Fourier-Transform IR spectroscopic investigations of Cobalt(II)–dextran complexes by using D₂O isotopic exchange

Žarko Mitić^{a,*}, Milorad Cakić^b and Goran Nikolić^b

^a *Department of Pharmacy, Faculty of Medicine, University of Niš, Niš, Serbia*

^b *Faculty of Technology, University of Niš, Leskovac, Serbia*

Abstract. Co(II) ion complexes with reduced low-molar dextran (RLMD) derivatives $M_w = 5000 - 6000$ g/mol, their FTIR spectroscopic characterization, as well as the spectra-structure correlation was investigated in this work. The samples of Co(II) ion complexes with RLMD were deuterated (D₂O, Merck) for 2 h, at room temperature, in vacuum. FTIR spectra as an average of 40 scans were recorded at room temperature in the range 4000–400 cm⁻¹. FTIR investigation of Co(II)–RLMD complexes by D₂O isotopic exchange proved to be a very sensitive method for determining OH group coordination and is related to the hydrogen bond strength. The results of our investigation point to the dextran and their complexes with Co(II) ion are crystalline hydrate molecules. The correlation of physicochemical, spectrophotometric and spectroscopic investigations of these complexes, coordination chemistry of Co(II) ion and the structure of an exopolysaccharide chain are proposed different model structures of the synthesized Co(II) complexes.

Keywords: FTIR, deuteration, complexes, Co(II) ion, dextran

1. Introduction

In the field of biocoordination chemistry a lot of investigations are based on the synthesis and characterizations of different metal complexes of ligands they present in biological systems, or synthetic ligands which will serve like the model-molecules for complex biomolecular structures [8]. Bio- or synthetic ligands are mainly natural chemical compounds of macromolecular type. In this group of products of special importance are chemical compounds of polysaccharide dextran [21], pullulan [9] and inulin [16] with cations of different d-biomaterials (Cu(II), Co(II), Zn(II) and Fe(III)). It is well known that raw microbiological exopolysaccharides dextran and pullulan are glucose polymers with large molar mass of a few millions g/mol and with own toxic and antigen characteristics so that they are not of pharmaceutical importance [6]. For commercial reasons, raw polysaccharides were depolymerized to the products with adequate molar masses with the aim of getting fractions with narrow molar mass distribution. Dextran is an extracellular, water-soluble neutral polysaccharide with a chain of α -(1 → 6) linked D-glucopyranose units. Dextran elaborated by *Leuconostoc mesenteroides* B-512(F) consists of a α -(1 → 6) linked glucan with side chains attached to the C3-positions of the backbone glucopyranose units. Dextran is a well-known polysaccharide with numerous applications. Various biometal ions (Fe,

*Corresponding author: Žarko Mitić, Faculty of Medicine, Department of Pharmacy, Bul. dr Zorana Đinđića 81, RS-18000 Niš, Serbia. Tel./Fax: +381 18 4238 770; E-mail: zak_chem2001@yahoo.com.

Cu, Co, Zn, Ca, Mg, etc.) form complexes with dextran in alkaline solutions. Iron [11,17] and copper [10,14] complexes with different polysaccharides have special importance and they have been described in detail. The metal content and the solution composition depended on pH value [14,17]. In both human and veterinary medicine commercial cobalt preparations based on carbohydrates and its derivatives are used for such purpose [1,7].

Fourier-Transform Infrared (FTIR) spectroscopic methods (microspectroscopy, low nitrogen temperature, attenuated total reflection and isotopic exchange) is now widely used for studying the composition of the complex carbohydrate systems, the molecular interactions, the molecular orientation and polysaccharide conformational transitions, and for testing sample homogeneities [5,19]. FTIR spectroscopic characterization of Co(II) complexes with reduced low-molar dextran (RLMD $M_w = 5000 \text{ g/mol}^{-1}$) as well as the spectra-structure correlation was done in this work.

2. Experimental

2.1. Complex synthesis

The Co(II)–RLMD complexes were synthesized in water solutions, at different pH values (7.5–13.5) and room temperature (298–373 K), using $\text{CoCl}_2 \times 6\text{H}_2\text{O}$ and low-molar polysaccharide dextran ($M_w = 5000 \text{ g/mol}^{-1}$). The synthesis has been described in detail by Mitić et al. [13]. The complexes were isolated in the solid state. The samples of Co(II)–RLMD were deuterated (D_2O , Merck) for 2 h, at room temperature, in vacuum.

2.2. IR spectroscopic characterization of synthesized complexes

FTIR spectroscopy. For a sample preparation the KBr pastille method was used. The FTIR spectra as an average of 40 scans were recorded at room temperature on a BOMEM MB-100 FTIR spectrometer (Hartmann & Braun, Canada) equipped with a standard DTGS/KBr detector in the range $4000\text{--}400 \text{ cm}^{-1}$ with a resolution of 2 cm^{-1} by the Win-Bomem Easy software. In the region all spectra were baseline-corrected and area-normalized. A Fourier self-deconvolution based on the Griffiths/Pariente method was applied to enhance the resolution in a spectral region of $4000\text{--}400 \text{ cm}^{-1}$.

ATR–FTIR microspectroscopy. ATR–FTIR microspectroscopy system Bruker Tensor-27 in conjunction with a FTIR Bruker Hyperion-1000/2000 microscopy attachment equipped with a $15\times$ objective and $250 \mu\text{m}$ liquid nitrogen cooled MCT detector (GMBH, Germany) with the range of $4000\text{--}400 \text{ cm}^{-1}$, was used in this work. The spectra were recorded with 4 cm^{-1} resolution and 320 scans co-addition.

3. Results and discussion

ATR–FTIR spectra of Co(II)–RLMD complexes with related FTIR microscopy images (Fig. 1) synthesized at different pH values, FTIR spectra of deuterated RLMD (Fig. 2A) and FTIR spectra of deuterated Co(II)–RLMD analog (Fig. 2B) are presented.

The spectroscopic analysis showed that IR spectra of RLMD and its complexes with Co(II) ions are basically similar. Exactly let's say we know that by the complexing Cu(II) ion with dextran [18,20], and pullulan [15] in the dependence of the pH, form different types of the complexes, and the spectral picture in this region is very similar. The similarity of the spectra indicate that during the reaction of the samples, there is no change in the dextrans linearity $\gamma(\text{C-H})$ as well as no change in the C_1 chair conformation of

Fig. 1. ATR-FTIR spectra of Co(II)-RLMD complexes, with related FTIR microscopy images, synthesized at different pH values: pH = 7.5 (1); pH = 8.5 (2); pH = 11.0 (3); pH = 12.0 (4); pH = 13.0 (5); pH = 13.5 (6).

Fig. 2. (A) FTIR spectra of deuterated RLMD in the range of: (a) $\nu(\text{O-H})$ and (b) $\delta(\text{HOH})$ vibrations, and (B) deconvoluted FTIR spectra of the Co(II)-RLMD complex was synthesized at pH 13.5 (b), and analog recrystallized from D_2O (a).

glucopyranosyl units (910 and 840 cm^{-1}). The spectroscopic study in a particular region of O-H (3400 and 1420 cm^{-1}) and C-H (2900 , 1460 and 1350 cm^{-1}) vibrations indicates different binding between the central metal Co(II) ion and ligand, depending on pH and metal contents. The reactivity of the dextran depends primarily on the reactivity of the secondary, equatorially oriented hydroxyl groups (OH-2, OH-3 and OH-4). There is a possibility of gradual complexing where reforming starts at pH 8. In the 1200 – 1000 cm^{-1} region, the spectra of the complexes comprise a number of highly fused bands [22]. The band at about 1155 cm^{-1} has been assigned to stretching vibrations of the C–O–C bond and glycosides bridge. The broad peak at 1110 cm^{-1} should most likely be ascribed to the vibration of the C–O bond at the C4 position of the glucopyranose units. Complex vibrations involving the stretching of the C6–

Fig. 3. Proposed structure models of Co(II)–RLMD complexes with: (a) two and (b) three glucopyranose units (six O-donor atoms in tetragonal distorted O_h environment).

O6 bond with participation of deformational vibrations of the C4–C5 bond result in the appearance of a band at 1077 cm^{-1} . The band at about 1043 and 1015 cm^{-1} found for saccharide in the spectra of the complexes were shown to relate to the crystalline and amorphous phases, respectively (Fig. 1). The changes in intensity of these bands are strongly associated with the alterations in the macromolecular order [15,18]. These bands in the spectra of the complexes can be responsible for more and less ordered structures.

FTIR investigation of Co(II)–RLMD complexes by D_2O isotopic exchange proved to be a very sensitive method for determining OH group coordination and is related to the hydrogen bond strength [2]. In the range of $\nu(OD)$ vibrations of HDO molecules (Fig. 2A) one band appears at about 2495 cm^{-1} for polysaccharide dextran. Partners of these vibrations were expected on 3400 cm^{-1} in $\nu(OH)$ region (in consideration of the experimental shift factor 1.35). In the IR spectra of deuterated analogues both chemical compounds (Fig. 2A and B), intensive band on the 1646 cm^{-1} also is sensitive on the isotopic exchange, and has needed attribute to the $\delta(HOH)$ vibrations of crystal water. D_2O -FTIR results point to the existence of crystal water molecules which is sensitive to deuteration [12]. Also, we applied an isotopic exchange by D_2O to determine spectral manifestation of the Co(II)–RLMD complex. In the range of $\nu(OD)$ vibrations (Fig. 2B) one band appears at about 2483 cm^{-1} for Co(II)–RLMD complex was synthesized at pH 13.5. Partners of these vibrations were expected in $\nu(OH)$ region on 3400 cm^{-1} . Band at 3636 cm^{-1} , needs attribute to $\nu(OH)$ vibration of the free OH groups, which has not been included in the formation of hydrogen bonds. On the basis of IR spectrum in the valent OD region of HDO molecules and Falk [4] criteria, it can be concluded that both dextran and Co(II)–RLMD complex have one crystallographic type of H_2O molecule. According to correlation of Berglund [3]:

$$\nu(OD) = 2727 - 8.97 \times 10^6 \times e^{-3.73 \times R(O_w, \dots, O)}$$

estimated $O_w, \dots, O$ distances are 283.1 pm for dextran and 281.8 pm for Co(II)–RNMD complex. H_2O protons take part in the formation of relatively weak hydrogen bonds [4,12]. Probably, Co(II)–RLMD complexes are formed by the displacement of H_2O molecules from the first coordination sphere of Co(II) ion by the OH groups. The correlation of FTIR spectroscopic investigations of these complexes are proposed different model structures of the synthesized Co(II)–RLMD complexes (Fig. 3).

4. Conclusion

ATR–FTIR and D_2O -FTIR spectra of dextran and their Co(II)-complexes were analyzed in order to obtain the information about the structure and the conformation of these compounds. The spectroscopic

data indicate that there is no difference in the conformation of the glucopyranose unit in the dextran and the complex molecule, and they probably exhibit C_1 chair conformation. The differences in the region $3600\text{--}3100\text{ cm}^{-1}$, indicate that complexes originate from the displacement of H_2O molecules by ligand O–H groups in the first coordination sphere of Co(II) ion. The results of D_2O -FTIR investigations point to dextran and their complexes with Co(II) ion being crystal hydrate molecules with one crystallographic type of H_2O .

Acknowledgement

This study was supported by the Ministry of Science and Technological Development of the Republic of Serbia.

References

- [1] R. Bandwar, M. Sastry, R. Kadam and C. Rao, Transition-metal saccharide chemistry: synthesis and characterization of D-glucose, D-fructose, D-galactose, D-xylose, D-ribose, and maltose complexes of Co(II), *Carbohydr. Res.* **297** (1997), 333–339.
- [2] B. Berglund, J. Lindgren and J. Tegenfeldt, O–H and O–D stretching vibrations in isotopically dilute HDO molecules in some solid hydrates, *J. Mol. Struct.* **43**(2) (1978), 169–177.
- [3] B. Berglund, J. Lindgren and J. Tegenfeldt, On the correlation between deuterium quadrupole coupling constants, O–H and O–D stretching frequencies and hydrogen-bond distances in solid hydrates, *J. Mol. Struct.* **43**(2) (1978), 179–191.
- [4] G. Brink and M. Falk, Infrared studies of water in crystalline hydrates: $Ba(NO_2)_2 \cdot H_2O$, *Spectrochim. Acta A Mol. Spectrosc.* **27**(9) (1971), 1811–1815.
- [5] M. Cakić, Ž. Mitić, G.S. Nikolić, L. Ilić and G.M. Nikolić, The investigations of bioactive copper(II) complexes with reduced low-molar dextran, *Spectroscopy* **22**(2,3) (2008), 177–185.
- [6] O. Elmalak, M.A. Lovich and E. Edelman, Correlation of transarterial transport of various dextrans with their physico-chemical properties, *Biomaterials* **21** (2000), 2263–2272.
- [7] Expert Group on Vitamins and Minerals, Review of cobalt, EVM/99/19, Secretariat, UK Government, London, May 2002.
- [8] B. Gyurcsik and L. Nagy, Carbohydrates as ligands: Coordination equilibria and structure of the metal complexes, *Coord. Chem. Rev.* **203** (2000), 81–149.
- [9] L. Ilić, S. Ristić, M. Cakić, G. Nikolić and S. Stanković, Polynuclear complex Fe(III) with pullulan oligomers, process of its obtaining, and pharmaceutical preparations on the basis of the complex, WO 02/046241 A3, 2002.
- [10] W.F. Leech, D.G. McLaren and K.D. McSporran, Administration of copper to an animal, US Patent 2009/0029942 A1, 2009.
- [11] E. London, The molecular formula and proposed structure of the iron–dextran complex, imferon, *J. Pharm. Sci.* **93**(7) (2004), 1838–1846.
- [12] Ž. Mitić, M. Cakić and G.S. Nikolić, FTIR spectroscopic investigations of Co(II)–dextran complexes by using D_2O isotopic exchange, in: *XIII European Conference on the Spectroscopy of Biological Molecules*, Palermo, Italy, 2009, p. 83.
- [13] Ž. Mitić, M. Cakić, G.S. Nikolić, R. Nikolić and L. Ilić, The investigation of Co(II) dextran complexes, *Hem. Ind.* **61**(5) (2007), 257–262.
- [14] Ž. Mitić, G.S. Nikolić, M. Cakić, R. Nikolić and L. Ilić, Synthesis and spectroscopic characterization of copper(II) dextran complexes, *Russ. J. Phys. Chem.* **81**(9) (2007), 1433–1437.
- [15] Ž. Mitić, G.S. Nikolić, M. Cakić, P. Premović and L. Ilić, FTIR spectroscopic characterization of Cu(II) coordination compounds with exopolysaccharide pullulan and its derivatives, *J. Mol. Struct.* **924–926** (2009), 264–273.
- [16] G.S. Nikolić and M.D. Cakić, Physical investigation of the colloidal iron–inulin complex, *Colloid J.* **69**(4) (2007), 464–473.
- [17] G. Nikolić, M. Cakić, L. Ilić, S. Ristić and Ž. Cakić, Synthesis of some new antianemics I. Iron pullulan complexes of pharmaceutical interest, *Pharmazie* **57**(3) (2002), 155–158.
- [18] G.S. Nikolić, M. Cakić, Ž. Mitić and L. Ilić, Deconvoluted Fourier-transform LNT-IR study of coordination copper(II) ion compounds with dextran derivatives, *Russ. J. Coord. Chem.* **34**(5) (2008), 322–328.
- [19] G.S. Nikolić, M. Cakić, Ž. Mitić, L. Ilić and P. Premović, Attenuated total reflectance-Fourier transform infrared microspectroscopy of Cu(II) complexes with reduced dextran derivatives, *Russ. J. Phys. Chem.* **83**(9) (2009), 1520–1525.

- [20] G. Nikolić, M. Cakić, Ž. Mitić, R. Nikolić and L. Ilić, Correlation between UV-VIS spectra and structure of Cu(II) complexes with hydrogenated dextran in alkaline solutions, *Hem. Ind.* **59**(1,2) (2005), 9–14.
- [21] M. Oshtrakh, E. Kopelyan, V. Semionkin, A. Livshits, V. Krylova, T. Prostakova and A. Kozlov, An analysis of iron–dextran complexes by Mössbauer spectroscopy and positron annihilation technique, *J. Inorg. Biochem.* **54**(4) (1994), 285–295.
- [22] K.I. Shingel, Determination of structural peculiarities of dextran, pullulan and γ -irradiated pullulan by Fourier-transform IR spectroscopy, *Carbohydr. Res.* **337**(16) (2002), 1445–1451.