

Association of DNA repair gene variants with colorectal cancer: risk, toxicity, and survival

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Abstract

Background : Single nucleotide polymorphisms (SNPs) in DNA repair genes have a potential clinical value in predicting treatment outcomes. In the current study, we examined the association of SNPs in the genes XRCC1-rs25487, ERCC1-rs11615, ERCC2-rs238406, and ERCC2-rs13181 with colorectal cancer (CRC) risk, relapse-free survival (RFS), overall survival (OS), and toxicity during chemotherapy.

Methods: SNPs were analysed in 590 CRC cases and 300 controls using TaqMan technology. The association of SNPs with CRC risk and toxicity during chemotherapy was analysed using Chi² test. The Kaplan–Meier method and Log-rank test was used to measure the effects of the SNPs on RFS and OS.

Results: The ERCC2-rs238406 A allele and the ERCC2-rs13181 C allele were associated with a significantly increased risk of CRC. The ERCC1-rs11615 genotype T/T was associated with stomatitis in adjuvant chemotherapy ($p = 0.03$). Also, more patients with the ERCC2rs13181 C allele needed dose reduction compared to patients with the A/A genotype ($p = 0.02$). In first line chemotherapy, more patients with the ERCC1-rs11615 C allele suffered from nausea compared with those with the T/T genotype ($p = 0.04$) and eye reactions and thrombocytopenia were more common in patients with the ERCC2-rs13181 C allele compared to the A/A genotype ($p = 0.006$ and $p = 0.004$, respectively). Also, ERCC2- rs238406 C/C was associated with a higher frequency of thrombocytopenia ($p = 0.03$). A shorter 5-year OS was detected in stage I & II CRC patients with the ERCC2- rs238406 C allele ($p = 0.02$). However, there was no significant association between the SNPs and 5-year RFS.

Conclusions: Both SNPs in ERCC2 were associated with risk of CRC as well as toxicity during first line treatment. In addition, ERCC2- rs238406 was linked to OS in early stage CRC. The ERCC1-rs11615 variant was associated with toxicity during adjuvant chemotherapy. The results add support to previous findings that SNPs in ERCC1 and ERCC2 have a prognostic and predictive value in clinical management of CRC.

Background

Colorectal cancer (CRC) is a major health concern with approximately 1.8 million incident cases each year worldwide [1]. Although survival of CRC has been improved with novel chemotherapeutic drugs [2], chemotherapy has not increased the overall survival (OS) dramatically in advanced CRC [3]. A meta-analysis confirmed a highly significant tumor response rate (23% vs 11%) in FLV therapy; that is, 5-fluorouracil (5-FU) plus leucovorin over 5-FU alone [4]. Moreover, adding oxaliplatin to FLV significantly improved OS in the adjuvant treatment of stage II/III CRC patients [5] and is considered the standard therapy for first-line treatment of metastatic CRC, with a response rate of over 40% [6]. However, oxaliplatin-based treatment has the serious drawback of tumor cell drug resistance, in which DNA repair plays a key role [7].

A number of single nucleotide polymorphisms (SNPs) in DNA repair genes have been known to affect cancer susceptibility, prognosis, and therapeutic outcomes [8]. Indeed, SNPs in drug-targeted genes [9], metabolizing enzymes [10], and DNA-repairing enzymes [11] have been linked to inter-individual

differences in the efficacy and toxicity of numerous drugs. Excision repair cross-complementing group 1 (ERCC1) and 2 (ERCC2) and X-ray repair cross-complementing group 1 (XRCC1) are DNA repair enzymes which play important roles in nucleotide excision repair [8].

The ERCC1 and ERCC2 proteins are highly conserved enzymes [12] which participate in the key steps of nucleotide excision repair such as the damage recognition and removal of DNA lesions induced by substances such as platinum [8, 13, 14]. SNPs in the ERCC1 and ERCC2 genes might be used as valuable predictive factors for oxaliplatin-based chemotherapy [15].

XRCC1 is known to play a critical role in DNA single-strand break repair and in the base excision repair pathway. Defects in these pathways may result in accumulation of DNA damage, carcinogenesis, and may reduce chemotherapeutic sensitivity [16].

Studies showed that the ERCC1, ERCC2, and XRCC1 polymorphisms may influence the clinical outcome in CRC patients treated with adjuvant [17] or palliative oxaliplatin-based chemotherapy [18, 19]. For instance, a recent meta-analysis showed that the ERCC1-rs11615 polymorphism is closely linked with the clinical outcomes of CRC patients treated with oxaliplatin-based chemotherapy [7].

To our knowledge, the association of polymorphisms with the survival of CRC patients has been sparsely studied yet. This study aimed to evaluate a possible link between SNPs in ERCC1 (rs11615), ERCC2 (rs238406 and rs13181), and XRCC1(rs25487) and the risk of CRC development, comparing 596 patients to 300 controls. The study further aimed to assess the link between the SNPs and toxicity during treatment with 5-FU-based chemotherapy. Moreover, the same set of SNPs were analyzed in association with relapse-free survival (RFS) and OS of CRC patients.

Methods

Patients and controls

In total, 596 CRC consecutive patients treated at Sahlgrenska University Hospital /Östra between 1990–2006 were included. EDTA venous blood samples were collected from patients and 300 healthy blood donors. Patients demographic and clinicopathological data was prospectively recorded based on medical records and follow up was done on a yearly basis. The tumour–node–metastasis staging system was used to classify tumours [20]. The regional ethical review board in Gothenburg approved the study and informed consent was obtained from all patients and controls.

Toxicity

Patients were assessed for adverse events before each treatment cycle using the National Cancer Institute's Common Terminology Criteria for Adverse Events (NCI-CTC AE) version 5.0 [21]. Toxicities known to be related with the given treatment (diarrhoea, nausea, vomiting, stomatitis, fatigue, eye and skin reactions, leukopenia, thrombocytopenia, neutropenia, and neurotoxicity) were evaluated. A final toxicity evaluation was made at the end of treatment (complete or terminated due to toxicity) and the

highest toxicity grade during treatment was noted. Toxicity was evaluated as a dichotomized variable: 'no toxicity vs any toxicity'.

Genotyping

Genomic DNA was extracted from EDTA venous blood samples using a magnetic bead extraction procedure on a Hamilton ML Star robot and quantified on agarose gel. The XRCC1 (rs25487), ERCC1 (rs11615), ERCC2 (rs13181), and ERCC2 (rs238406) genotypes were generated using TaqMan technology implemented on an ABI PRISM® 7900HT sequence detection system (Applied Biosystems, Foster City, CA). Genotyping PCR reactions contained 2.5 µL of ABI TaqMan PCR Master Mix, 0.10 µL of ABI SNP assay-by-design master mix containing 900 nmol/L forward primer, 900 nmol/L reverse primer, 200 nmol/L VIC-labelled MGB probe, and 200 nmol/L FAM-labelled MGB probe, 10–20 ng of template DNA, and H₂O to a final volume of 5 µL. Assay (Table 2) and TaqMan PCR mastermix was pipetted in a 384-well plate using a liquid-handling Biomek FX robot (Beckman Coulter Inc., San Diego, CA, USA). ABI PRISM® 7900HT Sequence Detection System (version 2.1) was used for TaqMan and fluorescent discrimination genotyping analyses. Unblinded control samples were included on each sample plate and were correctly genotyped by the SDS on 100% of occasions. Laboratory staff members employed in genotyping were blinded to clinical outcome.

Statistical analysis

To test for Hardy-Weinberg equilibrium of the SNPs, a Chi² test was applied. Also, the association of SNPs the risk of CRC development and with toxicity during adjuvant or first line chemotherapy were analysed using Chi² test. The 5-year OS was calculated for all CRC patients (n = 596) from the date of surgery to date of all cause death, whereas the 5-year RFS was calculated for stage III CRC patients (n = 170) from the start of adjuvant treatment to date of CRC relapse or all cause death. Patients lost to follow-up were censored. The Kaplan–Meier method, log-rank test and Cox regression model were employed to evaluate the effects of polymorphisms and other covariates on survival analysis, reporting hazard ratio (HR) and 95% confidence interval (CI). We plotted the OS and analysed the associations of the SNPs with response to adjuvant therapy in terms of toxicity in CRC patients. A P-value < 0.05 was considered to be significant. Analysis and plots were conducted using Stata MP v.14.

Results

Patients characteristics

Demographic and clinicopathological data is shown in Table 1. Mean age at diagnosis was 69.4 years. Most of the CRC patients were male (56.7%) and had a colon cancer (57.6%) stage II or III (73.4%), and a well/moderately differentiated tumour (75.0%). The lymph node ratio (LNR), i.e., the number of positive lymph nodes divided by the number of analysed lymph nodes, was calculated. In 69.3% of patients at least 12 lymph nodes were examined and 52.1% of patients were found to be node-positive. Among patients with rectal cancer, 21.7% received radiotherapy prior to surgery. Radical operation was conducted

in 86.3% and chemotherapy was administered in 39.6% of the patients. Relapse status was known for all but one stage I-III patients and relapse was confirmed in 32.1%. Three (0.5%) patients had unknown status at the last follow-up and 362 (60.7%) were deceased (Table 1) of which 225 (37.8%) were cancer-specific deaths.

Table 1 Patients characteristics (<i>n</i> =596)	
	<i>n</i> (%)
Age, mean (\pm SD) yrs	69.4 (\pm 12.1)
Gender (Male)	338 (56.7)
Tumor location	
Rectum	251 (42.4)
Left-sided colon	132 (22.3)
Right-sided colon	209 (35.3)
Tumor differentiation	
Well	22 (3.7)
Moderate	423 (71.3)
Poor	138 (23.3)
Mucinous	6 (1.0)
Stage	
I	62 (10.4)
II	203 (34.1)
III	234 (39.3)
IV	94 (15.8)
Lymph node count \geq 12	413 (69.3)
Positive lymph node	293 (52.1)
Received preoperative radiotherapy*	130 (21.7)
Radically operated	509 (86.3)
Received chemotherapy**	236 (39.6)
Adjuvant therapy	171 (55.1)
First-line therapy	101 (25.4)
Confirmed response to therapy	74 (78.7)
Relapsed	171 (28.7)
Status at last follow-up	
Dead	362 (60.7)

Alive

231 (38.8)

NOTE- Unknown data: Tumor location for 4 patients; Tumor differentiation for 7 patients; Tumor stage for 3 patients; Radical operation for 6 patients; relapse for 1 patient, status at last follow-up for 3 patients. *Only for rectal cancer patients; ** 41 patients had both adjuvant and first-line therapy, response to therapy was measured only for 94 patients who had undergone first-line therapy.

Polymorphism distribution and its correlation with CRC risk

All the studied polymorphisms were in Hardy-Weinberg equilibrium in both CRC patients and healthy controls (Table 2). Table 3 summarizes the SNPs distribution in CRC cases and the normal controls. The A allele of ERCC2-rs238406 and C allele of ERCC2-rs13181 was associated with a significantly increased risk of CRC, with odds ratios (95% CI) of 1.5 (1.1-2.0) and 0.7 (0.5–0.9), respectively (Table 3). There were no statistically significant correlations between genotype distributions and age, gender, tumour location, tumour stage, tumour differentiation, lymph node metastasis, and other cancer characteristics assessed in the current study (Data not shown).

Table 2 Genotype distributions in colorectal cancer patients and healthy controls

Gene	Group	Rs number	Locus/effect	Major homozygote	Heterozygote
XRCC1	Patients	rs25487	Gln399Arg	253 (G/G)	269 (G/A)
	Controls			128 (G/G)	136 (G/A)
ERCC1	Patients	rs11615	Asn118Asn	237 (T/T)	265 (C/T)
	Controls			122 (T/T)	151 (C/T)
ERCC2	Patients	rs238406	Arg156Arg	178 (C/C)	282 (C/A)
	Controls			70 (C/C)	162 (C/A)
ERCC2	Patients	rs13181	Lys751Gln	219 (A/A)	286 (A/C)
	Controls			138 (A/A)	125 (A/C)

NOTE- Missing data: XRCC1-rs25487 for 6 patients; ERCC1-rs11615 for 16 patients; ERCC2-rs238406 for 3 controls and 24 patients; ERCC2-rs13181 for 15 patients and 6 controls.

NOTE-*CI: confidence interval

Polymorphism distribution and its correlation with CRC toxicity

Significant results of the toxicity analysis are shown in Table 4. In patients with adjuvant chemotherapy, the ERCC1-rs11615 genotype T/T was significantly associated with stomatitis ($p = 0.03$), and significantly more patients with the ERCC2-rs13181 C allele needed dose reduction compared to patients

Table 3 Comparison of polymorphisms between colorectal cancer patients and controls					
	Total, <i>n</i> (%)	Patients, <i>n</i> (%)	Controls, <i>n</i> (%)	Odd ratio (95% CI)*	<i>p</i>
XRCC1-rs25487					
G/G	381 (42.8)	253 (42.9)	128 (42.7)		
G/A + A/A	509 (57.2)	337 (57.1)	172 (57.3)	1.0 (0.7-1.3)	0.95
ERCC1-rs11615					
T/T	359 (40.8)	237 (40.9)	122 (40.7)		
C/T + C/C	521 (59.2)	343 (59.1)	178 (59.3)	1.0 (0.7-1.3)	0.95
ERCC2-rs238406					
C/C	248 (28.5)	178 (31.1)	70 (23.6)		
C/A + A/A	621 (71.5)	394 (68.9)	227 (76.4)	1.5 (1.1-2.0)	0.01
ERCC2-rs13181					
A/A	357 (40.8)	219 (37.7)	138 (46.9)		
A/C + C/C	518 (59.2)	362 (62.3)	156 (53.1)	0.7 (0.5-0.9)	0.009

with the A/A genotype ($p = 0.02$). Among patients with first-line chemotherapy, significantly more patients with the ERCC1-rs11615 C allele suffered from nausea compared to those with the T/T genotype ($p = 0.04$). Also, eye reactions and thrombocytopenia were more common in patients with the ERCC2-rs13181 C allele compared to the A/A genotype ($p = 0.006$ and $p = 0.004$, respectively). Furthermore, the ERCC2-rs238406 C/C genotype was associated with a higher frequency of thrombocytopenia ($p = 0.03$).

Table 4 Polymorphisms and toxicity due to treatment of colorectal patients		
Polymorphism	Toxicity, n (%)	p
ERCC1-rs11615	Stomatitis*	
T/T	14/70 (20.0)	
C/T + C/C	8/94 (8.5)	0.03
ERCC1-rs11615	Nausea	
T/T	24/37 (64.9)	
C/T + C/C	48/58 (82.8)	0.04
ERCC2-rs13181	Eye reactions	
A/A	7/37 (18.9)	
A/C + C/C	27/58 (46.6)	0.006
ERCC2-rs13181	Thrombocytopenia	
A/A	8/36 (22.2)	
A/C + C/C	31/59 (52.5)	0.004
ERCC2-rs238406	Thrombocytopenia	
C/C	16/28 (57.1)	
C/A + A/A	23/67 (34.3)	0.03
ERCC2-rs13181	Dose reduction/discontinuation*	
A/A	38/70 (54.3)	
A/C + C/C	69/96 (71.9)	0.02
NOTE-*Patients who received adjuvant therapy		

Survival analysis

Patients who died within 30 days after surgery (n = 3) were excluded from survival analysis. By the median follow-up time of 2313 days, 362/593 (61.0%) of the patients were deceased and 329/593 lived

at least five years after the date of first surgery. Thus, the 5-year overall survival rate was 55.5% (95% CI, 51.4–59.5) and the 5-year cancer-specific survival was 67.5% (95% CI, 63.5–71.2). One hundred and seventy-one patients (28.7%) received adjuvant treatment (additional Table 1). Out of these patients, 156 were included in the 5-year RFS analysis (fifteen stage II patients were excluded from the RFS analysis, as was one stage IV patient down staged after surgery). Ninety-four of the 156 stage III CRC patients were relapse free at least five years after the start date of adjuvant treatment, resulting in a 5-year RFS of 60.3% (95% CI 52.1–68.0).

There were no significant associations of the studied SNPs with the 5-year OS of all stage CRC patients (Fig. 1a), nor with stage III or IV patients (Fig. 1c, d). However, the ERCC2-rs238406 polymorphism might affect survival in stage I & II CRC patients. As shown in Fig. 1b, significantly shorter 5-year OS was found to be associated with the ERCC2-rs238406 C allele ($p = 0.02$). There was no significant association with 5-year RFS of stage III patients (Data not shown).

Univariate analysis evaluating prognostic factors affecting the 5-year overall survival, are shown in Table 5. There was a statistical significant difference in 5-year OS for patient age at diagnosis ($p < 0.0001$), cancer stage ($p < 0.001$), differentiation grade ($p < 0.001$), number of lymph nodes examined after resection ($p < 0.001$), node-positivity rate ($p = 0.004$), radical operation ($p < 0.001$), and year of surgery ($p = 0.001$). However, gender, primary tumour location, and the XRCC1-rs25487, ERCC1-rs11615, ERCC2-rs238406, and ERCC2-rs13181 polymorphisms were not statistically associated with 5-year OS (p 's > 0.05).

Table 5 Prognostic factors of 5-year overall survival of colorectal cancer in univariate analysis				
	Total (<i>n</i> =593)	Events (<i>n</i> =268)	Hazard ratio (<i>95% confidence interval</i>)	<i>p</i> *
Age, mean (\pm SD) yrs	69.4 (\pm 12.2)	72.4 (\pm 12.3)	1.03 (1.0-1.1)	<0.0001
Gender, <i>n</i> (%)				
Male	337 (56.8)	157 (58.6)		
Female	256 (43.2)	111 (41.4)	0.9 (0.6-1.2)	0.4
Tumor location, <i>n</i> (%)				
Rectum	249 (42.3)	116 (43.8)		
Left-sided colon	132 (22.4)	53 (20.0)	0.8 (0.5-1.2)	0.2
Right-sided colon	208 (35.3)	96 (36.2)	1.0 (0.7- 1.4)	0.2
Tumor differentiation, <i>n</i> (%)				
Well & Moderate	442 (76.2)	183 (69.8)		
Poor	138 (23.8)	79 (30.2)	1.4 (1.1- 1.7)	<0.001
Stage, <i>n</i> (%)				
I & II	264 (44.8)	78 (29.1)		
III	232 (39.3)	105 (39.2)	1.9 (1.4- 2.8)	0.0002
IV	94 (15.9)	85 (31.7)	22.5 (10.8- 47.3)	<0.0001
Lymph Node Positive, <i>n</i> (%)				
No	268 (45.2)	83 (31.0)		
Yes	325 (54.8)	185 (69.0)	2.9 (2.1-4.1)	<0.001
Lymph Node Count, <i>n</i> (%)				
< 12	183 (30.9)	99 (36.9)		
\geq 12	410 (69.1)	169 (63.1)	0.6 (0.4-0.8)	0.001
Radical operation, <i>n</i> (%)				
No	81 (13.8)	77 (29.3)		
Yes	506 (86.2)	186 (70.7)	0.03 (0.01-0.1)	<0.0001

Year of surgery, <i>n</i> (%)				
1990-2000	140 (23.6)	80 (29.8)		
2001-2006	453 (76.4)	188 (70.2)	0.5 (0.4-0.8)	0.0009
XRCC1-rs25487, <i>n</i> (%)				
G/G	250 (42.6)	113 (43.1)		
G/A	269 (45.8)	117 (44.7)		
A/A	68 (11.6)	32 (12.2)	1.0 (0.7-1.4)	0.9
ERCC1-rs11615, <i>n</i> (%)				
T/T	236 (40.9)	105 (40.9)		
C/T	263 (45.6)	111 (43.1)		
C/C	78 (13.5)	41 (16.0)	1.1 (0.7-1.4)	0.9
ERCC2-rs238406, <i>n</i> (%)				
C/C	176 (30.9)	73 (29.0)		
C/A	281 (49.4)	130 (51.6)		
A/A	112 (19.7)	49 (19.4)	1.1 (0.6-1.2)	0.7
ERCC2-rs13181, <i>n</i> (%)				
A/A	219 (37.9)	99 (39.0)		
A/C	283 (49.0)	124 (48.8)		
C/C	76 (13.1)	31 (12.2)	1.1 (0.8-1.5)	0.7

Discussion

In this relatively large case-control study of 596 CRC patients and 300 controls, we assessed the influence of genetic polymorphisms on CRC risk, treatment toxicity, and survival in CRC patients. The patient cohort was well-monitored with a follow-up period of at least 5 years.

Polymorphisms and cancer risk

Data regarding the association between the investigated polymorphisms and CRC risk are controversial, which to a large extent is related to variability among populations. For each gene polymorphism, the minor allele varies greatly among ethnic groups. As an example, the XRCC1-rs25487 A allele ranges from 0.11 in the African population to 0.37 in European population [22], hence possibly contributing to different levels of susceptibility to CRC across populations. While previous studies on XRCC1-rs25487

confirmed the association of increased risk for CRC in particular among East Asians and Arab ethnicity [23–26], two meta-analysis studies, consistent with our results, suggested no association of this SNP and risk of CRC [27, 28]. Further large and well characterized studies, therefore, are needed to identify the association between the XRCC1-rs25487 polymorphism and CRC risk and how it varies in different populations.

Some Chinese [24, 29] and Norwegian [30] studies assessed the ERCC1-rs11615 polymorphism and CRC risk but found no significant correlations [31], in accordance with the findings of the present study. In contrast, a study of a Chinese population showed that the ERCC1-rs11615 genotype T/T contributed to a 1.9-fold increased CRC risk compared to CC genotype [32].

Our findings indicate that the A allele of ERCC2-rs238406 and the C allele of ERCC2-rs13181 have significantly increased risk of CRC which supports the study suggesting that the rs13181 heterozygote is linked to higher risk of CRC compared to TT or GG genotypes in a Spanish population [33]. Moreover, the risk of CRC was significantly increased with the ERCC2-rs13181 A allele in one Romanian study [34]. However, some studies conclude on the contrary that the CC genotype is associated with decreased CRC risk in American [35] and Iranian [36] populations. Furthermore, many studies, including one meta-analysis, which assessed the relation between the ERCC2-rs13181 polymorphism and CRC risk in multiple populations failed to find any link [37, 38]. Thus, more knowledge on the mechanisms of the ERCC2 variants is needed to clarify the implications of the present data.

Polymorphisms and toxicity

Treatment induced toxicity is an important factor that eventually can result in either dose reduction or termination of the treatment [39]. In our study patients receiving FLV or oxaliplatin-based adjuvant therapy, the ERCC1-rs11615 genotype T/T was significantly associated with stomatitis, while among patients receiving first-line chemotherapy, the ERCC1-rs11615 C allele was associated with nausea. However, we could not find any association between ERCC1-rs11615 and haematological toxicity, as has been reported in other studies. For instance, one study reported the ERCC1-rs11615 genotype T/T to be correlated with severe leukopenia in patients with non-small lung cancer receiving platinum-based therapy in a Chinese population [40].

The ERCC1-rs11615 T allele has been shown to be linked with reduced response to treatment and poor OS in Asians, probably due to high expression of ERCC1 [6], and may be a predictive factor for CRC patients treated with oxaliplatin and 5-FU combined [41]. Nevertheless, currently the European Society for Medical Oncology guidelines are against the use of ERCC1 expression status in therapeutic decisions on oxaliplatin use in routine clinical practice due to inconsistent results [42].

In our study, significantly more patients with the ERCC2-rs13181 C allele had eye reactions, thrombocytopenia, and needed dose reduction more often compared to patients with the A/A genotype. Haematological toxicity was also reported in a previous study, where the ERCC2-rs13181 C allele was

significantly associated with an increased risk of FOLFOX-induced toxicity [43]. We also find indications that the ERCC2-rs238406 C/C genotype is associated with a higher frequency of thrombocytopenia.

No association between XRCC1 polymorphism and any of the investigated toxicity parameters was found here. Our results are also consistent with the literature in failing to identify a significant prognostic effect of the XRCC1 SNP in metastatic CRC patients. Taken together we find no strong association of XRCC1 genotype with clinical outcome [44–46]. Nonetheless, other studies have shown that CRC patients who carry at least one A allele were at an increased risk of resistance to oxaliplatin-based treatment [47, 48].

Discrepancies regarding the association between polymorphisms and toxicity among studies might in addition to being population-dependent, be due to gender differences as reported in a recent publication by Ruzzo et al. [49]. However, the impact of gender could not be assessed in our study due to the relatively small number of patients in each toxicity subgroup. The type of chemotherapy given may also affect the results and larger more homogenous groups in terms of treatment regimens and gender distribution may provide stronger data.

Survival

In general, neither 5-year RFS or OS were associated with any of the polymorphisms in the present study with the exception of the ERCC2-rs238406 C allele that was associated with significantly shorter 5-year OS among stage I and II CRC patients. Our results are in agreement with one study in Nordic population that showed patients with the ERCC2-rs238406 A/A genotype had a significantly longer progression-free survival compared to patients with the C/A and C/C genotypes [39]. There was no significant difference, however, in the OS. Indeed, this polymorphism may reduce ERCC2 protein levels by altering mRNA stability [40] and a reduced ERCC2 protein activity in patients with the ERCC2-rs238406 the A/A genotype may lead to an increased sensitivity to DNA-damaging drugs like oxaliplatin and therefore a better progression-free survival [39].

According to the literature, the ERCC2-rs13181 has been shown to be a prognostic predictor for CRC [50] and one American study showed that CRC patients carrying the ERCC2-rs13181 C/C genotype displayed poor survival [51]. Furthermore, a meta-analysis indicated that the ERCC2-rs13181 C allele was linked with poorer OS in Caucasians [6]. The same study reported that the ERCC1-rs11615 T allele was associated with shorter OS in the oxaliplatin-treated Asians CRC patients [6]. Likewise, the prognostic effect of the XRCC1 polymorphism has been confirmed with shorter disease-free survival in patients with A/A genotype [18], yet, other studies failed to identify any significant association of this SNP with cancer-specific or disease-free survival in CRC patients [44–46, 52].

Although the present study is relatively large, the number of patients is still too small to permit robust analysis in selective sub-groups. For instance, it would be interesting to study the impact of gene variants in stage III and stage IV patients grouped by different treatment regimens. However, we used a well-defined patient cohort with a long follow-up time which provided potentially clinically reliable information.

Conclusions

Both SNPs in ERCC2 were associated with a significantly increased risk of CRC. In addition, the ERCC2-rs238406 was linked to OS in early stage CRC and both ERCC2-rs238406 and ERCC2-rs13181 were associated with toxicity during first line treatment. Specifically, the ERCC2-rs238406 variant was associated with thrombocytopenia whereas the ERCC2-rs13181 variant was correlated with thrombocytopenia as well as nausea. The ERCC1-rs11615 genotype T/T was significantly associated with stomatitis during adjuvant treatment, while among patients receiving first-line chemotherapy, the ERCC1-rs11615 C allele was associated with nausea. The results add support to previous findings that SNPs in ERCC1 and ERCC2 have a prognostic and predictive value in clinical management of CRC.

Abbreviations

SNP: Single nucleotide polymorphism; CRC: Colorectal cancer; RFS: Relapse-free survival; OS: Overall survival; 5-FU: 5-fluorouracil; FLV therapy: 5-FU plus leucovorin; ERCC1: Excision repair cross-complementing group 1; ERCC2: Excision repair cross-complementing group 2; XRCC1: X-ray repair cross-complementing group 1; NCI-CTC AE: National Cancer Institute's Common Terminology Criteria for Adverse Events; HR: Hazard ratio; CI: Confidence interval; LNR: Lymph node ratio.

Declarations

Ethics approval and consent to participate

Written informed consent to participate in this study was obtained from all participants. This study was conducted under the approval of the Swedish Ethical Review Authority (No. Ö445-00 and 118-15).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

HS and YW performed the statistical analysis and interpreted data and wrote the manuscript. YW designed the research and collected the data and performed the genetic examinations of the blood samples and the follow-up survey. DL, EBL, and BG edited and made critical revisions to the manuscript. All authors read and approved the final manuscript.

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Figures

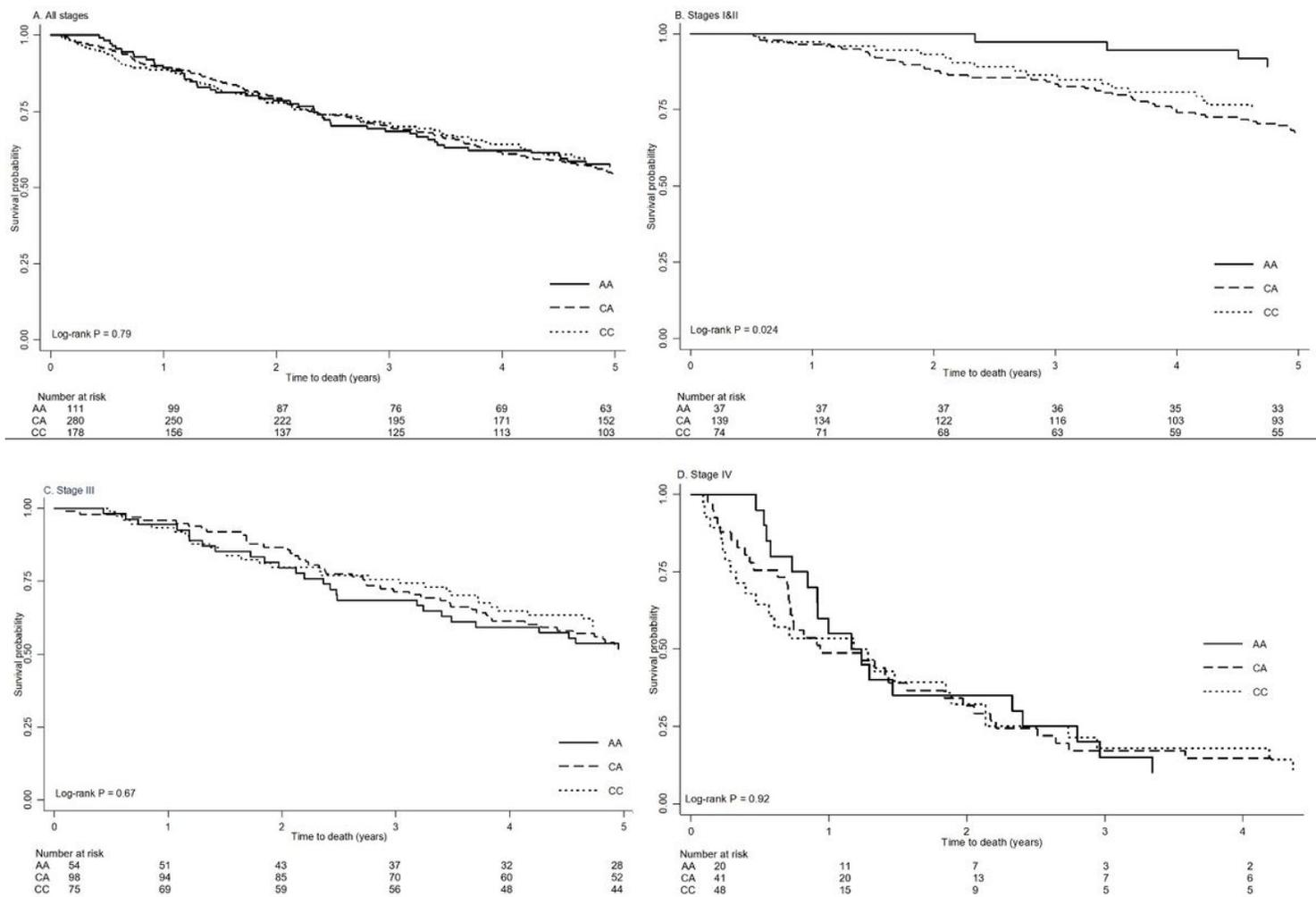


Figure 1. Five-year overall survival colorectal cancer by stage, ERCC2-rs238406 genotyp

Figure 1

5-year overall survival of colorectal cancer by stage, ERCC2-rs238406 genotype. Kaplan-Meier curves are shown for 5-year overall survival among colorectal cancer patients with ERCC2-rs238406 AA, CA, and CC genotypes. Survival curves are shown by cancer stage: all stages (a), stage I and II (b), stage III (c), and stage IV (d). The C allele was associated with significantly shorter survival among stage I and II patients (b).

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