (M^+ – OAc, 100). Anal. Calcd for $C_{17}H_{16}O_6$: C, 64.55; H, 5.1. Found: C, 64.4; H, 5.3.

The butenolide **24** was also obtained as a yellow oil: R_f 0.17 (Et_2O–hexane 1:1); $[\alpha]^{24}_D$ +75 (c 1.7, $CHCl_3$); IR 1746 (ester), 1785 cm^{-1} (conjugated α,β- and γ,δ-unsaturated γ-lactone); ^1H NMR δ 2.02 (3H, s), 2.12 (3H, s), 5.25 (1H, dt, J = 2.4, 8.7 Hz), 6.06–6.11 (2H, m), 6.20 (1H, d, J = 5.5 Hz), 7.26–7.36 (6H, m); ^{13}C NMR δ 20.16, 20.25, 69.79, 74.55, 107.25, 120.86, 126.52, 127.90, 128.08, 135.28, 143.11, 151.11, 168.02, 168.84, 168.99; MS m/z (relative intensity) (CI, isobutane) 257 (M^+ – OAc, 69.1), 317 (MH^+, 1.2). Anal. Calcd for $C_{17}H_{16}O_6$: C, 64.55; H, 5.1. Found: C, 64.2; H, 5.3.

7-*C*-Phenyl-L-*ido*-hept-2-enono-δ-lactone [(+)-7-*epi*-Goniotriol] (26). A solution of lactone **27** (157 mg, 0.54 mmol) in acetic acid (20 mL) and water (5 mL) was stirred at 90–100 °C for 3 h. Solvent removal followed by flash chromatography afforded **26** (111 mg, 82%) as a white solid. Recrystallization from EtOAc–hexane gave colorless needles: mp 127–129 °C; R_f 0.28 (EtOAc); $[\alpha]^{22}_D$ +88 (c 0.8, EtOH); IR 1719 (α,β-unsaturated δ-lactone), 3373 cm^{-1} (OH); ^1H NMR δ [$(CD_3)_2C$=O] 4.18 (1H, dd, J = 3.7, 6.2 Hz), 4.31 (1H, dd, J = 2.8, 6.2 Hz), 4.51 (1H, dd, J = 2.8, 5.8 Hz), 5.04 (1H, br d, J = 3.3 Hz), 6.02 (1H, d, J = 9.7 Hz), 7.06 (1H, dd, J = 5.8, 9.7 Hz), 7.22–7.49 (5H, m); MS m/z (relative intensity) (EI) 107 ($PhCHOH^+$, 100), 126 (MH^+ – PhCHOH – H_2O, 10.7), 144 (MH^+– PhCHOH,

9.6), 250 (M^+, 7.7,). Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.4; H, 5.6. Found: C, 62.0; H, 5.1.

4,6-*O*-Isopropylidene-7-*C*-phenyl-L-*ido*-hept-2-enono-δ-lactone (27). A solution of the unsaturated ester *Z*-**22** (278 mg, 0.86 mmol) in dry THF (30 mL) containing a catalytic amount of DBU was stirred at 60−70 °C for 24 h. The solution was then filtered through a bed of silica gel topped with Celite. Removal of solvent under reduced pressure gave a white solid (176 mg, 70%). Purification by flash chromatography (EtOAc−hexane, 1:1) afforded **27** as white crystals. Recrystallization from EtOAc−hexane gave colorless needles: mp 192 °C (sublim); R_f 0.36 (EtOAc−hexane, 2:1); $[\alpha]^{22}_D$ −89 (*c* 0.9, EtOH); IR 1732 (α,β-unsaturated δ-lactone), 3500 cm^{-1} (OH); ^1H NMR δ 1.53 (3H, s), 1.56 (3H, s), 2.84 (1H, d, *J* = 1.3 Hz), 3.63 (1H, t, *J* = 1.8 Hz), 3.91 (1H, dd, *J* = 1.7, 8.7 Hz), 4.18 (1H, dd, *J* = 1.9, 6.1 Hz), 5.15 (1H, br d, *J* = 8.7 Hz), 6.18 (1H, d, *J* = 9.6 Hz), 6.79 (1H, dd, *J* = 6.1, 9.6 Hz), 7.31−7.55 (5H, m); MS *m*/*z* (relative intensoty) (EI) 107 ($PhCHOH^+$, 44.9), 126 (MH^+ − PhCHOH, 10.4), 275 (M^+ − Me, 2.1). Anal. Calcd for $C_{16}H_{18}O_5$: C, 66.2; H, 6.25. Found: C, 65.9; H, 6.1.

4,6-*O*-Isopropylidene-7-*O*-methanesulfonyl-7-*C*-phenyl-L-*ido*-hept-2-enono-δ-lactone (28). A solution of the alcohol **27** (209 mg, 0.67 mmol) in dry CH_2Cl_2 (10 mL) was stirred at 0 °C. Pyridine (0.6 mL) and $MeSO_2Cl$ (0.6 mL) were added at 0 °C. The solution was then stirred at 0 °C for 24 h. The solution was diluted with EtOAc (50 mL) and washed with saturated NH_4Cl solution (20 mL) and then water (20 mL). The organic layer was dried with anhydrous $MgSO_4$ and filtered. Solvent removal followed by flash chromatography (EtOAc−hexane, 1:1) afforded **28** (248 mg, 93%) as a white solid. Recrystallization from EtOAc−hexane gave colorless needles: mp 97−98 °C; R_f 0.52 ($MeOH-CHCl_3$, 2:98); $[\alpha]^{22}_D$ −3.8 (*c* 0.5, EtOAc); ^1H NMR δ 1.51 (3H, s), 1.55 (3H, s), 3.01 (3H, s), 3.51 (1H, br s), 4.22−4.30 (2H, m), 5.83 (1H, d, *J* = 9.0 Hz), 6.16 (1H, d, *J* = 9.7 Hz), 6.78 (1H, dd, *J* = 6.0, 9.7 Hz), 7.38−7.56 (5H, m); MS *m*/*z* (relative intensoty) (EI) 90 ($PhCHOMs^+$ − OMs, 35.9), 91 ($PhCHOMsH^+$ − OMs, 100), 95 (OMs, 42.8), 183 (M^+ − PhCHOMs, 5.8), 185 ($PhCHOMs^+$, 8), 215 [M^+ − $(CH_3)_2CO_2$ − Ms, 9.0]. The unstable mesylate was used immediately after chromatography.

4,6-*O*-Isopropylidene-7-*C*-phenyl-D-*gluco*-hept-2-enono-δ-lactone (29). A solution of the unsaturated ester *Z*-**9** (517 mg, 1.61 mmol) in dry THF (30 mL) containing a catalytic amount of DBU was stirred at 60−70 °C for 24 h. The solution was then filtered through a bed of silica gel topped with Celite. Removal of solvent under reduced pressure gave a white solid. Purification by flash chromatography (Et_2O−hexane, 2:1) afforded **29** (325 mg, 70%) as white crystals. Recrystallization from EtOAc−hexane gave colorless needles: mp 190−191 °C; R_f 0.23 (Et_2O−hexane, 2:1); $[\alpha]^{24}_D$ +100 (*c* 1.2, MeOH); IR 1727 (α,β-unsaturated δ-lactone), 3401 cm^{-1} (OH); ^1H NMR δ 1.34 (6H, s), 2.89 (1H, d, *J* = 4.6 Hz), 4.05 (1H, dd, *J* = 1.8, 8.6 Hz), 4.34 (1H, dd, *J* = 2.0, 6.0 Hz), 4.50 (1H, t, *J* = 1.9 Hz), 5.11 (1H, dd, *J* = 4.5, 8.5 Hz), 6.25 (1H, d, *J* = 9.6 Hz), 6.89 (1H, dd, *J* = 6.1, 9.6 Hz), 7.29−7.45 (5H, m); MS *m*/*z* (relative intensity) (EI) 107 ($PhCHOH^+$, 48.2), 184 (MH^+ − PhCHOH, 10.3), 275 (M^+ − Me, 3.2). Anal. Calcd for $C_{16}H_{18}O_5$: C, 66.2; H, 6.25. Found: C, 66.1; H, 6.1.

(+)-Triacetylgoniotriol (30). A solution of the triol **7** (185 mg, 0.74 mmol) in dry CH_2Cl_2 (50 mL) was stirred at rt. Pyridine (0.36 mL), acetic anhydride (0.42 mL), and a catalytic amount of DMAP were added to the solution. The solution was stirred at rt for 21 h and then filtered through a bed of silica gel topped with Celite. Evaporation of the filtrate followed by flash chromatography (Et_2O−hexane, 2:1) gave **30** as a white solid (236 mg, 85%): mp 95−97 °C (lit.[6] mp 90−93 °C); R_f 0.28 (Et_2O−hexane, 2:1); $[\alpha]^{24}_D$ +121 (*c* 0.8, MeOH); IR 1743 cm^{-1} (ester and α,β-unsaturated δ-lactone); ^1H NMR δ 2.02 (3H, s), 2.07 (3H, s), 2.11 (3H, s), 4.53 (1H, dd, *J* = 3.0, 6.9 Hz), 5.28 (1H, dd, *J* = 3.0, 5.7 Hz), 5.74 (1H, dd, *J* = 4.8, 6.9 Hz), 5.96 (1H, d, *J* = 4.8 Hz), 6.17 (1H, d, *J* = 9.8 Hz), 6.93 (1H, dd, *J* = 5.7, 9.8 Hz), 7.34−7.44 (5H, m); MS *m*/*z* (relative intensity) (EI) 126 (MH^+ − PhCHOAc − OAc − Ac, 21.1), 149 ($PhCHOAc^+$, 7.7), 168 (M^+ − PhCHOAc − OAc, 21), 228 (MH^+ − PhCHOAc, 2.9). Anal. Calcd for $C_{19}H_{20}O_8$: C, 60.6; H, 5.4. Found: C, 60.5; H, 5.3.

7-*O*-Acetyl-4,6-*O*-isopropylidene-7-*C*-phenyl-D-*gluco*-hept-2-enono-δ-lactone (31). A solution of the alcohol **29** (325 mg, 1.12 mmol) in dry CH_2Cl_2 (20 mL) was stirred at rt. Pyridine (0.18 mL), acetic anhydride (0.21 mL), and a catalytic amount of DMAP were added to the solution. The solution was stirred at rt for 3 h. The solution was then filtered through a bed of silica gel topped with Celite. Evaporation of the filtrate under reduced pressure followed by flash chromatography (EtOAc−hexane, 1:1) gave **31** as white crystals (357 mg, 96%). Recrystallization from EtOAc−hexane gave colorless needles: mp 190−191 °C; R_f 0.18 (EtOAc−hexane, 1:1); $[\alpha]^{24}_D$ +45 (*c* 0.3, MeOH); IR 1725 (ester), 1739 cm^{-1} (α,β-unsaturated δ-lactone); ^1H NMR δ 1.30 (3H, s), 1.32 (3H, s), 2.04 (3H, s), 4.27 (1H, d, *J* = 9.3 Hz), 4.35−4.37 (2H, m), 5.99 (1H, d, *J* = 9.3 Hz), 6.27 (1H, d, *J* = 9.6 Hz), 6.88 (1H, dd, *J* = 5.8, 9.6 Hz), 7.29−7.37 (5H, m); MS *m*/*z* (relative intensity) (EI) 318 (MH^+ − Me, 5.2). Anal. Calcd for $C_{18}H_{20}O_6$: C, 65.05; H, 6.1. Found: C, 64.7; H, 5.9.

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Supplementary Material Available: ^1H NMR data with peak assignments for all compounds (4 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page ordering information.

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