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Abstract: The aim of this work is to reduce the time and cost of forecasting, preventing and treating patients with infectious complications with kidney injuries. The study is based on the results of a retrospective analysis of the medical records of 123 patients with various forms of kidney injury. Using the methods of analysis, it was shown that in order to achieve acceptable for practice quality prediction of possible infectious and inflammatory complications, the level of psycho-emotional stress and energy of biologically active points 'connected' to the kidneys is used as additional prognostic signs, with the confidence in the correct prediction increasing to 0.93.

Keywords: class membership functions; exploratory analysis; fuzzy logic; level of psycho-emotional stress; prognosis; risk of developing infectious; inflammatory complications; treatment regimens.

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1 Introduction

In some cases, kidney damage is observed without obvious violations of the integrity of the organ. Often, after bruises of the kidney, morphological examination reveals significant dystrophic changes in the parenchyma, and functional impairment due to such an injury can be more pronounced than with obvious kidney ruptures (Sergeev and Ryumin, 2001). The problem of infectious and inflammatory complications in the post-traumatic period remains insufficiently studied, the methods for their assessment in the near future after the injury are not specified, criteria for predicting complications and results of treatment are not developed.

The loss of kidney function is a life-changing event leading to life-long dependence on healthcare. Around 5,000 people are diagnosed with kidney failure every year. Historically, technology in renal medicine has been employed for replacement therapies. Recently, a lot of emphasis has been placed on technologies that aid early identification and prevent progression of kidney disease, while at the same time, empowering affected individuals to gain control over their chronic illness. There is a shift in diversity of technology development, driven by collaborative innovation initiatives such the National Institute's for Health Research Healthcare Technology Co-operative for Devices for Dignity. This has seen the emergence of the patient as a key figure in designing technologies that are fit for purpose, while business involvement has ensured uptake and sustainability of these developments. An embodiment of this approach is the first successful Small Business Research Initiative in the field of renal medicine in the UK (Chamney et al., 1999). These methods, percutaneous nephrolithotomy and extracorporeal stone disintegration, are examined with particular reference to the equipment necessary for stone disintegration. There is little doubt that these techniques will supersede conventional surgical procedures in the near future (Davis and Johns, 2009).

Numerous studies in the field of improving the prediction, diagnosis, prevention and treatment of various diseases, including the pathology under study, show that the best result is achieved by using adequate mathematical methods involving modern information and intellectual technologies (Chernega, 2014; Buchanan and Shortliffe, 1984; Korenevskiy et al., 2009a, 2013b; Zadeh and Klir, 1996).

Our experience in the field of the application of information and intelligent technologies in various medical problems, including the prediction and diagnosis of urological diseases, has shown that good results can be achieved using the methodology for the synthesis of hybrid fuzzy decision rules (Buchanan and Shortliffe, 1984; Zadeh and Klir, 1996).

In studies (Chernega, 2014; Buchanan and Shortliffe, 1984), using the methodology of synthesis of hybrid fuzzy decision rules, a mathematical model for predicting post-traumatic infectious-inflammatory complications in patients with closed kidney injury is described. The main disadvantage of this model is the large number of informative features, which leads to unjustified time and costs. The purpose of this study is to reduce the time and cost of research, while maintaining high quality forecasting. In Korenevskiy et al.'s (2021c) paper is a continuation of the work carried out under the guidance of Seregin. After the first generalising publication, Seregin made the assumption that the selected composition of informative signs does not take into account the special state of the body of pregnant women and, therefore, is not optimal (Seregin et al., 2019). In Korenevskiy et al. (2021c), this makes it advisable to clarify how a list of informative features and parameters of decision rules. To optimise the space of informative features, an in-depth exploratory analysis was carried out according to the authors methodology (Al-Kasasbeh et al., 2013b, 2016, 2017, 2018, 2019d, 2020a, 2020b, 2020c; Korenevskiy et al., 2013a) focused on working with poorly formalised, incomplete and fuzzy data.

As a result of this stage of research, it was shown that for the differential diagnosis of the considered forms of pyelonephritis in pregnant women with a quality comparable to (Seregin et al., 2019), it is sufficient to use indicators characterising the immune status of the body, excluding the block of indicators (signs) of oxidative status. This model allows reducing the time and costs by half while maintaining the required quality of diagnostics (Korenevskiy et al., 2021c).

Changing the composition of informative features required a re-synthesis of decision rules (Korenevskiy et al., 2021). The methodology used in the present work for building hybrid fuzzy decision rules combines the artificial intelligence method with the natural intelligence represented by fuzzy rules set by highly qualified medical experts. The methodology shows high efficiency in solving a wide range of problems in medicine, ergonomics, ecology, psychology, occupational health, and other related areas of human activity (Al-Kasasbeh, 2021; Al-Kasasbeh et al., 2021; Filist et al., 2021, 2022; Korenevskiy et al., 2013c, 2021a, 2021b, 2022a, 2022b; Shatalova et al., 2021, 2022)

2 Material and research

This study is based on the results of a retrospective analysis of medical records of 123 patients with various forms of kidney injury, as well as 100 patients with other urological pathologies who were treated in the urological departments of the city clinical emergency hospital (Kursk, Russia) for the period 2008–2013 years. The average age of patients with kidney injury was 48.2 years, of which 73 were men (59%) and 50 were women (41%). The greatest number of patients with kidney injury is of working age (80.1%). To assess the course of the post-traumatic period in patients with closed kidney injury and the development of prognostic signs of inflammatory complications, an analysis of the correlation relationships of physiological parameters was carried out. The parameters of the intensity of the processes of free-radical oxidation of serum lipids were evaluated.

The activity of lipid peroxidation (PLA) was assessed by the level of primary serum in the blood serum – diene conjugates (DC) and secondary – malonic dialdehyde (MDA), lipid peroxide digestion products. Blood samples were taken from patients from the

cubital vein before taking the drug on the 2nd, 7th, 14th day from the moment of admission and when the patient was discharged (21–24 days). EDTA was used as an anticoagulant and antioxidant at the rate of 1 mg/ml of blood. The content of DC in plasma was determined by pre-extraction with a mixture of heptane: isopropanol (1:1), followed by measuring the optical density at 233 nm on an spectrophotometer ‘SF 26’ and expressed in nmol/l.

The concentration of MDA in plasma was estimated by the reaction with 2-thiobarbituric acid in an acidic medium, analysing the amount of the trimethine complex formed by optical density at 532 nm on an SF 26 spectrophotometer and expressed in nmol/l. Patients were clinically examined using a survey, physical, auscultatory, and other generally accepted methods for monitoring the condition of patients, traditional clinical and biochemical blood tests, ultrasound and X-ray methods confirming the closed injury of the kidneys and the post-traumatic period.

The experience of observation of patients with closed kidney injury showed that the decision about the deterioration had to be made with minimal changes in clinical and laboratory data, and some even specific ultrasound and radiological signs are indistinct. Considering the above, to solve the problem of predicting inflammatory post-traumatic complications of a closed kidney injury and developing preventive methods, we have chosen the mathematical apparatus of fuzzy decision-making logic. In the course of the exploratory analysis, it was found that the signs chosen for the prediction of complications have a latent (hidden) relationship with the predicted classes of states. Under these conditions, to evaluate the informative value of the studied parameters in Sergeev and Ryumin (2001), Chamney et al. (1999) and Miller (1983), it is recommended to use the theory of measurement of latent variables with the G. Rush model implemented by the interactive package RUMM2020 (Shortliffe, 1976; Korenevskiy, 2015).

An assessment of the informative value of forty original signs using the RUMM2020 package in combination with expert assessment methods showed that only two signs of PLA and antioxidant activity (AOA) are sufficient information for practical forecasting. This formal study is confirmed by the fact that, according to modern views, the activation of PLA processes is crucial in the development of ischemic, dystrophic, degenerative conditions in the body. This, in turn, is accompanied by a decrease in AOA and an increase in the consumption of bioantioxidants, resulting in a decrease in the ability to regulate PLA and the development of tissue alteration. According to the general methodology of synthesis of hybrid fuzzy decision rules, the main element of fuzzy decision rules is the function of belonging to the studied (predicted) classes of states (Chernega, 2014; Buchanan and Shortliffe, 1984; Korenevskiy et al., 2009a, 2013b).

To build class membership functions, the risk of developing infectious and inflammatory complications in the post-traumatic period in terms of PLA and AOA, we chose scales of deviations of measured indicators from their nominal values, where the relative difference between the nominal values of PLA and AOA and their current indicators. In this way

$$\delta x_P = \frac{x_P^N - x_P^T}{x_P^N} \cdot 100\%, \delta x_A = \frac{x_A^N - x_A^T}{x_A^N} \cdot 100\%$$

where x_P^N and x_A^H – PLA and AOA, measured on a representative group of healthy people, $x_P^T = x_{39}$ and $x_A^T = x_{40}$ – PLA and AOA in a patient with a kidney injury at

admission. For these indicators, according to the method described in Korenevskiy et al. (2009a, 2013b) graphs and formulas of membership functions were obtained $\mu p(\delta x_P)$ and $\mu p(\delta x_A)$, which determine the degree of indicators of PLA and AOA. Based on the analysis of PLA and AOA values in patients with kidney injury with various post-traumatic outcomes, threshold values δx_P and δx_A were determined at the level of 10% after exceeding which there is a risk of investigated complications. Taking into account these results, a fuzzy mathematical model was obtained (Al-Kasasbeh et al., 2011, 2012, 2013a, 2014, 2015, 2019a, 2019b, 2019c; Korenevskiy et al., 2009b, 2015) for predicting the risk of infectious and inflammatory complications of the form:

IF $[(\delta x_P > 10\%) \text{ и } (\delta x_A > 10\%)]$ then
 $[CCp(i + 1) = \mu p(\delta x_P) + \mu p(\delta x_A)[1 - \mu p(\delta x_P)]]$,
 ELSE $(CCp = 0)$.

where CCp – the confidence coefficient for the prediction of the occurrence of infectious and inflammatory complications in the post-traumatic period, determined by the values of the PLA and AOA.

The calculations for the selected membership functions showed that with the maximum values of $\mu p(x_P)$ and $\mu p(x_A)$, the CCp reaches the value of 0.88. The obtained coefficient of confidence is sufficient for independent practical use in the prediction of infectious and inflammatory complications in the post-traumatic period in patients with closed kidney injury.

During the analysis of the dynamics of the state of the processes of PLA and AOA in patients with closed kidney injury, it was found that changes in these indicators are due to the presence of an infectious-inflammatory, purulent-necrotic process in the kidney and pronounced symptoms of endogenous intoxication syndrome (urosepsis). Given the relationship between the degree of endotoxemia and the functional state of the kidneys in the post-traumatic period, the severity of changes in PLA and AOA indicators can be used as a highly informative prognostic criterion.

Taking into account the experience of synthesising decision rules for prediction and medical diagnostics, the authors investigated the informative value of non-traditional signs for medical practice – the level of emotional tension and energy imbalance of biologically active points (BAT) ‘associated’ with the kidneys in the task of predicting infectious and inflammatory complications in closed kidney injuries. Mathematical models for assessing the level of psychoemotional stress (PES) and examples of their aggregation into general prognostic rules are described in Korenevskiy et al. (2009a), Zadeh and Klir (1996) and Al-Kasasbeh et al. (2019a).

Mathematical models for the selection of informative BAT and the mechanisms of their ‘embedding’ in prognostic and diagnostic decision rules are described in Al-Kasasbeh et al., 2011, 2013a, 2014, 2015, 2019a, 2019b, 2019c; Korenevskiy et al., 2009b, 2015).

A mathematical model for calculating the confidence (UR) in the risk of infectious and inflammatory complications in closed kidney injuries, taking into account (1), the level of psycho-emotional stress and energy imbalance BAT associated with the kidneys is described by the expression:

$$UR = CCP + UP + UB - CCP \cdot UP - CCP \cdot UB - UP \cdot UB + CCP \cdot UP \cdot UB \quad (2)$$

where UP is confidence in UR by the value of the PES level, UB – confidence in the UR on the energy imbalance of BAT ‘associated’ with the kidneys.

In the course of mathematical modelling and expert assessment, it was found that confidence in the correct prognosis in the risk of occurrence of infectious and inflammatory complications with closed kidney injuries when using model (2) increases to 0.93. However, for practical use of model (2), medical institutions should have means of assessing the level of PES and energy imbalance of BAT.

The description of the technical means for assessing these indicators is given in Korenevskiy et al. (2009a, 2013b) and Zadeh and Klir (1996).

3 Results

The study examined the same indicators in patients with kidney injury at different times depending on the method of prevention and treatment. The level of PLA, AOA products in the blood serum in patients with kidney injury in the post-traumatic period and after extracorporeal lithotripsy was: in patients with kidney injury on the third day: hydroperoxides – 0.10 ± 0.005 mg/dl, malondialdehyde – 3.29 ± 0.22 mg/dl, AOA – $36.74 \pm 1.58\%$; in patients with kidney injury on the fifth day: hydroperoxides – 0.099 ± 0.004 mg/dl, malondialdehyde – 3.30 ± 0.24 mg/dl, AOA – $37.92 \pm 1.32\%$; in patients with kidney injury on the tenth day: hydroperoxides – 0.12 ± 0.002 mg/dl, malondialdehyde – 3.31 ± 0.22 mg/dl, AOA – $31.23 \pm 1.73\%$. Obtained data indicate that PLA increases in the post-traumatic period in patients with kidney injury, and a decrease in AOA is noted by the 10th day.

Thus, kidney injury is a serious disease, accompanied by a violation of the oxidative and antioxidant systems, which is why infectious and inflammatory complications often develop in the post-traumatic period. The results obtained allow us to conclude that in order to prevent and treat these complications, it is necessary to carry out antioxidant therapy. When using antioxidants in the complex treatment of patients with kidney injury, positive dynamics were noted in the AOA indicators, if before the AOA treatment it was 36.84%, then on the seventh day this indicator increased to 44.71%.

To check the reliability of the decision rules obtained by expert and modelling, a representative control sample was created, the volume of which is calculated in accordance with the recommendations of Chernega (2014), Buchanan and Shortliffe (1984), Korenevskiy et al. (2009a) and Zadeh and Klir (1996).

In accordance with the calculations, to ensure the quality of the classification at the level of 0.95, the volume of the control sample in the class ω_0 must be at least 105 people ($n_{\omega_0} \geq 105$), in the ω_p class – at least 95 people ($n_{\omega_p} \geq 95$). In this study were selected volumes $n_{\omega_0} = n_{\omega_p} = 110$ people. As indicators of quality were selected diagnostic sensitivities (DS), specificity (DSp), efficiency (DE), positive predictive value (PV+) and negative (PV–) the results calculated according to the methods described in Sergeev and Ryumin (2001), Chamney et al. (1999) and Miller (1983). The calculations showed that for model (2) all indicators exceed 0.97. This allows to conclude that the selected composition of informative features and the resulting decision rule provide an acceptable forecasting quality for medical practice. Taking into account the analysis of the values of PLA and AOA, we evaluated the treatment of patients with closed kidney injury and found that changes in the state of PLA and AOA against the background of the combined

use of antioxidant and detoxification therapy in combination with physiotherapeutic methods in the complex therapy of infectious and inflammatory complications in the post-traumatic period indicate about the quality of pathogenetically justified treatment of these complications in the perioperative period. According to the recommendations of Buchanan and Shortliffe (1984), the indicators of CC_p and UR can be used to select adequate schemes of prevention and treatment.

To solve the problem of choosing rational preventive schemes in accordance with the general recommendations for the synthesis of hybrid fuzzy decision rules on the CC_p scale, experts identified two membership functions: $\pi_{P1}(CC_p)$ confidence in preference to the first prevention scheme *P1*; $\pi_{P2}(CC_p)$ – confidence in preference to the second prevention scheme *P2*. The choice of a joint venture prevention scheme (SP) is carried out according to the maximum value of the corresponding membership function.

4 Conclusions

In the course of the study, the purpose of which was to improve the quality of medical care for patients who had closed kidney injuries, the following results were obtained:

- 1 Based on the analysis of information about the features of the studied disease, it was found that the most adequate mathematical apparatus is the theory of fuzzy decision-making logic, adapted for classification problems in medical applications.
- 2 According to the results of studying the characteristics of data presentation, the space of informative features has been formed and optimised, designed to build decisive rules for determining the risk of developing infectious and inflammatory complications in the post-traumatic period in patients with closed kidney injury. As a result of the optimisation, it was shown that the quality of forecasting acceptable for practice is achieved using indicators characterising PLA and AOA.

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