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Synthesis and Structure of 1,9-Dinitro-5-oxa-11-azatricyclo[6.4.0.04,9]dodecan-2-one

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Abstract—A series of 6,11-disubstituted 1,9-dinitro-5-oxa-11- azatricyclo[6.4.0.0^{4,9}]dodecan-2-ones were prepared from anionic adducts of 2,4-dinitrophenol with propanone and 2-phenylethanone carbanions by successive selective reduction with sodium borohydride and aminomethylation with formaldehyde and primary amines. By spectral methods and by quantum-chemical calculations following PM3 method the structure of the molecules synthesized was shown to contain all the three rings in a *chair* form with equatorial substituents in positions *6* and *11*.

Nitroarenes are fairly often involved in the synthesis of polyfunctional N,O-heterocyclic compounds possessing quite a number of useful properties [1]. In continuation of investigations [2–8] on applying anionic σ-adducts of dinitroarenes **I** to preparation of polyfunctional derivatives of 3-azabicyclo[3.3.1]nonane, an important class of compounds possessing versatile biological activity [9], in the present study syntheses were performed of a series of 6-R-11-R'-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-ones **IIa–IIj**. The preparation of compound **IIa** at reduction of Janovsky σ-adduct of 2,4-dinitrophenol and acetone (**Ia**) with sodium borohydride was first reported [10], but no reliable proofs of tricyclic compound formation were given. Therefore we carried out a more detailed investigation of the molecular structure of compounds synthesized by means of NMR spectroscopy.

The reduction of carbonyl group in oxopropyl and 2-phenyloxoethyl substituents in the Janovsky adducts **Ia** and **Ib** was performed with the use of $NaBH_4$. This reagent of high chemoselectivity is commonly used for selective reduction of an isolated carbonyl group of a saturated ketone in the presence of a conjugated C=O bond [11]. The forming intermediate secondary alcohols **A** without separation from the reaction mixture were brought into the Mannich condensation with primary amines and formaldehyde. As a result we obtained in 50–70% yields N,O-containing tricyclic compounds **IIa–IIj**. The maximum yield of the compounds was obtained in a mixture MeCN–water at 20°C and the solution pH 6.0.

The structure of 6-R-11-R'-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-ones **IIa–IIj** is confirmed by the presence in their IR spectra of strong absorption bands in the region 1545–1550 and 1340–1365 cm^{-1} corresponding to the stretching vibrations of nitro groups. The vibrations of the C=O bond of the endocyclic keto group give rise to absorption in the region 1725–1755 cm^{-1}. The absorption band at lower frequencies (1085–1145 cm^{-1}) belongs to the stretching vibrations of the ether group COC in pyran ring.

The assignment of the signals in the NMR spectra of compounds synthesized was done with the help of two-dimensional homo- (COSY, NOESY) and heteronuclear (HSQC, HMBC) spectroscopy ensuring the reliable proof of the structure and conformation of the compounds. For instance, in the ^{1}H NMR spectrum of compound **IIa** appear 11 signals of chemically or magnetically non-equivalent protons, and in the ^{13}C NMR spectrum signals from 10 carbon atoms in the rings are present. The signals having no correlation peaks in the 2D HSQC spectrum at δ_C 197.14, 93.19, and 86.39 ppm belong to the carbon of C=O group and to atoms C^1 and C^9 respectively. The signals of the quaternary carbon atoms are revealed by the appearance of the corresponding cross-peaks through two bonds H^4/C^9, H^{10e}/C^9, H^{10a}/C^9, and H^{12e}/C^1, H^{12a}/C^1 in the spectrum HMBC (Table 1).

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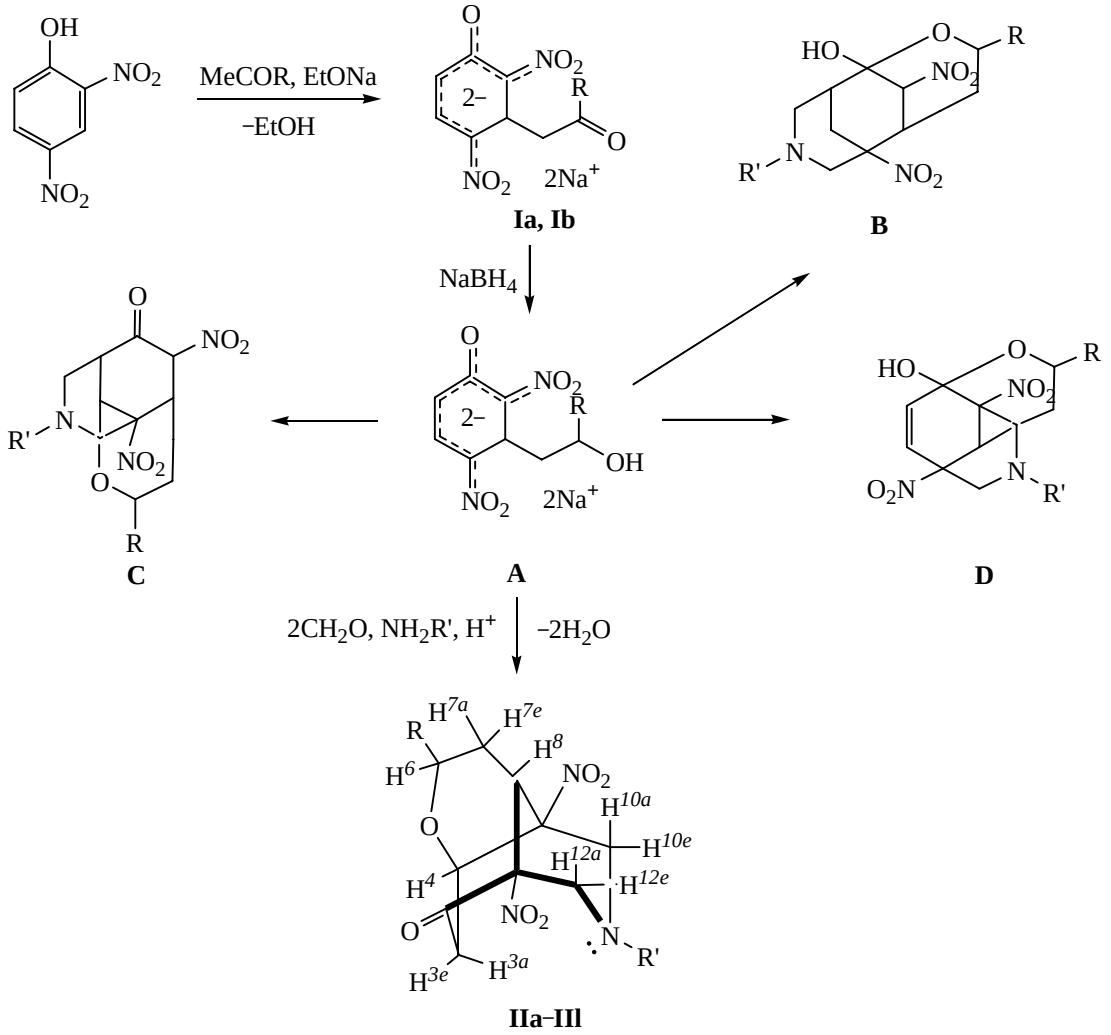

I, R = Me (**a**), Ph (**b**); **II**, R = Me, R' = Me (**a**), Et (**b**), Bu (**c**), $(CH_2)_2Br$ (**d**), Bn (**e**), $(CH_2)_2CO_2H$ (**f**); R = Ph, R' = Me (**g**), Et (**h**), $(CH_2)_2Br$ (**i**), Bn (**j**).

Table 1. Correlation peaks in the HMBC spectrum of 6,11-dimethyl-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (**IIa**)

Atom number	δ_H, ppm	δ_C, ppm	HMBC[a]	J_{HH}, Hz
1	–	93.19	H^{3a}, H^{12e}, H^{12a}	–
2	–	197.14	H^{3a}, H^{3e}, H^{4}, H^{12a}	–
3	3.35 d.d, 2.99 d	44.62	H^{12e}	19.03, 5.09
4	5.02 m	71.95	H^{3a}, H^{10e}, H^{10a}	–
6	3.79 m	61.64	H^{4}, 6-Me	–
7	1.98 d.t, 1.80 d.d.d	29.60	6-Me	15.09, 12.20, 4.27, 2.44
8	3.55 d.d, 2.99 d	41.18	H^{12a}	19.03, 5.90
9	–	86.39	H^{3a}, H^{4}, H^{7e}, H^{10e}, H^{10a}	–
10	3.36 d, 2.89 d	60.30	H^{4}, H^{8}, H^{12a}, NMe	11.20
12	3.27 d, 2.57 d	59.55	H^{2}, H^{8}, H^{10a}, NMe	11.20
6-CH_3	1.14 d	21.05	–	5.91
NCH_3	2.33 s	43.87	–	–

[a] Atoms are numbered according to the carbon atom notation.

A quantum-chemical calculation of some conformations of 6,11-dimethyl-1,9-dinitro-5-oxa-11-azatricyclo-[6.4.0.0^{4,9}]dodecan-2-one (**IIa**) by PM3 procedure [12] showed that all three rings in the molecule existed in the *chair* form (Table 2). The results of geometrical parameters optimization also indicated that although the values of enthalpies of formation were fairly close (the difference did not exceed 5%) the conformer 1*S*,4*R*,6*R*,8*R*,9*R*,11*R* with a diequatorial position of 6,11-methyl groups was somewhat more stable (the torsion angles C^{13}C^{6}C^{7}C^{8} and C^{9}C^{10}N^{11}C^{14} are equal respectively to –164.21 and –173.15°).

In the ^{1}H NMR spectrum of compound **IIa** the α-protons of pyran ring H^4 and H^6 give rise to multiplet signals in the weakest field at δ 5.02 and 3.79 ppm respectively, and have cross-peaks through one bond in the HSQC spectrum with the signals of atoms C^4 and C^6 (δ_C 71.95 and 61.64 ppm). The signal of the axial proton H^{7a} at δ 1.80 ppm appears as a doublet of doublets of doublets due to couplings with the neighboring protons (^2J 15.09, ^3J 12.20, and 4.27 Hz). One of the vicinal constants observed in the spectrum (12.20 Hz) has the value characteristic of the coupling constant of *trans*-diaxial protons $^3J_{aa}$ in cyclohexane systems of *chair* conformation [13]. Because of rigid junction of the oxygen-containing and nitrogen-containing rings proton H^8 is in equatorial position with respect to the pyran ring (in axial position in the piperidine ring). Therefore the axial position is occupied by proton H^6. The value of the vicinal constant for the dihedral angle of –163.79° between the protons H^6 and H^7 in the optimized structure of molecule **IIa** calculated by the Karplus–Buthner-By equation [14] equaled to 11.76 Hz in good agreement with the experimental value. Therefore the methyl group in position *6* of the compound under study takes an equatorial position. This conclusion on the stereochemistry of the substitient at the atom C^6 is confirmed by the ^{1}H NMR spectra of compounds **IIf–IIj** where the signal from the H^6 proton appears as a doublet of doublets with vicinal constants ^3J 11.5–12.5 and 2.5–3.0 Hz.

Diastereotopic protons H^{10} and H^{12} of the piperidine ring give rise to a group of four well resolved doublets (^2J ~11 Hz) at δ 3.36 (H^{10e}), 3.27 (H^{12e}), 2.89 (H^{12a}), and 2.57 (H^{10a}) ppm. In the HSQC spectrum appear the cross-peaks H^{10e}/C^{10}, H^{10a}/C^{10}, H^{12e}/C^{12} and H^{12a}/C^{12} corresponding to these protons and atoms C^{10} and C^{12} at δ_C 60.30 and 59.55 ppm, and in the HMBC spectrum (Table 1) apart of the above mentioned constants $^2J_{CH}$ from the coupling with atoms C^9 and C^1 are revealed coupling constants $^3J_{CH}$ H^{10a}/C^4, H^{10e}/C^4, H^{10e}/C^8, H^{10e}/C^{12} and H^{12a}/C^2, H^{12e}/C^{10}, H^{12e}/C^8, H^{12a}/C^8. The assignement of signals from the methylene protons of the piperidine fragment given above is in agreement with the known fact that the signals of the axial protons of the six-membered rings are located upfield with respect to those of the equatorial protons in keeping with the diamagnetic anisotropy of the C–C bonds [15]. The signals belonging to protons of the methylene group at atom C^8 are observed in the ^{1}H NMR spectrum of compound **IIa** as a doublet (^2J 19.03 Hz) and doublet of doublets (^2J 19.03, ^3J 5.90 Hz) at δ 2.99 and 3.55 ppm respectively as proved by the presence in the homonuclear correlation spectrum COSY of cross-peaks H^{3e}/H^4 and H^{3a}/H^4 due to coupling with a constant $^3J_{HH}$.

According to the structure of compound **IIa** calculated by PM3 method a nuclear Overhauser effect should exist for axial protons H^{12a} and H^{10a} with the proton H^8 that was confirmed by the NOESY experiment (see the figure). No NOE for ptotons H$^3_{endo}$ and H^{12e}, H^{10e} evidence a considerable flattening of the cyclohexanone fragment of the molecule.

The structure of compounds synthesized is additionally proved by their dissociative decomposition under the electron impact For instance, in the mass spectrum of compound **IIj** alongside the molecular ion peak $[M]^+$ *m/z* 437 are present also fragment ions peaks $[M - NO]^+$, $[M - NO - OH]^+$, $[M - 1 - 2NO_2]^+$, $[M - C_6H_5]^+$, *m/z* respectively 407, 390, 344, 360.

Thus the analysis of spectral data permits a conclusion that under conditions of the experiment simultaneously with aminomethylation of adduct **A** and formation of piperidine ring occurs intramolecular nucleophilic addition of the oxygen from the hydroxy group to the β-carbon of the endocyclic fragment of the unsaturated ketone affording an additional pyran ring. The presence in the molecule of the intermediately formed alcohol **A** of several reactive sites capable of attack either by nucleophilic mode (carbon atom of the C=O bond and β-carbon of the double bond) or by electrophilic mechanism (carbon atoms attached to *aci*-nitro groups and α-carbon of the C=C) makes it possible to form isomeric structures **B**–**D**. However in the ^{1}H NMR spectra of compounds synthesized the proton signal from $CHNO_2$ fragment in the region 6.0–6.5 ppm characteristic of nitroketone **C** is lacking. The formation of hemiacetals **B** and **D** is also hardly probable for in the IR spectra of the tricyclic compounds no band of stretching vibrations ν(OH) is observed in the region 3500–3600 cm^{-1} and a strong band appears in the region of C=O bond C=O (1725–1755 cm^{-1}).

Table 2. Results of quantum-chemical calculations by PM3 procedure of some conformations of 6,11-dimethyl-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (**IIa**)

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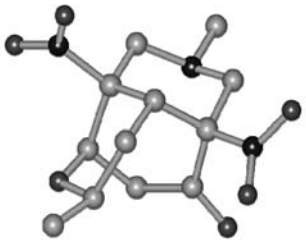
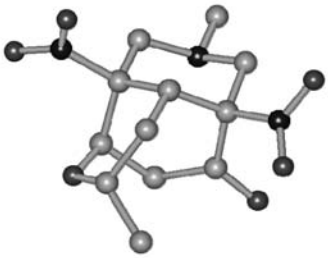
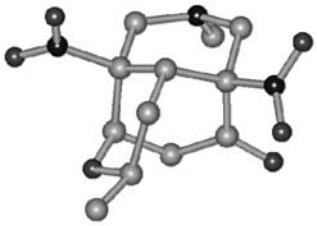
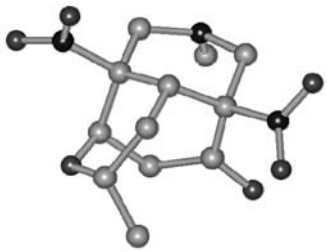
 1*S*,4*R*,6*R*,8*R*,9*R*,11*R*	–339	 1*S*,4*R*,6*S*,8*R*,9*R*,11*R*	–329
 1*S*,4*R*,6*R*,8*R*,9*R*,11*S*	–331	 1*S*,4*R*,6*S*,8*R*,9*R*,11S	–322

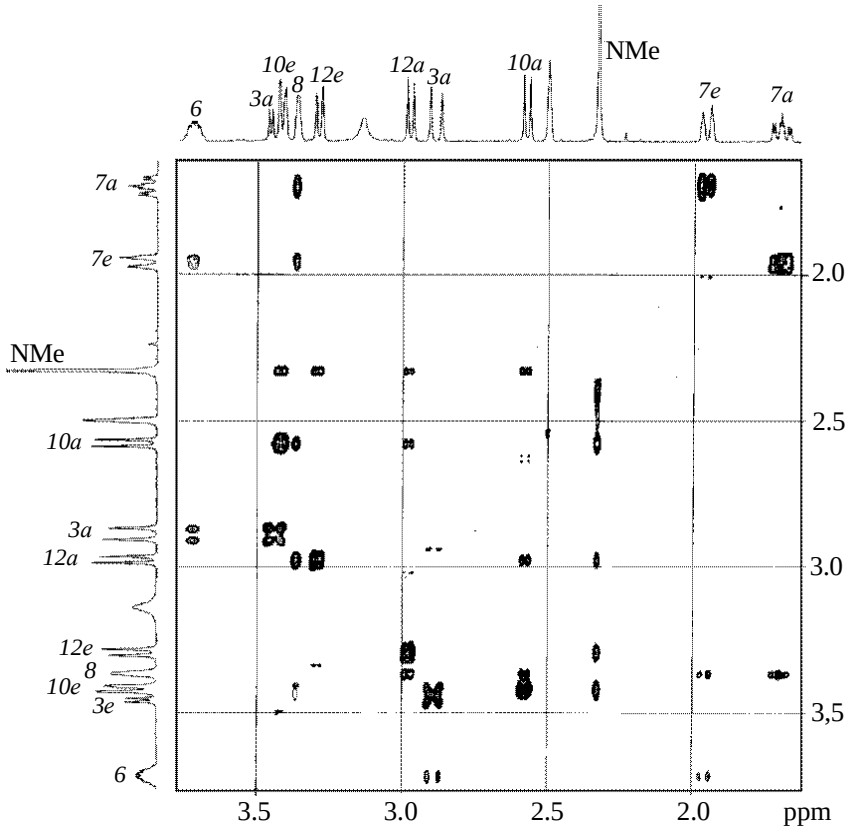
EXPERIMENTAL

IR spectra were recorded on a spectrophotometer Specord 75IR from films prepared from solutions in acetone or acetonitrile or samples pelletized with KBr. ^{1}H NMR spectra were registered on spectrometer Bruker DRX-500 (500.13 MHz) in DMSO-d_6, internal reference HMDS. Mass spectra were obtained on a Varian MAT-311 instrument at the energy of ionizing electrons 70 eV. Retention factors R_f were evaluated on Silufol UV-254 plates, eluent toluene–acetone–hexane, 4:1:1, spots visualized under UV irradiation. Melting points of compounds were measured on a Bo¸tius heating block at a heating rate 1 deg/min. Quantum-chemical calculations were carried out on PC (550 MHz) using software package HyperChem 6.02.

Disodium salts of 3-oxopropyl-2,4-bis(*aci*-nitro)-cyclohex-5-en-1-one (**Ia**) and 3-(2-phenyl-2-oxoethyl)-2,4-bis(*aci*-nitro)cyclohex-5-en-1-one (**Ib**) were obtained by previously described procedures [4, 8].

6-R-11-R'-1,9-Dinitro-5-oxa-11-azatricyclo-[6.4.0.0^{4,9}]dodecan-2-ones IIa–IIj. Into a solution of 0.61 g (0.015 mol) of $NaBH_4$ in 8 ml of water cooled with ice water was added by portions 1.52 g (0.005 mol) of disodium salt of 3-oxopropyl-2,4-bis(*aci*-nitro)cyclohex-5-en-1-one (**Ia**) or 1.81 g (0.005 mol) of disodium salt of 3-(2-phenyl-2-oxoethyl)-2,4-bis(*aci*-nitro)cyclohex-5-en-1-one (**Ib**). The reaction mixture was stirred for 20 min at 15°C. Then 3 ml (0.035 mol) of a cooled solution of 32% formaldehyde and 0.015 mol of an appropriate amine hydrochloride (hydrobromide) or free amine in 8 ml of a mixture water–acetonitrile (1:1 by volume) was added. The temperature during aminomethylation was kept within 15–20°C. By adding 20% solution of orthophosphoric acid the pH of the reaction mixture was adjusted at 6.0. The reaction product was extracted into toluene, the organic layer was washed with water, dried with anhydrous calcium chloride, and the solvent was distilled off in a vacuum. The residue was subjected to column chromatography on silica gel (ASKG), eluent toluene. Compounds **IIa–IIc** and **IIe–IIj** were precipitated from toluene by adding hexane.

6,11-Dimethyl-1,9-dinitro-5-oxa-11-azatricyclo-[6.4.0.0^{4,9}]dodecan-2-one (IIa). Yield 72%, mp 158–159°C [10], R_f 0.53. IR spectrum (acetonitrile), cm^{-1}: 1550 [$\nu_{as}(NO_2)$], 1342 [$\nu_s(NO_2)$], 1364, 1756 (C=O), 1090, 1129, 1146 (C–O), 2805, 2887, 2925, 2968 (CH_{aliph}), 1474, 1483 [$\delta(CH_{aliph})$]. Found, %: C 48.59; H 5.76; N 13.88. $C_{12}H_{17}N_3O_6$. Calculated, %: C 48.16; H 5.73; N 14.05.



Two-dimensional ^{1}H-^{1}H correlation spectrum NOESY of 6,11-dimethyl-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (**IIa**).

6-Methyl-1,9-dinitro-11-ethyl-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IIb). Yield 63%, mp 121–122°C, R_f 0.60. IR spectrum (acetonitrile), cm^{-1}: 1543 [$\nu_{as}(NO_2)$], 1333, 1364 [$\nu_s(NO_2)$], 1726 (C=O), 1084, 1126, 1145 (C–O), 2836, 2877, 2940, 2978 (CH_{aliph}), 1445, 1469 [$\delta(CH_{aliph})$]. ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 5.01 br.d (1H, H^4, ^3J 5.49 Hz), 3.69 m (1H, H^6), 3.46 m (1H, H^8), 3.36 d (1H, H^{12e}, ^2J 10.37 Hz), 3.45 d (1H, H^{10e}, ^2J 10.98 Hz), 3.42 d.d (1H, H^{3e}, ^2J 19.53, ^3J 6.72 Hz), 3.03 d (1H, H^{12a}, ^2J 10.37 Hz), 2.66 d (1H, H^{10a}, ^2J 10.98 Hz), 2.93 d (1H, H^{3a}, ^2J 19.53 Hz), 1.94 d.t (1H, H^{7e}, ^2J 15.26, ^3J 2.44 Hz), 1.65 d.d.d (1H, H^{7a}, ^2J 15.26, ^3J 12.21, $^{3'}J$ 4.27 Hz), 1.07 d (3H, CH_3, ^3J 6.11 Hz), 2.52 q (2H, $\underline{CH_2}CH_3$, ^2J 7.32 Hz), 0.98 t (2H, $CH_2\underline{CH_3}$, ^2J 7.32 Hz). Found, %: C 50.38; H 6.13; N 12.73. $C_{13}H_{19}N_3O_6$. Calculated, %: C 49.83; H 6.07; N 13.41.

11-Butyl-6-methyl-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IIc). Yield 52%, mp 110–111°C, R_f 0.81. IR spectrum (acetonitrile), cm^{-1}: 1543 [$\nu_{as}(NO_2)$], 1339, 1356, 1371 [$\nu_s(NO_2)$], 1726 (C=O), 1092, 1127, 1149, 1169 (C–O), 2830, 2871, 2928, 2957 (CH_{aliph}), 1452, 1456 [$\delta(CH_{aliph})$]. ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 5.04 br.d (1H, H^4, ^3J 3.66 Hz), 3.68 m (1H, H^6), 3.50 m (1H, H^8), 3.36 d (1H, H^{12e}, ^2J 10.38 Hz), 3.46 d (1H, H^{10e}, ^2J 10.99 Hz), 3.38 d.d (1H, H^{3e}, ^2J 19.53, ^3J 6.70 Hz), 3.01 d (1H, H^{12a}, ^2J 10.38 Hz), 2.65 d (1H, H^{10a}, ^2J 10.99 Hz), 2.97 d (1H, H^{3a}, ^2J 19.53 Hz), 1.92 d.t (1H, H^{7e}, ^2J 15.25, ^3J 2.44 Hz), 1.62 d.d.d (1H, H^{7a}, ^2J 15.25, ^3J 12.21, $^{3'}J$ 4.28 Hz), 1.05 d (3H, CH_3, ^3J 5.5 Hz), 2.43 t (2H, H$^\alpha$, ^2J 7.02 Hz), 1.37 m (2H, H$^\beta$), 1.17 m (2H, H$^\gamma$), 0.85 t (3H, H$^\delta$, ^2J 7.02 Hz). Found, %: C 52.83; H 6.85; N 12.49. $C_{15}H_{23}N_3O_6$. Calculated, %: C 52.78; H 6.74; N 12.31.

11-(2-Bromoethyl)-6-methyl-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IId). Yield 54%, mp 143–144°C, R_f 0.57. IR spectrum (acetone), cm^{-1}: 1529 [$\nu_{as}(NO_2)$], 1326, 1352 [$\nu_s(NO_2)$], 1725 (C=O), 1081, 1110, 1117, 1142 (C–O), 2824, 2896, 2924, 2941, 2970 (CH_{aliph}), 1438, 1477 [$\delta(CH_{aliph})$]. ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 5.00 br.d (1H, H^4, ^3J 4.27 Hz), 3.70 m (1H, H^6), 3.47 m (1H, H^8), 3.44 d (1H, H^{12e}, ^2J 10.99 Hz), 3.52 d (1H, H^{10e}, ^2J 10.99 Hz), 3.63 d.d (1H, H^{3e}, ^2J 19.03, ^3J 6.07 Hz), 2.81 d (1H, H^{10a}, ^2J 10.99 Hz), 3.19 d (1H, H^{12a}, ^2J 10.99 Hz), 2.94 d (1H, H^{3a}, ^2J 19.03 Hz), 1.95 d.t (1H,

H^{7e}, ^2J 15.26, ^3J 2.44 Hz), 1.65 d.d.d (1H, H^{7a}, ^2J 15.26, ^3J 11.20, $^{3'}J$ 4.28 Hz), 1.08 d (3H, CH_3, ^3J 6.0 Hz), 3.57 m (2H, $CH_2\underline{CH_2}Br$), 2.89 m (2H, $\underline{CH_2}CH_2Br$). Found, %: C 40.49 ; H 4.66; Br 19.99; N 12.07. $C_{13}H_{18}BrN_3O_6$. Calculated, %: C 39.81; H 4.62; Br 20.37; N 10.71.

11-Benzyl-6-methyl-1,9-dinitro-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IIe). Yield 58%, mp 134–136°C, R_f 0.63. IR spectrum (acetone), cm^{-1}: 1536[$\nu_{as}(NO_2)$], 1330, 1369 [$\nu_s(NO_2)$], 1721 (C=O), 1092, 1112, 1152 (C–O), 2841, 2890, 2944, 2982 (CH_{aliph}), 1441, 1481 [$\delta(CH_{aliph})$]. ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 4.98 br.d (1H, H^4, ^3J 5.49 Hz), 3.69 m (1H, H^6), 3.44 m (1H, H^8), 3.49 d (1H, H^{10e}, ^2J 11.30 Hz), 3.24 d (1H, H^{12e}, ^2J 10.38 Hz), 3.54 d.d (1H, H^{3e}, ^2J 19.23, ^3J 6.71 Hz), 2.75 d (1H, H^{10a}, ^2J 11.30 Hz), 2.99 d (1H, H^{12a}, ^2J 10.99 Hz), 2.98 d (1H, H^{3a}, ^2J 19.23 Hz), 1.93 d.t (1H, H^{7e}, ^2J 15.51, ^3J 2.44 Hz), 1.66 d.d.d (1H, H^{7a}, ^2J 15.51, ^3J 11.85, $^{3'}J$ 3.66 Hz), 1.08 d (3H, CH_3, ^3J 5.50 Hz), 3.75 d (1H, Hα, ^2J 13.43 Hz), 3.53 d (1H, Hβ, ^2J 13.43 Hz), 7.20 d (2H, $H^{2',6'}$, ^2J 7.32 Hz), 7.33 t (2H, $H^{3',5'}$, ^2J 7.32 Hz), 7.28 t (1H, $H^{4'}$, ^2J 7.32 Hz). Found, %: C 58.26; H 5.63; N 11.67. $C_{18}H_{21}N_3O_6$. Calculated, %: C 57.59; H 5.63; N 11.19.

3-(6-Methyl-1,9-dinitro-2-oxo-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodec-11-yl)propanoic acid (IIf). Yield 60%, mp 173–174°C, R_f 0.62. ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 4.96 d.d (1H, H^4, ^3J 5.5, 2.44 Hz), 3.72 m (1H, H^6), 3.45 m (1H, H^8), 3.50 d (1H, H^{10e}, ^2J 10.99 Hz), 3.35 d (1H, H^{12e}, ^2J 10.99 Hz), 3.40 d.d (1H, H^{3e}, ^2J 19.53, ^3J 6.01 Hz), 2.69 d (1H, H^{10a}, ^2J 10.99 Hz), 3.1 d (1H, H^{12a}, ^2J 10.99 Hz), 2.9 d (1H, H^{3a}, ^2J 19.53 Hz), 1.96 d.t (1H, H^{7e}, ^2J 15.87, ^3J 2.44 Hz), 1.72 d.d.d (1H, H^{7a}, ^2J 15.87, ^3J 12.21, $^{3'}J$ 4.27 Hz), 1.12 d (3H, CH_3, J 5.49 Hz), 11.9 br.s (COOH), 2.68 m (2H, $C\underline{H_2}CH_2COOH$), 2.36 m (2H, CH_2CH_2COOH). Found, %: C 47.53; H 5.60; N 11.82. $C_{14}H_{19}N_3O_8$. Calculated, %: C 47.05; H 5.35; N 11.76.

11-Methyl-1,9-dinitro-6-phenyl-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IIg). Yield 69%, mp 178–179°C, R_f 0.66. IR spectrum (acetonitrile), cm^{-1}: 1536 [$\nu_{as}(NO_2)$], 1330, 1369 [$\nu_s(NO_2)$], 1721 (C=O), 1092, 1112, 1152 (C–O), 2841, 2890, 2944, 2982 (CH_{aliph}), 1441, 1481 [$\delta(CH_{aliph})$], 3017 (CH_{arom}). ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 5.22 br.d (1H, H^4, ^3J 5.60 Hz), 4.64 d.d (1H, H^6, ^3J 2.67, ^2J 12.59 Hz), 3.59 m (1H, H^8), 3.51 d (1H, H^{10e}, ^2J 11.14 Hz), 3.37 d (1H, H^{12e}, ^2J 10.37 Hz), 3.54 d.d (1H, H^{3e}, ^2J 19.38, ^3J 5.95 Hz), 2.67 d (1H, H^{10a}, ^2J 11.14 Hz), 3.07 d (1H, H^{12a}, ^2J 10.37 Hz), 3.11 d (1H, H^{3a}, ^2J 19.38 Hz), 2.21 d.t (1H, H^{7e}, ^2J 15.49, ^3J 2.44 Hz), 1.95 d.d.d (1H, H^{7a}, ^2J 15.49, ^3J 12.58, $^{3'}J$ 3.55 Hz), 7.20 d (2H, $H^{2',6'}$, ^2J 7.33 Hz), 7.34 t (2H, $H^{3',5'}$, ^2J 7.33 Hz), 7.28 t (1H, $H^{4'}$, ^2J 7.33 Hz). Found, %: C 56.55; H 5.34; N 11.64. $C_{17}H_{19}N_3O_6$. Calculated, %: C 56.50; H 5.29; N 11.63.

1,9-Dinitro-6-phenyl-11-ethyl-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IIh). Yield 67%, mp 164–165°C, R_f 0.48. IR spectrum (acetonitrile), cm^{-1}: 1535 [$\nu_{as}(NO_2)$], 1328, 1347, 1370 [$\nu_s(NO_2)$], 1720 (C=O), 1116, 1139, 1154 (C–O), 2827, 2878, 2935, 2970 (CH_{aliph}), 1439, 1465, 1488 [$\delta(CH_{aliph})$], 3032 (CH_{arom}). ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 5.23 br.d (1H, H^4, ^3J 4.88 Hz), 4.67 d.d (1H, H^6, ^3J 2.44, ^4J 11.59 Hz), 3.52 m (1H, H^8), 3.06 d (1H, H^{12e}, ^2J 10.38 Hz), 3.55 d (1H, H^{10e}, ^2J 11.29 Hz), 3.53 d.d (1H, H^{3e}, ^2J 19.53, ^3J 5.49 Hz), 2.73 d (1H, H^{10a}, ^2J 11.29 Hz), 3.06 d (1H, H^{12a}, ^2J 10.38 Hz), 3.07 d (1H, H^{3a}, ^2J 19.53 Hz), 2.21 d.t (1H, H^{7e}, ^2J 15.26, ^3J 2.44 Hz), 1.99 d.d.d (1H, H^{7a}, ^2J 15.26, ^3J 11.90, $^{3'}J$ 3.66 Hz), 7.21 d (2H, $H^{2',6'}$, ^2J 7.63 Hz), 7.29 t (2H, $H^{3',5'}$, ^2J 7.63 Hz), 7.23 t (1H, $H^{4'}$, ^2J 7.63 Hz), 2.60 q (2H, $\underline{CH_2}CH_3$, ^2J 7.33 Hz), 1.07 t (2H, $CH_2\underline{CH_3}$, ^2J 7.33 Hz). Found, %: C 56.84; H 5.71; N 11.03. $C_{18}H_{21}N_3O_6$. Calculated, %: C 57.59; H 5.63; N 11.20.

11-(2-Bromoethyl)-1,9-dinitro-6-phenyl-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IIi). Yield 59%, mp 192–193°C, R_f 0.34. IR spectrum (acetonitrile), cm^{-1}: 1534 [$\nu_{as}(NO_2)$], 1339, 1355, 1372 [$\nu_s(NO_2)$], 1725 (C=O), 1116, 1152 (C–O), 2847, 2893, 2915, 2956 (CH_{aliph}), 1437, 1455, 1467 (CH_{aliph}), 3034 (CH_{arom}). ^{1}H NMR spectrum (500.13 MHz, $CDCl_3$), δ, ppm: 5.23 br.d (1H, H^4, ^3J 5.49 Hz), 4.67 d.d (1H, H^6, ^3J 2.44, ^4J 12.21 Hz), 3.54 m (1H, H^8), 3.61 d (1H, H^{10e}, ^2J 10.99 Hz), 3.51 d (1H, H^{12e}, ^2J 10.37 Hz), 3.76 d.d (1H, H^{3e}, ^2J 19.31, ^3J 5.80 Hz), 2.89 d (1H, H^{10a}, ^2J 10.99 Hz), 3.24 d (1H, H^{12a}, ^2J 10.37 Hz), 3.06 d (1H, H^{3a}, ^2J 19.23 Hz), 2.22 d.t (1H, H^{7e}, ^2J 15.87, ^3J 2.44 Hz), 1.98 d.d.d (1H, H^{7a}, ^2J 15.87, ^3J 11.90, $^{3'}J$ 3.97 Hz), 7.21 d (2H, $H^{2',6'}$, ^2J 7.32 Hz), 7.29 t (2H, $H^{3',5'}$, ^2J 7.32 Hz), 7.23 t (1H, $H^{4'}$, ^2J 7.32 Hz), 3.56 m (2H, $CH_2\underline{CH_2}Br$), 2.96 m (2H, $\underline{CH_2}CH_2Br$). Found, %: C 49.32; H 4.50; N 9.12. $C_{18}H_{20}BrN_3O_6$. Calculated, %: C 47.59; H 4.43; N 9.25.

11-Benzyl-1,9-dinitro-6-phenyl-5-oxa-11-azatricyclo[6.4.0.0^{4,9}]dodecan-2-one (IIj). Yield 61%, mp 176–178°C, R_f 0.67. IR spectrum (acetonitrile), cm^{-1}:

1538 [$\nu_{as}(NO_2)$], 1330, 1369, 1376, 1397 [$\nu_s(NO_2)$], 1720 (C=O), 1089, 1116, 1127, 1143 (C–O), 2831, 2872, 2920, 2950 (CH_{aliph}), 1448, 1464, 1493 [$\delta(CH_{aliph})$], 3028, 3056 (CH_{arom}). ^{1}H NMR spectrum (500.13 MHz, DMSO-d_6), δ, ppm: 5.17 br.d (1H, H^4, ^3J 4.88 Hz), 4.76 d.d (1H, H^6, ^3J 12.21, ^4J 3.05 Hz), 3.40 d.d (1H, H^8, ^3J 6.1, ^4J 4.27 Hz), 3.57 d (1H, H^{10e}, ^2J 10.99 Hz), 3.42 d (1H, H^{12e}, ^2J 11.3 Hz), 3.51 d.d (1H, H^{3e}, ^2J 19.53, ^3J 6.1 Hz), 2.70 d (1H, H^{10a}, ^2J 10.99 Hz), 3.02 d (1H, H^{12a}, ^2J 11.3 Hz), 3.19 d (1H, H^{3a}, ^2J 19.23 Hz), 2.22 d.t (1H, H^{7e}, ^2J 15.87, ^3J 3.05 Hz), 2.12 d.d.d (1H, H^{7a}, ^2J 15.87, ^3J 12.21, $^{3'}J$ 3.66 Hz), 7.28 m (5H, Ph), 3.68 d (H$^{\alpha}$, J 13.13 Hz), 3.62 d (H$^{\alpha'}$, J 13.13 Hz), 7.28 m (H_{arom}). Found, %: C 63.05; H 5.46; N 9.94. $C_{23}H_{23}N_3O_6$. Calculated, %: C 63.15; H 5.29; N 9.60.

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