INTRODUCTION

Modern tactics for localized rectal cancer treatment is strictly standardized and regulated by International Guidelines (NCCN Guidelines v.2. 2017) [1]. In contrast to localized forms, for LARC that features high probability of relapse and inner organs systemic lesion there still is no finally formulated treatment and diagnostic standard and until very recently even definition by itself was not formulated [2].

To reach proper resectability levels, NCRT is the only solution it was supported by 100% of the experts and certified as the form of Consensus (2013). This procedure enables “stage downgrade” – transformation of locally spread form into localized one, significantly improves post-poned treatment results and decreases the number of local relapses. Tumour regression degree after NCRT directly correlates to survival rates and local relapses frequency [3]. Tumour regression reaction on CRT can vary from complete pathological regression (pCR) to full resistance (according to different authors, regression value makes from 3 to 54 %) [4]. Tumour regression degree after NCRT directly correlates to survival rates and local relapses frequency. Based on randomized clinical trials, it is proved that preliminary course of radiotherapy both fluorouracil and with oxaliplatin promotes tumour regression. Such effect enables definitive organ preserving surgery and leads to local relapses decrease in postsurgical period. NCRT is integral part of combined LARC treatment and can induct partial, significant and total regression of primary tumour with long lasting PFS [5, 6].

Nowadays, the main goal of LARC NCRT is to decrease the relapse development risk in true pelvis by means of maximal reduction of primary tumour size and tumour process stage downgrade. To meet this goal, modified re- gime of neoadjuvant chemotherapy (NCT) – replacement of fluoropyrimidine monochemotherapy to oxaliplatin polychemotherapy, looks as a very promising strategy. Yet, growing NCRT interruption frequency resulting from toxicity increase remains to be an issue. Positive impact on general ten-years survival was showed only in one of four multi-institutional randomized research published as for today [7-10]. Nevertheless, in recently published scientific
reports there is no any data about any of chemotherapy agents’ advantages. The results of STAR-01, ACCORD 12/0405-Prodige-2, NSAPB P-04, PETACC-6 randomized studies did not demonstrate significant improvement in pathological complete locoregional response and increase in survival rates connected to oxaliplatin addition to the treatment regimen. Moreover, in patients treated with oxaliplatin toxicity increase of 3-4 grade was observed [11-33].

Opposed to this, German CAO/ARO/AIO-04 studies involving integration of oxaliplatin into fluoropyrimidine-based NRT of rectal cancer demonstrated higher pathological complete response (pCR – 17% versus 13%; p = 0.038), higher 3-years PFS (75.9% versus 71.2%; p = 0.03) and no increase of general toxicity in oxaliplatin group [14, 15].

Though, there is no clear data about efficacy of NCRT with multimodal oxaliplatin including treatment in patients with LARC. According to ESMO and NICE recommendations, improved treatment results can be expected in field of personalized approach that considers immediate and postponed relapse risks. The problem of choosing right NCRT should be further investigated taking into account clinical, radiological, pathomorphological data and prognostic markers.

Other very important and insufficiently studied aspects are immunohistochemical and genetic peculiarities of tumour as prognostic factor in RC.

Level of malignancy maturation depends on intensity of tissue and cellular atypism and mitotic activity level. To assess cell proliferation in tumor, series of markers are commonly used. Conventional cell proliferation marker Ki-67 is one of them. This protein is expressed in proliferating cells during G1 phase and is absent in G0 resting cells [16]. This makes Ki-67 clinically significant proliferation marker for prognosis of several cancer types [17-21].

Clinical trials of Z. Pap et al. showed that in adenoma of the large intestine the Ki-67 expression level directly correlates with seriousness of dysplastic changes [22]. Several studies showed that significant Ki-67 expression is mainly connected to lower overall survival rates [23-27], while other studies highlight that high Ki-67 expression correlates with improvement of general survival and better oncological prognosis [28-30].

It is well known that gene polymorphisms participate in colorectal cancer pathogenesis and many chemotherapeutical drugs metabolism. Individual peculiarities of glutathione S-transferase (GSTP1) and methylene-tetra-hydro-folate-reductase (MTHFR) enzymatic activity mediated by gene polymorphism can predict rectal cancer and development of the resistance to NCT (oxaliplatin, 5-fluorouracil, irinotecan). GSTP1 and MTHFR polymorphism detection in patients with RC can be efficient for predicting tumor cell response to chemotherapy and toxicity effects of NCT [31-33].

It is very important that MTHFR participates in anti-neoplastic agent metabolism (methotrexat, fluorouracil). 5-fluorouracil acts via fluorodeoxyuridine monophosphate and inhibits thymidilate synthase [34]. Drop of MTHFR fermentative activity leads to increase of methylenetetrahydrofolate level and thereby enhances 5-fluorouracil cytotoxicity. MTHFR gene polymorphism and efficacy of 5-fluorouracil therapy were estimated in experimental research and clinical trials [35, 36].

It is known that chemical cancerogens such as polycyclic aromatic hydrocarbons and heterocyclic aromatic amines are connected to RC; aromatic amines and some of cytostatins such as platinum products, anthracyclines and steroid hormones are the substrates for GSTP1 enzyme. Substitution of adenine for guanine in position 313 of the 5th exon in GSTP1 gene leads to isoleucine substitution for valine in position 104 and reduction of its affinity to electrophilic substances [37].

Moreover, polymorphic variants of GSTP1 and MTHFR are the risk factor for gastrointestinal and cardiovascular toxicity that can be associated with development of resistance to chemotherapy. Genotyping of MTHFR C677T polymorphism enables personalization of chemotherapy agents.

In a number of scientific studies, much attention is paid to tumor microenvironment that is one of the key progression factors of tumor resistance to chemotherapy [38]. In addition, further investigations of superoxide radicals and 8-oxoguanine influence as potential markers of RC development are very promising [39-41]. 8-oxodGu present in DNA in the absence of reparation can cause cell cycle arrest and apoptosis. Most scientific research indicate the role of oxidative stress in pathogenesis of colon cancer. Chang et al. report that 8-oxodGu content in blood serum can serve as a sensitive biomarker in patients with rectal adenocarcinoma [42] and is considered as a high-informative marker of tumourogenesis [43] and important marker of tumor response to treatment [44].

As a result, this review of combined LARC treatment based on immunohistochemical and genetic prognosis factors implies many complicated unresolved issues that should be addressed in future scientific studies.

THE AIM

Our aim was to define prognostic factors of NCRT efficacy in patients with LARC, namely the prognostic factors of PFS using molecular (8-oxodGu), immunohystochemical (Ki-67) and genetic (GSTP1 and MTHFR genes polymorphism) markers.

MATERIAL AND METHODS

This research is based on the retrospective data analysis from 110 patients, who underwent combined treatment of LARC in Oncocolonoproctology Department of National Cancer Institute from 2016 to 2019 years.

The diagnostic algorithm included estimation of overall patient’s status according to ECOG scale, fibrocolonoscopy with biopsy and morphological verification, magnetic resonance imaging (MRI) of thoracic, abdominal and pelvic organs with intravenous contrast, laboratory tests and
immunohistochemical and genetic prognostic factors of neoadjuvant chemoradiotherapy...

electrocardiography. Local staging was conducted using Philips Intera 1.5 T MRI scanner according to MERCURY protocol [45]. All patients confirmed by MRI to be CRM+ were included into the research. It means tumor invasion, metastatic transformation of lymph nodes or extranodal tumor deposits, tumor infiltration of mesorectal soft tissue to a distance of not less than 1 cm from the edge. Accuracy of tumor topography in relation to mesorectal fascia played a critical role in choosing treatment plan, namely administration of NCRT and was the most important reference point for total mesorectal excision (TME). Estimation of tumor regression grade according to MRI is based on mrTRG and RECIST 1.1 (Response Evaluation Criteria in Solid Tumours) criteria.

All patients with LARC considering NCRT method were randomized at a ratio of 1:1 with respect to cTNM-pTNM (T3-4 N0-2 M0, CRM+) index.

Patients from MG underwent radiotherapy with total radiation dose of 50.4 Gy (28 sessions 1.8 Gy each) and polychemotherapy according to CAPOX regimen with oxaliplatin in non-adjuvant regime: capecitabine 200 mg/m² in two equal doses, one in the morning and one in the evening, peroral in 30 minutes after meals from day 1 to day 14; oxaliplatin 130 mg/m² intravenous on day one of the cycle. The interval between cycles made 21 days.

Patients from CG underwent radiotherapy with total radiation dose of 50.4 Gy (28 sessions 1.8 Gy each) and monochemotherapy based on fluoropyrimidines in non-adjuvant regime: capecitabine 200 mg/m² twice a day. The interval between cycles made 5 days. In general, every patient underwent two cycles of chemotherapy. Toxicity effects of NCRT were evaluated according to CTC-NCIC scale (version 4.03, 2010). Eight days after NCRT course its efficacy in all patients was evaluated using MRI according to H.T. Lee [42]. The 8-oxo-dGuo was evaluated in eluate on spectrophotometer.

To study Ki-67 expression, obtained material was fixed in buffered 10% formaldehyde, pH 7.4, and embedded in paraffin using Histos-5 (Milestone, Italy). Histological slices 5 µm in depth were obtained using Microm HM325 (Thermo Scientific, USA). The slices were stained with haemotoxilin and eosin and general tumor estimation was conducted. Immunohistochemistry was performed using rabbit monoclonal antibodies to Ki-67 (Dako, Denmark) on EnVision™ FLEX detection system (Dako, Denmark).

For antigen retrieval, citric buffer with pH 6.0 was used. Neutrophils were separated from granulocytes of LARC patients were measured 1 day before surgery [46]. For this purpose, 5 mL of patient's blood from median cubital vein were collected into centrifuige tube with 1 mL of Trilon B. Neutrophils were separated from according to H.T. Lee [42]. The 8-oxo-dGuo was evaluated in eluate on spectrophotometer.

RESULTS AND DISCUSSION

Fifty seven patients were randomized into MG and fifty three to CG. Average age of the patients in MG makes 59.3 ± 11.4 years, in CG – 62.5 ± 10.2 years. There were no statistically significant differences in gender, age and anthropometric parameters (body-weight index and total body area) between patients. According to the pathology report, all tumors were adenocarcinomas on varied differentiation stages. Full scale NCRT was conducted in all patients. As a result, the groups were representative.

After the analysis of regression value after NCRT according to MRI (mrTRG and RECIST 1.1 scales), it was determined that tumor response to NCRT was higher in MG – 34 patients (59.7%) and 37 (64.9%) than in CG – 25 (47.2%) and 26 (49.1 %), respectively, however, this difference was statistically insignificant (p<0.576; p<0.329).
Significant difference was observed in conversion level of CRM+ to CRM: in MG – 39 (68.4%) and 24 (45.3%) (p<0.05).

The estimation of morphometric and topographic anatomy features of tumor regression depending on NCRT scheme showed that in MG the distance between dental line and lower edge of the tumor significantly increased and made 1.1 ± 0.1 cm versus 0.7 ± 0.1 cm in CG (p <0.005). The length of the tumor decreased by 28.1 ± 2.1% versus 20.4 ± 2.7% (p = 0.024), respectively. Thus, positive effect of NCRT on tumor pathogenesis treatment conducted according to the CAPOX scheme and on the quality of TME was proved.

To make oxaliplatin-bazed NCT more personalized, the level of 8-oxodGu in neutrophils from human blood of LARC patients in both groups was measured. Physiological level of 8-oxo-dGuo makes 0.23±0.04 nmol/mL xmin [19].

The statistical analysis of 8-oxodGu level dependent on chemotherapy scheme prescribed, reveiled that application of oxaliplatin-bazed NCT as a part of comprehensive treatment of LARC patients aids the significant decrease of studied marker levels: (R2 = 0.465; 95% CI: 0.004 – 0.016, p<0.0001). Before NCRT 8-oxodGu level in MG was 3.07±0.08 nmol/mL xmin, in CG – 2.94±0.06 nmol/mL xmin, after it – 1.96±0.04 nmol/mL xmin and 2.72±0.04 nmol/mL xmin (p<0.001), respectively. Thus, we can conclude, that 8-oxodGu level can be considered as an independent prognostic marker of NCRT efficacy in LARC patients.

Based on logistic regression analysis, the concentration border level of 8-oxodGu in blood is 2.9 nmol/mL xmin. Based on the data supplied above, lowering of 8-oxodGu concentration is recommended before NCRT according to CAPOX scheme when its level is ≥2.9 nmol/mL xmin.

All patients in both groups underwent surgery 8 weeks after the NCRT. Surgery extent was determined depending on localization and primary tumor expansion rate. All surgical procedures were R0-resections. In MG 37 patients (65%) and in CG 26 patients (47%) underwent laparoscopic surgery. There was no statistically significant difference between groups in terms of surgical intervention structure (p=0.196). According to visual estimation, TME performance in both groups was satisfactory. Positional level of tumor location related to anus (r = 0.431 in MG and r = 0.417 in CG) positively correlated (p<0.005) to distal border of rectum resection (r = 0.510 and r = 0.532), respectively, and inversely correlates to malignancy stage after NCRT (r = −0.390 and r = −0.370) involving circumferential resection margin (CRM+) (r = −0.514 and r = −0.522). Quality of mesorectumectomy was evaluated after Quirke P et al. However, there was no significant difference between groups in terms of differences in surgical intervention method.

In postsurgical period, surgical material was investigated in terms of morphology. Therapeutic pathomorphosis level was evaluated according to parenchymatous tumor tissue percentage, fibrosis and necrosis levels, considering NCRT conducted (CAPOX regimen and capecitabine-based NCRT). Therapeutic pathomorphosis level in MG was 42.0 %, 56.9 %, 43.1 %, 34.3 %, 39.2 %, respectively. Evaluation of prescribed NCRT regimen did not confirm higher efficacy of them in terms of stronger pathological response. In this context we talk about polychemotherapy according to CAPOX scheme versus capecitabine-based monochemotherapy. The fact that we did not observe any significant statistical difference in cumulative frequency of PFS between MG and CG (73.5 ± 8.5 % versus 70.2 ± 2.5 %, p=0.522) and correlative general survival (87 ± 7.0 % and 96 ± 2.7 %) proves this. However, according to morphometrical data, there is a statistically significant difference in locoregional therapy response, namely a decrease of parenchymatous tissue and stroma volume 56.9 % and 43.1% in CG resulting from CAPOX scheme NCRT compared to 42 % i 58% in MG (p<0.001). This findings lead to the conclusion that none of above described chemotherapy agents has advantages over the

**Fig.1.** The effect of A313G GSTP1 gene polymorphism on 3-year PFS rate in LARC patients after combined treatment. a – patients received capecitabine as neoadjuvant chemotherapy; b – patients received CAPOX as neoadjuvant chemotherapy.
others. A series of international randomized studies listed in introduction came to the same output.

At the same time, to define prognostic factors of rectal cancer course we measured Ki-67 expression levels. The single-factor logistic regression analysis showed that probability of tumor relapse increases when Ki-67 expression level drops. The critical value of Ki-67 expression makes <27% where the probability of tumor relapse chance makes 50%. According to the literature, Ki-67 expression level is a prognostic immunohistochemical biomarker that can predict survival rates decrease in patients with rectal cancer [57]. Comparison of Ki-67 expression level and PFS revealed statistically significant difference in terms of

![Fig. 2. The effect of C667T MTHFR gene polymorphism on 3-year PFS rate in LARC patients after combined treatment. a — patients received capecitabine as neoadjuvant chemotherapy; b — patients received CAPOX as neoadjuvant chemotherapy.](image)

![Fig. 3. The effect of Ki-67 protein expression on 3-year PFS rate in LARC patients after combined treatment. a — patients received capecitabine as neoadjuvant chemotherapy; b — patients received CAPOX as neoadjuvant chemotherapy.](image)

![Fig. 4. The personalized algorithm of NCRT application in patients with LARC.](image)
PFS rate in CG. Patients with Ki-67 expression >27% have 27.5 times higher relapse risk compared to patients with Ki-67 expression <27%. In MG, such statistically significant difference was not observed (Fig.1).

Detection of polymorphism in GSTP1 and MTHFR genes in LARC patients is a new innovative research direction. Three-year PFS in patients from CG that carry GSTP1 and MTHFR polymorphism is significantly higher. According to logistic regression analysis, relapse risk in patients who carries GSTP1 and MTHFR polymorphism is 12.3 and 16.3 times higher compared to patients without it, respectively. In CG three-year PFS decreases significantly in patients with A313G GSTP1 and C667T MTHFR polymorphisms compared to the patients without these mutations (p<0.001). In MG, there was no statistically significant difference in relapse-free survival level in patients with or without GSTP1 and MTHFR polymorphism (Fig.2, Fig.3).

Based on such factors as GSTP1 and MTHFR gene polymorphism and Ki-67 expression level, we developed a mathematical model of relapse in LARC patients (Table I). Based on multifactorial logistic regression analysis next formula was generated (Formula 1):

\[
p = \frac{1}{1 + e^{-Z}}
\]

where \( Z = c + \beta_1 \times \text{GSTP1} + \beta_2 \times \text{MTHFR} - \beta_3 \times \text{Ki-67} ;
\]
\( e = 2.72 \); \( Z \) – likelihood of relapse; \( c = 1.397 \) (constant); \( \beta_1 \) – coefficient for GSTP1 factor; \( \beta_2 \) – coefficient for MTHFR factor; \( \beta_3 \) – coefficient for Ki-67 factor.

It helps estimate relapse risk patient-specifically within 3 years after treatment. Prognostic probability of relapse can be evaluated within 51–99% depending on GSTP1, MTHFR and Ki-67 factors combination.

As a result, personalized algorithm of NCRT selection was developed (Fig.4). In case of GSTP1 and MTHFR polymorphism or their combination as significant prognosis factors, CAPOX scheme NCRT is recommended. If polymorphisms in these genes are absent, Ki-67 (<27%) and 8-oxoGu (≥ 2.9 nmol/mL/min) expression levels should be considered prior to NCRT prescription.

**CONCLUSIONS**

The analysis of many scientific publications proves that LARC diagnostics and treatment is an essential and very complicated issue in modern clinical oncology. Based on our own knowledge and practical experience in optimization of combined modality LARC treatment considering prognostic factors (8-oxoGu, Ki-67, A313G GSTP1 and C667T MTHFR) we came to clear understanding of personalized NCRT schemes. The algorithm developed from multifactorial system allows to predict and monitoring LARC relapse development. Consequently, it will improve immediate and postponed results of treatment in patients with this complicated heterogeneous oncological disease.

**REFERENCES**


**Table 1.** Recurrence prognostic model in patients with local advanced RC (β coefficient value and probability levels for independent prognostic factors)

<table>
<thead>
<tr>
<th>Value</th>
<th>β*</th>
<th>Valid.*</th>
<th>P</th>
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<tbody>
<tr>
<td>GSTP1</td>
<td>3.036</td>
<td>4,293</td>
<td>0.038</td>
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<tr>
<td>MTHFR</td>
<td>3.169</td>
<td>4,270</td>
<td>0.039</td>
</tr>
<tr>
<td>Ki-67</td>
<td>-0.141</td>
<td>4,520</td>
<td>0.034</td>
</tr>
<tr>
<td>Constant</td>
<td>1.397</td>
<td>0,330</td>
<td>0,565</td>
</tr>
</tbody>
</table>

* – β coefficient in logistic regression; ** – significance criterion for β coefficient.


25. Wu XS, Xi HQ, Chen L. Lgr5 is a potential marker of colorectal carcinoma stem cells that correlates with patient survival. World J Surg Oncol. 2012;10:244.


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**ORCID and contributionship:**

- Vitalii Zvirych – 0000-0002-3502-1886
- Yuriy Mikhailovich – 0000-0003-3551-2148
- Oleksandr Gorbach – 0000-0003-2922-6049
- Natalia Khranovska – 0000-0002-0800-2540

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The authors have no financial conflicts of interest.

**CORRESPONDING AUTHOR**
Vitalii V. Zvirych
National Cancer Institute
Lomonosov Str, 33/43, 03022, Kyiv, Ukraine
tel: +38 098 850 80 76
e-mail: zvirvit@ukr.net

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