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Reaction of Arylpropargyl Aldehydes with 2,3-Bis-hydroxylamino-2,3-dimethylbutane: Synthesis of 2-(1-Hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-arylethanones

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Abstract—Reaction of arylpropargyl aldehydes with 2,3-dihydroxylamino-2,3-dimethylbutane results in the formation of 2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-arylethanones in high yields (70–80%). Allowing availability of propargyl aldehydes, this method gives new possibilities for the preparation of 2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-arylethanones.

Introduction

In continuation of our study on possible ways of synthesis and of the properties of new Ullman's radicals,[1] we required alkynyl derivatives of nitronyl- and iminonitroxides.[2] One of the key steps in the synthesis of spin-labelled 2-imidazoline derivatives is the condensation of aldehydes (or their synthetic equivalents) with 2,3-dihydroxylamino-2,3-dimethylbutane (introduced as a free base or its acid salt), leading to formation of the corresponding 1,3-dihydroxy-4,4,5,5-tetramethylimidazolidines. Ullman reported that condensation of bis-hydroxylamine with phenylpropargyl aldehyde yielded the corresponding imidazolidine which gave the corresponding nitronylnitroxide in an overall yield of 11% upon treating with an oxidizing agent.[2] In our hands, this procedure led to negative results, necessitating an extended study of the reaction of propargyl aldehydes with 2,3-bis-hydroxylamino-2,3-dimethylbutane. We have found that 1,3-dihydroxy-4,4,5,5-tetramethylimidazolidines are not formed in the reaction of arylpropargyl aldehydes with 2,3-dihydroxylamino-2,3-dimethylbutane under the conditions of the Ullman's synthesis. In fact, the major products of the reaction with arylpropargyl aldehydes[1] were 2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-arylethanones.[2]

Careful review of the literature revealed that the first synthesis of 2-(1-hydroxyimidazolidin-2-ylidene)ethanones was claimed only very recently in connection with new ideas, arising in the field of the design of magnetically active systems on the basis of transition metal complexes with stable nitroxyls.[3] The synthetic scheme includes condensations of a substituted bis-hydroxylamine with a keto-aldehyde and provides certain simple compounds, although the authors state that their synthesis is unacceptable for the preparation of complex derivatives due to some specific problems associated with the ketoaldehyde component. An alternative way of synthesising such compounds is by the interaction of the dilithium derivative of 1-hydroxy-2,4,4,5,5-pentamethylimidazoline with esters of carboxylic acids.[4] Hence, the present formation of 2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-arylethanones **2** by the reaction of propargyl aldehydes with 2,3-dihydroxylamino-2,3-dimethylbutane seems to be a viable alternative to the known synthetic methods for the preparation of these compounds, which are of interest both as a potential precursor for magneto-active systems as well as biologically active compounds.

In this paper, we wish to report the results of our study of the behaviour of a variety of propargyl aldehydes in such

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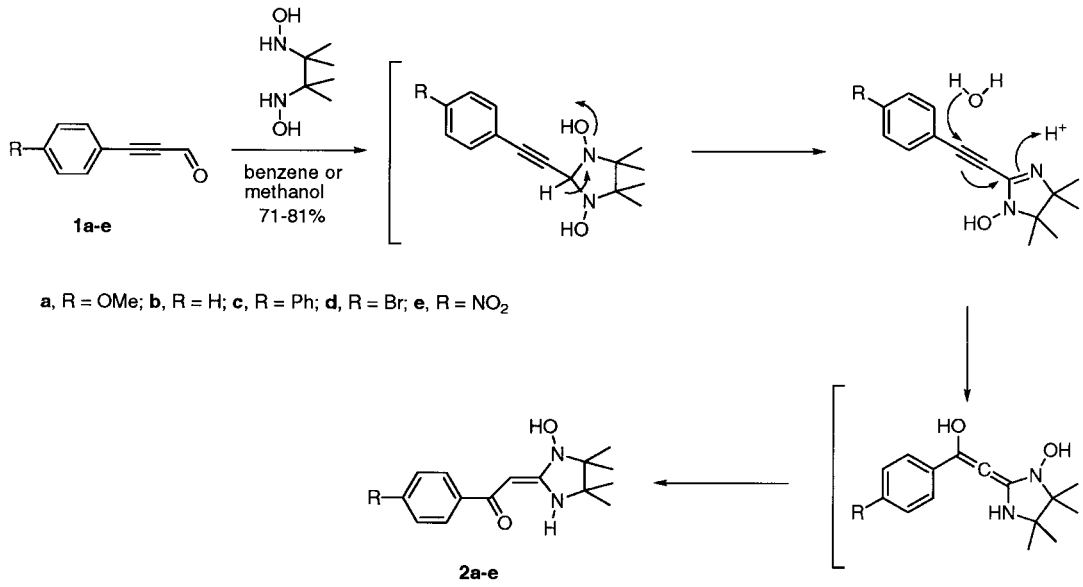


Scheme 1.

chemistry and include some discussion of the peculiar features and possible mechanism of the reaction.

Results and Discussion

Unfortunately, in the original Ullman paper,[2] there were no details of the condensation reaction between phenylpropargyl aldehyde and 2,3-dihydroxylamino-2,3-dimethylbutane, except for the temperature range (0–80°C) and the solvents used (methanol or benzene). We followed these conditions but obtained another product. The reactions of propargyl aldehydes having aromatic substituents with 2,3-dihydroxylamino-2,3-dimethylbutane were carried out as follows: 2,3-bis-hydroxylamino-2,3-dimethylbutane was added to a solution of the propargyl aldehyde **1a**–**e** in benzene at 5°C or in methanol at −30°C and the resulting solution was stirred at the temperature mentioned until disappearance of the starting material (TLC). The total yields of the reaction products were between 71 and 81%. We have tested different *p*-substituted benzene derivatives **1a**–**e** (Scheme 1) and have found that a decrease of the temperature of the reaction mixture usually results in better yields and increased purity of the products.

The data from combustion analysis and mass spectra of the reaction products **2a**–**e** formally correspond to the products of condensation of the propargyl aldehydes with the bis-hydroxylamine and loss of a molecule of water. However, ^{1}H NMR and ^{13}C NMR spectra, as well as IR data, were not consistent with the structure of the 'Ullman' alkyne derivatives. NMR and IR data of the reaction products showed that these all belonged to one and the same structural type, so we performed an X-ray single crystal analysis on

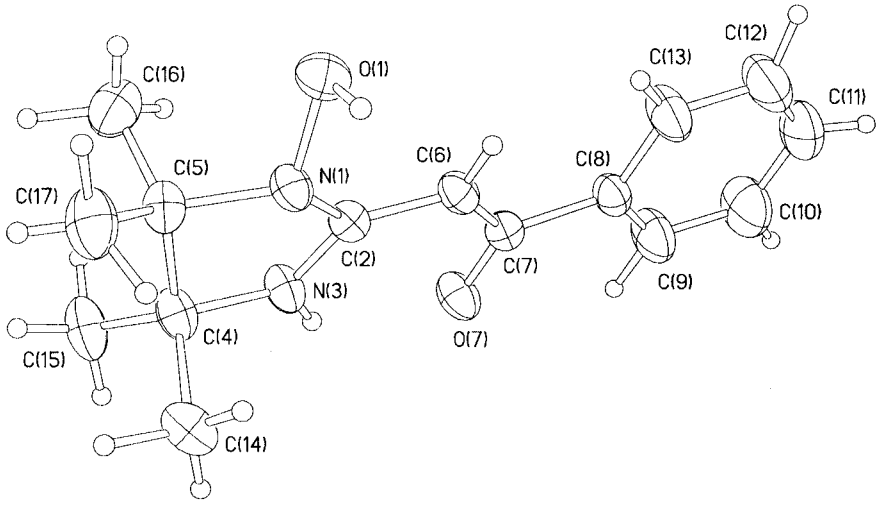


Figure 1. Molecular structure of compound **2b** according to single crystal X-ray analysis. Selected bond lengths (Å) and torsional angles (°) are as follows: C(2)═C(6) 1.409(5), C(6)–C(7) 1.370(5), C(7)═O(7) 1.278(4), C(13)–C(8)–C(7)–C(6) –6.7(6), C(7)–C(6)–C(2)–N(3) 1.0(6), C(2A)═C(6A) 1.390(5), C(6A)–C(7A) 1.385(5), C(7A)═O(7A) 1.268(4), C(13A)–C(8A)–C(7A)–C(6A) –19.2(6), C(7A)–C(6A)–C(2A)–N(3A) 2.0(7).

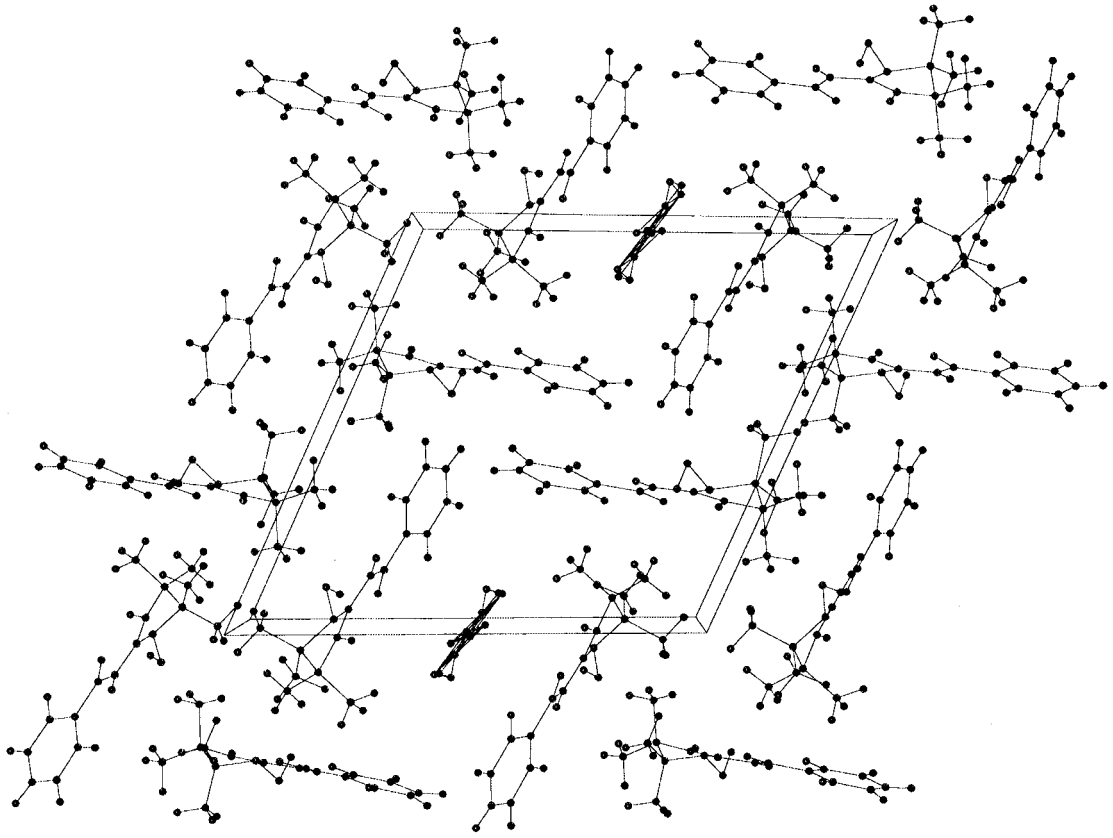


Figure 2. Packing scheme of the molecules **2b** and the solvent molecules (ethyl acetate) in the crystalline state according to X-ray crystallography. The ethyl acetate solvate molecules are in high disorder. The solvate molecules are in high disorder and occupy special positions in throughout cavities.

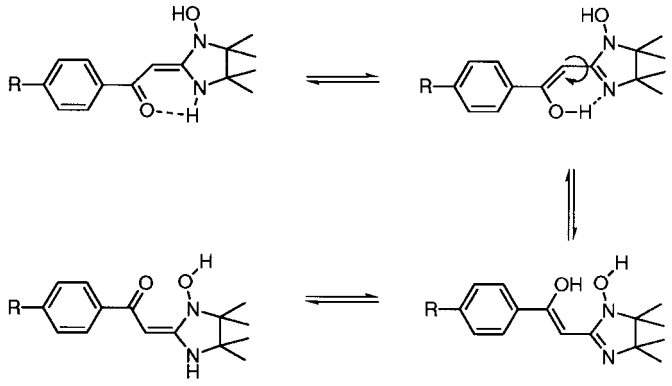
the simplest phenyl derivative **2b** and proved it to belong to a series of 2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-arylethanones (Fig. 1).

The crystal structure of the first molecule from the two crystallographically independent ones is shown in Fig. 1. The $(N)_2C{=}C{-}C(=O){-}Ph$ fragment is planar within ±0.092(3) and ±0.225(3) Å, correspondingly, for both molecules. The envelope-like conformation of the imidazolidine rings can be characterised with C(5) and C(5A) atom deviations from the plane of the rest of the four atoms by 0.563(6) and 0.587(7) Å. It is worth noting the bond length equalizing of the C=C–C=O fragment (1.399, 1.378, 1.273 Å, averaged for two molecules, as compared to the expected mean values[5] 1.340(13), 1.464(18) and 1.222(10) Å). A search for the fragment $(N)_2C{=}C{-}C(=O){-}C$ in the Cambridge structural database[6] revealed five derivatives of 3-aryl-2-(2-oxoarylethyl)-3H-quinazolin-4-one having anticonvulsant activity as well as in 2-(benzoylmethylene)-hexahydropyrimidine[7] and 2-(benzoylmethylene)-imidazolidine.[8] For all these molecules, the equalising of the bond lengths is also typical, although in the two later compounds, the formally single bonds were even shorter than formally double bonds (1.432, 1.382, 1.287 and 1.403, 1.384, 1.241 Å for the string C=C–C=O). The pyramidal structure of the N(1) and N(1A) atoms (heights of pyramids 0.358(4) and 0.357(4) Å) and the more planar structure of the N(3) and N(3A) atoms (heights 0.08(2) and 0.20(2) Å) were also features of the structure. Infinite chains of molecules along the *a* axis are formed in the crystal by the H-bonds O(1)–H…O(7) ($x-1$, y, z) (H…O(7) 1.64(6) Å, O(1)–H…O(7) 148(5)°) and O(1A)–H…O(7A) ($x+1$, y, z) (H…O(7A) 1.70(4) Å, O(1A)–H…O(7A) 176(4)°). Solvent molecules (ethyl acetate) occupy special positions (0, 0, 0.5) throughout the cavities (Fig. 2). Parameters of the intramolecular H-bonds N–H…O are as follows: N(3)–H…O(7) (H…O(7) 2.08(4) Å, N(3)–H…O(7) 126(3)°), N(3A)–H…O(7A) (H…O(7A) 2.08(4) Å, N(3A)–H…O(7A) 121(3)°).

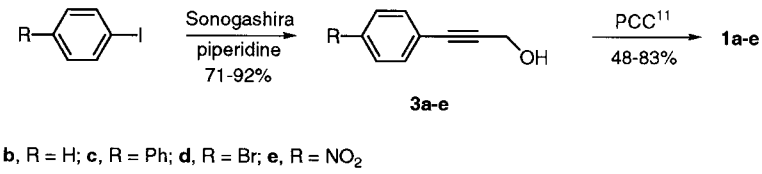
The 1-hydroxyimidazolidin-2-ylidenel-1-aryl ethanones **2a–e** are coloured solids with different tints of yellow, which are quite stable in the crystalline state but are unstable in solution, especially in the open air. NMR spectra of all the compounds **2a–e** have more or less broad lines (methyls, NH, NOH, O=C–CH=N) due to an exchange process. The lines become narrower upon heating and come to the original width on cooling. The exchange might be due to proton transfer processes and *cis-trans*-isomerisation, as shown in Scheme 2.

The mechanism of the formation of the condensation products **2a–e** is not clear yet, although the hypothetical scheme could be described as a two step process (Scheme 1): (1) condensation of the bis-hydroxylamine with the propargyl aldehydes followed by (2) intramolecular transfer of the hydroxyl group to the β-carbon of the triple bond.

As can be seen from the procedure and the yields, the reaction is a very simple route to functionalized 1-hydroxy-2-



Scheme 2.



Scheme 3.

imidazolines **2**, provided that the corresponding arylpropargyl aldehydes are available. There are a number of methods for the preparation of arylpropargyl aldehydes. In our hands, the most convenient method is oxidation of the corresponding arylpropargyl alcohols (prepared from terminal alkynes or by the method we used) or hydrolysis of arylpropargyl aldehyde diethyl acetal (precursors—terminal alkynes). The terminal acetylenes can be easily synthesised by cross-coupling of organic halides with trimethylsilylacetylene or 2-methylbut-3-yn-2-ol, followed by removal of the protecting groups.[9]

We prepared arylpropargyl alcohols **3a–e** by palladium-catalysed cross-coupling of aryl iodides with propargyl alcohol (Scheme 3).[10] We have improved the cited method by using organic solvents in the presence of two equivalents of piperidine instead of in neat diethylamine. Under these conditions, aryl iodides react with propargyl alcohol at 30–35°C to give arylpropargyl alcohols **3** in high yields (71–92%). Arylpropargyl aldehydes **1** were then prepared by oxidation of the corresponding alcohols with pyridinium chlorochromate similar to the procedure described in ref.[11]

Thus, the reaction of substituted propargyl aldehydes with 2,3-dihydroxylamino-2,3-dimethylbutane seems to be a general synthetic method for the preparation of 2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-arylethanones **2** and can be used as the final step in the reaction sequence leading from organic halides via substituted propargyl aldehydes **1**.

Experimental

All the solvents used were reagent quality. Removal of all solvents was carried out under reduced pressure and all commercial reagents were used without additional purification. Analytical TLC plates were Silufol® UV-254 (Silpearl on aluminum foil, Czecho-Slovakia). Silica gel 'KSK' (Russia, 100–200 mech., air dried and activated at 130°C for 5 h) was used for filtration. IR spectra were obtained for KBr pellets using a Bruker IFS 66 infrared spectrometer. Melting points were obtained using a Kofler melting point apparatus. Microanalyses were obtained using a Hewlett Packard 185 analyser and a Carlo Erba 1106 analyser. Mass spectra were recorded on a Finnigan MAT-8200 instrument using Electron Impact Ionisation technique (70 eV). For imidazilidines **2a–e**, ^{1}H and ^{13}C NMR spectra were recorded at +27°C using a Bruker DRX-500 spectrometer locked to the deuterium resonance of the solvent. Chemical shifts were calculated relative to solvent signals used as the internal standards: δ_H 7.240 ppm and δ_C 76.900 ppm for $CDCl_3$, δ_H 7.190 ppm and δ_C 123.500 ppm for Py-d_5. The other ^{1}H NMR spectra were recorded on a Bruker Avance 300 spectrometer.

(4-Methoxyphenyl)propynal (1a). The compound was prepared by oxidation of **3a** according to Ref. 11

Biphenyl-4-ylpropynal (1c). The compound was synthesised by the procedure similar to that described in Ref. 11 Pyridinium chlorochromate (1.20 g, 5.57 mmol) was added to a stirred solution of **3c** (1.05 g, 5.05 mmol) in dichloromethane (20 ml) at room temperature. The resulting mixture was stirred for 1.5 h (disappearance of the starting propargyl alcohol, TLC), then filtered through silica gel. The filtrate was concentrated in vacuum to give compound **1c** (0.86 g, 83%) as a yellow solid: mp 78–79°C (benzene–hexane 5:1, v/v); IR, ν_{max}=3080, 2179, 1648, 1599, 1480, 1445, 1389, 1263, 1108, 1070, 1038, 1019, 1000, 973, 844 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 7.35–7.85 (m, 9H, aromatic H), 9.49 (s, 1H, CHO). Anal. Calcd for $C_{15}H_{10}O$: C, 87.36; H, 4.89. Found: C, 87.2; H, 5.0.

(4-Bromophenyl)propynal (1d). The compound was prepared from compound **3d** (1.05 g, 4.98 mmol) to give a yellow viscous oil which was treated with hexane to afford a solid which was then purified by crystallisation from a mixture of benzene and hexane to yield the title compound (0.50 g, 48%) as yellowish crystals with mp 54–55°C; lit.: crude oil;[12] IR: ν_{max}=3087, 2199, 1651, 1581, 1474, 1385, 1263, 1062, 1009, 980, 821; ^{1}H NMR ($CDCl_3$) δ 7.51 (d, 2H, J=10 Hz, H^2 and H^6), 7.60 (d, 2H, J=10 Hz, H^3 and H^5), 9.56 (s, 1H, CHO).

(4-Nitrophenyl)propynal (1e). The compound was prepared from compound **3e** in 55% yield. Yellow crystals with mp 122–123°C; {lit.[13]: mp 123–123.5°C}.

Reaction of propargyl aldehydes with 2,3-bishydroxylamino-2,3-dimethylbutane. General procedure

2,3-Bishydroxylamino-2,3-dimethylbutane[14] (0.30 g, 2.03 mmol) was added to a stirred solution of the propargyl aldehyde **1a–e** (2.03 mmol) in benzene (20 ml) at 5°C or in methanol (20 ml) at −30°C for 10 min. The reaction mixture was kept at the same temperature for 1–3 h (disappearance of the starting propargyl aldehyde, TLC). Evaporation of the solvent gave the crude product, which was purified by filtration through silica gel followed by crystallisation.

2-(1-Hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-(4-methoxyphenyl)ethanone (2a). Yield 71%. Yellowish powder with mp 194–195°C (benzene–chloroform 10:1, v/v); IR: ν_{max}=3350, 3140, 2985, 2839, 1596, 1573, 1499, 1460, 1391, 1298, 1252, 1218, 1176, 1143, 1112, 1020, 940, 894, 874, 844; ^{1}H NMR ($CDCl_3$:Py-d_5=5:2) δ 0.83 (s, 6H, 2 CH_3), 0.85 (s, 6H, 2 CH_3), 3.38 (s, 3H, OCH_3), 5.49 (s, 1H, CH═), 6.52 (d, 2H, J=9 Hz, H^2 and H^6), 7.60 (d, 2H, J=9 Hz, H^3 and H^5), 8.8 (br. s, 1H, N–OH), 10.9 (br. s, 1H, NH); ^{13}C NMR ($CDCl_3$:Py-d_5=5:2) δ 17.20 (imidazolidine-4-C(CH_3)$_2$), 22.68 (imidazolidine-5-C(CH_3)$_2$), 54.22 (OCH_3), 59.43 (imidazolidine-C^4), 67.87 (imidazolidine-C^5), 73.60 (CH═), 112.31 (phenyl-C^3 and C^5), 127.72 (phenyl-C^2 and C^6), 133.08 (phenyl-C^1), 160.33 (phenyl-C^4), 163.55 (imidazolidine-C^2), 184.56 (CO). Anal. Calcd for $C_{16}H_{22}N_2O_3$: C, 66.18; H, 7.64; N, 9.65. Found: C, 66.4; H, 7.7; N, 9.4.

2-(1-Hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-phenylethanone (2b). Yield 76%. Yellowish powder with mp 177–178°C (ethyl acetate–hexane 5:1, v/v); IR: ν_{max}=3360, 3089, 2982, 2811, 1599, 1578, 1522, 1487, 1460, 1394, 1295, 1263, 1217, 1164, 1146, 1121, 1095, 1046, 1018, 951, 893, 871; ^{1}H NMR ($CDCl_3$) δ 1.07 (s, 6H, 2 CH_3), 1.10 (s, 6H, 2 CH_3), 5.58 (s, 1H, CH═), 7.25–7.35 (m, 3H, H^2, H^4 and H^6), 7.70–7.80 (m, 2H, H^3 and H^5), 8.9 (br. s, 1H, N–OH); ^{13}C NMR ($CDCl_3$) δ 17.92 (imidazolidine-4-C(CH_3)$_2$), 23.25 (imidazolidine-5-C(CH_3)$_2$), 60.31 (imidazolidine-C^4), 69.18 (imidazolidine-C^5), 78.30 (CH═), 126.88 (phenyl-C^3 and C^5), 127.90 (phenyl-C^2 and C^6), 129.72 (phenyl-C^4), 130.11 (phenyl-C^1), 164.00 (imidazolidine-C^2), 187.00 (CO). Anal. Calcd for $C_{15}H_{20}N_2O_2$: C, 69.20; H, 7.74; N, 10.76. Found: C, 69.3; H, 7.9; N, 10.5.

1-Biphenyl-4-yl-2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)ethanone (2c). Yield 81%. Yellowish powder with mp 127–128°C (benzene–hexane 5:1, v/v); IR: ν_{max}=3350, 3090, 2979, 2929, 1597, 1562, 1524, 1484, 1443, 1393, 1295, 1264, 1218, 1168, 1149, 1123, 1001, 894, 854; ^{1}H NMR ($CDCl_3$) δ 1.13 (s, 6H, 2 CH_3), 1.14 (s, 6H, 2 CH_3), 5.60 (s, 1H, CH═), 7.30–7.90 (m, 9H, aromatic H), 8.9 (br. s, 1H, N–OH); ^{13}C NMR ($CDCl_3$) δ 18.01 (imidazolidine-4-C(CH_3)$_2$), 23.33 (imidazolidine-5-C(CH_3)$_2$), 60.91 (imidazolidine-C^4), 69.25 (imidazolidine-C^5), 78.30 (CH═), 126.57 (aromatic C), 126.93 (aromatic C), 127.44 (aromatic C), 128.20 (aromatic C), 128.65 (aromatic C), 137.72 ($C^{1''}$), 139.71 ($C^{4'}$), 140.22 ($C^{1'}$), 164.50 (imidazolidine-C^2), 186.00 (CO). Anal. calcd for $C_{21}H_{24}N_2O_2$: C, 74.97; H, 7.19; N, 8.33. Found: C, 74.7; H, 7.3; N, 8.4. MS, m/z (%): 336.18350 (M^+, 75, calcd for $C_{21}H_{24}N_2O_2$ 336.18377), 84 (26), 98 (52), 100 (23), 152 (32), 153 (22), 181 (100), 182 (15), 207 (13), 222 (15), 262 (15), 263 (11), 320 (9), 336 (75), 337 (17), 338 (3).

1-(4-Bromophenyl)-2-(1-hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)ethanone (2d). Yield 71%. Yellowish powder with mp 189–190°C (benzene–chloroform 10:1, v/v); IR: ν_{max}=3306, 3102, 2972, 2836, 1589, 1567, 1516, 1480, 1451, 1380, 1298, 1266, 1212, 1173, 1149, 1106, 1088, 1068, 1023, 1008, 957, 894, 874, 837; ^{1}H NMR ($CDCl_3$:Py-d_5=4:1) δ 0.92 (s, 6H, 2 CH_3), 0.95 (s, 6H, 2 CH_3), 5.51 (s, 1H, CH═), 7.20 (d, 2H, J=9 Hz, H^2 and H^6), 7.54 (d, 2H, J=9 Hz, H^3 and H^5), 8.8 (br. s, 1H, N–OH), 11.1 (br. s, 1H, NH); ^{13}C NMR ($CDCl_3$:Py-d_5=4:1) δ 17.41 (imidazolidine-4-C(CH_3)$_2$), 22.83 (imidazolidine-5-C(CH_3)$_2$), 59.83 (imidazolidine-C^4), 68.30 (imidazolidine-C^5), 74.11 (CH═), 123.52 (phenyl-C^4), 127.90 (aromatic C), 130.36 (aromatic C), 139.51 (phenyl-C^1), 163.99 (imidazolidine-C^2), 183.80 (CO). Anal. Calcd for $C_{15}H_{19}BrN_2O_2$: C, 53.11; H, 5.65; Br, 23.55. Found: C, 53.3; H, 5.7; Br, 23.7.

2-(1-Hydroxy-4,4,5,5-tetramethylimidazolidin-2-ylidene)-1-(4-nitrophenyl)ethanone (2e). Yield 76%. Yellow powder with mp 214–214.5°C (benzene–chloroform 5:1, v/v); IR: ν_{max}=3450, 3380, 3108, 2966, 2847, 1589, 1525, 1486, 1463, 1392, 1368, 1344, 1318, 1295, 1265, 1228, 1209, 1166, 1146, 1114, 1086, 1024, 897, 853; ^{1}H NMR ($CDCl_3$:Py-d_5=4:1) δ 0.95 (s, 6H, 2 CH_3), 0.99 (s, 6H, 2 CH_3), 5.56 (s, 1H, CH═), 7.78 (d, 2H, J=10 Hz, H^2 and H^6), 7.92 (d, 2H, J=10 Hz, H^3 and H^5), 8.9 (br. s, 1H, N–OH), 11.3 (br. s, 1H, NH); ^{13}C NMR ($CDCl_3$:Py-d_5=5:2) δ 17.46 (imidazolidine-4-C(CH_3)$_2$), 22.81 (imidazolidine-5-C(CH_3)$_2$), 60.13 (imidazolidine-C^4), 68.61 (imidazolidine-C^5), 75.19 (CH═), 122.57 (phenyl-C^3 and C^5), 127.04 (phenyl-C^2 and C^6), 146.42 (phenyl-C^1), 147.86 (phenyl-C^4), 164.20 (imidazolidine-C^2), 182.14 (CO). Anal. Calcd for $C_{15}H_{19}N_3O_4$: C, 59.01; H, 6.27; N, 13.76. Found: C, 59.2; H, 6.0; N, 13.8. MS, m/z (%): 305.13749 (M^+, 100, calcd for $C_{15}H_{19}N_3O_4$ 305.13756), 84 (68), 98 (100), 100 (52), 150 (32), 191 (27), 215 (12), 231 (23), 232 (13), 288 (21), 289 (24), 290 (16), 305 (100), 306 (19), 307 (3).

3-(4-Methoxyphenyl)prop-2-yn-1-ol (3a). The compound was prepared according to the procedure described in Ref. 10 with some modification. Bis(triphenylphosphine)-palladium(II) chloride (120 mg, 0.171 mmol) was added to

a stirred solution of propargyl alcohol (5.60 g, 0.10 mole), 1-iodo-4-methoxybenzene (23.00 g, 0.0983 mole), piperidine (17.0 g, 0.2 mole), and copper iodide (60 mg, 0.32 mmol) in benzene (30 ml) under an argon atmosphere. The mixture was stirred at 30–35°C for 2 h and then filtered through silica gel. The solvent was distilled off and the residue was chromatographed on a silica gel column ($CHCl_3$) followed by crystallisation from benzene/hexane to afford compound **3a** (11.78 g, 74%). White powder, mp 61–63°C; {lit.[11]: mp 62.5–64.5°C}.

3-Biphenyl-4-ylprop-2-yn-1-ol (3b). Yield 88%. Yellowish crystals with mp 88–89°C (benzene–hexane 5:1, v/v); IR: ν_{max}=3287, 2921, 2860, 2225, 1483, 1447, 1404, 1041, 1015, 953, 841; ^{1}H NMR ($CDCl_3$) δ 1.71 (br. s, 1H, OH), 4.57 (s, 2H, CH_2), 7.32–7.63 (m, 9H, aromatic H). Anal. Calcd for $C_{15}H_{12}O$: C, 86.51; H, 5.81. Found: C, 86.4; H, 6.0.

3-(4-Bromophenyl)prop-2-yn-1-ol (3d). Yield 92%. Yellowish crystals with mp 68–69°C (benzene–hexane 5:1, v/v); IR: ν_{max}=3276, 2918, 2860, 2237, 1483, 1393, 1348, 1259, 1238, 1097, 1072, 1027, 951, 823; ^{1}H NMR ($CDCl_3$) δ 1.72 (br. s, 1H, OH), 4.53 (s, 2H, CH_2), 7.32 (d, 2H, J=10 Hz, H^2 and H^6), 7.50 (d, 2H, J=10 Hz, H^3 and H^5). Anal. Calcd for C_9H_7BrO: C, 51.22; H, 3.34; Br, 37.86. Found: C, 51.2; H, 3.3; Br, 37.9.

3-(4-Nitrophenyl)prop-2-yn-1-ol (3e). Yield 71%. Yellow crystals with mp 95–96°C (benzene); {lit.[15]: mp 97–98°C}.

X-Ray crystallographic study of compound 2b

Using a Bruker P4 diffractometer with graphite monochromated Mo K_α radiation, 5458 independent reflections were measured ($\theta/2\theta$ scans with $\theta<25°$). The crystal system of compound **2b** is triclinic, space group P $\bar{1}$, a=6.953(2), b=15.681(4), c=16.542(4) Å, α=113.40(2), β=95.69(1), γ=95.07(2)°, V=1630.9(7) Å^3, ?$_{15}H_{20}N_2O_2$+1/4($C_4H_8O_2$), M=282.36, Z=4, D_c=1.150 g/cm^3, μ=0.078 mm^{-1}, F(000)=608, crystal size 0.04×0.17×0.96 mm.

The structure was solved by direct methods (SHELXS-97) and refined in the anisotropic-isotropic (for atoms H) approximation using SHELXS-97 to wR_2=0.2169, S=1.011 for all reflections (R=0.0672 for 2749 $F>4\sigma$). The hydrogen atoms were positioned geometrically. Due to high disorder of the ethyl acetates, solvate molecule we were unable to interpret the peaks of solvate obtained by differential synthesis.

The crystal structure data has been deposited at the Cambridge Crystallographic Data Centre and allocated the deposition number CCDC 149659.

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References

1. Tretyakov, E. V.; Samoilova, R. I.; Ivanov, Y. V.; Plyusnin, V. F.; Pashchenko, S. V.; Vasilevsky, S. F. *Mendeleev Commun.* **1999**, 92.
2. Ullman, E. F.; Osiecki, J. H.; Boocock, D. G. B.; Darcy, R. *J. Am. Chem. Soc.* **1972**, *94*, 7049.
3. Mazhukin, D. G.; Tikhonov, A. Ya; Reznikov, V. A.; Volodarsky, L. B. *Mendeleev Commun.* **2000**, 69.
4. Reznikov, V. A.; Volodarsky, L. B. *Russ. Chem. Bull.* **1996**, *45*, 1699.
5. Allen, F. A.; Kennard, O.; Watson, D. G.; Brammer, L.; Orpen, A. G.; Taylor, R. *J. Chem. Soc., Perkin Trans. 2* **1987**, *12*, 1.
6. Allen, F. H.; Kennard, O. *Chem. Des. Automat. News* **1993**, *8*, 31.
7. Xiaojun, J.; Naujue, Z.; Fang, G.; Zhirong, L.; Zhitang, H. *Jiegou Huaxue (J. Struct. Chem.)* **1987**, *6*, 62.
8. Xiao-Jun, W.; Nai-Jue, Z.; Fang, G.; Zhi-Rong, L.; Zhi-Tang, H. *Jiegou Huaxue (J. Struct. Chem.)* **1991**, *10*, 103.
9. Brandsma, L.; Vasilevsky, S. F.; Verkruijsse, H. D. *Application of Transition Metal Catalysts in Organic Synthesis*; Springer: Heidelberg, Berlin, 1998; p 180.
10. Sonogashira, K.; Tohda, Y.; Hagihara, N. A. *Tetrahedron Lett.* **1975**, 4467.
11. Wadsworth, D. H.; Geer, S. M.; Detty, M. R. *J. Org. Chem.* **1987**, *52*, 3662.
12. Heindel, N. D.; Reid, J. R. *J. Heterocycl. Chem.* **1980**, *17*, 1087.
13. Manecke, G.; Schenck, H. U. *Chem. Ber.* **1971**, *104*, 3395.
14. Ovcharenko, V.; Fokin, S.; Rey, P. *Mol. Cryst. Liq. Cryst.* **1999**, *334*, 109.
15. Bumagin, N. A.; Ponomaryov, A. B.; Beletskaya, I. P. *Synthesis* **1984**, 728.