8. Poryadok provedennya naukovymy ustanovamy doslidiv, eksperymentiv na tvarynakh. Ofitsiynyy visnyk Ukrayiny. Ofits. vyd. 2012. (24): 82s. (Normatyvnyi dokument Ministerstva osvity, nauky, molodi ta sportu Ukrayiny. Nakaz vid 01.03.2012 № 249). [in Ukrainian]
9. Skrypnykov PM. Vikovi osoblyvosti anatomiyi slyzovoi obolonky orhaniv porozhnyny rota: znachennia v diahnostychnomu protsesi. Visnyk problem biolohiyi i medytsyny. 2016;1(2):261–6. [in Ukrainian]
10. Dursun A, Kastamonı Y, Kacaroglu D, Yuzbasıoglu N, Ertekın T. Morphometric development of the tongue in fetal cadavers. Surg Radiol Anat. 2020 Jan;42(1):3–8. doi: 10.1007/s00276-019-02301-z. Epub 2019 Aug 10. PMID: 31401676.
11. Garcia Martins RH, Marques Madeira SL, Fabro AT, Rocha Nde S, de Oliveira Semenzati G, Alves KF. Effects to exposure of tobacco smoke and alcohol on the tongue and pharynx of rats. Inhal Toxicol. 2012;24(3):153–60. doi: 10.3109/08958378.2011.649190. Epub 2012 Feb 10. PMID: 22324907.
12. Gunnars K. Are Nitrates and Nitrites in Foods Harmful? Healthline [updated Febr 10, 2020; cited 2020 Nov 24]. Available from: nitrates and nitrites harmful https://www.healthline.com/nutrition.
13. Mangge H, Summers K, Almer G, Prassl R, Weghuber D, Schnedl W, et al. Antioxidant food supplements and obesity-related inflammation. Current Medicinal Chemistry. 2013; 20(18):2330–7. Doi: 10.2174/0929867311320180004.
14. Seeker P, Osswald S. Tongue Discoloration. N Engl J Med. 2021;384(25):e102. doi: 10.1056/NEJMicm2100706.
15. Yeroshenko GA, Semenova AK. Structural features of the tongue dorsum mucosa in rats after the methacrylate effect. World of medicine and biology.2018;3(65):146–149. DOI 10.26724/2079-8334-2018-3-65-146-149

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LECTINS IN THE INVESTIGATION OF RENAL PATHOLOGIES

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Carbohydrate-rich biopolymers – glycoproteins and proteoglycans – play an extremely important role in renal histophysiology. In particular, glycoproteins podoplanin and podocalyxin of podocytes maintain the morpho-functional status of these cellular elements: formation of pedicels, slit diaphragms, and, together with the glomerular membrane – a negative electrical charge and selective permeability of the filtration barrier. Proximal tubules brush border glycoproteins megalin and kubilin are in charge of endocytosis and reabsorption of macromolecules from the ultrafiltrate. Glycoproteins of extracellular matrix – fibronectin, laminin, tenascin, nidogen, various types of collagen, heparan-sulfate proteoglycans perlecan and agrin, dermatan-sulfate proteoglycans versican, biglycan and decorin provide adhesive, mechanical support and inductive properties of renal micro- and ultrastructures. Therefore, lectins as reagents capable of selective recognition of specific glycoepitopes proved to be a valuable tool in the investigation of both normal renal morphogenesis and pathogenesis of nephropathies. Special attention is paid to modern trends in lectinology – investigation of endogenous lectins of humans and animals and their role in health and disease. Practical examples of lectins application as selective histological markers of renal structures are depicted.

Key words: lectins, glycoconjugates, kidney, histopathology.

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ЛЕКТИНИ У ДОСЛІДЖЕННІ ГІСТОПАТОЛОГІЇ НИРКИ

У гістофізіології нирок виключно важлива роль належить високомолекулярним вуглеводовмісним біополімерам – глікопротеїнам і протеогліканам. Зокрема, глікопротеїни подоцитів подопланін і подокаліксин забезпечують підтримання морфо-функціонального статусу означених клітинних елементів: формування цитоподій, щілинних діафрагм, та, спільно з мембраною ниркового клубочка – негативний електричний потенціал і селективну проникність фільтраційного бар'єру. Глікопротеїни щіточкової облямівки епітеліоцитів проксимальних трубочок нефронів мегалін і кубілін відіграють провідну роль у механізмах ендоцитозу та реабсорбції макромолекул з ультрафільтрату. Глікопротеїни екстрацелюлярного матриксу – фібронектин, ламінін, тенасцин, нідоген, колаген IV типу, гепаран-сульфат протеоглікани перлекан та агрин, дерматан-сульфат протеоглікани версикан, біглікан та декорин забезпечують адгезивні, опорно-механічні та індуктивні властивості ниркових мікроструктур. Лектини як реагенти здатні до вибіркового розпізнавання глікополімерів у залежності від складу та конфігурації їхніх кінцевих вуглеводних детермінант представляють собою цінний інструмент у дослідженні як нормального морфогенезу нирок, так і етіопатогенезу нефропатій. Особлива увага приділена сучасним тенденціям у лектинології – дослідженню ендогенних лектинів людини і тварин та їхній ролі за фізіологічних умов та у патогенезі ниркових хвороб. Наведено приклади практичного застосування лектинів як селективних гістологічних маркерів ниркових структур.

Ключові слова: лектини, глікокон'югати, нирка, гістопатологія.

The study is an initiative.

Carbohydrate-rich biopolymers – glycoproteins and proteoglycans – play an extremely important role in renal histophysiology. In particular, glycoproteins podoplanin and podocalyxin maintain the morpho-functional status of podocytes: formation of pedicells, slit diaphragms, and, combined with glomerular membrane – a negative electrical charge and selective permeability of the filtration barrier [18, 20]. Proteoglycans possess dual nature: from one hand, some of them expose glycosidic moieties (e.g.

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DGalβ1–4DGlc terminus) in core proteins and, therefore, can be treated as lectin receptors [6]; from the other hand, proteoglycans like versican and aggrecan contain sugar-binding domains, which belong to C-type superfamily of animal lectins. Moreover, recently was reported an intimate correlation between the inadequate activities of animal lectins (e.g. Galectin-3) and the development of renal pathologies [4–7].

This paper is summarizing our experience and relevant literature information concerning lectins application in fundamental and clinical research on kidney histopathology.

Diabetic nephropathy (DN), also known as diabetic kidney disease, is defined as the chronic loss of kidney function occurring in those with diabetes mellitus. Diabetic nephropathy is one of the leading causes of chronic kidney disease and end-stage renal disease globally and, probably, is the most thoroughly investigated renal pathology by means of lectin histochemistry [3, 9, 12, 15, 16, 19]

We used a set of 14 lectins with different carbohydrate affinities to study the redistribution of renal glycoepitops in streptozotocin-induced diabetic rats. The most representative results were obtained with lectins as follows: LCA (DMan/DGlc specific), SNA (NeuNAcα2-6DGal specific), WGA (DGlcNAc > NeuNAc), RCA (DGal > NeuNAc), PNA (DGalβ1-3GalNAc specific), HPA (αDGalNAc specific) and LABA (αLFuc specific) [3, 15]. We used a set of 14 lectins with different carbohydrate affinities to study the redistribution of renal glycoepitops in streptozotocin induced diabetic rats.

It was detected in streptozotocin-treated rats reduced reactivity of renal epithelium cytoplasmic glycoconjugates, of proximal tubules brush border, as well as of collecting duct luminal surface with LCA, SNA, WGA, RCA and LABA with simultaneous enhanced labeling of these same structures by PNA and HPA lectins. However there can exist another possibility described in paper of Bilyy and Stoika [5] concerning pre-apoptotic events in the cell cultures – activation of sialidases resulting in demasking of sub-terminal DGal and DGalNAc residues, to which are directed affinities of PNA and SBA lectins.

In the control group rats CNFA selectively labeled renal corpuscles and brush border of proximal tubules; in diabetic rats reactivity of renal corpuscles enhanced, while brush border exposed heterogeneity of this lectin binding two weeks after streptozotocin administration and complete areactivity two months later; instead CNFA label was uniformly distributed in the cytoplasm of proximal tubules epitheliocytes, this observation apparently encompass alteration of cellular mechanisms responsible for polarization of plasma membrane in these cells [2].

MPFA in control group rats demonstrated rather selective reactivity with podocytes, mesangial cells and filtration membrane, brush border of proximal tubules, distal tubules and collecting duct cells. LPFA under both – physiological and pathological conditions – in renal cortex strongly labeled corpuscles, in medulla – luminal surface of tubular labyrinth, in papillary region – loops of Henle and stromal components. Intensity of binding elevated in kidneys of streptozotocin treated rats, being similar, but not identical to that of PNA and HPA lectins [3].

Taking into account obtained results the following conclusions could be elaborated: (1) streptozotocin-induced diabetes cause significant remodeling of kidney glycome – reducing of DMan/DGlc, DGlcNAc, NeuNAc and LFuc sugar determinants with simultaneous exposure/unmasking of DGal and DGalNAc residues; (2) lectins demonstrated selective labeling of rat kidney constituents: WGA, RCA – of renal corpuscles and tubules of outer medulla; HPA – of cortical tubules; (3) original lectin preparations – MFA, LPFA and CNFA can be recommended for further application for selective kidney structures labeling and in experimental histopathology research.

Significant differences in UEA-I, PHA-E, GS-I, PNA and RCA reactivity with rat kidney protein blots reflect altered glycosylation patterns accompanying progression of diabetic nephropathy [19]. Ostergaard et al. [16] reported that progression of streptozotocin-induced diabetic nephropathy in murine model correlated with marked elevation (approx. 2 times fold) autoreactivity of endogenous mannose-binding lectin (MBL), which, in its turn, induce the formation of circulating complement activation product C3a, which as proinflammatory mediator playes crucial role in plenty of kidney diseases [9].

Microarray assays of sialospecific lectins (SNA, SSA and SJA-I) were recommended for quantitative evaluation of urinary fetuin A level, which can serve as a reliable prediction marker of diabetic nephropathy progression in humans [12]. Recent publication of Zhu et al. [24] specified the latter data reporting that enhanced exposure of glycoepitopes with terminal NeuNAc2-6Gal/GalNAc recognized by lectin SNA in human urine correlates with diabetic nephropathy progression, while glycopatterns of GlcNAc, recognized by STA lectin can be used for differentiation of diabetic and nondiabetic nephropathies. Interestingly that similar sugar determinants of DMan/DGlc and NeuNAc were referred to as the chief players in the mechanisms of cellular apoptosis [5].

Polycystic kidney disease (PKD) is an inherited disorder in which clusters of cysts develop primarily within the kidneys, causing them to enlarge and lose function over time. Cysts are noncancerous

round sacs containing fluid. The cysts vary in size, and they can grow very large. Studies of ethiopathogenesis of PKD recruiting different methodological approaches, including lectin histochemistry, are currently in progress.

In PKD of adults, there was identified a mixture of two types of cysts: one positive to PNA, the other positive to LTA. Moreover, some cysts did not stain with either lectin. The authors suggested that in adult PKD cysts could originate from any portion of the nephron.

In several investigations, directed towards the clarification of polycystic kidney disease pathogenesis, LTA was used as a reliable marker of Bowman`s capsule-proximal tubule integrity in mouse models [8]. It is noteworthy that in murine kidney urinary pole of Bowman`s capsule similarly to proximal tubule is lined by tall parietal cells, both avidly binding LTA. Shortly after unilateral ureteral obstruction these cells become flattened and loss affinity to LTA lectin; due to apoptosis and autophagy renal corpuscle becomes atubular, further transforming into cystic lesion [8].

Some of Bowman`s capsule parietal cells, which resemble immature podocytes, were round shaped, protruded into urinary space, formed cytotrabecules, pedicels and filtration slits, and like typical podocytes exposed WGA receptor sites. The presence of these cells, named parietal podocytes, in all cysts suggests that abnormal differentiation may play important role in the pathogenesis of this type polycystic kidney disease.

Nephrosis is defined as degenerative and inflammatory pathology primarily affecting the renal tubules, particularly proximal convoluted tubules.

Electron microscopic examination of rat kidney under experimental puromycin-induced nephrosis in comparison with intact organ revealed a significant loss of sialic acid from podocalyxin molecules, located in podocytes, glomerular basement membrane and mesangial matrix of injured renal tissues.

In several different kidney diseases the glomerular endothelium expressed also α2.3 linked sialic acid alongside with increased TMA lectin reactivity of epithelial cells related to α2.6 linked sialic acid. The study did not show changes characteristic of specific diseases; increased sialic acid expression on glomerular endothelium and podocytes was linked to a vide variety of pathological changes, just encompassing pathological chages of renal glycoepitopes.

Glomerulonephritis (GN) is defined as inflammatory condition and damage of kidney glomeruli. GN is subdivided to non-proliferative and proliferative, the latter including: (I) IgA nephropathy; (II) post-infectious; and (III) membranoproliferative GN. Despite the fact that glomerulus is among the chief structures involved in renal pathologies development, publications strictly regarding the rearrangement of glomerular glycoepitopes in membranoproliferative glomerulonephritis are sparse. However papers reporting aberrant glycosylation of immunoglobulin glycoreceptors in IgA nephropathy are more numerous and recently published.

Kidneys of dogs with immune-complex mediated glomerulonephritis were studied by lectin histochemistry methods using WGA, RCA-I, Con A, PNA, SBA, DBA, and UEA-I. Their lectin-binding patterns were compared with those from normal dogs. RCA-I binding to brush borders of the proximal tubules decreased, whereas DBA binding became positive in previously negative Bowman's capsules. Also, varying intensity of the UEA-I dynding was noted in the distal tubules, especially their macula densa segments. A conclusion was made that binding pattern profiles varied among the cases apparently due to the diverse canine renal pathologies being under investigation [23].

IgA nephropathy, the most common primary glomerular disease worldwide, is characterized by mesangial deposition of IgA1-containing immune complexes. Mesangial cells exposed to these IgA immune complexes proliferate and adopt pro-inflammatory phenotype: they secrete cytokines, chemokines, growth factors and extracellular matrix components promoting glomerular inflammation and glomerulosclerosis.

For the prediction of renal prognosis in IgA nephropathy Kawakita et al. [14] recommend to use as biomarkers ECA (specific to Galβ1–4GlcNAc) and NPA (specific to Manα1-6Man) lectin arrays for urinary glycan profiling, since IgA1 molecules are characterized by galactose deficiency, while ECA and NPA recognize intermediate glycans during subsequent steps of glycosylation.

Renal neoplasia. First attempts to track the origin of renal neoplastic lesions by means of nephron segments-specific lectins were made by Holthofer et al. [11]. For this goal were used LTA, SBA, DBA and UEA-I lectins, supplemented with tissue-specific antibodies against intermediate filaments of cytokeratin, desmin and vimentin, as well as against proximal tubular brush border and distal tubular Tamm-Horsfall glycoprotein antigens. 80% of the renal carcinomas expressed brush border antigens, whereas Tamm-Horsfall glycoprotein could not be found. 93% of the carcinomas tumor cells showed reactivity with

antikeratin antibodies. Vimentin, the cytoskeletal protein of mesenchymal cells, was present in the carcinoma cells of 53% of the tumors, although it was absent in normal tubular epithelium.

Binding sites for LTA and SBA, normally present in the cells of proximal tubules, were lacking or only faintly detectable in the neoplastic cells. DBA, normally present in collecting ducts, was not detected in tumors. The results show that most renal carcinomas express cytokeratin antigens as a sign of their epithelial origin and also show characters of proximal tubular cells. On the other hand, the results indicate that lectin-binding sites typical for normal differentiated tubular cells are profoundly modified in renal carcinomas. UEA-I did not bind to the malignant cells but selectively decorated the endothelial cells of tumors.

However, modern trends in lectin histochemistry research are directed towards the discovery and characterization of endogenous lectins of human and animal origin, as well as to understanding their role in homeostasis and immune system influences.

Animal and human lectins in kidney diseases. While previous segments of this review article were describing different modes of lectins application as tools in biomedical research and practice, this last segment will give a brief survey on fundamentals of animal and human lectins, being a biological counterpart to carbohydrate moieties previously detected and studied with lectins as histochemical reagents of predominantly plant origin.

Galectins (Gal-1…Gal-15) are family of 15 endogenous animal and human lectins with carbohydrate specificity directed towards galactose residues of biopolymers. Galectins participate in many fundamental life processes, such as the interaction (including adhesion) of cells with each other and with the extracellular matrix, migration, growth, proliferation, differentiation, immune responses, autophagy, inflammation. They are also linked to diseases such as fibrosis, cancer and heart disease [13].

Furthermore, it was observed an increase of nuclear translocation of lectin in tumor samples. In the review article of Desmedt et al. [7], special attention is paid to the pivotal role of Gal-3 in the onset and development of diabetic and non-diabetic nephropathies, interstitial fibrosis and progression of chronic kidney disease; the therapeutic potential of anti-galectin-3 inhibitors is under discussion.

Recently, Ficolins and Collectins supplemented the MBL lectin pathway. The binding of these initiators (MBL/Ficolins/Collectins) to molecular patterns (glycoepitopes) triggers complement activation scenario [4, 10].

Under experimental conditions, after ischemia/reperfusion kidney injury, MBL was found to induce tubular cell death independent of the complement system. In addition, after binding to vascular endothelial cells, MBL and its associated serine proteases were able to trigger a proinflammatory reaction and contribute to endothelial dysfunction [17].

In the cohort study of 382 kidney recipients was documented correlation between low level of MBL inhibitor at the time of transplantation and increased overall mortality in kidney recipients, these observations apparently encompass negative impact of elevated MBL level on the physiological compensatory mechanisms [21].

Lectin complement protein Collectin 11 (CL-K1), a member of the vertebrate C-type lectin superfamily, has recently been identified as pattern recognition molecule in the lectin complement pathway. It protects the urinary tract from schistosomiasis, a helminthic disease common in sub-Saharan Africa. Schistosome integuments are fucosylated and CL-K1 has, through its collagen-like domain, a high binding affinity to fucose [4]. Another C-type lectin called Mincle (Macrophage-Inducible C-type Lectin) mediates cell death-triggered inflammation in acute kidney injury [22].

Currently is generally accepted that blocking/inhibiting the lectin activation pathway of complement facilitates the progression of glomerular and tubulointerstitial diseases, while its effects on urinary tract infections are quite opposite [1, 4, 9, 10]. The data obtained on the redistribution of animal lectins during pre- and postnatal morphogenesis, as well as in renal histopathology indicate that they are sensitive acceptors of end products of biopolymers glycosylation.

Conclusions

1. Lectins are sensitive histochemical tools for selective binding to renal glycoepitopes under physiological conditions and provide valuable information of their rearrangement in different forms of renal histopathology.

2. In human kidney lectins exposed specific labeling: LTA and SBA – of proximal tubule cells; DBA – of collecting duct cells; UEA-I – endothelial cells of kidney interstitium.

3. In the rat kidney lectin labels were as follows: WGA – renal corpuscles, brush border of proximal tubules, luminal surface of collecting ducts; HPA and DBA – intercalated cells of collecting ducts; LTA – of proximal tubule cells.

4. New original lectins purified from fungi – CNFA, MPFA, LPFA – should be recommended for future application in carbohydrate histochemistry: i. e. MPFA and LPFA – as markers of rat kidney filtration membrane; CNFA – as renal corpuscles and brush border of proximal tubules marker.

5. Since there exist certain signs of pathology-induced aberrant/incomplete glycosylation patterns of glycoconjugates, tracking the origin of pathological lesions based on the identification of normal cell glycoepitopes are of limited value.

6. However using composite panels of selective lectin- and immune-histochemical labels of different renal cell subpopulations, supplemented with morphometric database will enrich the existing knowledge in diagnostic histopathology.

7. Modern trends in basic and applied lectinology directed towards functional glycomics – understanding the role of endogenous animal/human lectins interaction with specific carbohydrates receptor sites in health and disease.

References

1. Alghadban S, Kenawy HI, Dudler T, Schwaeble WJ, Brunskill NJ. Absence of the lectin activation pathway of complement ameliorates proteinuria-induced renal injury. Front Immunol. 2019: 02238. doi: 10.3389/fimmu.2019.02238.
2. Ambarova NO. Lectin from Clitocybe nebularis fungus: a new histochemical reagent for the investigation of renal morphogenesis and histopathology. World of Medicine and Biology. 2016; 1(55): 119–121.
3. Ambarova NO, Lutsyk OD. Selective histochemical labeling of normal rat kidney and that affected by strezotocin-induced diabetes mellitus using lectin from Lactarius pergamenus fungus. Morphologia. 2017; 11(4): 23–27.
4. Antony JS, Ojurongbe O, Kremsner PG, Velavan TP. Lectin complement protein Collectin 11 (CL-K1) and susceptibility to urinary schistosomiasis. PLoS Negl Trop Dis. 2015; 9(3): e0003647. doi: 10.1371/journal.pntd.0003647.
5. Bilyy R, Stoika R. Sweet taste of cell death: role of carbohydrate recognition systems. Ukr Biochem J. 2013; 85(6): 183–196.
6. Dam T, Talaga M, Fueri A, Brown R, Bandyopadhyay P. Human lectin Galectin-3 recognizes chondroitin sulfate proteoglycans (CSPGs) and sulfated glycosaminoglycans. FASEB J. 2018; 31(S1): 784.8. doi: 10.1096/fasebj.31.1_supplement.784.8.
7. Desmedt V, Desmedt S, Delanghe JR, Speeckaert R, Speeckaert MM. Galectin-3 in renal pathology: more than just an innocent bystander? Am J Nephrol. 2016; 43: 305–317. doi: 10.1159/000446376.
8. Galarreta CI, Grantham JJ, Forbes MS, Maser RL, Wallace DP, Chevalier RL. Tubular obstruction leads to progressive proximal tubular injury and atubular glomeruli in polycystic kidney disease. Am J Pathol. 2014; 184: 1957–1966. doi: 10.1016/j.ajpath.2014.03.007.
9. Gao S, Cui Z, Zhao M. The complement C3a and C3a receptor pathway in kidney diseases. Front Immunol. 2020; 11: 1875. doi: 10.3389/fimmu.2020.01875.
10. Gaya da Costa M, Poppelaars F, Berger SP, Daha MR, Seelen MA. The lectin pathway in renal disease: old concept and new insights. Nephrol Dial Transplant. 2018; 33: 2073–2079. doi: 10.1093/ndt/gfy073.
11. Holthofer H, Miettinen A, Paasivuo R. Cellular origin and differentiation of renal carcinomas. A fluorescense microscopic study with kidney specific antibodies, anti-intermediate filament antibodies and lectins. Lab Invest. 1983; 49(3): 317–326.
12. Inoue K, Wada J, Eguchi J, Nakatsuka A, Teshigawara S, Murakami K, Ogava D, Terami T, Katayama A, Tone A, Iseda I, Hida K, Yamada M, Ogava T, Makino H. Urinary fetuin-A is a novel marker for diabetic nephropathy in type 2 diabetes identified by lectin microarray. PLoS ONE. 2013; 8(10): e77118. doi: 10.1371/ journal.pone.0077118.
13. Johannes L, Jacob R, Leffler H. Galectins at a glance. J Cell Sci. 2018. 131: jcs 208884. doi: 10.1242/jcs.208884.
14. Kawakita C, Mise K, Onishi Y, Sugiyama H, Yoshida M, Yamada M, Wada J. Novel urinary glycan profiling by lectin array serves as the biomarkers for predicting renal prognosis in patients with IgA nephropathy. Nature Sci Reports. 2021; 11: 3394. doi: 10.1038/s41598-020-77736-1.
15. Lutsyk A, Ambarova N, Antonyuk V. Diabetic alteration versus postnatal maturation of rat kidney glycoconjugates – comparative detection by lectin probes. Folia Histochem Cytobiol. 2013; 51(1): 92–102.
16. Ostergaard JA, Ruseva MM, Malik TH, Hoffman-Petersen IT, Pickering MC, Thiel S, Hansen TK. Increased autoreactivity of the complement-activating molecule mannan-binding lectin in type 1 diabetes model. J Diab Res. 2016; 1825738. doi: 10.1155/2016/1825738.
17. Osthoff M, Trendelenburg M. Impact of mannose-binding lectin deficiency on radiocontrast-induced renal disfunction. BioMed Res International. 2013: 962695. doi: 10.1155/2013/962695.
18. Quintanilla M, Montero-Montero L, Renart J, Martin-Villar E. Podoplanin in inflammation and cancer. Int J Mol Sci. 2019; 20(3): 707. doi: 10.3390/ijms 2003707.
19. Ravida A, Musante L, Kreivi M, Miinalainen I, Byrne B, Sarasvat M, Henry M, Meleady P, Clynes M, Holthofer H. Glycosylation patterns of kidney proteins differ in rat diabetic nephropathy. Kidney International. 2015; 87: 963–974.
20. Refaeli I, Hughes MR, Wong AK, Bissonnette ML, Roskelley CD, Vogl AW, Barbour SJ, Freedman BS, McNagny KM. Distinct functional requirements for podocalyxin in immature and mature podocytes reveal mechanisms of human kidney disease. Sci Reports. 2020; 10: 9419. doi: 10.1038/s41598-020-64907-3.
21. Smedbraten J, Mjoen G, Hartmann A, Asberg A, Rollag H, Mollnes TE, Sandvik L, Fagerland MW, Thiel S, Sagedal S. Low level of MAp44, an inhibitor of the lectin complement pathway, and long-term graft and patient survival; a cohort study of 382 kidney recipients. BMC Nephrology. 2016; 17: 148. doi: 10.1186/s12882-016-0373-9.
22. Tanaka M, Tanaka MS, Ochi K, Fujieda K, Sugiura Y, Miyamoto T, Kohda H, Suganami T. C-type lectin Mincle mediates cell death-triggered inflammation in acute kidney injury. J Exp Med. 2020; 217(11): e20192230. doi: 10.1084/jem.20192230.
23. Yabuki A, Yamamoto T, Rahman MM, Yamatu O. Changes in lectin-binding patterns in the kidneys of canines with immune-complex mediated glomerulonephritis. J Vet Med Sci. 2018; 80(10): 1562–1566. doi: 10.1292/jvms.18-0331.
24. Zhu H, Liu M, Yu H, Liu X, Zhong Y, Shu H, Fu X, Cai G, Chen X, Geng W, Yang X, Wu M, Li Z, Zhang D. Glycopatterns of urinary protein as new potential diagnosis indicators for diabetic nephropathy. J Dibet Res. 2017; doi: 10.1155/2017/5728087.

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