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Photodegradation of some 14,15-bisnorlabdene-13-ones, derived from larixol. Synthesis of drimanic dienes with functional groups at C-6

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Abstract—Valuable chiral drimanic dienic synthons have been prepared by a photolytic Norrish type II degradation of the corresponding 14,15-bisnorlabdene-13-ones. Minor by-products with unexpected bi- and tricyclic structures were formed and some of them were isolated and identified.

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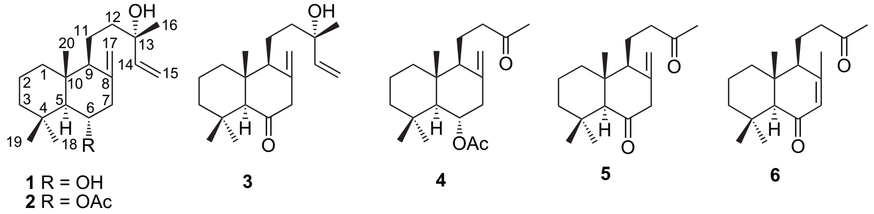
1. Introduction

Drimane sesquiterpenes continue to attract attention due to their wide range of biological activities.[1,2] One way for the preparation of natural optically active drimanes is to start from the related and easily accessible labdane diterpenes.[3] For the synthesis of drimanes with functional groups at C-6, the labdane diol larixol **1** is a suitable starting material because it is easily available from the oleoresin of larch (*Larix decidua*, *Larix europea*).[4] For the conversion of larixol **1** into drimanes it is necessary to shorten its side chain with one isoprenic unit, which necessitates a multistep sequence. Recently, an efficient method for the oxidative degradation of the side chains of larixyl acetate **2** and keto-alcohol **3** to methylketones **4** and **5**, respectively, has been developed using oxidation with $KMnO_4$ in CH_2Cl_2.[5,6] Methylketone **5** can be isomerized with sodium methoxide in good yield to 14,15-bisnorlabd-7-ene-6,13-dione **6**[5,7] (Scheme 1). These 14,15-bisnorlabdene-13-ones **4–6** would be suitable starting chirons for the preparation of drimanes when a Norrish II type photochemical degradation could be realized, through which another three carbons would be eliminated. In this way a multifunctionalized drimane skeleton should be obtained as one of the major reaction products.[8,9] In addition, information would be obtained about the influence of structural variation in the starting



Scheme 1.

Keywords: Larixol; 14,15-Bisnorlabdene-13-ones; Chiral drimane synthons; Photolysis; Norrish type II reactions.

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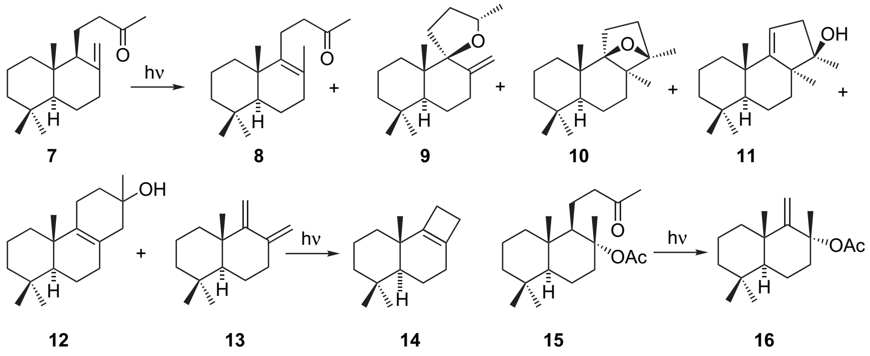


Scheme 2.

14,15-bisnorlabdenes on the yields and product formation of the photolytic reactions.

In 1976 Jeger and co-workers[8] established that exhaustive photolysis of labdanic methylketone **7** led to a complex mixture of more than 12 products, from which compounds **8–13** were isolated and identified, one of these being the drimanic diene **13** (yield 18%) (Scheme 2). Upon further irradiation this compound was transformed into the unstable tricyclic hydrocarbon **14**. This group[9] also investigated the photolysis of the enantiomer of the ketone **7** and demonstrated that the product composition depends on the duration of the irradiation and on the reaction temperature. Thus, the yield of the enantiomer of the diene **13** was quantitative at −72 °C, at 0 °C it constituted 72% (conversion 64%) and at 35 °C only 31% (conversion 81%).

Nakano and Mailo[10] have elaborated a method for the transformation of ketone **7** into diene **13** in a high yield (~78%), but with a low conversion (~7%). The unreacted ketone **7** could be recovered nearly quantitatively and can be used again. Some other photolytic degradations have been published[11] giving comparable results, with the 8α-acetoxy-14,15-bisnorlabdan-13-one **15**, giving 90% yield of alkene **16** with 50% conversion, as a favourable exception.[12,13]

2. Results and discussion

The above mentioned experiments show that the photolysis of bisnorlabdenic methylketones **4–6** should preferably be performed in a solution of low-molecular weight hydrocarbons (*n*-pentane, *n*-hexane and light petroleum ether), at low temperature and using a short period of irradiation. Although under these conditions the conversion of the ketones is low, the formation of secondary reaction products usually can be avoided and the unreacted starting material can be recycled.

The Norrish II type photochemical degradation of the 14,15-bisnorlabdenes **4–6** was carried out in hexane solution at 5 °C for 3 h and the main reaction product and several predominating side products were isolated by chromatography and their structures elucidated.

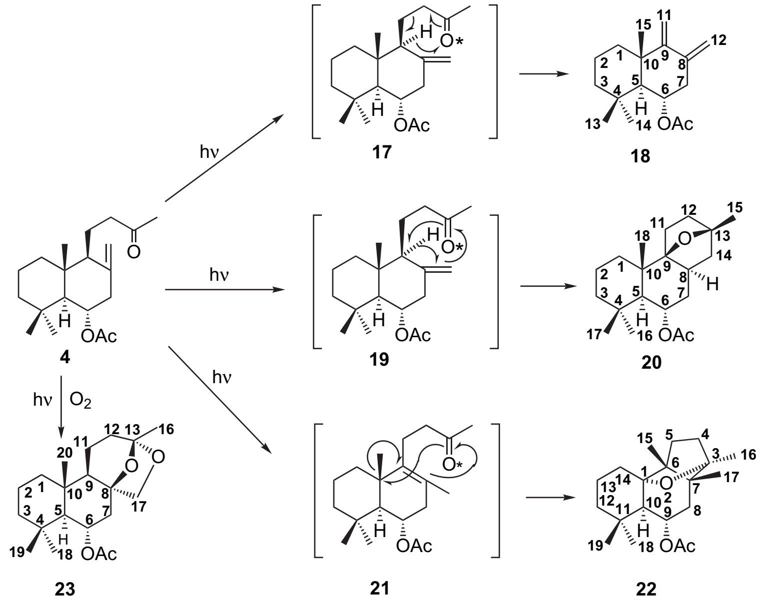
The 6α-acetoxy-14,15-bisnorlabd-8(17)-ene-13-one **4** was prepared from larixyl acetate **2** as described by Bolster et al.[5] The photolytic cleavage of this compound leads to a complex mixture of more than 10 products (TLC data). Column chromatography of the crude reaction product on SiO_2 permits the recovery of 88% of the starting ketone **4**, the conversion being 12%. The conversion of ketone **4** increases at longer irradiation times, but simultaneously the complexity of the reaction mixture also increases.

Among the reaction products the expected drimanic acetoxy-diene **18** could be isolated as the main product in 76% yield, calculated on converted ketone **4** (Scheme 3). Its structure follows from the spectral data, which indicate an acetoxy group, three methyl groups at quaternary carbon atoms and a conjugated system consisting of two exocyclic double bonds.

The next compound, eluted in 3.5% yield, calculated on converted ketone **4**, turns out to be 6α-acetoxy-9,13β-epoxy-13β-methylpodocarpane **20**. The structure of this compound was confirmed by analytical and spectral data,[14] and by X-ray analysis (Fig. 1).[15] A probable way of formation of **20** is indicated in formula **19** in Scheme 3.

The next product **22**, eluted in 2.4% yield, calculated on converted ketone **4**, is an oxygen containing compound with an elemental composition identical to that of the starting compound **4**. From the ^{13}C NMR data it can be concluded that this substance contains six methyl groups (one of them belongs to the acetate group), four quaternary, two tertiary and seven secondary carbon atoms, and an oxygen atom connected to two quaternary carbon atoms. Finally the structure of compound **22** was determined by X-ray analysis (Fig. 2),[15] which showed its tricyclic nature with the *cis*-decalin skeleton condensed with a cyclopentane ring. Its formation can be explained by isomerization of the double bond in ketone **4** to the endocyclic position as in ketone **21**[8] followed by the photochemical rearrangement and cyclization that is indicated in Scheme 3.

The next compound, eluted from the chromatographic column in 17% yield, calculated on converted ketone **4**, was the photodegradation product **23**. The NMR evidence shows that this compound contains five methyl groups (including the acetoxy group), four completely substituted, three tertiary and seven secondary carbon atoms, and also two oxygen containing rings. In one of them, the oxygen atom is connected to two completely substituted carbon atoms and in the second ring the oxygen atom is connected to one



Scheme 3.

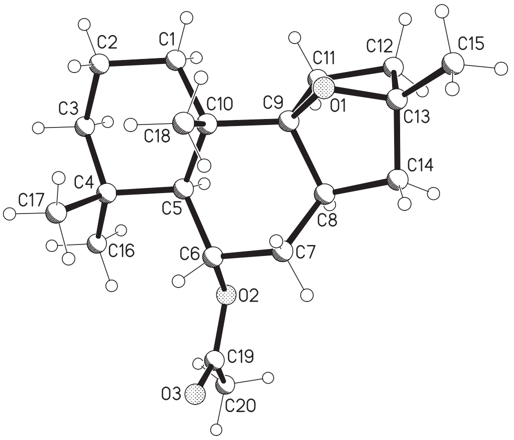


Figure 1. X-ray structure of compound **20**.

completely substituted and one secondary carbon atoms. These data led to the conclusion that this compound contains an intramolecular ketal group. This structural moiety is confirmed by the presence of the signals of an AB-system at 3.31 ppm and 3.76 ppm, and a singlet of a methyl group at 1.42 ppm in the NMR spectrum. From comparison of its spectral data with those of similar known diastereomeric ketoketals from the literature[16,17] the 6α-acetoxy-8β,13;13α,17-diepoxy-14,15-bisnorlabdane structure **23** was attributed to this compound. This structure was proven by X-ray analysis of its monocrystal (Fig. 3).[15] Finally the starting acetoxyketone **4** was eluted from the column (88%).

Compound **23** is formed as the result of a reaction between acetoxyketone **4** (probably, in the photoexcited state) and oxygen from the reaction medium. Although the reaction was carried out in an inert atmosphere, the solution was not degassed before the photolysis and apparently enough oxygen was dissolved in the reaction medium to allow the formation of this product. This supposition is supported by two additional reactions, one carried out in an atmosphere of argon, the other under oxygen. In the reaction under argon 78% of the acetoxyketone **4** was recovered, the yield of acetoxydiene **18** was 72%, and the yield of acetoxyketal **23** was

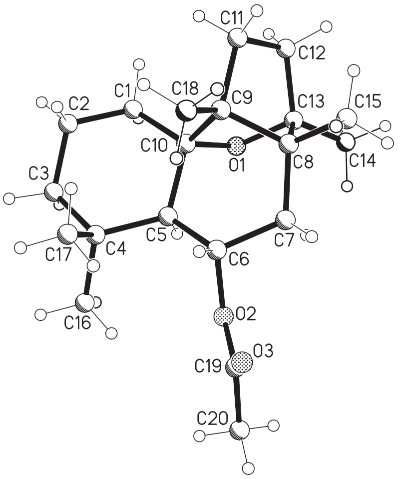


Figure 2. X-ray structure of compound **22**.

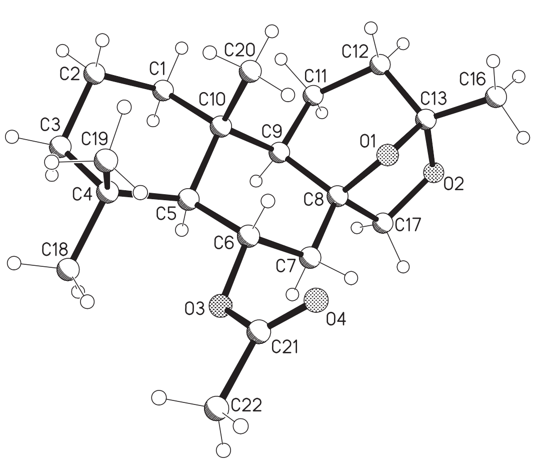
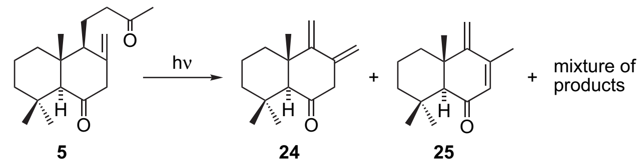


Figure 3. X-ray structure of compound **23**.

26%. In the reaction under oxygen only 46% of **4** was recovered and 14% of **18** and 40% of **23** was obtained. This 40% yield of **23** obtained under oxygen is 1.5 times higher than the yield of **23** under argon and 2.3 times higher than the 17% yield of **23** under nitrogen. Formation of **23** via epoxidation of the double bond in **4** cannot be excluded, but seems to be less probable because the reaction medium was neutral.

The photochemical degradation of the diketone **5** also affords a mixture of products, but in this case the conversion was rather high (~63%). The yield of the major Norrish type II reaction product, drim-8(12),9(11)-diene-6-one **24**, was 36% based on converted starting diketone **5** (Scheme 4). The reason for this moderate yield is again the formation of a large number of by-products, with the isomerized ketone **25** as the major one. The structure of ketodiene **24** is confirmed by elemental and spectral analyses. The spectra showed two exocyclic double bonds and a carbonyl group. Besides it contains five completely substituted, one tertiary and six secondary carbon atoms, and three methyl groups bonded to completely substituted carbon atoms.



Scheme 4.

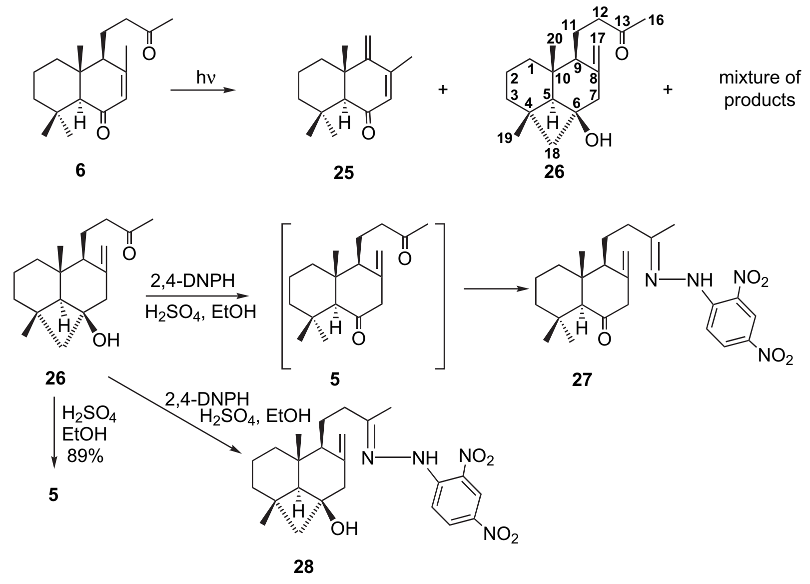
The second product, ketodiene **25**, was isolated in 19% yield based on converted diketone **5**. Its formation can be explained either by isomerization of the starting diketone **5**, before its photofragmentation, or by isomerization of ketodiene **24**. Both **24** and **25** are useful starting materials for drimane synthesis and their combined yields of 55% together with accessibility and the relatively high conversion of the starting ketone **5** makes this to be one of the shortest routes to highly functionalized drimanes.

The photolysis of diketone **6** gave a very complex mixture of at least 12 products, with one main component. Also in this case the reaction was not carried out with full transformation of the starting compound. The conversion was 23%, and the starting material was recovered by chromatography. According to spectral data, the major reaction product was the expected result from the Norrish type II reaction of diketone **6**, namely, the known drim-7,9(11)-diene-6-one **25**, which could be isolated in 67.5% yield based on converted ketone **6** (Scheme 5). The spectral data of this compound were identical to those in the literature.[4,18]

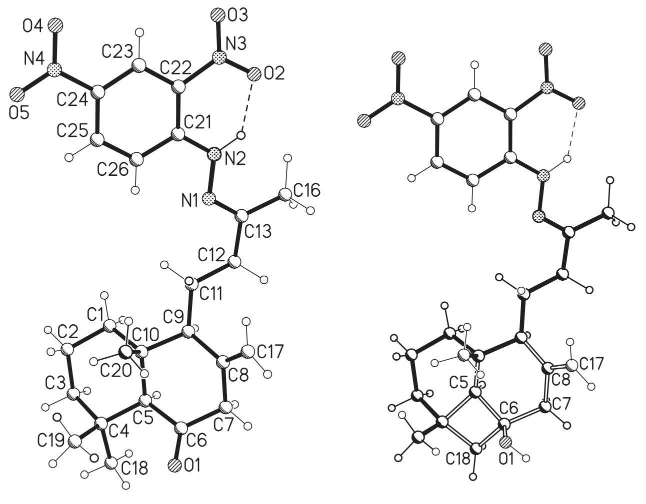
Besides ketodiene **25** a second liquid compound **26** could be isolated from the photolysis mixture. According to analytical and spectral data this compound has the same composition as the starting diketone **6** and contains a tertiary hydroxylic and methylketonic groups, an exocyclic double bond and, unlike the starting compound **6**, only three methyl groups. However, the spectral data of this compound did not allow a full characterization of the structure. For an unambiguous structure determination a 2,4-DNPH derivative of **26** was prepared for X-ray analysis.

Upon chromatographic purification of the reaction product, two 2,4-DNPH fractions with identical R_f value were collected, which had different melting points and crystal forms. X-ray studies[15] revealed that both these fractions consist of mixed crystals of 2,4-DNPH's **27** and **28** with different ratios of them. The 13-mono-2,4-DNPH **27** derived from the known 14,15-bisnorlabd-8(17)-ene-6,13-dione **5**, in which compound **26** is isomerized on its treatment with a solution of 2,4-dinitrophenylhydrazine in EtOH containing H_2SO_4 (Scheme 5). Indeed, in a separate experiment it was shown that on interaction with an ethanolic solution of H_2SO_4 the hydroxyketone **26** isomerized to diketone **5** (Fig. 4).

The second compound represented the 2,4-DNPH **28**, which contains an exocyclic double bond in C-8-C-17 position and a cyclobutane ring, obtained as the result of bond formation between C-18 and C-6. We didn't investigate in detail the



Scheme 5.



Molecule **27**

Molecule **28**

Figure 4. X-ray structures of the major **27** (74.7%) and the minor **28** fractions (25.3%) of the molecules in the crystal of compound $\mathbf{27}\cdot0.5H_2O$. The open lines and numbered atoms of **28** in Figure 4 correspond to the fragment whose position does not coincide in the structure with the corresponding fragment of compound **27**.

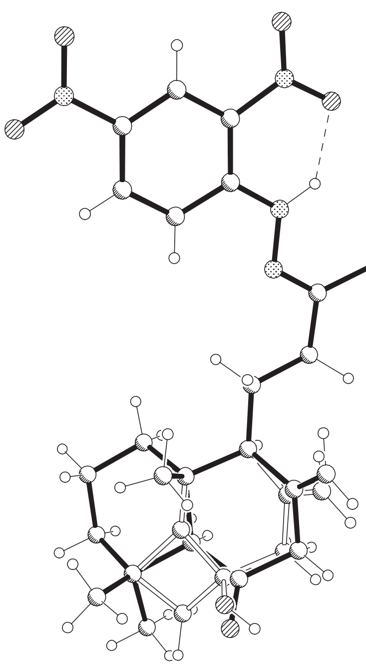


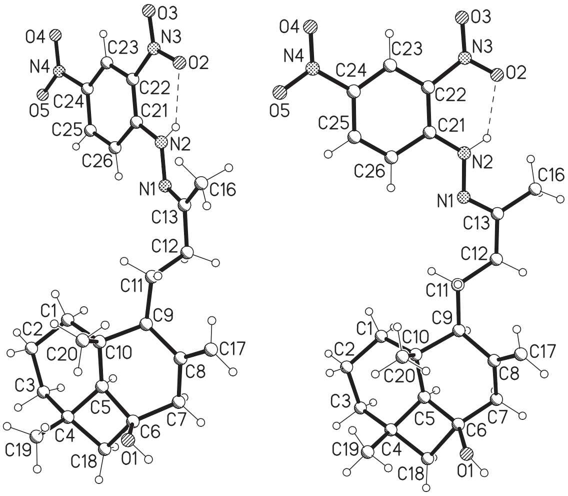
Figure 5. The overlap of positions of two different molecules in the crystal structure of **27**.

process of formation of compound **26** from the diketone **6**. However it should be mentioned that analogical transformations with the formation of compounds containing strained cyclobutane rings have been earlier observed on photolysis of some triterpene derivatives.[19–22]

Comparison of the influence of the structural variation in ketones **4**–**6** on the yield of the desired Norrish type II products in the photolysis reactions does not allow firm conclusions. The relatively good results in the photolysis of ketone **5**, a good yield in combination with a high conversion, cannot be explained easily. Although the end products are stabilized by conjugation, this is also the case in the products of the photolysis of ketones **4** and **6**, but their reactions follow the usual high yield low conversion pattern.

It should be noted that compounds **27** and **28** form mixed crystals in different ratios. In the crystal of compound **27** 25.3% of the molecules are isomorphously substituted by molecules of compound **28**. The composition of the crystal is $\{0.747(\mathbf{27})\cdot0.253(\mathbf{28})\cdot0.5H_2O\}$. Two different molecules reside statistically in the same position in the crystal. The positions of the majority of atoms for two different molecules overlap in the crystal structure within the resolution of data (Fig. 5). In each molecule, N-2-H···O-2 intramolecular hydrogen bonds facilitates the planarity of the hydrazone and 2,4-dinitrophenyl moieties.

The asymmetric part of the unit cell contains two molecules of **28a** and **28b** as crystallographically independent units (Fig. 6), which differ by their conformation. The torsion angle around the C-12-C-13 bond is *syn-clynal* in molecule **a** and *syn-periplanar* in molecule **b**. Two six-membered rings have chair conformation and four-membered ring is folded in both molecules. The OH groups are axial with respect to the four- and six-membered rings and trans to the H atom on C-5. The intramolecular N-2-H···O-2 H-bonds are presented in both molecules **a** and **b**.



Molecule **28a**

Molecule **28b**

Figure 6. X-ray structure of two different molecules (**a** and **b**) in the crystal of compound **28** with a numbering scheme.

In the crystal of **28** molecules **a** partially (33.2%) are isomorphically substituted by molecules of compound **27** (Fig. 7). The overall composition of crystal **28** is {0.834(**28**)/0.166(**27**)}.

3. Conclusions

It was shown that the drimanic dienic syntons **18**, **24** and **25** can be prepared by a photolytic Norrish type II reaction of the corresponding 14,15-bisnorlabdene-13-ones **4**, **5** and **6**, respectively. Besides the major reaction products, complex mixtures of minor by-products with unexpected bi- and tricyclic structures were formed, part of which were isolated

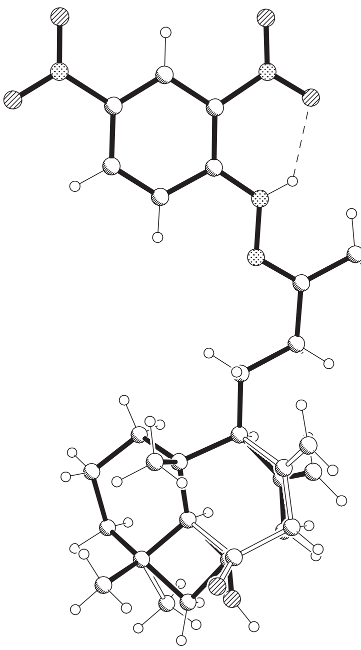


Figure 7. The overlap of positions of molecule **28a** and **27** in the crystal structure of **28**.

and identified. The good conversion (63%) of ketone **5**, combined with the good total yield of dienes **24** and **25** (55%) makes the photolysis of this easily accessible ketone as the best starting material for the synthesis of highly functionalized drimanes.

4. Experimental

4.1. General

Melting points (mp) were determined in capillary tubes and on a Boetius hot stage. IR spectra were obtained on Bio-Rad-Win-IR and Perkin–Elmer Models spectrometer in CCl_4. ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$ on a Bruker AC-E 200 (200.13 and 50.32 MHz, respectively) and on a Bruker Avance DRX 400 (400.13 and 100.61 MHz) spectrometers. Chemical shifts are given in parts per million values in δ scale with $CHCl_3$ as reference (set δ_H at 7.24 ppm and δ_C 77.00 ppm) and coupling constants in Hertz. Carbon substitution degrees were established by DEPT pulse sequence. Mass spectra (MS) were run on an AEI MS 902 spectrometer (EI, 70 eV). Optical rotations were determined on a Perkin–Elmer 241 polarimeter with a 1 dm microcell, using $CHCl_3$ as solvent. Photolytic cleavage was effectuated by *n*-hexane in quartz flask using UV high-pressure lamps Heraeus TQ-718 Hg vapour, 700 W and LP Hg vapour, 450 W. For analytical TLC Merck silica gel 60 G in 0.25 mm layers was used. Chromatographic column separations were carried out on Merck silica gel 60 (70–230 mesh) using petroleum ether (bp 40–60 °C) and mixtures of petroleum ether with EtOAc of increasing polarity. All solvents were purified and dried by standard techniques just before use. Usual work-up means that water was added to the reaction mixture, which was then extracted with ether, the combined organic layers were washed with brine, dried over Na_2SO_4 or $MgSO_4$ and solvent evaporated under reduced pressure.

4.1.1. Photolysis of 6α-acetoxy-14,15-bisnorlabd-8(17)-ene-13-one (4). A solution of compound **4** (5.345 g, 16.7 mmol) in dry hexane (800 mL) was poured into the quartz flask of the photoreactor and a stream of dry nitrogen was bubbled through the solution before and during the irradiation. The solution was cooled to 5 °C and irradiated for 3 h with a UV lamp (750 W). Evaporation of the solvent afforded a yellow oil, which was purified by column chromatography on silica gel (200 g, eluent: PE/EtOAc 9:1), to give *6α-acetoxy-drim-8(12),9(11)-diene* **18** (410 mg, yield 76%, conversion 13%) as an colourles oil; [Found: C, 77.6; H, 10.4. $C_{17}H_{26}O_2$ requires C, 77.82; H, 9.99%]; $[\alpha]_D^{20}$ +27.34 (*c* 1.22); ν_{max} 1742, 1639, 1241, 896 cm^{-1}; δ_H (400.13 MHz) 5.22 (1H, m, *H*-6), 4.95 (1H, m), 4.91 (1H, d, *J* 1.6 Hz) (C*H*$_2$=), 4.73 (1H, m), 4.64 (1H, d, *J* 1.6 Hz) (C*H*$_2$=), 2.82 (1H, dd, *J* 13.4, 5.2 Hz, *H*-7α), 2.06–2.22 (1H, m, *H*-1), 2.05 (3H, s, OCO*Me*), 1.20–1.70 (7H, m), 1.03 (3H, s, *Me*), 1.00 (3H, s, *Me*), 0.94 (3H, s, *Me*); δ_C (100.61 MHz) 170.3 (C), 159.0 (C), 145.4 (C), 110.9 (CH_2), 104.3 (CH_2), 72.0 (CH), 54.1 (CH), 43.7 (CH_2), 41.0 (CH_2), 39.8 (C), 38.0 (CH_2), 35.8 (CH_3), 33.8 (C), 22.6 (CH_3), 22.3 (CH_3), 21.9 (CH_3), 18.8 (CH_2); *m/z* 262 (M^+, 18), 260 (100), 189 (24), 149 (20), 125 (44), 115 (42), 69 (32), 42 (46%); HRMS (EI): M^+, found 262.2132. $C_{17}H_{26}O_2$ requires 262.1933.

Further elution with the same eluent yielded 23 mg (3.5%) of *6α-acetoxy-9,13β-epoxy-13β-methylpodocarpane* **20** as white crystals, mp 156–157 °C (from hexane); [Found: C, 75.4; H, 10.2. $C_{20}H_{32}O_3$ requires C, 74.96, H, 10.21%]; $[\alpha]_D^{20}$ +7.67 (*c* 0.01); ν_{max} (Nujol) 1733, 1248, 1090, 1016 cm^{-1}; δ_H (400.13 MHz) 5.19 (1H, dd, *J* 8.0, 5.2 Hz, *H*-6), 2.00 (3H, s, OCO*Me*), 0.90–1.98 (16H, m), 1.42 (3H, s, *Me*), 1.16 (3H, s, *Me*), 1.05 (3H, s, *Me*), 0.83 (3H, s, *Me*); δ_C (100.61 MHz) 170.7 (C), 91.3 (C), 81.3 (C), 72.5 (CH), 50.7 (CH), 45.2 (CH_2), 42.9 (CH_2), 39.4 (CH), 39.0 (CH_2), 37.1 (C), 36.2 (CH_2), 34.9 (CH_2), 34.3 (C), 34.2 (CH_3), 33.1 (CH_2), 23.8 (CH_3), 21.9 (CH_3), 21.2 (CH_3), 19.4 (CH_3), 18.7 (CH_2).

The next compound eluted with the same eluent was *(1S,3S,6R,7R,9S,10R)-3,6,7,11,11-pentamethyl-2-oxatetracyclo[8.4.0.0*^{1,6}*.0*^{3,7}*]tetradec-9-yl acetate* **22** (16 mg, yield 2.4%) as crystals, mp 102–103 °C (from *n*-hexane); [Found: C, 75.1; H, 10.2. $C_{20}H_{32}O_3$ requires C, 74.95; H, 10.07%]; $[\alpha]_D^{20}$ +1.53 (*c* 0.01); ν_{max} (Nujol) 1724, 1235, 1006, 954, 908 cm^{-1}; δ_H (400.13 MHz) 5.24 (1H, dd, *J* 15.6, 7.6 Hz, *H*-6), 2.01 (3H, s, OCO*Me*), 1.23–2.18 (13H, m), 1.09 (3H, s, *Me*), 1.06 (3H, s, *Me*), 0.90 (6H, s, *Me*$_2$), 0.76 (3H, s, *Me*); δ_C (100.61 MHz) 170.7 (C), 85.1 (C), 84.9 (C), 68.8 (CH), 58.1 (CH), 49.6 (C), 49.1 (C), 41.4 (CH_2), 35.0 (CH_2), 34.5 (CH_2), 34.1 (CH_3), 33.9 (C), 33.0 (CH_2), 30.1 (CH_2), 26.0 (CH_3), 21.7 (CH_3), 19.7 (CH_2), 17.8 (CH_3), 17.4 (CH_3), 15.7 (CH_3).

The next compound, eluted from the chromatographic column with the same solvent mixture was *6α-acetoxy-8β,13;13,17-diepoxy-14,15-bisnorlabdane* **23** (118 mg, 17%), mp 121–122 °C (from *n*-hexane); [Found: C, 71.7; H, 9.6. $C_{20}H_{32}O_4$ requires C, 71.39; H, 9.59%]; $[\alpha]_D^{20}$ +25.3 (*c* 0.04); ν_{max} (Nujol) 1730, 1243, 1155, 1015 cm^{-1}; δ_H (400.13 MHz) 5.33 (1H, dt, *J* 11.08, 4.48 Hz, *H*-6), 3.76 (1H, d, *J* 6.75 Hz), 3.31 (1H, d, *J* 6.75 Hz, *H*$_2$-17), 2.03

(3H, s, OCOMe), 1.42 (3H, s, *Me*), 1.18 (3H, s, *Me*), 1.16 (3H, s, Me), 0.90–2.20 (14H, m), 0.91 (3H, s, *Me*); δ_C (100.61 MHz) 169.9 (C), 108.8 (C), 81.7 (C), 75.7 (CH_2), 70.5 (CH), 57.4 (CH), 49.7 (CH), 43.7 (CH_2), 41.2 (CH_2), 40.3 (C), 40.2 (CH_2), 36.7 (CH_3), 33.5 (CH_2), 33.2 (C), 24.9 (CH_3), 22.5 (CH_3), 21.9 (CH_3), 18.2 (CH_2), 17.7 (CH_3), 16.9 (CH_2).

The last compound, eluted from the chromatographic column with the same solvent mixture, was the *starting ketone* **4** (4.687 mg, 88%).

4.1.2. Photolysis of acetoxyketone (4) in argon atmosphere. A solution of acetoxyketone **4** (100 mg, 0.313 mmol) in dry *n*-hexane (320 mL) was poured into the quartz flask of the photoreactor and a stream of dry argon was bubbled through the solution before and during the irradiation. The solution was cooled to 5 °C and irradiated for 2 h with the 450-W UV lamp. The removal of the solvent afforded an yellow oil (119 mg), which was purified by column chromatography on silica gel (12 g, eluent PE/EtOAc 85:15), yielding *acetoxydiene* **18** (15 mg, 78.5%) as a colourless oil, unreacted *starting material* **4** (78 mg, 78%) and *acetoxyketal* **23** (6 mg, 26%).

4.1.3. Photolysis of acetoxyketone (4) in oxygen atmosphere. A solution of **4** (100 mg, 0.313 mmol) in dry *n*-hexane (320 mL) was poured into the quartz flask of the photoreactor and a stream of dry oxygen was bubbled through the solution before and during the irradiation. The solution was cooled to 5 °C and irradiated for 2 h with the 450-W UV lamp. The removal of the solvent afforded a yellow oil (114 mg), which was purified by column chromatography on silica gel (12 g, eluent: PE/EtOAc 85:15), yielding *acetoxydiene* **18** (7 mg, 14%) as an oil, unreacted *starting material* **4** (46 mg, 46%) and *acetoxyketal* **23** (23 mg, 40%).

4.1.4. Photolysis of 14,15-bisnorlabd-8(17)-ene-6,13-dione (5). A solution of the diketone **5** (260 mg, 0.94 mmol) in dry hexane (800 mL) was poured into quartz flask of the photoreactor and a stream of dry nitrogen was bubbled through the solution before and during the irradiation. The solution was cooled to 5 °C and irradiated for 4 h with the 700-W UV lamp. The removal of the solvent afforded the crude product (224 mg), which was purified by column chromatography on silica gel (22 g, eluent: PE/EtOAc, 98:2), to yield *ketodienes* **24** (46 mg, 36%), and **25** (25 mg, 19.4%) as yellow oils and unreacted *starting material* **5** (97 mg, 37%).

Drim-8(12),9(11)-diene-6-one (**24**), oil; [Found: C, 82.2; H, 10.1. $C_{15}H_{22}O$ requires C, 82.51; H, 10.16%]; $[\alpha]^{22}_{D}$ +15.3 (*c* 0.085); ν_{max} (liquid film) 1715, 1673, 1628, 901 cm^{-1}; δ_H (200.13 MHz) 5.08 (1H, s), 5.02 (1H, m) (CH_2═), 4.80 (1H, s), 4.69 (1H, m) (CH_2═), 3.14 (1H, d, *J* 16.6 Hz), 3.04 (1H, d, *J* 16.6 Hz, *H_2*-7), 2.18 (1H, s, *H*-5), 1.00–1.80 (6H, m), 1.20 (3H, s, *Me*), 0.97 (6H, s, *Me_2*); δ_C (50.32 MHz) 208.1 (C), 158.4 (C), 144.1 (C), 111.8 (CH_2), 106.6 (CH_2), 62.5 (CH), 50.7 (CH_2), 42.9 (CH_2), 40.6 (C), 37.8 (CH_2), 32.9 (CH_3), 32.8 (C), 23.6 (CH_3), 21.8 (CH_3), 18.6 (CH_2).

Drim-7,9(11)-diene-6-one (**25**), oil; $[\alpha]^{25}_{D}$ −101.3 (*c* 0.075); ν_{max} (liquid film) 3092, 1710, 1667, 893, 853 cm^{-1}; δ_H (200.13 MHz) 5.76 (1H, s, *H*-7), 5.25 (1H, s), 5.19 (1H, d, *J* 1.66 Hz, *H_2*-11), 2.19 (1H, s, *H*-5), 1.97 (3H, s, *Me*), 1.20–1.90 (6H, m), 1.12 (3H, s, *Me*), 1.09 (3H, s, *Me*), 1.08 (3H, s, Me); δ_C (50.32 MHz) 200.3 (C), 156.1 (C), 149.6 (C), 128.0 (CH), 111.8 (CH_2), 61.1 (CH), 43.1 (CH_2), 42.9 (C), 37.8 (CH_2), 33.3 (CH_3), 32.7 (C), 23.2 (CH_3), 21.7 (CH_3), 20.3 (CH_3), 18.4 (CH_2). Lit.[18] $[\alpha]^{20}_{D}$ −160.8; the spectral data are identical with those described in the literature.[4,18]

4.1.5. Photolysis of 14,15-bisnorlabd-7-ene-6,13-dione (6). A solution of diketone **6** (420 mg, 1.51 mmol) in dry *n*-hexane (800 mL) was poured into the quartz flask of the photoreactor and a stream of dry nitrogen was bubbled through the solution before and during the irradiation. The solution was cooled to 5 °C and irradiated for 4 h with the 700-W UV lamp. The removal of the solvent afforded a yellow oil (384 mg), which was purified by column chromatography on silica gel (35 g, eluent: PE/EtOAc 9:1), to give successively *diene* **25** (73 mg, 67.5%), *ketoalcohol* **26** as an oil (24 mg, 17.5%) and unreacted *starting material* **6** (283 mg, 67%).

The spectral data of ketodiene **25** are identical with those mentioned above.

Cyclobuto(18→6)-14,15-bisnorlabd-8(17)-ene-6-ol-13-one (**26**), oil; [Found: C, 78.1; H, 10.4. $C_{18}H_{28}O_2$ requires C, 78.21; H, 10.21%]; $[\alpha]^{20}_{D}$ +45.5 (*c* 0.02); ν_{max} 3577, 3090, 1705, 1635, 1145, 885 cm^{-1}; δ_H (400.13 MHz) 5.03 (1H, s), 4.79 (1H, s) (CH_2═), 2.12 (3H, s, CO*Me*), 2.05–2.62 (6H, m), 1.49 (3H, s, *Me*), 0.86–1.90 (11H, m), 0.85 (3H, s, *Me*); δ_C (100.61 MHz) 209.0 (C), 147.5 (C), 112.7 (CH_2), 78.6 (C), 59.9 (CH), 58.2 (CH), 54.5 (CH_2), 53.2 (CH_2), 42.3 (CH_2), 42.0 (CH_2), 41.9 (CH_2), 41.0 (C), 37.9 (C), 30.0 (CH_3), 21.4 (CH_2), 20.2 (CH_3), 19.6 (CH_2), 12.6 (CH_3).

4.1.6. Preparation of 2,4-DNPH of ketoalcohol (26). To the solution of ketoalcohol **26** (20 mg) in ethanol (1 mL) was added freshly prepared solution of 2,4-dinitrophenylhydrazine (30 mg) in EtOH (0.8 mL) containing 0.05 mL of concd H_2SO_4. The mixture was stirred at room temperature for 3 h (the course of the reaction was controlled by TLC). Then the reaction mixture was diluted with water (4 mL) and extracted with diethyl ether (3×10 mL). The organic layer was washed with water and dried. After removal of the solvent under reduced pressure the crude product (53 mg) was purified by column chromatography on silica gel (5 g, eluent: PE/EtOAc 95:5), to give two fractions (18 mg and 14 mg), and both were rechromatographied on SiO_2 (3 g). Two products were obtained and recrystallized from a *n*-hexane–EtOAc mixture to give **27** mp 133–133.5 °C and **28** mp 155–157.5 °C. Their structures were established by X-ray analysis.

4.1.7. Isomerization of hydroxyketone (26). To a solution of hydroxiketone **26** (3.5 mg, 0.013 mmol) in 0.5 mL EtOH were added two drops of concd H_2SO_4 and the mixture was stirred at room temperature for 48 h (the course of the reaction was controlled by TLC). Then reaction mixture was diluted with water (5 mL) and extracted with diethyl ether (2×5 mL). The organic layer was washed with water (2×5 mL) and dried. The removal of the solvent under reduced pressure afforded *ketone* **5** (3.1 mg, 88.6%), mp 73–74 °C (from petroleum ether); $[\alpha]_D^{20}$ +79.0 (*c* 1.0); ν_{max} (KBr) 1714, 1644, 894 cm^{-1}; δ_H (200.13 MHz) 4.87 (1H, s), 4.59 (1H, br s) (H_2-17), 3.06 (1H, d, *J* 13.5 Hz), 2.95 (1H, d, *J* 13.5 Hz) (H_2-7), 2.55–2.75 (1H, m), 2.30–2.54 (1H, m) (H_2-12), 2.12 (3H, s, *Me*), 1.17 (3H, s, *Me*), 1.00–2.20 (11H, m), 0.96 (3H, s, *Me*), 0.64 (3H, s, Me); δ_C (50.32 MHz) 208.8 (C), 207.9 (C), 143.1 (C), 109.7 (CH_2), 66.2 (CH), 56.0 (CH), 55.7 (CH_2), 42.3 (CH_2), 41.2 (C), 38.6 (CH_2), 32.7 (C), 32.5 (CH_3), 30.1 (CH_3), 21.5 (CH_3), 18.8 (CH_2), 17.6 (CH_2), 15.7 (CH_3); *m/z* (M^+, 54), 258 (20), 151 (57), 124 (20), 123 (94), 109 (100), 107 (26), 95 (40), 81 (45), 43 (57%). Lit.[6] mp 72–74 °C; $[\alpha]_D^{20}$ +80.4.

4.2. Crystal structure determination

X-ray diffraction measurements for **20** and **22** were performed at room temperature on a KUMA Diffraction KM4 diffractometer using graphite monochromatized Mo Kα radiation for compound **20** and Cu Kα for compound **22**. Lattice parameters were obtained from least-squares refinement of 29 reflections with 7.5≤0≥18° for **20** and 30 reflections with 17.5≤0≥65° for **22**. Intensities were measured using ω/20 and ω scan technique at variable speed 1.2–12° min^{-1}. The data were corrected for Lorentz and polarization effects, but not for absorption. X-ray diffraction measurements for **23** were performed at 120 K temperature on a Nonius Kappa CCD diffractometer using graphite monochromatized Mo Kα radiation and at 100 K on Xcalibur Px kappa-geometry diffractometer, using graphite-monochromated Cu Kα radiation for **27** and **28**. Analytical absorption correction was applied for **27** and **28**. The structure were solved by direct methods and refined by full-matrix least-square techniques based on F^2. The non-H atoms were refined with anisotropic displacement parameters. Hydrogen atoms in all structures and non-H atoms of minor fraction molecules in disordered fragments in the structures **27** and **28** were refined using isotropic thermal factors. Calculations were performed using SHELX-97 crystallographic software package.[22]

4.2.1. Crystal data for 20.[23] $C_{20}H_{32}O_3$, Mr=320.46 g mol^{-1}, size 0.30×0.10×0.10 mm^3, orthorhombic, space group $P2_12_12_1$, *a*=7.946(2) Å, *b*=13.503(3) Å, *c*=16.798(3) Å, *V*=1802.3(7) Å^3, *Z*=4, ρ_{calcd}=1.181 g cm^{-3}, μ(Mo Kα)=0.77 cm^{-1}, *F*(000)=704, 2217 reflections in *h*(−10/1), *k*(0/17), *l*(0/21), measured in the range 1.94≤Θ≤26.82, completeness Θ_{max}=94.5%, 2091 independent reflections, R_{int}=0.0340, 209 parameters, 0 restraints, $R1_{obs}$=0.0466, $wR2_{obs}$=0.1273, $R1_{all}$=0.0971, $wR2_{all}$=0.1500, GOOF=1.023, largest difference peak and hole: 0.211/−0.192 e Å^{-3}.

4.2.2. Crystal data for 22.[23] $C_{20}H_{32}O_3$, Mr=320.46 g mol^{-1}, size 0.25×0.10×010 mm^3, orthorhombic, space group $P2_12_12_1$, *a*=9.420(2) Å, *b*=11.300(2) Å, *c*=17.302(3) Å, *V*=1841.7(6) Å^3, *Z*=4, ρ_{calcd}=1.156 g cm^{-3}, μ(Cu Kα)=5.93 cm^{-1}, *F*(000)=704, 2122 reflections in *h*(−11/1), *k*(−14/0), *l*(−21/0), measured in the range 4.67≤Θ≤73.49, completeness Θ_{max}=94.1%, 2004 independent reflections, R_{int}=0.0513, 209 parameters, 0 restraints, $R1_{obs}$=0.0510, $wR2_{obs}$=0.1382, $R1_{all}$=0.1572, $wR2_{all}$=0.1802, GOOF=1.002, largest difference peak and hole: 0.366/−0.252 e Å^{-3}.

4.2.3. Crystal data for 23.[23] $C_{20}H_{32}O_4$, Mr=336.46 g mol^{-1}, size 0.25×0.10×0.10 mm^3, monoclinic, space group $P2_1$, *a*=6.099(1) Å, *b*=28.941(6) Å, *c*=21.090(4) Å, β=90.08(3)°, *V*=3722.6(12) Å^3, *Z*=8, ρ_{calcd}=1.201 g cm^{-3}, μ(Mo Kα)=0.82 cm^{-1}, *F*(000)=1472, 21171 reflections in *h*(−7/7), *k*(−34/34), *l*(−24/24), measured in the range 1.19≤Θ≤25.00, completeness Θ_{max}=94.5%, 11801 independent reflections, R_{int}=0.0740, 886 parameters, 7 restraints, $R1_{obs}$=0.0774, $wR2_{obs}$=0.1237, $R1_{all}$=0.1228, $wR2_{all}$=0.1369, GOOF=1.030, largest difference peak and hole: 0.249/−0.272 e Å^{-3}.

4.2.4. Crystal data for 26.[23] $C_{24}H_{32}N_4O_5\cdot0.5(H_2O)$, Mr=465.54 g mol^{-1}, size 0.45×0.11×0.04 mm^3, monoclinic, space group *C*2, *a*=16.717(5) Å, *b*=6.565(3) Å, *c*=22.362(6) Å, β=106.78(3)°, *V*=2349.7(14) Å^3, *Z*=4, ρ_{calcd}=1.316 g cm^{-3}, μ(Cu Kα)=7.73cm^{-1}, *F*(000)=988, 9122 reflections in *h*(−20/18), *k*(−8/6), *l*(−19/27), measured in the range 4.13≤Θ≤76.09, completeness Θ_{max}=90.1%, 3774 independent reflections, R_{int}=0.0425, 416 parameters, 1 restraints, $R1_{obs}$=0.0558, $wR2_{obs}$=0.1391, $R1_{all}$=0.0655, $wR2_{all}$=0.1493, GOOF=1.008, largest difference peak and hole: 0.411/−0.271 e Å^{-3}.

4.2.5. Crystal data for 27.[23] $C_{24}H_{32}N_4O_5$, Mr=456.54 g mol^{-1}, size 0.15×0.10×0.03 mm^3, orthorhombic, space group $P2_12_12_1$, *a*=7.157(3) Å, *b*=15.012(5) Å, *c*=43.51(2) Å, *V*=4675(3) Å^3, *Z*=8, ρ_{calcd}=1.297 g cm^{-3}, μ(Cu Kα)=7.51 cm^{-1}, *F*(000)=1952, 41120 reflections in *h*(−7/8), *k*(−18/14), *l*(−46/53), measured in the range 3.58≤Θ≤72.50, completeness Θ_{max}=99.4%, 8882 independent reflections, R_{int}=0.1533, 623 parameters, 0 restraints, $R1_{obs}$=0.0837, $wR2_{obs}$=0.1784, $R1_{all}$=0.1527, $wR2_{all}$=0.2181, GOOF=0.994, largest difference peak and hole: 0.261/−0.237 e Å^{-3}.

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