Synthetic transformations of sesquiterpene lactones
6.* Alantolactone and isoalantolactone derivatives in the Heck reaction

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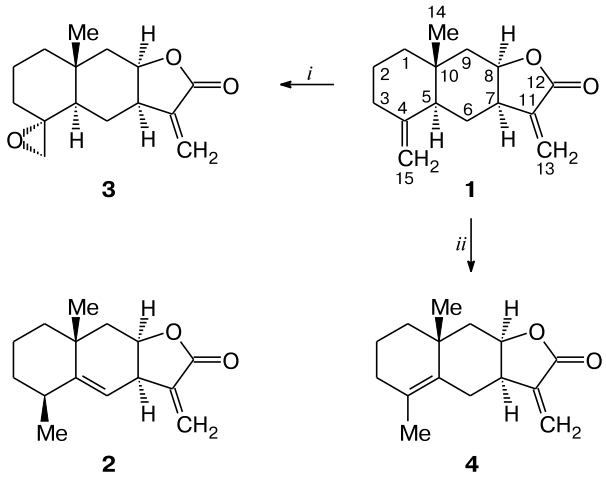
The Heck reaction of the eudesman-type methylidenelactones (alantolactone, alloalantolactone, and 4,15-epoxyisoalantolactone) with haloarenes afforded the corresponding (*E*)-13-aryleudesma-4(15),11(13)-dien-8β,12-olides and 11-arylmethyl-13-noreudesma-4(15),7(11)-dien-8α,12-olides. The yields and the ratios of the arylation products depended on the reaction conditions and the structure of lactone. Certain side processes were found to take place.

Key words: alantolactone, isoalantolactone, epoxyisoalantolactone, alloalantolactone, Heck reaction.

In the preceding works,[1—3] we have shown that sesquiterpene α-methylidenelactones, *viz.*, isoalantolactone (**1**) and alantolactone (**2**) taken as examples, can be modified by the Heck reaction with aryl halides *via* the introduction of aromatic substituents at position C(13). Such a modification of sesquiterpenoids was of interest, since it was found that the presence of an arylidene fragment in the lactone ring is responsible for the valuable pharmacological properties of the indicated metabolites and their derivatives.[4] Thus, certain 13-aryleudesmanolides have been patented as promising antiulcer agents.[5] In the present work, we report the results of our studies of the arylation reaction of available isoalantolactone (**1**) derivatives: 4,15-epoxyisoalantolactone (**3**)[6] and alloalantolactone (**4**),[7] as well as alantolactone **2** (Scheme 1).

Scheme 1



Reagents and conditions: *i*. MCPBA; CH_2Cl_2, 20 °C; *ii*. CF_3COOH, $CHCl_3$, 20 °C.

The reaction of 4,15-epoxyisoalantolactone **3** with 4-fluoroiodobenzene (**5a**), 4-iodoveratrole (**5b**), and 4-bromopyrochatehol (**5c**) catalyzed by the system $Pd(OAc)_2$—tri(*o*-tolyl)phosphine (4/16 mol.%) in DMF in the presence of triethylamine as a base (120 °C, 8 h, Scheme 2) led to the corresponding mixtures of (*E*)-13-aryleudesma-4(15),11(13)-dien-8β,12-olides (**6—8**) (yields 55—80%) and endocyclic isomeric 11-arylmethyl-13-noreudesma-4(15),7(11)-dien-8α,12-olides (**9—11**) (yields 10—20%). The highest total yield of the mixture of compounds **7** and **10** (90%) was achieved in the reaction of lactone **3** with 4-iodoveratrole **5b**; in the reaction of compound **3** with 4-bromopyrochatehol **5c** under the same experimental conditions, a decrease in the total yield of products **8** and **11** (to 65%) was observed. In the reaction of methylydenelactone **3** with 4-fluoroiodobenzene **5a**, besides compounds **6** (60%) and **9** (10%), (*Z*)-isomer (**12**) was also isolated (yield 6%). The reaction of methylidenelactone **3** with 4-bromoiodobenzene (**5d**) proceeded in acetonitrile under conditions of non-ligand catalysis with the formation of compounds **13** and **14** in 60 and 20% yields, respectively.

Earlier,[2] we have shown that the reaction of alantolactone **2** with 4-iodoveratrole **5b** in DMF in the presence of catalytic amounts of palladium acetate and tri(*o*-tolyl)-phosphine, as well as triethylamine, (120 °C, 8 h) gave rise to aryl-substituted derivatives **15** and **16** in low yields (the conversion was 75%; the yields were 20 and 36%, respec-

* For Part 5, see Ref. 1.

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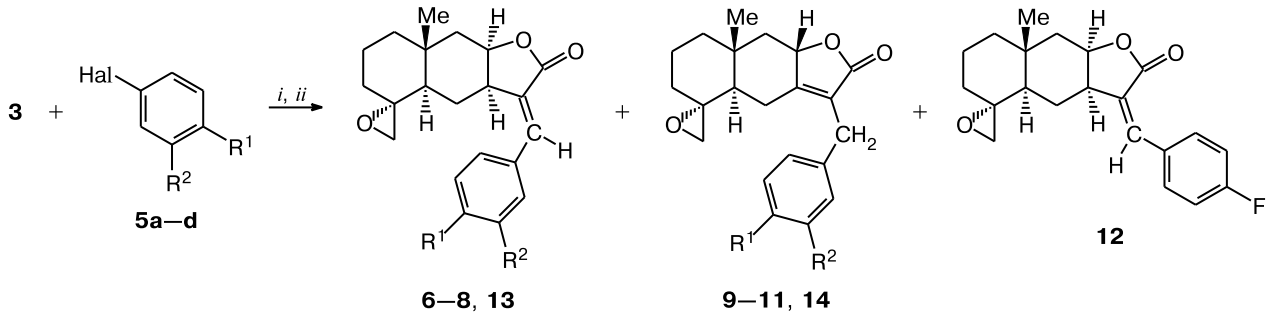
Scheme 2



i. $Pd(OAc)_2$, $(2\text{-}MeC_6H_4)_3P$, DMF, Et_3N, 120 °C, 8 h; *ii*. $Pd(OAc)_2$, MeCN, Et_3N, 80 °C, 12 h.

R^1 = F, R^2 = H (**5a**, **6**, **9**, **12**); R^1 = R^2 = OMe (**5b**, **7**, **10**); R^1 = R^2 = OH (**5c**, **8**, **11**); R^1 = Br, R^2 = H (**5d**, **13**, **14**)
Hal = I (**5a,b,d**), Br (**5c**)

tively). The reaction of lactone **2** with 4-fluoroiodobenzene (**5a**), 4-iodoanisole (**5e**), 2,4-dimethoxyiodobenzene (**5f**), and 4-iodobenzonitrile (**5g**) also led to the corresponding mixtures of two isomeric products (**17**—**20** and **21**—**24**). Based on the analysis of the ^1H NMR spectra and the chromato-mass spectrometric data of the reaction mixtures, it was determined that the conversion of lactone **2** was 70—75%, whereas the ratios of lactones **17** : **21**, **18** : **22**, **19** : **23**, and **20** : **24** were within the range 1.0 : 1.0 → → 0.75 : 1.0. After the reaction mixtures were subjected to chromatography, compounds **17**—**20** and **21**—**24** were isolated in 15—21 and 22—29% yields, respectively. The conversion of the starting compounds and the selectivity of the reaction are considerably influenced by the temperature regime. Thus, when the reaction of lactone **2** with 2,4-dimethoxyiodobenzene **5f** was carried out at 90, 105, and 120 °C, the ratios of products **19** and **23** were 1.4 : 1, 1.05 : 1, and 0.85 : 1, respectively, and the conversions of the starting compounds were 20, 30, and 75%. An elevation of the temperature to 140 °C caused a deep resinification of the reaction mixture (to 60%). A two-fold increase in the time of the reaction of lactone **2** with 4-iodoanisole **5e** did not result in any noticeable changes in the conversion (~35% of the starting lactone remained unconsumed). If the amount of palladium acetate was increased (8—10 mol.%), the conversion of lactone **2** increased to 85—95%, with the ratio of the products remaining virtually unchanged.

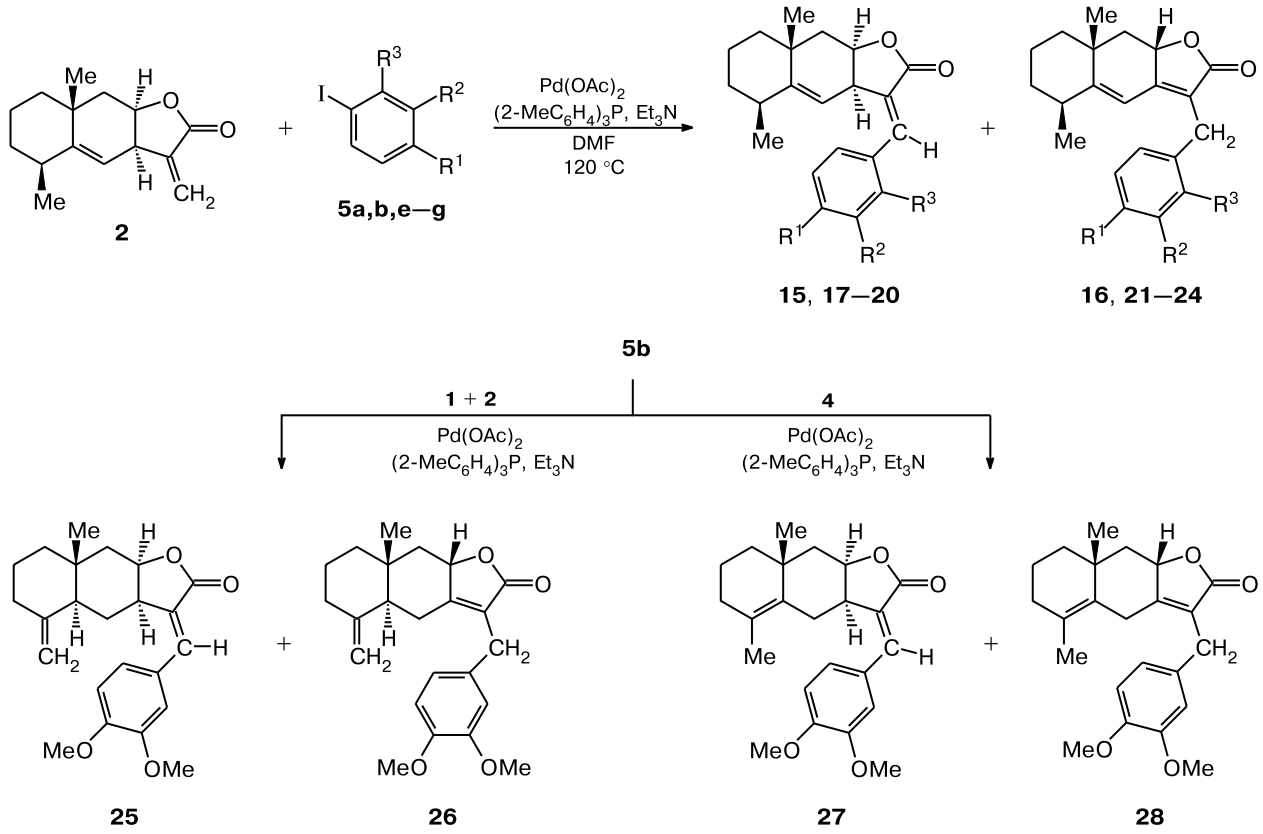
It should be noted that the activity of alantolactone **2** in the reaction with aryl bromides, such as bromobenzene and 4-bromotoluene, is low. When the reaction with these bromides was carried out in DMF in the presence of $Pd(OAc)_2/(2\text{-}MeC_6H_4)_3P$ and triethylamine (120 °C), the conversion of substrate **2** after 20 h did not exceed 10%. The reaction of methylidenelactone **2** with 4-iodoveratrole **5b** under conditions of non-ligand catalysis [$Pd(OAc)_2$—Et_3N—MeCN] was also slow: 80% of compound **2** was recovered. A competing reaction of a mixture of methylidenelactones **1** and **2** (1 : 1) (the mixture with such a ratio of lactones is easily isolated by the extraction of the root *Inula helenium*) with iodide **5b**, four compounds were identified in the reaction mixture: the isomeric aryl-substituted eudesmanolides **25** and **26** (the content of ~70 and 20%, respectively, calculated based on the converted lactone); isoalantolactone **1** (20% from the starting amount), and alantolactone **2** (90% from the starting amount) (according to the ^1H NMR spectroscopic and chromato-mass spectrometric data for the reaction mixture).

The reaction of alloalantolactone **4** with 4-iodoveratrole **5b** catalyzed by the system palladium acetate—tri(*o*-tolyl)phosphine in DMF in the presence of triethylamine (120 °C, 10 h) proceeded with the formation of compounds **27** and **28** (yields 30 and 35%, respectively) (Scheme 3).

As it is seen, the yield and the composition of the reaction products significantly depended on the structure of methylidenelactone. The reaction of epoxyisoalantolactone **3** with haloarenes was distinguished by the formation of high yields of the exocyclic lactones **6**—**8** and **13**. The endocyclic alkenes **16**, **21**—**24**, and **28** were isolated as the major reaction products of arylation of methylidenelactones **2** and **4**. In the specially designed experiments, it was found that no isomerization of 13-aryleudesmanolides **6** or **17** to compounds **9** or **21** occurred when the starting methylidenelactones were subjected to the reaction conditions ($Pd(OAc)_2$—$(2\text{-}MeC_6H_4)_3P$—Et_3N—DMF, 120 °C, 15 h).

The fact that the outcome of the Heck reaction is significantly influenced by the structure of methylidenelactone is also confirmed by the literature data. Thus, the arylation of eudesmanolides of partenolide or 11,13-dehydrosantonine containing *trans*-annulated lactone ring was reported to be selective and exclusively resulted to the corresponding exocyclic 13(*E*)-arylidenelactones.[9] The arylation of unsubstituted α-methylidene-γ-butyrolactone with

Scheme 3



$R^1 = R^2 = OMe$, $R^3 = H$ (**15**, **16**); $R^1 = F$, $R^2 = R^3 = H$ (**5a**, **17**, **21**); $R^1 = OMe$, $R^2 = R^3 = H$ (**5e**, **18**, **22**); $R^1 = R^3 = OMe$, $R^2 = H$ (**5f**, **19**, **23**); $R^1 = CN$, $R^2 = R^3 = H$ (**5g**, **20**, **24**)

iodoarenes in the presence of the catalytic system $Pd(OAc)_2/(2\text{-}MeC_6H_4)_3P$ and triethylamine in DMF proceeded with the formation of two isomeric products with exo- and endocyclic position of the double bond.[10] The structure of α-methylidenelactones **1**—**4** is distinguished by the *cis*-annulation of the lactone ring to the octahydronaphthalene fragment, and in this case compounds **2** and **4** do not contain an αH-atom at position C(5) that, probably, is the reason for the increase in the yield of the products with the endocyclic double bond in the Heck reaction of the lactones indicated.

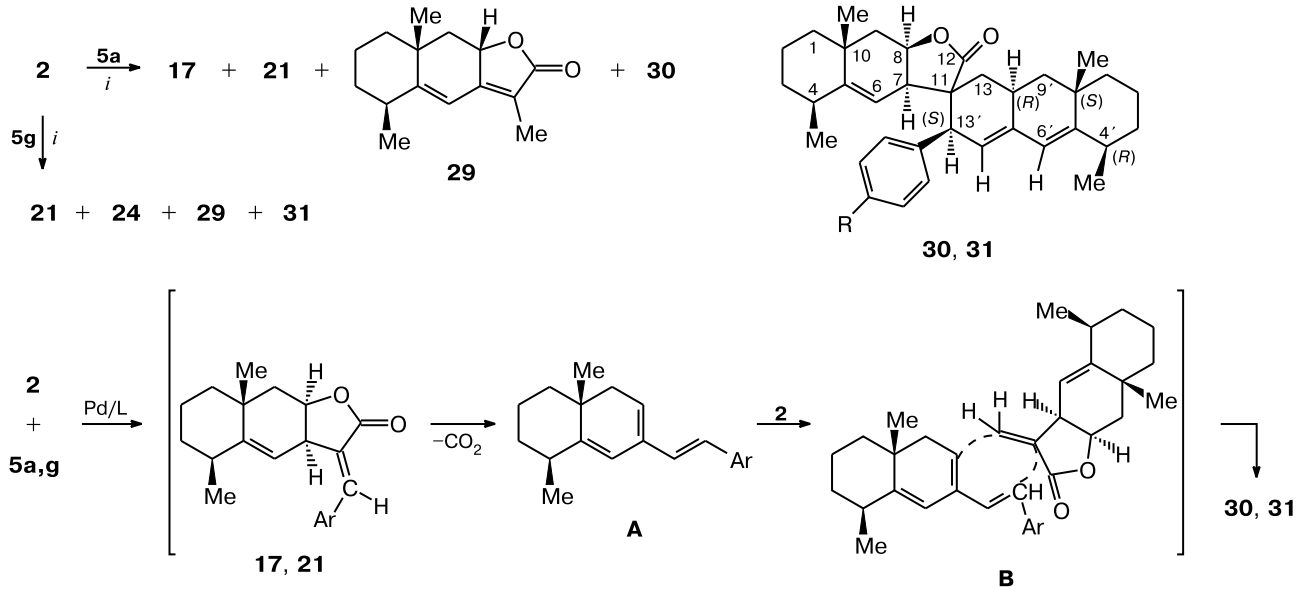
A thorough examination of the minor reaction products of alantolactone **2** with iodoarenes **5a**,**g** resulted in the isolation of isomerization products: alantolactone (**29**) (yield 3—5%) and spiro compounds (**30** or **31**) (yields 2 and 3%, respectively) (Scheme 4).

The most plausible scheme for the formation of spirolactones **30** and **31** is based on the [4+2] cycloaddition reaction of alantolactone **2** (see Scheme 4). It can be suggested that the forming 13-aryleudesmanolides **17** and **21** upon the action of the catalytic system undergo decarboxylation, leading to trienes **A**. Then follows a diene synthesis through the formation of the transition state **B**. Earlier, the C(11)=C(13) double bond in lactones **1** and **2** was found to be active in the Diels—Alder reaction.[11]

The structures of compounds synthesized were established based on the combination of the elemental analysis data and spectroscopic characteristics. The (*E*)-configuration of the C(11)=C(13) double bond in arylidenelactones **6**—**8**, **13**, **15**, **17**—**20**, and **27** was concluded from the presence in the ^{13}C NMR spectrum (monoresonance mode) of the *cis*-spin-spin coupling constant between the olefin proton and the carbonyl carbon atom of the lactone ($^3J_{cis}$ = 6.9—7.5 Hz); the corresponding *trans*-constant for the (*Z*)-isomer **12** is equal to 13.2 Hz. The signal for the proton H(13) in the ^1H NMR spectra of (*E*)-isomers **6**—**8**, **13**, **15**, **17**—**20**, and **27** was found in the region of δ 7.34—7.46, whereas for the (*Z*)-isomer **12**, at δ 6.81. The ^1H NMR spectra of compounds **6**—**8**, **13**, **15**, **17**—**20**, and **27** are characterized by a downfield shift of the signal for the proton H(7) (δ 3.28—4.07) as compared to the signal for the corresponding proton in the spectrum of lactone **1** or in the spectrum of (*Z*)-isomer **12** (δ 2.89).

An indicative feature of the ^1H NMR spectra of compounds **9**—**11**, **14**, **16**, **21**—**24**, **26**, and **28** is the presence of signals for the protons of the methylene group at the

Scheme 4



i. $Pd(OAc)_2$, $(2\text{-}MeC_6H_4)_3P$, Et_3N, DMF.

R = F (**30**), CN (**31**)

C(13) atom (for example, for compound **14**, δ = 3.43 and 3.49 (both d, 2 H, H(13), J = 14.8 Hz)) and a significant increase in the difference of chemical shifts for the protons H(9) (Δδ 1.0—1.3 ppm). The upfield signal for the proton H(9) (δ 1.06 for **14**) has an axial-axial constant with the proton H(8) (J = 11.9 Hz). The (8*S*)-configuration of compounds **14**, **16**, **22**, **28**, and **29** was confirmed by the data of the NOESY experiments: the cross-peaks between the signals for the protons of the methyl group $C(14)H_3$ and the proton H(8) were observed.

The chromato-mass spectra of dimeric compounds **30** and **31** exhibited peaks with the *m/z* 514 and 521, respectively. According to the data of ^{13}C NMR spectroscopy, the number of carbon atoms is equal to 35 and 36, respectively. The ^1H NMR spectra of compounds **30** and **31** contain signals for the protons of the aromatic substituent and a set of signals for the terpene framework corresponding to the framework of alantolactone. The splitting of the signals H(7) and H(13) indicates that the C(11) carbon atom is quaternary. The formation of the regioisomers indicated (the orientation of the aromatic substituent in the diene at position C(11)) can be concluded from the pattern of the signal for the H(13´) proton (δ 3.68, J = 4.5, J = 1.0, J = 1.5 Hz) interacting with the methine proton H(11´) (δ 5.23), as well as with the protons H(7) and H(8´) (J = 1.0 and J = 1.5 Hz). A characteristic feature of the ^1H NMR spectra is the presence of an unresolved multiplet at δ 3.38—3.41 (for compound **31**, the half-height width is equal to 28 Hz), corresponding to the proton H(8´) and having in the $^1H—^1H$ COSY spectra cross-peaks with the H atoms at δ 1.48, 1.87, 1.27, 1.57, 3.68, and 5.23. The spin-spin coupling constants of the indicated proton obtained from the NMR experiments with the decoupling of one of the signals for compound **31** indicate the presence of two axial-axial (J = 12.2, J = 10.9 Hz) and two axial-equatorial interactions with protons H(9´) and H(13). All the interactions were found and assignment for all the signals were made using the data of 2D NMR spectroscopy (COSY, HMBC, HSQC, J-Resolved, NOESY, HOESY).

The configuration of the chiral centers formed can be concluded from the consideration of the interactions of protons H(7), H(8), H(8´), H(9´), H(13), and H(13´). The presence of the NOE between the atom H(13´) and the atoms H_α (H(7) and H(8)), as well as between the atoms H(13´) and H(8´) indicates their *sin*-arrangement (Fig. 1). The presence of the indicated interactions confirms the 13´(*S*)-configuration. According to the molecular mechanics data (the MM2 method), in the case when the 13´(*S*)-configuration is effected, the atom H(13´) is equidistant from the atoms H(7) and H(8), whereas in the 13´(*R*)-configuration the distance H(8)—H(13´) is significantly larger than the H(7)—H(13´) (in this case, the NOE observed with the atom H(8) is stronger than in the case of H(7)). The configuration of the atoms C(10´) and C(4´) is also postulated based on the calculated data (MM2), according to which only in such arrangement of the atoms the conformation, in which the atom H(8´) has two axial-axial interactions with hydrogen atoms of the neighboring methylene groups, is possible and a NOE-effect

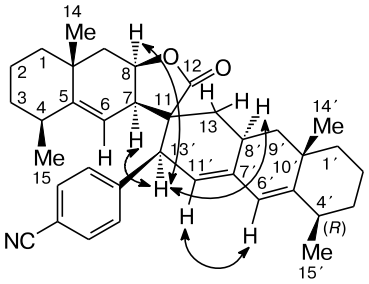


Fig. 1. Configurations of chiral centers and indicative interactions of protons in the $^1H—^1H$ NOESY spectrum of compound **31**.

between protons H(8′) and H(13′) will be observed in the 8′(*R*)-configuration. The 11(*S*)-configuration also followed from the stereoselectivity of the Diels—Alder reaction and was confirmed by the result of the reaction of lactone **1** with α-phellandren.[11]

Experimental

^1H and ^{13}C NMR spectra of solutions of compounds in $CDCl_3$ were recorded on Bruker AV-300 (300.13 (^1H) and 75.47 MHz (^{13}C)), Bruker AV-400 (400.13 (^1H) and 100.78 MHz (^{13}C)), Bruker AV-600 (600.13 (^1H) and 150.96 MHz (^{13}C)) spectrometers using signals of the solvent as references (δ_H 7.24 and δ_C 77.0). The numeration of atoms of the sesquiterpene framework given in Scheme 1 was used in the description of the ^1H and ^{13}C NMR spectra. Different types of proton-proton and carbon-proton shift correlation spectroscopy (COSY, COXH, COLOC, NOESY) were used to assign signals in the NMR spectra. Recording spectra in the *J*-modulation mode was useded to determine the splitting of the signals in the ^{13}C NMR spectra. To obtain mass spectra and to determine molecular masses and elemental composition, a DFS Thermo Scientific high resolution mass spectrometer was used (EI, 70 eV, the temperature of the injector was 230—280 °C). Melting points were measured on a Stuart SMF-38 heating stage.

IR spectra were recorded on a Vector-22 spectrometer, UV absorption spectra were recorded on a HP 8453 UV—Vis spectrometer (in ethanol). Specific rotation $[\alpha]_D^{20}$ was measured on a PolAAr3005 polarimeter. Reaction mixtures were examined by chromato-mass spectrometry on a Hewlett—Packard 5890/II MSD gas chromatograph equipped with a HP MSD 5971 quadrupole mass spectrometer as a detector. A 30-m HP-5MS quartz column was used (copolymer diphenyl (5%)—dimethylenesiloxane (95%)) with the internal diameter of 0.25 mm and the stationary phase film thickness of 0.25 μm; the temperature was raised within the range of 50—280 °C at the speed of 4 °C min^{-1}, then kept for 15 min at 280 °C.

Elemental analysis was performed on a Carlo Erba CHN-analyzer (model 1106).

Reaction products were isolated by column chromatography on silica gel (Acros, 0.035—0.070 mm) and, if necessary, additionally by preparative TLC on a non-bound 1-mm thick layer of silica gel containing 1% K-35 luminophore on 20×20-cm plates (eluents: benzene—ethyl acetate, chloroform—ethanol). The isolation of the individual products by column chromatography was complicated by their lability in the adsorbed state and close values of the separation factor. For the separation of mixtures of compounds **17**—**20** and **21**—**24** obtained by the reaction of alantolactone **2** with iodides **5a**,**e**,**f**,**g**, the silica gel impregnated with $AgNO_3$ (10%)[12] was used. For the separation of compounds **15** and **16**, the use of alumina has proved preferable, with the mixture of benzene—ethyl acetate (100 : 0 → 10 : 1) being an eluent.

Lactones **1** and **2** were isolated by the extraction of *Inula helenium* with subsequent separation through the morpholine adducts according to the procedures described earlier.[13] In this work, we used commercially available iodoarenes **5a**,**b**,**e**,**g**. 3,4-Dihydroxybromobenzene **5c**,[14] 4-iodobromobenzene **5d**,[15] 2,4-dimethoxyiodobenzene **5f**,[16] as well as $Pd(OAc)_2$ (see Ref. 17), were obtained according to the known procedures.

The Heck reaction of methylidenelactones 1—4 with aryl halides (general procedure). A two-neck glass tube was filled with argon. The tube was sequentially loaded with lactone **1**—**4** (1.0—2.15 mmol), haloarene (1.10—2.36 mmol), palladium acetate (4 mol.%), tri(*o*-tolyl)phosphine (16 mol.%), DMF (4—12 mL), triethylamine (1.5—2.0 equiv.), and molecular sieves 3 Å under a constant flow of argon, then the tube was sealed (with slight excessive pressure of argon). The reaction mixture was heated for 8—16 h at 120 °C. Then, the system was allowed to cool down, the tube was unsealed, and the content was poured in a Petri dish. The solid residue was dissolved in minimum amount of chloroform and subjected to chromatography on silica gel (eluent chloroform—ethanol, 100 : 0 → 10 : 1). The following compounds were sequentially eluted: tri(*o*-tolyl)phosphine, the starting lactone, a mixture of the lactone and the reaction product, and a mixture of two reaction products (eluent chloroform). For the isolation of individual compounds, an additional chromatographic separation and recrystallization from the corresponding solvent were used. Analytically pure samples were purified using preparative TLC. Spectroscopic characteristics of compounds **15**, **16** and **25**, **26** have been published earlier.[1,2]

The reaction of (534 mg, 2.15 mmol) epoxyisoalantolactone **3** and 4-iodofluorobenzene **5a** (525 mg, 2.36 mmol) in the presence of palladium acetate (19 mg, 0.086 mmol), tri(*o*-tolyl)phosphine (103 mg, 0.34 mmol), DMF (10 mL), and triethylamine (0.5 mL, 3.61 mmol) during 8 h gave **(2′*R*,3a*R*,4a*R*,8a*R*,9a*R*,*E*)-3-(4-fluorobenzylidene)-8a-methyldecahydro-2*H*-spiro[naphtho[2,3-*b*]furan-5,2′-oxiran]-2-one** (**6**) (440 mg, 60%), **(2′*R*,4a*R*,8a*R*,9a*R*)-3-(4-fluorobenzyl)-8a-methyl-4,4a,6,7,8,8a,9,9a-octahydro-2*H*-spiro{naphtho-[2,3-*b*]furan-5,2′-oxiran}-2-one** (**9**) (74 mg, 10%), and **(2′*R*,3a*R*,4a*R*,8a*R*,9a*R*,*Z*)-3-(4-fluorobenzylidene)-8a-methyldecahydro-2*H*-spiro{naphtho[2,3-*b*]furan-5,2′-oxiran}-2-one** (**12**) (45 mg, 6%). Compound **6**, m.p. 178—180 °C (from ethanol), $[\alpha]_D^{20}$ +292 (*c* 0.8, $CHCl_3$). IR (KBr), ν/cm^{-1}: 839, 996, 1161, 1224, 1507, 1598, 1661, 1755, 2934. UV, λ_{max}/nm (logε): 201 (4.02), 220 (4.04), 226 (3.94), 284 (4.26). ^1H NMR (600.13 MHz), δ: 0.94 (ddd, 1 H, H(6), *J* = 13.2 Hz, *J* = 13.2 Hz, *J* = 12.8 Hz); 0.99 (s, 3 H, C(14)H_3); 1.19 (m, 1 H, H(1)); 1.33 (dm, 1 H, H(3), *J* = 11.9 Hz); 1.51 (dd, 1 H, H(9), *J* = 15.7 Hz, *J* = 4.6 Hz); 1.59 (dm, 1 H, H(5), *J* = 13.7 Hz); 1.65—1.71 (m, 2 H, H(1), H(2)); 1.75 (dd, 1 H, H(6), *J* = 13.0 Hz, *J* = 2.4 Hz); 1.83—1.90 (m, 2 H, H(2), H(3)); 2.22 (dd, 1 H, H(9), *J* = 15.7 Hz, *J* = 1.5 Hz); 2.51 (d, 1 H, H(15), *J* = 4.4 Hz); 2.61 (dd, 1 H, H(15), *J* = 4.4 Hz, *J* = 1.9 Hz); 3.29 (ddd, 1 H, H(7), *J* = 11.9 Hz, *J* = 6.0 Hz, *J* = 5.5 Hz); 4.45 (ddd, 1 H, H(8), *J* = 4.6 Hz, *J* = 4.6 Hz,

J = 1.3 Hz); 7.07 (dddd, 2 H, H(3´), H(5´), *J* = 8.8 Hz, *J* = 8.4 Hz, *J* = 2.9 Hz, *J* = 1.5 Hz); 7.34 (br.s, 1 H, H(13)); 7.49 (dddd, 2 H, H(2´), H(6´), *J* = 8.9 Hz, *J* = 5.3 Hz, *J* = 2.9 Hz, *J* = 2.1 Hz). ^{13}C NMR, δ: 18.47 (C(14)); 20.23 (C(2), C(6)); 34.33 (C(10)); 35.25 (C(3)); 39.16 (C(7)); 41.27 (C(9)); 41.70 (C(1)); 44.17 (C(5)); 50.54 (C(15)); 58.46 (C(4)); 76.62 (C(8)); 116.17 (C(3´), C(5´)); 130.13 (C(1´)); 131.41 (C(11)); 131.51 (C(2´), C(6´)); 134.04 (C(13)); 163.25 (C(4´), J_{C-F} = 252.0 Hz); 172.10 (C(12)). MS, *m*/*z* (I_{rel} (%)): 342 (2), 328 (8), 327 (34), 189 (7), 161 (8), 147 (7), 140 (11), 139 (100), 138 (9), 137 (33), 135 (9), 133 (13), 109 (10), 108 (21), 107 (14), 105 (7), 91 (10), 79 (13). Found: *m*/*z* 342.1615 $[M]^+$. $C_{21}H_{23}FO_3$. Calculated: *M* = 342.1626.

Compound **9**, oily substance, $[\alpha]_D^{20}$ +102 (*c* 0.3, $CHCl_3$). ^{1}H NMR (400.13 MHz), δ: 0.98 (s, 3 H, C(14)H_3); 1.14 (dd, 1 H, H(9), *J* = 12.1 Hz, *J* = 11.6 Hz); 1.32 (m, 2 H, H(1), H(3)); 1.57 (m, 2 H, H(1), H(5)); 1.63 (m, 2 H, H(2), H(6)); 1.80 (m, 1 H, H(2)); 1.95 (m, 1 H, H(3)); 2.38 (dd, 1 H, H(9), *J* = 12.1 Hz, *J* = 5.8 Hz); 2.47 (d, 1 H, H(15), *J* = 4.2 Hz), 2.58 (dd, 1 H, H(15), *J* = 4.2 Hz, *J* = 1.9 Hz); 2.74 (dd, 1 H, H(6), *J* = 10.8 Hz, *J* = 3.9 Hz); 3.50 (d, 1 H, H(13), *J* = 14.6 Hz); 3.56 (d, 1 H, H(13), *J* = 14.6 Hz); 4.82 (dd, 1 H, H(8), *J* = 10.7 Hz, *J* = 6.8 Hz); 6.95 (dd, 2 H, H(3´), H(5´), *J* = 9.1 Hz, *J* = 8.5 Hz); 7.17 (m, 2 H, H(2´), H(6´)). ^{13}C NMR, δ: 16.33 (C(14)); 21.78 (C(2)); 25.66 (C(6)); 28.78 (C(13)); 36.42 (C(3)); 37.21 (C(10)); 40.61 (C(1)); 47.54 (C(9)); 50.16 (C(5)); 51.26 (C(15)); 58.13 (C(4)); 78.11 (C(8)); 115.55 (C(3´), C(5´)); 123.87 (C(11)); 129.88 (C(2´), C(6´)); 133.65 (C(1´)); 161.46 (C(4´), J_{C-F} = 244.7 Hz); 163.88 (C(7)); 174.11 (C(12)). Found (%): C, 73.48; H, 6.52; F, 5.34. $C_{21}H_{23}FO_3$. Calculated (%): C, 73.66; H, 6.77; F, 5.55.

Compound **12**, m.p. 110—114 °C, $[\alpha]_D^{20}$ +50 (*c* 0.8, $CHCl_3$). ^{1}H NMR (400.13 MHz), δ: 0.95 (m, 1 H, H(6)); 1.01 (s, 3 H, C(14)H_3); 1.20—1.36 (m, 3 H, H(1), H(3), H(9)); 1.53 (m, 1 H, H(5)); 1.63—172 (m, 2 H, H(1), H(2)); 1.78 (dd, 1 H, H(6), *J* = 12.8 Hz, *J* = 2.6 Hz); 1.85—1.94 (m, 2 H, H(2), H(3)); 2.21 (dd, 1 H, H(9), *J* = 15.6 Hz, *J* = 1.9 Hz); 2.52 (d, 1 H, H(15), *J* = 4.2 Hz); 2.64 (br.d, 1 H, H(15), *J* = 4.2 Hz); 2.89 (ddd, 1 H, H(7), *J* = 11.6 Hz, *J* = 5.9 Hz, *J* = 5.5 Hz); 4.45 (m, 1 H, H(8)); 6.81 (s, 1 H, H(13)); 7.08 (m, 2 H, H(3´), H(5´)); 7.86 (dddd, 2 H, H(2´), H(6´), *J* = 8.8 Hz, *J* = 8.6 Hz, *J* = 2.9 Hz, *J* = 2.3 Hz). ^{13}C NMR, δ: 18.11 (C(14)); 22.77 (C(2)); 27.69 (C(6)); 34.45 (C(10)); 36.88 (C(3)); 41.78 (C(9)); 42.56 (C(1)); 44.76 (C(7)); 46.28 (C(5)); 52.04 (C(15)); 58.81 (C(4)); 79.88 (C(8)); 115.31 (C(3´), C(5´)); 129.45 (C(1´)); 132.07 (C(11)); 133.11 (C(2´), C(6´)); 136.68 (C(13)); 163.57 (C(4´), J_{C-F} = 251.1 Hz); 169.08 (C(12)). Found (%): C, 73.29; H, 7.05; F, 5.44. $C_{21}H_{23}FO_3$. Calculated (%): C, 73.66; H, 6.77; F, 5.55.

The reaction of epoxyisoalantolactone **3** (248 mg, 1 mmol) and 4-iodoveratrole **5b** (290 mg, 1.1 mmol) in the presence of palladium acetate (9 mg, 0.04 mmol), tri(*o*-tolyl)phosphine (49 mg, 0.16 mmol), DMF (4 mL), and triethylamine (0.28 mL, 2.0 mmol) during 10 h resulted in the synthesis of **(2´*R*,3a*R*,4a*R*,8a*R*,9a*R*,*E*)-3-(3,4-dimethoxybenzylidene)-8a-methyldecahydro-2*H*-spiro{naphtho[2,3-*b*]furan-5,2´-oxiran}-2-one (7)** (307 mg, 80%) and **(2´*R*,4a*R*,8a*R*,9a*R*)-3-(3,4-dimethoxybenzyl)-8a-methyl-4,4a,6,7,8,8a,9,9a-octahydro-2*H*-spiro-[naphtho[2,3-*b*]furan-5,2´-oxiran]-2-one (10)** (38 mg, 10%). Compound **7**, m.p. 84—86 °C (from diethyl ether), $[\alpha]_D^{20}$ +352 (*c* 0.56, $CHCl_3$). IR (KBr), ν/cm^{-1}: 772, 818, 952, 997, 1022, 1090, 1101, 1140, 1173, 1215, 1249, 1270, 1334, 1461, 1519, 1596, 1649, 1743, 2848, 2933. UV, λ_{max}/nm (logε): 221 (3.96), 238 (4.03), 300 (4.11), 327 (4.25). ^{1}H NMR (400.13 MHz), δ: 0.92 (ddd, 1 H, H(6), *J* = 13.1 Hz, *J* = 13.0 Hz, *J* = 12.8 Hz); 0.98 (s, 3 H, C(14)H_3); 1.18 (m, 1 H, H(1)); 1.31 (dm, 1 H, H(3), J_{gem} = 12.6 Hz); 1.49 (dd, 1 H, H(9), *J* = 15.7 Hz, *J* = 4.7 Hz); 1.55—1.74 (m, 3 H, H(1), H(2), H(5)); 1.81—1.96 (m, 3 H, H(2), H(3), H(6)); 2.20 (dd, 1 H, H(9), *J* = 15.7 Hz, *J* = 1.2 Hz); 2.47 (d, 1 H, H(15), *J* = 4.4 Hz); 2.59 (dd, 1 H, H(15), *J* = 4.3 Hz, *J* = 1.6 Hz); 3.28 (ddd, 1 H, H(7), *J* = 11.8 Hz, *J* = 5.9 Hz, *J* = 5.4 Hz); 3.85 (s, 3 H, OMe); 3.87 (s, 3 H, OMe), 4.42 (ddd, 1 H, H(8), *J* = 4.8 Hz, *J* = 4.7 Hz, *J* = 1.5 Hz); 6.86 (d, 1 H, H(5´), *J* = 8.4 Hz); 6.94 (d, 1 H, H(2´), *J* = 2.0 Hz); 7.08 (dd, 1 H, H(6´), *J* = 8.4 Hz, *J* = 2.0 Hz); 7.30 (br.s, 1 H, H(13)). ^{13}C NMR, δ: 18.43 (C(14)); 20.15 (C(6)); 20.25 (C(2)); 34.30 (C(10)), 35.13 (C(3)); 39.39 (C(7)); 41.24 (C(9)); 41.71 (C(1)); 44.27 (C(5)); 50.52 (C(15)), 55.48 (OMe); 55.51 (OMe); 58.29 (C(4)); 76.46 (C(8)); 111.21 (C(2´)); 112.43 (C(5´)); 123.13 (C(6´)); 126.74 (C(1´)); 129.30 (C(11)); 135.31 (C(13)); 148.90 (C(4´)); 150.42 (C(3´)); 172.36 (C(12)). Found (%): C, 71.42; H, 7.60. $C_{23}H_{28}O_5$. Calculated (%): C, 71.85; H, 7.34.

Compound **10**. ^{1}H NMR (300.13 MHz), δ: 1.01 (s, 3 H, C(14)H_3); 1.15 (dd, 1 H, H(9), *J* = 12.3 Hz, *J* = 11.8 Hz); 1.35 (m, 2 H, H(1), H(3)); 1.57—1.72 (m, 3 H, H(1), H(2), H(6)); 1.82 (m, 1 H, H(2)); 1.95 (m, 1 H, H(3)); 2.36 (dd, 1 H, H(9), *J* = 12.3 Hz, *J* = 6.2 Hz); 2.47 (d, 1 H, H(15), *J* = 4.2 Hz); 2.58 (dd, 1 H, H(15), *J* = 4.2 Hz, *J* = 1.9 Hz); 2.80 (dd, 1 H, H(6), *J* = 11.0 Hz, *J* = 3.5 Hz); 3.45 (d, 1 H, H(13), *J* = 14.5 Hz); 3.52 (d, 1 H, H(13), *J* = 14.6 Hz); 3.82 (s, 3 H, OMe); 3.85 (s, 3 H, OMe); 4.79 (ddd, 1 H, H(8), *J* = 11.3 Hz, *J* = 6.3 Hz); 6.72 (dd, 1 H, H(6´), *J* = 8.1 Hz, *J* = 2.0 Hz); 6.76 (d, 1 H, H(5´), *J* = 8.2 Hz); 6.81 (d, 1 H, H(2´), *J* = 2.0 Hz). ^{13}C NMR, δ: 16.45 (C(14)); 21.25 (C(2)); 25.77 (C(6)); 29.01 (C(13)); 35.51 (C(3)), 38.18 (C(10)); 40.75 (C(1)); 47.18 т (C(9)); 50.32 (C(5)); 51.80 (C(15)), 55.12 (OMe); 56.02 (OMe); 58.22 (C(4)); 78.80 (C(8)); 111.13 (C(2´)); 112.48 (C(5´)); 122.82 (C(6´)); 123.58 (C(11)); 126.41 (C(1´)); 147.26 (C(4´)); 151.05 (C(3´)); 163.65 (C(7)); 174.25 (C(12)). Found (%): C, 71.64; H, 7.65. $C_{23}H_{28}O_5$. Calculated (%): C, 71.85; H, 7.34.

The reaction of epoxyisoalantolactone **3** (248 mg, 1 mmol) and 4-bromopyrochatehol **5c** (207 mg, 1.1 mmol) in the presence of palladium acetate (9 mg, 0.04 mmol), tri(*o*-tolyl)-phosphine (49 mg, 0.16 mmol), DMF (4 mL), and triethylamine (0.28 mL, 2.0 mmol) during 10 h resulted in the synthesis of **(2´*R*,3a*R*,4a*R*,8a*R*,9a*R*,*E*)-3-(3,4-dihydroxybenzylidene)-8a-methyldecahydro-2*H*-spiro[naphtho[2,3-*b*]furan-5,2´-oxiran]-2-one (8)** (196 mg, 55%). According to the chromato-mass spectrometric data, the content of isomer **11** can reach 10%. This compound was not isolated in the pure form. Compound **8**, m.p. 80—84 °C (from chloroform), $[\alpha]_D^{20}$ +298 (*c* 1.06, $CHCl_3$). IR (neat), ν/cm^{-1}: 755, 1149, 1171, 1218, 1247, 1264, 1288, 1298, 1446, 1517, 1524, 1603, 1646, 1723, 1738. UV, λ_{max}/nm (logε): 201 (3.99), 221 (3.87), 239 (3.76), 249 (3.76), 316 (3.90), 336 (4.06). ^{1}H NMR (600.13 MHz), δ: 0.95 (m, 1 H, H(6)); 0.97 (s, 3 H, C(14)H_3); 1.20 (m, 1 H, H(1)); 1.38 (dm, 1 H, H(3), *J* = 12.4 Hz); 1.49 (dd, 1 H, H(9), *J* = 15.6 Hz, *J* = 4.0 Hz); 1.59—1.75 (m, 3 H, H(1), H(2), H(5)); 1.87—1.97 (m, 3 H, H(2), H(3), H(6)); 2.23 (br.d, 1 H, H(9), *J* = 15.6 Hz); 2.61 (d, 1 H, H(15), *J* = 4.0 Hz); 2.72 (d, 1 H, H(15), *J* = 3.0 Hz); 3.30 (ddd, 1 H, H(7), *J* = 11.2 Hz, *J* = 5.5 Hz, *J* = 5.0 Hz); 4.45 (dd, 1 H, H(8), *J* = 4.6 Hz, *J* = 4.0 Hz); 6.90 (m, 2 H, H(5´), H(6´)); 7.10 (br.s, 1 H, H(2´)); 7.30 (br.s, 1 H, H(13)); 8.81 (br.s, 1 H, OH). ^{13}C NMR, δ: 18.42 (C(14)); 20.13 (C(2), C(6));

34.34 (C(10)); 35.13 (C(3)); 39.12 (C(7)); 41.13 (C(9)); 41.63 (C(1)); 43.93 (C(5)); 51.17 (C(15)); 59.49 (C(4)); 76.98 (C(8)); 115.61 (C(2′)); 116.07 (C(5′)); 124.04 (C(6′)); 126.35 (C(1′)); 128.34 (C(11)); 136.21 (C(13)); 144.24 (C(3′)); 146.59 (C(4′)); 173.45 (C(12)). MS, m/z (I_{rel} (%)): 357 (4), 356 (17), 338 (5), 310 (4), 228 (5), 225 (6), 219 (6), 218 (12), 217 (13), 204 (23), 199 (11), 178 (19), 176 (27), 175 (17), 174 (17), 173 (33), 162 (11), 161 (14), 123 (12), 87 (12), 85 (67), 83 (100), 77 (8). Found: m/z 356.1617 $[M]^+$. $C_{21}H_{24}O_5$. Calculated: M = 356.1618. Signals characteristic of compound **11** in the ^{1}H NMR spectrum (400.13 MHz), δ (the data were obtained for the sample with the purity of 82%): 1.05 (s, 3 H, C(14)H_3); 1.18 (m, 1 H, H(9)); 1.35 (m, 2 H, H(1), H(3)); 1.53—1.70 (m, 3 H, H(1), H(2), H(6)); 1.85 (m, 1 H, H(2)); 1.98 (m, 1 H, H(3)); 2.38 (dd, 1 H, H(9), J = 12.1 Hz, J = 6.0 Hz); 2.49 (d, 1 H, H(15), J = 4.1 Hz); 2.60 (dd, 1 H, H(15), J = 4.1 Hz, J = 1.9 Hz); 2.88 (dd, 1 H, H(6), J = 11.2 Hz, J = 3.6 Hz); 3.48 (d, 1 H, H(13), J = 14.5 Hz); 3.55 (d, 1 H, H(13), J = 14.5 Hz); 4.79 (ddd, 1 H, H(8), J = 11.3 Hz, J = 6.3 Hz, J = 2.0 Hz); 6.78 (m, 2 H, H(6′), H(5′)); 6.92 (d, 1 H, H(2′), J = 1.8 Hz).

The heating of a mixture of epoxyisoalantolactone **3** (500 mg, 2.01 mmol) and 4-iodobromobenzene **5d** (630 mg, 2.21 mmol) in the presence of palladium acetate (22.5 mg, 0.1 mmol) and triethylamine (0.39 mL, 2.8 mmol) in acetonitrile (10 mL) in a sealed tube during 16 h, concentration, and subsequent separation of the reaction products by column chromatography resulted in the preparation of **(2′*R*,3a*R*,4a*R*,8a*R*,9a*R*,*E*)-3-(4-bromobenzylidene)-8a-methyldecahydro-2*H*-spiro[naphtho[2,3-*b*]furan-5,2′-oxiran]-2-one (13)** (486 mg, 60%) and **(2′*R*,4a*R*,8a*R*,9a*R*)-3-(4-bromobenzyl)-8a-methyl-3-4,4a,6,7,8,8a,9,9a-octahydro-2*H*-spiro[naphtho[2,3-*b*]furan-5,2′-oxiran]-2-one (14)** (162 mg, 20%). Compound **13**, m.p. 171—173 °C (from acetonitrile), $[\alpha]_D^{20}$ +320 (c 0.56, $CHCl_3$). IR (KBr), ν/cm^{-1}: 761, 817, 830, 899, 950, 997, 1071, 1172, 1220, 1250, 1302, 1357, 1405, 1445, 1488, 1585, 1655, 1664, 1755, 2851, 2927. UV, λ_{max}/nm (logε): 201 (4.14), 223 (4.07), 230 (3.99), 291 (4.38), 296 (3.90), 306 (4.29). ^{1}H NMR (600.13 MHz), δ: 0.92 (ddd, 1 H, H(6), J = 13.1 Hz, J = 12.9 Hz, J = 12.9 Hz); 0.99 (s, 3 H, C(14)H_3); 1.19 (m, 1 H, H(1)); 1.33 (dm, 1 H, H(3), J = 12.5 Hz); 1.48 (dd, 1 H, H(9), J = 15.7 Hz, J = 4.6 Hz); 1.59 (dm, 1 H, H(5), J = 13.7 Hz); 1.64—1.73 (m, 2 H, H(1), H(2)); 1.77—1.93 (m, 3 H, H(2), H(3), H(6)); 2.22 (dd, 1 H, H(9), J = 15.6 Hz, J = 1.6 Hz); 2.50 (d, 1 H, H(15), J = 4.4 Hz); 2.60 (dd, 1 H, H(15), J = 4.4 Hz, J = 1.8 Hz); 3.28 (ddd, 1 H, H(7), J = 11.8 Hz, J = 6.0 Hz, J = 5.3 Hz); 4.45 (ddd, 1 H, H(8), J = 4.6 Hz, J = 4.6 Hz, J = 1.4 Hz); 7.30 (br.s, 1 H, H(13)); 7.31 (ddd, 2 H, H(2′), H(6′), J = 8.4 Hz, J = 2.1 Hz, J = 1.7 Hz); 7.51 (ddd, 2 H, H(3′), H(5′), J = 8.6 Hz, J = 2.1 Hz, J = 1.9 Hz). ^{13}C NMR, δ: 18.13 (C(14); 19.85 (C(2), C(6)); 33.98 (C(10)); 34.90 (C(3)); 38.93 (C(7)); 40.94 (C(9)); 41.35 (C(1)); 43.84 (C(5)); 50.20 (C(15)); 58.11 (C(4)); 76.29 (C(8)); 123.81 (C(4′)); 130.85 (C(2′), C(6′)); 131.91 (C(3′), C(5′)); 132.25 (C(11)); 132.45 (C(1′)); 133.67 (C(13)); 171.61 (C(12)). Found (%): C, 62.25; H, 5.74; Br, 20.18. $C_{21}H_{23}BrO_3$. Calculated (%): C, 62.54; H, 5.75; Br, 19.81.

Compound **14**, m.p. 157—159 °C (from ethanol), $[\alpha]_D^{20}$ +28 (c 0.6, $CHCl_3$). IR (KBr), ν/cm^{-1}: 783, 816, 827, 840, 897, 966, 1011, 1024, 1057, 1094, 1132, 1146, 1264, 1449, 1485, 1687, 1741, 2864, 2935. UV, λ_{max}/nm (logε): 218 (4.20), 282 (3.26). ^{1}H NMR (600.13 MHz), δ: 1.00 (s, 3 H, C(14)H_3); 1.06 (dd, 1 H, H(9), J = 12.0 Hz, J = 11.9 Hz); 1.21 (1 H, ddd, H(1), J = 12.9 Hz, J = 11.7 Hz, J = 6.3 Hz); 1.33 (dddd, 1 H, H(3), J = 12.8 Hz, J = 3.5 Hz, J = 2.8 Hz, J = 1.5 Hz); 1.56 (dddd, 1 H, H(1), J = 13.2 Hz, J = 3.4 Hz, J = 3.1 Hz, J = 1.5 Hz); 1.63 (dd, 1 H, H(5), J = 13.1 Hz, J = 3.7 Hz); 1.67—1.73 (m, 2 H, H(2)); 1.78 (dd, 1 H, H(6), J = 13.3 Hz, J = 12.9 Hz); 1.79 (m, 1 H, H(3)); 2.36 (dd, 1 H, H(9), J = 12.0 Hz, J = 6.3 Hz); 2.59 (d, 1 H, H(15), J = 4 Hz); 2.73—2.75 (m, 2 H, H(6), H(15)); 3.43 (d, 1 H, H(13), J = 14.8 Hz); 3.49 (d, 1 H, H(13), J = 14.8 Hz); 4.75 (dd, 1 H, H(8), J = 11.9 Hz, J = 6.3 Hz); 7.06 (dm, 2 H, H(2′), H(6′), J = 8.4 Hz, J = 2.6 Hz, J = 1.9 Hz); 7.34 (dm, 2 H, H(3′), H(5′), J = 8.4 Hz, J = 2.6 Hz, J = 1.9 Hz). ^{13}C NMR, δ: 17.03 (C(14)); 20.03 (C(2)); 21.69 (C(6)); 28.44 (C(13)); 34.75 (C(3)); 36.88 (C(10)); 39.76 (C(1)); 47.63 (C(5)); 47.76 (C(9)); 50.14 (C(15)); 58.67 (C(4)); 77.60 (C(8)); 120.12 (C(4′)); 123.29 (C(11); 130.03 (C(2′), C(6′)); 131.44 (C(3′), C(5′)); 137.10 (C(1′)); 162.63 (C(7)); 173.44 (C(12)). Found (%): C, 62.18; H, 5.45; Br, 19.60. $C_{21}H_{23}BrO_3$. Calculated (%): C, 62.54; H, 5.75; Br, 19.81.

The reaction of alantolactone **2** (464 mg, 2.0 mmol) and 4-iodofluorobenzene **5a** (489 mg, 2.2 mmol) in the presence of palladium acetate (17.7 mg, 0.08 mmol),tri(*o*-tolyl)phosphine (97 mg, 0.32 mmol), DMF (10 mL), and triethylamine (0.5 mL, 3.61 mmol) during 16 h and subsequent column chromatography on an impregnated silica gel resulted in the isolation of **(3a*R*,5*S*,8a*R*,9a*R*,*E*)-3-(4-fluorobenzylidene)-5,8a-dimethyl-3,3a,6,7,8,8a,9,9a-octahydronaphtho[2,3-*b*]furan-2(5*H*)-one (17)** (117 mg, 18%), **(5*S*,8a*R*,9a*S*)-3-(4-fluorobenzyl)-5,8a-dimethyl-6,7,8,8a,9,9a-hexahydronaphtho[2,3-*b*]furan-2(5*H*)-one (21)** (182 mg, 28%), **(5*S*,8a*R*,9a*S*)-3,5,8a-trimethyl-6,7,8,8a,9,9a-hexahydronaphtho[2,3-*b*]furan-2(5*H*)-one (29)** (12 mg, 5%), and **(2*S*,3*S*,3a′*R*,5*R*,5′*S*,8a*S*,8a′*R*,9a*R*,9a′*R*)-3-(4-fluorophenyl)-5,5′,8a,8a′-tetramethyl-3,3a′,5,5′,6,6′,7,7′,8,8a,8′,8a′,9,9a,9′,9a′-hexadecahydro-1*H*,2′*H*-spiro[anthracene-2,3′-naphtho[2,3-*b*]furan]-2′-one (30)** (21 mg, 2%). Compound **17**, oily substance, $[\alpha]_D^{20}$ +213 (c 1.1, $CHCl_3$). IR (KBr), ν/cm^{-1}: 760, 1024, 1140, 1185, 1230, 1250, 1275, 1331, 1510, 1590, 1650, 1740. UV, λ_{max}/nm (logε): 235 (3.96), 330 (3.54). ^{1}H NMR (400.13 MHz), δ: 1.05 (d, 3 H, C(15)H_3, J = 7.6 Hz); 1.14 (ddd, 1 H, H(1), J = 13.5 Hz, J = 13.2 Hz, J = 3.5 Hz); 1.25 (s, 3 H, C(14)H_3); 1.35—1.66 (m, 5 H, H(1), H(2), H(3), H(3), H(9)); 1.83 (m, 1 H, H(2)); 2.15 (dd, 1 H, H(9), J = 14.5 Hz, J = 3.1 Hz); 2.40 (ddd, 1 H, H(3), J = 7.9 Hz, J = 4.4 Hz, J = 3.0 Hz); 4.05 (ddd, 1 H, H(7), J = 6.5 Hz, J = 3.2 Hz, J = 1.6 Hz); 4.79 (ddd, 1 H, H(8), J = 6.5 Hz, J = 3.0 Hz, J = 2.6 Hz); 5.39 (d, 1 H, H(6), J = 3.2 Hz); 7.07 (m, 2 H, H(3′), H(5′)); 7.21 (ddd, 2 H, H(2′), H(6′), J = 8.0 Hz, J = 6.5 Hz, J = 2.0 Hz); 7.39 (d, 1 H, H(13), J = 1.6 Hz). ^{13}C NMR, δ: 16.70 (C(2)); 22.38 (C(15)); 28.46 (C(14)); 32.57 (C(10)); 32.91 (C(3)); 38.31 (C(4)); 38.73 (C(7)); 42.31 (C(1)); 43.08 (C(9)); 77.36 (C(8)); 117.27 (C(3′), C(5′)); 115.09 (C(6)); 128.64 (C(11)); 130.98 (C(1′)); 132.71 (C(2′), C(6′)); 136.34 (C(13)); 151.87 (C(5)); 161.83 (C(4′), J_{C-F} = 287.0 Hz); 173.81 (C(12)). Found (%): C, 77.05; H, 6.78; F, 5.65. $C_{21}H_{23}FO_2$. Calculated (%): C, 77.27; H, 7.10; F, 5.82.

Compound **21**, oily substance, $[\alpha]_D^{20}$ −78 (c 0.7, $CHCl_3$). UV, λ_{max}/nm (logε): 230 (4.00), 276 (3.79). ^{1}H NMR (400.13 MHz), δ: 1.16 (d, 3 H, C(15)H_3, J = 6.8 Hz); 1.28 (m, 1 H, H(1)); 1.30 (s, 3 H, C(14)H_3); 1.36—1.49 (m, 2 H, H(2), H(9)); 1.55—1.69 (m, 2 H, H(1), H(3)); 1.80 (m, 2 H, H(2), H(3)); 2.12 (dd, 1 H, H(9), J = 11.7 Hz, J = 5.1 Hz); 2.57 (ddd, 1 H, H(4), J = 12.9 Hz, J = 7.0 Hz, J = 5.2 Hz); 3.43 (d, 1 H, H(13), J = 14.2 Hz); 3.58

(d, 1 H, H(13), J = 14.2 Hz); 4.99 (dd, 1 H, H(8), J = 13.2 Hz, J = 5.1 Hz); 6.10 (s, 1 H, H(6)); 7.08 (m, 2 H, H(3´), H(5´)); 7.29 (m, 2 H, H(2´), H(6´)). ^{13}C NMR, δ: 16.48 (C(2)); 22.56 (C(15)); 26.63 (C(14)); 27.91 (C(13)), 32.60 (C(3)), 37.88 (C(10)); 38.08 (C(4)); 41.98 (C(1)); 46.71 (C(9)); 77.18 (C(8)); 113.97 (C(6)); 117.59 (C(3´), C(5´)); 119.60 (C(11)); 130.11 (C(1´)); 131.93 (C(2´), C(6´)); 157.70 (C(7)); 160.82 (C(4´)); 162.25 (C(5)); 174.76 (C(12)). Found (%): C, 76.89; H, 6.81; F, 5.58. $C_{21}H_{23}FO_2$. Calculated (%): C, 77.27; H, 7.10; F, 5.82.

Compound **29**, the yield was 5%, oily substance, $[\alpha]_D$ +156 (c 1.1, $CHCl_3$). ^{1}H NMR (400.13 MHz), δ: 1.23 (s, 3 H, C(14)H$_3$); 1.25 (d, 3 H, C(15)H$_3$, J = 7.5 Hz); 1.45 (dd, 1 H, H(9), J = 13.3 Hz, J = 12.6 Hz); 1.50—1.57 (m, 3 H, H(1), H(2), H(3)); 1.64 (ddd, 1 H, H(1), J = 13.0 Hz, J = 12.6 Hz, J = 4.2 Hz); 1.69 (dm, 1 H, H(3), J = 12.0 Hz); 1.82 (d, 3 H, C(13)H$_3$, J = 1.5 Hz); 1.91 (ddddd, 1 H, H(2), J = 12.5 Hz, J = 12.5 Hz, J = 12.4 Hz, J = 4.3 Hz, J = 3.8 Hz); 2.11 (dd, 1 H, H(9), J = 12.7 Hz, J = 5.1 Hz); 2.74 (quint, 1 H, H(4), J = 7.2 Hz); 4.72 (ddd, 1 H, H(8), J = 13.3 Hz, J = 5.7 Hz, J = 1.5 Hz); 6.18 (br.s, 1 H, H(6)). ^{13}C NMR, δ: 17.99 (C(2)); 20.66 (C(15)); 29.41 (C(14)); 29.59 (C(13)); 34.02 (C(3)); 38.57 (C(10)); 39.79 (C(1)); 40.40 (C(4)); 43.68 (C(9)); 75.85 (C(8)); 112.89 (C(6)); 116.07 (C(11)); 158.89 (C(7)); 161.12 (C(5)); 175.67 (C(12)). Found (%): C, 77.81; H, 8.51. $C_{15}H_{20}O_2$. Calculated (%): C, 77.55; H, 8.68.

Compound **30**, white amorphous substance, $[\alpha]_D$ +78 (c 0.8, $CHCl_3$). IR (neat), ν/cm^{-1}: 839, 987, 1018, 1042, 1099, 1120, 1159, 1185, 1227, 1375, 1457, 1509, 1604, 1760, 2868, 2929. UV, λ_{max}/nm (logε): 201 (4.67), 250 (4.08). ^{1}H NMR (600.13 MHz), δ: 1.01 (ddd, 1 H, H(1), J = 13.2 Hz, J = 12.9 Hz, J = 3.7 Hz); 1.13 (d, 3 H, C(15)H$_3$, J = 7.6 Hz); 1.19 (d, 3 H, C(15´)H$_3$, J = 7.5 Hz); 1.24 (s, 3 H, C(14)H$_3$); 1.24—1.30 (m, 2 H, H(1´), H(9´)); 1.31 (s, 3 H, C(14´)H$_3$); 1.36 (dd, 1 H, H(9), J = 15.0 Hz, J = 3.2 Hz); 1.37 (m, 1 H, H(2)); 1.47 (dd, 1 H, H(13), J = 13.4 Hz, J = 11.3 Hz); 1.47 (m, 1 H, H(2´)); 1.51—1.63 (m, 7 H, H(1), H(1´), H(3), H(3), H(3´), H(3´), H(9´)); 1.77 (ddddd, 1 H, H(2), J = 13.4 Hz, J = 13.4 Hz, J = 13.4 Hz, J = 3.2 Hz, J = 3.2 Hz); 1.84 (m, 1 H, H(2´)); 1.84 (dd, 1 H, H(13), J = 13.9 Hz, J = 5.9 Hz); 2.02 (dd, 1 H, H(9), J = 14.9 Hz, J = 3.5 Hz); 2.34 (dd, 1 H, H(7), J = 6.0 Hz, J = 3.7 Hz); 2.36 (m, 1 H, H(4)); 2.48 (m, 1 H, H(4´)); 3.40 (ddd.ddd, 1 H, H(8´), J = 12.1 Hz, J = 10.9 Hz, J = 6.2 Hz, J = 3.6 Hz, J = 2.5 Hz, J = 1.4 Hz); 3.61 (dd, 1 H, H(13´), J = 4.7 Hz, J = 1.8 Hz); 4.72 (ddd, 1 H, H(8), J = 5.8 Hz, J = 3.1 Hz, J = 2.8 Hz); 4.87 (d, 1 H, H(6), J = 3.6 Hz); 5.28 (dd, 1 H, H(11´), J = 4.7 Hz, J = 2.3 Hz); 5.75 (s, 1 H, H(6´)); 7.01 (dddd, 2 H, H(3″), H(5″), J = 8.5 Hz, J = 8.5 Hz, J = 2.0 Hz, J = 1.9 Hz); 7.15 (dddd, 2 H, H(2″), H(6″), J = 8.6 Hz, J = 5.3 Hz, J = 3.0 Hz, J = 2.3 Hz). ^{13}C NMR, δ: 16.78 (C(2)); 17.26 (C(2´)); 22.58 (C(15´)); 22.90 (C(15)); 26.75 (C(14´)); 26.88 (C(8´)); 28.55 (C(14)); 30.05 (C(13)); 32.72 (C(10)); 32.85 (C(3)); 32.95 (C(3´)); 36.05 (C(10´)); 37.40 (C(4´)); 38.40 (C(4)); 41.75 (C(1´)); 42.09 (C(1)); 42.92 (C(9)); 43.11 (C(7)); 46.27 (C(13´)); 49.19 (C(9´)); 50.59 (C(11)); 74.23 (C(8)); 115.55 (C(3″), C(5″)); 115.56 (C(6)); 119.88 (C(11´)); 123.60 (C(6´)); 130.88 (C(2″), C(6″)); 137.32 (C(1″)); 138.22 (C(7´)); 149.60 (C(5)); 150.57 (C(5´)); 161.93 (C(4″)); 178.48 (C(12)). Found (%): C, 81.37; H, 8.18; F, 3.28. $C_{35}H_{43}FO_2$. Calculated (%): C, 81.67; H, 8.42; F, 3.69.

The reaction of alantolactone **2** (464 mg, 2.0 mmol) and 4-iodoanisole **5e** (515 mg, 2.2 mmol) in the presence of palladium acetate (17.7 mg, 0.08 mmol), tri(o-tolyl)phosphine (97 mg, 0.32 mmol), DMF (10 mL), and triethylamine (0.5 mL, 3.61 mmol) during 16 h and subsequent column chromatography on an impregnated silica gel resulted in the isolation of **(3a*R*,5*S*,8a*R*,9a*R*,*E*)-3-(4-methoxybenzylidene)-5,8a-dimethyl-3,3a,6,7,8,8a,9,9a-octahydronaphtho[2,3-*b*]furan-2(5*H*)-one** (**18**) (122 mg, 18%) and **(5*S*,8a*R*,9a*S*)-3-(4-methoxybenzyl)-5,8a-dimethyl-6,7,8,8a,9,9a-hexahydronaphtho[2,3-*b*]furan-2(5*H*)-one** (**22**) (149 mg, 22%).

In the reaction of lactone **2** (232 mg, 1.0 mmol) and 4-iodoanisole **5e** (258 mg, 1.1 mmol) in the presence of palladium acetate (17.7 mg, 0.08 mmol), tri(o-tolyl)phosphine (97 mg, 0.32 mmol), DMF (10 mL), and triethylamine (0.25 mL, 1.8 mmol) during 16 h, the conversion of lactone **2** was 95% (according to the chromato-mass spectrometric data, the ratio **18** : **22** = = 1 : 1.4). The isolation by column chromatography gave compound **18** (102 mg, 30%) and compound **22** (119 mg, 35%). Compound **18**, oily substance, $[\alpha]_D^{20}$ +248 (c 1.6, $CHCl_3$). ^{1}H NMR (400.13 MHz), δ: 1.04 (d, 3 H, C(15)H$_3$, J = 7 Hz); 1.12 (ddd, 1 H, H(1), J = 13.2 Hz, J = 12.9 Hz, J = 3.2 Hz); 1.24 (s, 3 H, C(14)H$_3$); 1.40—1.64 (m, 5 H, H(1), H(2), H(3), H(3), H(9)); 1.80 (m, 1 H, H(2)); 2.16 (dd, 1 H, H(9), J = 14.9 Hz, J = 3.0 Hz); 2.41 (m, 1 H, H(4)); 3.83 (s, 3 H, OMe); 4.06 (m, 1 H, H(7)); 4.77 (ddd, 1 H, H(8), J = 6.4 Hz, J = 3.2 Hz, J = 2.5 Hz); 5.37 (d, 1 H, H(6), J = 3.3 Hz); 6.94 (dm, 2 H, H(3´), H(5´), J = 8.4 Hz); 7.39 (d, 1 H, H(13), J = 1.7 Hz); 7.54 (dm, 2 H, H(2´), H(6´), J = 8.4 Hz). ^{13}C NMR, δ: 16.76 (C(2)); 22.25 (C(15)); 28.51 (C(14)); 32.76 (C(10)); 32.83 (C(3)); 38.02 (C(4)); 38.91 (C(7)); 42.02 (C(1)); 42.45 (C(9)); 55.97 (OMe); 76.09 (C(8)); 114.47 (C(3´), C(5´)); 114.62 (C(6)); 127.31 (C(11)); 127.83 (C(1´)); 131.54 (C(2´), C(6´)); 135.88 (C(13)); 151.02 (C(5)); 159.13 (C(4´)); 172.14 (C(12)). Found (%): C, 77.68; H, 7.57. $C_{22}H_{26}O_3$. Calculated (%): C, 78.07; H, 7.74.

Compound **22**, m.p. 118—121 °C (from ethanol), $[\alpha]_D^{20}$ –46 (c 1.3, $CHCl_3$). ^{1}H NMR (400.13 MHz), δ: 1.20 (d, 3 H, C(15)H$_3$, J = 7.5 Hz); 1.29 (ddd, 1 H, H(1), J = 13.5 Hz, J = 13.4 Hz, J = 3.8 Hz); 1.33 (s, 3 H, C(14)H$_3$); 1.36 (dd, 1 H, H(9), J = 12.9 Hz, J = 11.2 Hz); 1.48—1.65 (m, 4 H, H(1), H(2), H(3), H(3)); 1.85 (m, 1 H, H(2)); 2.30 (dd, 1 H, H(9), J = 11.7 Hz, J = 4.7 Hz); 2.62 (m, 1 H, H(4)); 3.50 (d, 1 H, H(13), J = 14.9 Hz); 3.60 (d, 1 H, H(13), J = 14.9 Hz); 3.77 (s, 3 H, OMe); 4.96 (dd, 1 H, H(8), J =13.7 Hz, J = 4.3 Hz); 6.11 (s, 1 H, H(6)); 6.82 (dm, 2 H, H(3´), H(5´), J = 8.2 Hz); 7.17 (dm, 2 H, H(2´), H(6´), J = 8.2 Hz). Found (%): C, 77.87; H, 7.60. $C_{22}H_{26}O_3$. Calculated (%): C, 78.07; H, 7.74.

The reaction of alantolactone **2** (464 mg, 2.0 mmol) and 2,4-dimethoxyiodobenzene **5f** (580 mg, 2.2 mmol) in the presence of palladium acetate (17.7 mg, 0.08 mmol), tri(o-tolyl)-phosphine (97 mg, 0.32 mmol), DMF (10 mL), and triethylamine (0.5 mL, 3.61 mmol) during 16 h and subsequent column chromatography on an impregnated silica gel resulted in the isolation of **(3a*R*,5*S*,8a*R*,9a*R*,*E*)-3-(2,4-dimethoxybenzylidene)-5,8a-dimethyl-3,3a,6,7,8,8a,9,9a-octahydronaphtho[2,3-*b*]-furan-2(5*H*)-one** (**19**) (154 mg, 21%) and **(5*S*,8a*R*,9a*S*)-3-(2,4-dimethoxybenzyl)-5,8a-dimethyl-6,7,8,8a,9,9a-hexahydronaphtho[2,3-*b*]furan-2(5*H*)-one** (**23**) (214 mg, 29%). Compound **19**, oily substance, $[\alpha]_D$ +188 (c 1.8, $CHCl_3$). ^{1}H NMR (300.13 MHz), δ: 1.04 (d, 3 H, C(15)H$_3$, J = 7.7 Hz); 1.18 (m, 1 H, H(1)); 1.22 (s, 3 H, C(14)H$_3$); 1.28 (m, 1 H, H(2)); 1.44 (dd, 1 H, H(9), J = 12.8 Hz, J = 10.6 Hz); 1.58—1.64 (m, 2 H, H(1), H(2)); 1.78—2.01 (m, 2 H, H(3), H(5)); 2.13 (dd, 1 H, H(9), J = 15.1 Hz, J = 2.7 Hz); 2.41 (m, 1 H, H(4)); 3.82 (s, 6 H,

2 OMe); 4.00 (ddd, 1 H, H(7), J = 6.0 Hz, J = 2.5 Hz, J = 1.9 Hz); 4.75 (ddd, 1 H, H(8), J = 6.0 Hz, J = 3.0 Hz, J = 2.9 Hz); 5.33 (d, 1 H, H(6), J = 3.4 Hz); 6.46 (d, 1 H, H(3′), J = 2.2 Hz); 6.52 (dd, 1 H, H(5′), J = 8.6 Hz, J = 2.2 Hz); 7.58 (d, 1 H, H(6′), J = 8.6 Hz); 7.86 (d, 1 H, H(13), J = 1.8 Hz). Found: m/z 368.1980 $[M]^+$. $C_{23}H_{28}O_4$. Calculated: M = 368.1982.

Compound **23**, oily substance, $[\alpha]_D^{20}$ −46 (c 1.2, $CHCl_3$). ^{1}H NMR (300.13 MHz), δ: 1.22 (d, 3 H, C(15)H_3, J = 6.3 Hz); 1.23 (s, 3 H, C(14)H_3); 1.25—1.44 (m, 3 H, H(1), H(2), H(9)); 1.53—1.62 (m, 3 H, H(1), H(3), H(3)); 1.81 (m, 1 H, H(2)); 2.29 (dd, 1 H, H(9), J = 12.4 Hz, J = 5.1 Hz); 2.64 (m, 1 H, H(4)); 3.47 (d, 1 H, H(13), J = 15.5 Hz); 3.54 (d, 1 H, H(13), J = 15.5 Hz); 3.76 (s, 6 H, 2 OMe); 4.67 (dd, 1 H, H (8), J = 13.3 Hz, J = 5.9 Hz); 6.06 (s, 1 H, H(6)); 6.44 (d, 1 H, H(3′), J = 2.4 Hz); 6.50 (dd, 1 H, H(5′), J = 8.6 Hz, J = 2.4 Hz); 7.82 (d, 1 H, H(6′), J = 8.6 Hz). ^{13}C NMR, δ: 17.20 (C(2)); 21.02 (C(15)); 28.01 (C(14)); 29.74 (C(13)); 33.15 (C(3)); 38.24 (C(10)); 38.73 (C(4)); 41.17 (C(1)); 46.50 (C(9)); 55.72 (2 OMe); 75.99 (C(8)); 100.50 (C(3′)); 102.23 (C(5′)); 113.97 (C(6)); 118.65 (C(1′)); 119.60 (C(11)); 130.98 (C(6′)); 157.7 (C(7)); 157.93 (C(2′)); 162.25 (C(5)); 162.82 (C(4′)); 174.76 (C(12)). MS, m/z (I_{rel} (%)): 370 (3), 369 (29), 368 (100), 323 (77), 324 (24), 246 (26), 215 (13), 201 (21), 171 (12), 151 (44). Found: m/z 368.1986 $[M]^+$. $C_{23}H_{28}O_4$. Calculated: M = 368.1982.

The reaction of alantolactone **2** (464 mg, 2.0 mmol) and 4-iodobenzonitrile **5g** (504 mg, 2.2 mmol) in the presence of palladium acetate (17.7 mg, 0.08 mmol), tri(*o*-tolyl)phosphine (97 mg, 0.32 mmol), DMF (10 mL), and triethylamine (0.5 mL, 3.61 mmol) during 16 h resulted in the obtaining of a reaction mixture containing the starting lactone **2** (the conversion was 78%) and a mixture of products. Column chromatography on an impregnated silica gel and subsequent TLC of the enriched fractions resulted in the isolation of the following individual compounds: **(5*S*,8a*R*,9a*S*)-3-(4-cyanobenzyl)-5,8a-dimethyl-6,7,8,8a,9,9a-hexahydronaphtho[2,3-*b*]furan-2(5*H*)-one** (**24**) (160 mg, 24%), **4-{(2*S*,3*S*,3a′*R*,5*R*,5′*S*,8a*S*,8a′*R*,9a*R*,9a′*R*)-5,5′,8a,8a′-tetramethyl-2′-oxo-3,3a′,5,5′,6,6′,7,7′,8,8a,8′,8a′,9,9a,9′,9a′-hexadecahydro-1*H*,2′*H*-spiro[anthracene-2,3′-naphtho[2,3-*b*]furan]-3-yl}benzonitrile** (**31**) (32 mg, 3%), lactone **29** (7 mg, 3%), and **(3a*R*,5*S*,8a*R*,9a*R*,*E*)-3-(4-cyanobenzylidene)-5,8a-dimethyl-3,3a,6,7,8,8a,9,9a-octahydronaphtho[2,3-*b*]-furan-2(5*H*)-one** (**20**) (103 mg, 15%). Compound **20**, oily substance, $[\alpha]_D$ +102 (c 1.3, $CHCl_3$). ^{1}H NMR (300.13 MHz), δ: 0.88 (s, 3 H, C(14)H_3); 1.21 (m, 1 H, H(1)); 1.39 (m, 1 H, H(6)); 1.47—1.68 (m, 4 H, H(1), H(2), H(2), H(9)); 1.90—2.06 (m, 3 H, H(3), H(5), H(6)); 2.28 (dd, 1 H, H(9), J = 13.3 Hz, J = 1.2 Hz), 2.39 (m, 1 H, H(3)); 3.42 (ddd, 1 H, H(7), J = 11.8 Hz, J = 5.8 Hz, J = 5.1 Hz); 4.40 (br.s, 1 H, H(15)); 4.51 (dd, 1 H, H(8), J = 4.8 Hz, J = 3.6 Hz); 4.74 (br.s, 1 H, H(15)); 7.30 (d, 2 H, H(2′), H(6′), J = 8.8 Hz); 7.37 (s, 1 H, H(13)); 7.58 (d, 2 H, H(3′), H(5′), J = 8.8 Hz). ^{13}C NMR, δ: 16.40 (C(2)); 22.20 (C(15)); 26.00 (C(14)); 32.76 (C(10)); 32.45 (C(3)); 38.25 (C(4)); 38.32 (C(7)); 41.76 (C(1)); 43.63 (C(9)); 76.18 (C(8)); 110.37 (C(4′)); 113.45 (C(6)); 117.65 (CN), 129.54 (C(2′), C(6′)); 132.32 (C(3′), C(5′)); 127.77 (C(11)); 128.19 (C(1′)); 137.87 (C(13)), 152.68 (C(5)); 172.28 (C(12)). Found (%): C, 79.18; H, 6.78; N, 4.37. $C_{22}H_{23}NO_2$. Calculated (%): C, 79.25; H, 6.95; N, 4.20.

Compound **24**, m.p. 66—69 °C (from diethyl ether), $[\alpha]_D$ −68 (c 0.9, $CHCl_3$). ^{1}H NMR (600.13 MHz), δ: 1.20 (d, 3 H, C(15)H_3, J = 7.5 Hz); 1.32 (ddd, 1 H, H(1), J = 13.5 Hz, J = 13.4 Hz, J = 3.8 Hz); 1.34 (s, 3 H, C(14)H_3); 1.26 (dd, 1 H, H(9), J = 12.9 Hz, J = 12.5 Hz); 1.48—1.65 (m, 4 H, H(1), H(2), 2 H(3)); 1.85 (ddddd, 1 H, H(2), J = 13.3 Hz, J = 13.3 Hz, J = 12.8 Hz, J = 4.3 Hz, J = 3.8 Hz); 2.24 (dd, 1 H, H(9), J = 11.7 Hz, J = 5.0 Hz); 2.63 (quint, 1 H, H(4), J = 7.0 Hz); 3.60 (d, 1 H, H(13), J = 15.6 Hz); 3.68 (d, 1 H, H(13), J = 15.6 Hz); 5.01 (dd, 1 H, H(8), J = 13.4 Hz, J = 5.0 Hz); 6.10 (s, 1 H, H(6)); 7.35 (d, 2 H, H(2′), H(6′), J = 8.2 Hz); 7.56 (d, 2 H, H(3′), H(5′), J = 8.2 Hz). ^{13}C NMR, δ: 17.90 (C(2)); 20.66 (C(15)); 29.50 (C(14)); 29.74 (C(13)); 33.92 (C(3)); 38.65 (C(10)); 38.73 (C(1)); 41.17 (C(4)); 46.50 (C(9)); 75.99 (C(8)); 110.37 (C(4′)); 112.19 (C(6)); 117.65 (CN); 117.86 (C(11)); 129.31 (C(2′), C(6′)); 132.32 (C(3′), C(5′)); 143.87 (C(1′)); 158.57 (C(7)); 163.60 (C(5)); 174.54 (C(12)). Found (%): C, 79.16; H, 6.59; N, 4.11. $C_{22}H_{23}NO_2$. Calculated (%): C, 79.25; H, 6.95; N, 4.20.

Compound **31**, white amorphous substance, $[\alpha]_D$ +109 (c 0.8, $CHCl_3$). IR (neat), ν/cm^{-1}: 756, 843, 890, 1018, 1122, 1181, 1375, 1456, 1606, 1763, 2229, 2867, 2928. UV, λ_{max}/nm (logε): 201 (4.57), 238 (4.39). ^{1}H NMR (600.13 MHz), δ: 1.02 (ddd, 1 H, H(1), J = 13.5 Hz, J = 13.2 Hz, J = 3.3 Hz); 1.12 (d, 3 H, C(15)H_3, J = 7.5 Hz); 1.16 (d, 3 H, C(15′)H_3, J = 7.5 Hz); 1.22 (s, 3 H, C(14)H_3); 1.24 (m, 1 H, H(1′)); 1.27 (dd, 1 H, H(9′), J = 13.0 Hz, J = 12.2 Hz); 1.29 (s, 3 H, C(14′)H_3); 1.37—1.40 (m, 2 H, H(2), H(9)); 1.47 (dd, 1 H, H(13), J = 14.0 Hz, J = 10.9 Hz); 1.48 (m, 1 H, H(2′)); 1.49—1.55 (m, 3 H, H(1), H(3), H(3)); 1.57 (dd, 1 H, H(9′), J = 13.0 Hz, J = 3.5 Hz); 1.59—1.61 (m, 3 H, H(1′), 2 H(3′)); 1.77 (ddddd, 1 H, H(2), J = 13.6 Hz, J = 13.3 Hz, J = 13.2 Hz, J = 3.3 Hz, J = 2.9 Hz); 1.85 (m, 1 H, H(2′)); 1.87 (dd, 1 H, H(13), J = 14.0 Hz, J = 6.2 Hz); 2.02 (dd, 1 H, H(9), J = 14.7 Hz, J = 3.5 Hz); 2.25 (ddd, 1 H, H(7), J = 5.8 Hz, J = 3.7 Hz, J = 1.0 Hz); 2.36 (m, 1 H, H(4)); 2.49 (m, 1 H, H(4′)); 3.41 (ddd.ddd, 1 H, H(8′), J = 12.2 Hz, J = 10.9 Hz, J = 6.2 Hz, J = 3.5 Hz, J = 2.5 Hz, J = 1.5 Hz); 3.68 (ddd, 1 H, H(13′), J = 4.5 Hz, J = 1.5 Hz, J = 1.0 Hz); 4.72 (ddd, 1 H, H(8), J = 5.8 Hz, J = 3.4 Hz, J = 3.0 Hz); 4.84 (d, 1 H, H(6), J = 3.7 Hz); 5.23 (dd, 1 H, H(11′), J = 4.5 Hz, J = 1.5 Hz); 5.74 (s, 1 H, H(6′)); 7.29 (d, 2 H, H(2″), H(6″), J = 8.6 Hz); 7.60 (d, 2 H, H(3″), H(5″), J = 8.6 Hz). ^{13}C NMR, δ: 16.71 (C(2)); 17.18 (C(2′)); 22.52 (C(15′)); 22.85 (C(15)); 26.64 (C(14′)); 26.85 (C(8′)); 28.51 (C(14)); 30.02 (C(13)); 32.70 (C(10)); 32.77 (C(3)); 32.87 (C(3′)); 36.06 (C(10′)); 37.40 (C(4′)); 38.38 (C(4)); 41.67 (C(1′)); 42.00 (C(1)); 42.78 (C(9)); 43.09 (C(7)); 46.90 (C(13′)); 49.05 (C(9′)); 50.29 (C(11)); 74.21 (C(8)); 111.18 (C(4″)); 115.93 (C(6)); 118.39 (C(11″)); 118.42 (CN); 123.29 (C(6′)); 130.22 (C(2″), C(6″)); 132.32 (C(3″), C(5″)); 139.15 (C(7′)); 147.24 (C(1″)); 150.10 (C(5)); 151.41 (C(5′)); 178.48 (C(12)). Found (%): C, 82.68; H, 8.24; N, 2.77. $C_{36}H_{43}NO_2$. Calculated (%): C, 82.87; H, 8.31; N, 2.68.

The reaction of a mixture of eudesmanolides of isoalantolactone **1** (232 mg, 1.0 mmol) and alantolactone **2** (232 mg, 1.0 mmol) with 4-iodoveratrole **5b** (580 mg, 2.2 mmol) in the presence of palladium acetate (17.7 mg, 0.08 mmol), tri(*o*-tolyl)phosphine (97 mg, 0.32 mmol), DMF (10 mL), and triethylamine (0.5 mL, 3.61 mmol) during 16 h afforded a mixture containing compounds **25**, **26**, and the starting lactones **1**, **2**. Column chromatography on silica gel gave the following individual compounds: isoalantolactone **1** (20 mg), alantolactone **2** (160 mg), **(3a*R*,4a*S*,8a*R*,9a*R*,*E*)-3-(3,4-dimethoxybenzylidene)-8a-methyl-5-methylidenedecahydronaphtho[2,3-*b*]furan-2(3*H*)-**

one (**25**) (202 mg, 55%), and **(4a*S*,8a*R*,9a*S*)-3-(3,4-dimethoxybenzyl)-8a-methyl-5-methylidene-4a,5,6,7,8,8a,9,9a-octahydronaphtho[2,3-*b*]furan-2(4*H*)-one** (**26**) (56 mg). Compound **25**, m.p. 160—162 °C (from ethanol), $[\alpha]_D$ +534 (*c* 1.05, $CHCl_3$). IR (KBr), ν/cm^{-1}: 808, 890, 1001, 1033, 1139, 1172, 1214, 1248, 1272, 1327, 1337, 1464, 1520, 1594, 1651, 1743. UV, λ_{max}/nm (logε): 202 (4.20), 246 (4.13), 326 (4.32). ^{1}H NMR (600.13 MHz), δ: 0.81 (s, 3 H, C(14)H$_3$); 1.22 (m, 1 H, H(1)); 1.34 (ddd, 1 H, H(6), *J* = 13.0 Hz, *J* = 12.8 Hz, *J* = 12.6 Hz); 1.45—1.58 (m, 4 H, H(1), H(2), H(2), H(2), H(9)); 1.87 (d, 1 H, H(5), *J* = 12.9 Hz); 1.91—2.04 (m, 2 H, H(3), H(6)); 2.19 (d, 1 H, H(9), *J* = 15.5 Hz); 2.28 (d, 1 H, H(3), *J* = 13.2 Hz); 3.37 (ddd, 1 H, H(7), *J* = 11.4 Hz, *J* = 5.6 Hz, *J* = 5.5 Hz); 3.82 (s, 3 H, OMe); 3.85 (s, 3 H, OMe); 4.36 (br.s, 1 H, H(15)); 4.44 (dd, 1 H, H(8), *J* = 4.1 Hz, *J* = 3.6 Hz); 4.70 (br.s, 1 H, H(15)); 6.86 (d, 1 H, H(5´), *J* = 8.5 Hz); 6.97 (s, 1 H, H(2´)); 7.12 (d, 1 H, H(6´), *J* = 7.0 Hz); 7.30 (s, 1 H, H(13)). ^{13}C NMR, δ: 17.47 (C(14)); 22.53 (C(2)); 24.56 (C(6)); 34.34 (C(10)); 36.68 (C(3)); 39.40 (C(7)); 41.21 (C(9)); 42.02 (C(1)); 46.20 (C(5)); 55.76 (2 OMe); 76.66 (C(8)); 106.48 (C(15)); 111.22 (C(6´)); 112.72 (C(2´)); 122.92 (C(5´)); 126.97 (C(1´)); 129.93 (C(11)); 134.84 (C(13)); 148.88 (C(4), C(3´)); 150.37 (C(4´)); 172.44 (C(12). Found (%): C, 74.90; H, 7.92. $C_{23}H_{28}O_4$. Calculated (%): C, 74.97; H, 7.66.

Compound **26**, oily substance. ^{1}H NMR (600.13 MHz), δ: 0.87 (s, 3 H, C(14)H$_3$); 1.12 (dd, 1 H, H(9), *J* = 11.8 Hz, *J* = 11.8 Hz); 1.29 (ddd, 1 H, H(1), *J* = 13.3 Hz, *J* = 13.3 Hz, *J* = 5.3 Hz); 1.55—1.64 (m, 3 H, H(1), H(2), H(2)); 1.80 (dddd, 1 H, H(5), *J* = 12.5 Hz, *J* = 3.3 Hz, *J* = 1.7 Hz, *J* = 1.3 Hz); 1.93 (ddd, 1 H, H(3), *J* = 12.8 Hz, *J* = 12.8 Hz, *J* = 5.8 Hz); 2.28 (m, 1 H, H(6)); 2.30 (dd, 1 H, H(9), *J* = 12.3 Hz, *J* = 6.4 Hz); 2.36 (dddd, 1 H, H(3), *J* = 13.4 Hz, *J* = 3.8 Hz, *J* = 2.2 Hz, *J* = 1.8 Hz), 2.77 (dd, 1 H, H(6), *J* = 13.8 Hz, *J* = 3.8 Hz); 3.50 (d, 1 H, H(13), *J* = 15.5 Hz); 3.56 (d, 1 H, H(13), *J* = 14.8 Hz); 3.83 (s, 3 H, OMe); 3.84 (s, 3 H, OMe); 4.55 (dd, 1 H, H(15), *J* = 3.0 Hz, *J* = 1.2 Hz); 4.84 (dd, 1 H, H(8), *J* = 11.5 Hz, *J* = 6.3 Hz); 4.85 (dd, 1 H, H(15), *J* = 2.8 Hz, *J* = 1.4 Hz); 6.73 (dd, 1 H, H(6´), *J* = 8.2 Hz, *J* = 2.0 Hz); 6.76 (d, 1 H, H(5´), *J* = 8.2 Hz); 6.97 (d, 1 H, H(2´), *J* = 2.0 Hz). ^{13}C NMR, d: 16.35 (C(14)); 22.18 (C(2)); 25.70 (C(6)); 28.77 (C(13)); 36.14 (C(10)); 36.83 (C(3)); 40.68 (C(1)); 47.55 (C(9)); 49.97 (C(5)); 55.72 (2 OMe); 77.82 (C(8)); 106.89 (C(15)); 111.15 (C(6´)); 111.67 (C(2´)); 120.04 (C(5´)); 123.76 (C(1´)); 130.97 (C(11)); 147.53 (C(3´)); 148.17 (C(4)); 148.99 (C(4´)); 163.41 (C(7)); 174.05 (C(12)). Found (%): C, 74.90; H, 7.92. $C_{23}H_{28}O_4$. Calculated (%): C, 74.97; H, 7.66.

The reaction of alloalantolactone **4** (464 mg, 2 mmol) and 4-iodoveratrole **5b** (580 mg, 2.2 mmol) in the presence of palladium acetate (18 mg, 0.08 mmol), tri(*o*-tolyl)phosphine (98 mg, 0.32 mmol), DMF (10 mL), and triethylamine (0.5 mL, 4.2 mmol) during 10 h and subsequent chromatography of the reaction mixture on silica gel gave **(3a*R*,8a*R*,9a*R*,*E*)-3-(3,4-dimethoxybenzylidene)-5,8a-dimethyl-3a,4,6,7,8,8a,9,9a-octahydronaphtho[2,3-*b*]furan-2(3*H*)-one** (**27**) (221 mg, 30%) and **(8a*R*,9a*S*)-3-(3,4-dimethoxybenzyl)-5,8a-dimethyl-6,7,8,8a,9,9a-hexahydronaphtho[2,3-*b*]furan-2(4*H*)-one** (**28**) (258 mg, 35%). Compound **27**, m.p. 96—98 °C (from ethanol), $[\alpha]_D^{20}$ +155 (*c* 0.76, $CHCl_3$). IR (KBr), ν/cm^{-1}: 625, 758, 814, 843, 891, 920, 951, 1024, 1075, 1140, 1165, 1215, 1269, 1333, 1372, 1416, 1246, 1447, 1518, 1593, 1647, 1746, 2737, 2837, 2862, 2930, 2974, 3082. UV, λ_{max}/nm (logε): 201 (4.25), 238 (3.94), 327 (4.15). ^{1}H NMR (400.13 MHz), δ: 1.12 (s, 3 H, C(14)H$_3$); 1.36 (m, 1 H, H(1)); 1.50—1.58 (m, 3 H, H(1), H(2), H(2)); 1.66 (s, 3 H, C(15)H$_3$); 1.68 (dd, 1 H, H(9), *J* = 15.0 Hz, *J* = 4.7 Hz); 1.85—1.96 (m, 3 H, H(3), H(3), H(6)); 2.07 (dd, 1 H, H(9), *J* = 15.0 Hz, *J* = 3.9 Hz); 2.91 (dd, 1 H, H(6), *J* = 14.5 Hz, *J* = 6.4 Hz); 3.38 (dddd, 1 H, H(7), *J* = 12.2 Hz, *J* = 6.4 Hz, *J* = 5.4 Hz, *J* = 1.5 Hz); 3.89 (s, 3 H, OMe); 3.90 (s, 3 H, OMe); 4.49 (ddd, 1 H, H(8), *J* = 5.4 Hz, *J* = 4.8 Hz, *J* = 3.9 Hz); 6.88 (d, 1 H, H(5´), *J* = 8.4 Hz); 7.04 (d, 1 H, H(2´), *J* = 2.0 Hz); 7.13 (dd, 1 H, H(6´), *J* = 8.4 Hz, *J* = 2.0 Hz); 7.37 (d, 1 H, H(13), *J* = 1.5 Hz). ^{13}C NMR, δ: 18.55 (C(2)), 19.39 (C(15)); 25.09 (C(6)); 32.25 (C(3)); 33.26 (C(10)); 39.27 (C(9)); 40.77 (C(7)); 42.04 (C(1)); 55.87 (2 OMe); 76.95 (C(8)); 111.06 (C(6´)); 111.85 (C(2´)); 123.75 (C(5´)); 127.11 (C(1´)); 127.20 (C(11)); 129.39 (C(4)); 131.21 (C(5)); 135.41 (C(13)); 149.01 (C(3´)); 150.44 (C(4´)); 163.08 (C(7)); 172.70 (C(12)). Found (%): C, 74.57; H, 7.43. $C_{23}H_{28}O_4$. Calculated (%): C, 74.97; H, 7.66.

Compound **28**, oily substance, $[\alpha]_D^{20}$ +61 (*c* 0.53, $CHCl_3$). IR (neat), ν/cm^{-1}: 693, 760, 795, 1028, 1106, 1237, 1262, 1341, 1377, 1462, 1514, 1592, 1680,1752, 2834, 2864, 2932. UV, λ_{max}/nm (logε): 204 (4.49), 225 (4.26), 279 (3.60). ^{1}H NMR (400.13 MHz), δ: 1.05 (dd, 1 H, H(9), *J* = 12.2 Hz, *J* = 11.8 Hz); 1.15 (s, 3 H, C(14)H$_3$); 1.34 (ddd, 1 H, H(1), *J* = 13.9 Hz, *J* = 13.2 Hz, *J* = 3.0 Hz); 1.53 (s, 3 H, C(15)H$_3$); 1.56—1.62 (m, 3 H, H(1), H(2), H(2)); 1.90 (m, 2 H, H(3), H(3)); 2.25 (dd, 1 H, H(9), *J* = 11.8 Hz, *J* = 6.1 Hz); 2.77 (dm, 1 H, H(6), *J* = 15.6 Hz); 3.49 (d,1 H, H(13), *J* = 15.2 Hz); 3.57 (d, 1 H, H(13), *J* = 15.2 Hz); 3.70 (d, 1 H, H(6), *J* = 15.5 Hz); 3.80 (s, 3 H, OMe); 3.82 (s, 3 H, OMe); 4.96 (dd, 1 H, H(8), *J* = 11.8 Hz, *J* = 5.0 Hz); 6.73—7.12 (m, 3 H, H(2´), H(5´), H(6´)). ^{13}C NMR, δ: 18.34 (C(2)); 19.50 (C(15)); 24.58 (C(14)); 26.72 (C(6)); 28.84 (C(13)); 32.83 (C(3)); 35.01 (C(10)); 39.13 (C(1)); 47.61 (C(9)); 55.59 (OMe); 55.79 (OMe); 77.92 (C(8)); 111.16 (C(6´)); 111.50 (C(2´)); 120.21 (C(5´)); 122.16 (C(1´)); 129.02 (C(11)); 129.33 (C(4)); 130.79 (C(5)); 147.53 (C(3´)); 148.90 (C(4´)); 163.08 (C(7)); 174.20 (C(12)). Found (%): C, 75.12; H, 7.81. $C_{23}H_{28}O_4$. Calculated (%): C, 74.97; H, 7.66.

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