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***Retrospective Study***

**Integrating *TYMS*, *KRAS* and *BRAF* testing in patients with metastatic colorectal cancer**

Ntavatzikos A *et al.* Molecular profiling in mCRC

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**Abstract**

***AIM***

To investigate the impact of thymidylate synthase(*TYMS*)*, KRAS* and *BRAF* in the survival of metastatic colorectal cancer (mCRC) patients treated with chemotherapy.

***METHODS***

Clinical data were collected retrospectively from records of consecutive patients with mCRC treated with fluoropyrimidine-based chemotherapy from 1/2005 to 1/2007. Formalin-fixed paraffin-embedded tissues were retrieved for analysis. *TYMS* genotypes were identified with restriction fragment analysis PCR, while *KRAS* and *BRAF* mutation status was evaluated using real-time PCR assays. *TYMS*-gene polymorphisms of each of the 3’ untranslated region (UTR) and 5’UTR were classified into three groups according to the probability they have for high, medium and low TYMS expression (and similar levels of risk) based on evidence from previous studies. Univariable and multivariable survival analyses were performed.

***RESULTS***

The analysis recovered 89 patients with mCRC (46.1% *de novo* metastatic disease and 53.9% relapsed). Of these, 46 patients (51.7%) had colon and 43 (48.3%) rectal primary. All patients were treated with fluoropyrimidines-based chemotherapy (5FU or capecitabine) single-agent or in combination with irinotecan or/and oxaliplatin or/and bevacizumab. With a median follow up time of 14.8 mo (range 0-119.8), 85 patients (95.5%) experienced disease progression and 63 deaths (70.8%) were recorded. The 3-year and 5-year OS rate was 25.4% and 7.7% while the 3-year progression-free survival (PFS) rate was 7.1%. Multivariate analysis of *TYMS* polymorphisms, *KRAS* and *BRAF* with clinicopathological parameters indicated that *TYMS* 3’UTR polymorphisms are associated with risk for disease progression and death (*P <* 0.05 and *P <* 0.03 respectively). When compared to tumors without any del allele (genotypes ins/ins and ins/ loss of heterozygosity (LOH) linked with high *TYMS* expression) tumors with del/del genotype (low expression group) and tumors with ins/del or del/LOH (intermediate expression group) have lower risk for disease progression (HR 0.432 95%CI 0.198-0.946 *P <* 0.04 and HR 0.513 95%CI 0.287-0.919 *P <* 0.03 respectively) and death (HR 0.366 95%CI 0.162-0.827 *P <* 0.02 HR 0.559 95%CI 0.309-1.113 *P <* 0.06 respectively). Additionally, *KRAS* mutation was associated independently with the risk of disease progression (HR 1.600 95%CI 1.011-2.531 *P <* 0.05). The addition of irinotecan in 1st line chemotherapy was associated independently with lower risk for disease progression and death (HR 0.600 95%CI 0.372-0.969 *P <* 0.04 and HR 0.352 95%CI 0.164-0.757 *P <* 0.01 respectively).

***CONCLUSION***

The *TYMS* genotypes ins/ins and ins/LOH associate with worst prognosis in mCRC patients under fluoropyrimidine-based chemotherapy. Large prospective studies are needed for validation of our findings.

**Key words:** Thymidylate synthase; Polymorphisms; mCRC; Loss of heterozygosity; Survival; Chemotherapy; *KRAS*; *BRAF; TYMS*

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**Core tip:** The etiology of resistance to new targeted agents and chemotherapy is currently being investigated into the patients’ genetic profile in order to develop a prognostic model that could lead to individualized treatment. In this context, we studied the effect of thymidylate synthase(*TYMS*) polymorphisms that have been described so far, taking into account the presence of *KRAS* and *BRAF* mutations in association with the treatment. *TYMS* 3’ untranslated region polymorphism ins/ins and ins/loss of heterozygosity emerged as an independent factor that increases the risk of both disease progression and death. Regimens that included irinotecan had reduced risk of disease progression and death.

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**INTRODUCTION**

Metastatic colorectal cancer (mCRC) is the second and third leading cause of cancer-related death in Europe[1] and the United States[2], respectively, although important and constant overall survival (OS) improvements have been achieved[3] in the last decades. Even though today there are more treatment options including several basic chemotherapy regimens in combination with targeted agents[4], it has been found that large variation exists in individual patient prognosis and response to chemotherapy, caused by molecular heterogeneity[5]. As a result, treatment decisions are more complex and largely empirical[6]. This depicts our lack of understanding of the molecular background and the interplay of different oncogenic pathways such as *RAS* and *BRAF* with gene polymorphisms, such as thymidylate synthase (*TYMS*), responsible for the heterogeneity of responses to treatments.

*KRAS* is a member of the *RAS* family of genes (*KRAS, NRAS* and *HRAS*) that encode quanosine-5’-triphosphate (GTP)-binding proteins which acts as a molecular switch linking receptor and non-receptor tyrosine kinase activation to downstream cytoplasmic or nuclear events. Activating mutations in RAS results in stimulating cell proliferation and inhibiting apoptosis. Around 32-40% of CRC harbor a *KRAS* mutation[7,8] which is a predictor of response to anti-EGFR treatment[9,10]. *BRAF* is a *KRAS* downstream abnormally activated kinase that has been shown to have a similar adverse effect on treatment response[7,8].

The backbone of mCRC chemotherapy are fluoropyrimidines (5-FU and capecitabine) that cause inhibition of de-novo thymidine creation from uracil by the TYMS enzyme. Potential resistance mechanisms to fluoropyrimidines include *TYMS* gene amplification[11], loss of heterozygosity (LOH)[12] and a negative feedback mechanism[13]. The *TYMS* gene (GeneID 7298[14]) is located on the short arm of chromosome 18 (18p11.32) and several polymorphisms of the *TYMS* gene have been connected to variable TYMS protein levels and therapeutic outcome in relation to 5-FU.

The first polymorphism has been identified in the 5’ untranslated region (UTR) and includes an insertion of a 28 base-pair (bp) repeat (rs34743033[14]), that adds an extra binding site for the Upstream Stimulatory Factor 1 (USF-1) transcription factor (E-box CACTTG[15]). This USF-1 extra binding site acts as an enhancer to the *TYMS* promoter which leads to increased *TYMS* expression and thus to increased TYMS enzyme activity[16]. This results in alleles with two or three 28bp tandem repeats (2R or 3R respectively). The second polymorphism (rs2853542[14]) is a G->C single nucleotide polymorphism (SNP) in the second 28bp repeat of 3R alleles that abolishes the extra USF-1 binding site[17] and leading to conversion of the transcriptional activity from a 3R to a 2R. The third polymorphism is located on the 3’ UTR (rs34489327[14]) and is a 6bp insertion linked to stabilization of the mRNA transcript[18,19]. The above polymorphisms produce three genotypes: ins/ins (homozygous for insertion of 6bp), del/del (homozygous for deletion of the 6bp) and ins/del (heterozygous).

This study aims to investigate the associations of *TYMS* polymorphisms, LOH, *KRAS* / *BRAF* mutations and clinicopathologic characteristics with the survival outcomes of patients with mCRC treated with 1st line fluoropyrimidine–based chemotherapy.

**MATERIALS AND METHODS**

***Patients and clinical data***

This was a retrospective study carried out by a single institution (University General Hospital “ATTIKON”). Clinical data were collected from records of consecutive patients with mCRC treated with fluoropyrimidine-based chemotherapy from 1/2005 to 1/2007. Formalin-fixed paraffin-embedded tissues (FFPE) from consecutive patients with mCRC were retrieved for analysis.

The study protocol was approved by the Institutional Review Board and Ethical Committee (University General Hospital “ATTIKON”, Athens, Greece).

***DNA extraction***

Five 5μm thick FFPE sections from a site containing at least 30% of malignant cells were used for DNA extraction using a commercially available kit (Purelink Genomic DNA kit, Thermo Fisher Scientific, Germany). DNA was quantified using qPCR (Quant-iT™ PicoGreen® dsDNA Assay Kit, Thermo Fisher Scientific, Germany) and was diluted accordingly to achieve a concentration of 10 ng/μL for *TYMS* polymorphisms and 4ng/μL for *KRAS* mutation detection.

***TYMS* polymorphisms**

Analysis was performed as previously described with minor modifications[20]. PCR was performed using 1U of Platinum® Taq DNA Polymerase (Thermo Fisher Scientific, Germany), 1.5 mmol/L of Mg and 200nM of dNTPs and primers. The same primers were used, but 5-UTR amplification was performed using a GC rich amplification kit (PCRX Enhancer System, Thermo Fisher Scientific, Germany) adding 1x of PRCx Enhancer. Genotyping for the 2R/3R polymorphism was performed by running 10 μL of the PCR product on a 1.5% agarose gel and staining with EthBr (Figure 1). For the 12G>C substitution, 10 μL of PCR product was digested with 1U of HaeIII (Takara, Japan) for 1 hour at 37 ℃ and run on an 8% 19:1 polyacrylamide gel (Figure 2). The 3’ UTR was also analyzed on polyacrylamide gels (Figure 3) LOH analysis was performed via analyzing the intensity of the 5’UTR and 3’UTR bands of the pictures acquired using the GeneTools software (Syngene, the United Kingdom) (Figures 1 and 3). When either of the bands had an intensity of < 50% of the other, the sample was categorized as having a LOH. Samples showing LOH were defined as 2R/3RGLOH, 2RLOH/3RG, 2R/3RCLOH and 2RLOH/3RC to indicate the allele that was partially lost. Selected products were sequenced to verify the sequence amplified. Blast of the sequenced products and alignment with the latest human assemblies revealed that the amplified product was 242bp for 3R and 214bp for 2R genotypes.

***Mutation detection***

Detection of *KRAS* mutations of codons 12 and 13 was performed with a commercially available Real-Time (RT) PCR kit (Therascreen *KRAS*, DxS Diagnostics, the United Kingdom) detecting 6 mutations of codon 12 (G12D, G12A, G12V, G12S, G12R, G12C) and 1 mutation of codon 13 (G13D)[21]. A positive reaction mix for all mutations was included. A second exogenous reaction was simultaneously taking place, to avoid false negative results caused by PCR inhibitors. Samples were characterized as bearing a mutation only if ΔСt (Ct of control reaction - Ct mutation reaction) was lower than the value set by the manufacturer.

The activating mutation V600E of *BRAF* was identified using molecular beacons as previously described[21]. One beacon for the wild type and one for the mutant allele were added at a final concentration of 100 nmol/L in a 25 μL PCR reaction containing 1 × PCR Buffer, 6 mmol/L MgCl2, 200 nmol/L dNTPs, 300 nmol/L of each primer and 1U of Platinum® Taq. PCR profile used was 95 ℃ 2 min, followed by 40 cycles of 95 ℃ for 10 s, 62 ℃ for 60 s and 72 ℃ for 20 s. SKMEL2 and SKMEL20 DNA extracts were used as positive controls for both the wild type and mutant allele (CLS, Germany). All RT-PCR experiments were performed on an ABI 7500 Fast (Thermo Fisher Scientific, Germany).

***TYMS-gene polymorphisms stratification model***

The polymorphisms of *TYMS*-gene of each of the 3’UTR and 5’UTR were classified into three groups according to the probability they have for high, medium and low TYMS expression (and similar levels of risk[22]), taking into account the following evidence from previous studies: (1) 3R polymorphism has higher translation efficiency than that of the 2R, leading to higher TYMS protein expression associated with resistance to 5FU-based chemotherapy[18,23] while the 2R/3R has an intermediate TYMS protein expression profile[24]; (2) The SNP G->C results to 3RC genotype reported to display a similar transcriptional activity as the 2R genotype (since 3RC and 2R have the same number of binding sites for the USF-1)[17,25]; (3) the 6bp insertion, located in the 3’UTR of the *TYMS* primary transcript, favors the *TYMS* mRNA stability increasing the TYMS protein expression[26] and the possibility of resistance to 5FU[18]; (4) lower TYMS protein expression leads to higher sensitivity to fluoropyrimidine-based therapy[27,28]; and (5) LOH is associated with a higher risk of resistance to 5FU chemotherapy[12,29]. Genotypes categorized into expression groups are shown in Table 1.

***Statistical analyses***

OS was defined as the time from the initiation of 1st line chemotherapy to the date of death by any cause. PFS was calculated as the time from 1st line chemotherapy initiation to the date of verified progression of the disease or the date of death by any cause. Surviving patients were censored at the date of last contact.

The relationship of *TYMS* polymorphisms and the groups to which classified with OS and PFS was assessed by univariate Cox regression analysis. Time-to-event distributions were estimated using Kaplan-Meier curves. Correlation of *TYMS* polymorphisms among them and with selected clinicopathological characteristics were performed using the × 2 test. For all correlations, the level of statistical significance was set at *P* = 0.05.

The Cox proportional hazards model was used to assess the relationship of clinicopathological parameters and the examined polymorphisms with OS and PFS. In the multivariate Cox regression analysis, a backward selection procedure with a removal criterion of *P* > 0.10 based on likelihood ratio test was performed to identify significant variables among the following: age, gender (female *vs* male), histological grade (III-IV *vs* I-II), primary site (rectal *vs* colon), *KRAS* and *BRAF* status, groups of *TYMS* polymorphisms, existence of LOH, history of relapse or de novo metastatic disease and treatment.

Statistical analysis was conducted using SPSS software for Windows (version 24; SPSS Inc, Chicago, IL, the United States of America).

**RESULTS**

***Patient and tumor characteristics***

Patients’ information including age, gender, primary tumor site, histological grade, treatment and survival are presented in Table 2. The median age was 65 years (range 27-86), and the primary site was colon or rectum in 46 and 43 patients respectively. *De novo* metastatic disease was present in 41 patients (46.1%). First-line fluoropyrimidine-based chemotherapy was administered to 88 patients with a median number of six cycles (range 1-12). In total, 5FU-based chemotherapy was given to 13 patients (14.6%) while 75 patients (84.3%) received capecitabine-based chemotherapy. Fluoropyrimidine-based regimens were combined with irinotecan (31.4%), oxaliplatin (49.4%) or both drugs (6.7%). Bevacizumab was included in the first line treatment of 61 patients (68.5%). With a median follow-up of 14.8 mo (range 0-119.8), 85 patients (95.5%) experienced disease progression and 63 deaths (70.8%) were recorded. The 3- and 5-year OS rate was 25.4% and 7.7% respectively while the 3-year PFS rate was 7.1%.

***TYMS* *genotypes***

The detected genotypes of *TYMS* according to de novo metastatic or relapsed patients are shown in Supplemental Table 1. The wide variations deriving from *TYMS* polymorphisms combinations and the presence of LOH according to de novo metastatic and relapsed patients are shown in Supplemental Table 2. The 3’UTR polymorphisms had no association with the 5’UTR polymorphism or the SNP G->C. The ins alleles correlated almost statistically significantly with LOH, as shown in Supplemental Table 3.

Analysis of significant association of *TYMS* polymorphisms with patient and tumor characteristics is shown in Table 3. Younger patients (< 65 years old) were more frequently found to carry 2R but not in a statistically significant way. Also low grade tumors (I, II) associated with 2RG/3RG (*P <* 0.05). The absence of mutations in *KRAS* correlated with 3RG/3RC (*P <* 0.04).

***Correlations of clinicopathological features and genotype with survival outcomes***

Analysis of patients according to *TYMS* expression groups and genotypes are shown in Table 4. Univariate Cox regression analysis of clinicopathological parameters in relation to PFS and OS showed no significant association in our set of data. Univariate Cox regression analysis of *TYMS* polymorphisms and groups, *KRAS* and *BRAF* mutations and LOH are shown in Table 5. The univariate analysis of TYMS 3’UTR polymorphisms and LOH, demonstrated a trend of lower risk for disease progression and death for the genotypes del/del, ins/del and even ins/LOH compared with ins/ins. There is a trend for increased risk of death for patients with *KRAS* mutation. The analysis of *TYMS* 5’UTR polymorphisms, whether taking into consideration the SNP G>C and LOH or not, also showed no significant effect.

Multivariate analysis of *TYMS* polymorphisms groups and selected clinicopathological parameters are shown in Table 6. *KRAS* mutation, existence of LOH and the group of *TYMS* polymorphisms ins/LOH – ins/ins were associated with increased risk for disease progression while the addition of irinotecan in the 1st line chemotherapy was associated with lower risk. In terms of OS, the group of *TYMS* polymorphisms ins/LOH – ins/ins was associated with increased statistical risk both of disease progression and death. Kaplan-Meier curves for PFS and OS according to *TYMS* 3’UTR polymorphisms groups are shown in Figure 4A and 4B respectively. Furthermore, the addition of irinotecan or oxaliplatin to fluoropyrimidine-based chemotherapy was associated with lower risk of death. Also, a statistical trend for a higher risk of death was shown in male patients. These findings were consistent in multivariate Cox regression analysis when the history of relapse or de novo metastatic disease was considered.

**DISCUSSION**

This is a retrospective study of 89 patients with mCRC treated with fluoropyrimidine-based chemotherapy, interrogating the association of *TYMS* polymorphisms, LOH, *KRAS*/*BRAF* status with survival outcome. To the best of our knowledge, this is the first time that *TYMS*-genotype, LOH and mutations in *KRAS* and *BRAF* were analyzed in relation to the chemotherapy treatment and the survival outcome of patients with mCRC. We report that the polymorphisms of the *TYMS* 3’UTR is an independent factor increasing the risk for both disease progression and death of mCRC patients under fluoropyrimidines-based treatment as monotherapy or in combination with oxaliplatin or/and irinotecan, or/and targeted therapy. Also, an independent factor decreasing the risk of both disease progression and death was the administration of fluoropyrimidine-based chemotherapy in combination with irinotecan while the combination of fluoropyrimidines with oxaliplatin was associated with lower risk of death.

In search of prognostic markers towards personalized therapy, studies have investigated *TYMS* gene polymorphisms[30,31], *TYMS* mRNA expression[32,33] and TYMS protein expression[34-38]/activity[39] . Such studies have conflicting results for the way *TYMS* polymorphisms seem to affect the therapeutic result in CRC patients[30,36,38,40-46]. The numerous *TYMS* polymorphisms and their combination could explain the inconclusive results. For example the SNP G>C was not considered for many years until its discovery[15,17,19]. Thus the homozygous 3R group was considered to be related with high expression[15] could include three subgroups with a different impact in *TYMS* expression (low expression subgroup 3RC/3RC and high expression subgroups 3RG/3RG and 3RG/3RC[24,28]). Our results indicate that only 8 (21.6%) out of 37 tumors with 3R polymorphism are 3RG, without the presence either of LOH or SNP G>C. Similarly, 21 (50%) out of 42 heterozygous 2R/3R tumors are 2RG/3RG. The different distribution of these subgroups in various studies could explain the differential effect on survival. Moreover, another factor held responsible for generating inconclusive results is the addition to fluoropyrimidines of newer chemotherapeutics and targeted agents[28] which incommode the interpretation of how *TYMS* polymorphisms influence survival outcome across different treatment populations. Also there are other genes, such as *p53*[47], astrocyte elevated gene-1 (*AEG-1*)[48], and enolase superfamily member 1 (*ENOSF1*)[49]proved to participate in the final level of *TYMS* expression[18,47-50]. Thus, the rather small size samples used in most studies could not examine thoroughly the plethora of all these factors and possible interactions among them, without conflicting results.

Another reason, responsible for conflicting results across studies, is the categorization of *TYMS* polymorphisms in only two groups[18,51], which leads to misclassifying polymorphisms with uncertain effect . Although such a classification model is preferred because it facilitates statistical processing (e.g., by increasing the size of each group) and the interpretation of statistical processing. It entails the risk of increasing the probability of classification error.

Different to previous studies[30,31,50-53], ours took into consideration the extensive number of *TYMS* polymorphisms, their combinations with LOH and *KRAS* / *BRAF* mutations. Additionally, for the first time, we classified the polymorphisms of each UTR region into three groups according to the level of *TYMS* expression.

The low expression group of 5’UTR polymorphism includes tumors with two alleles each with one active USF-1 binding site. Members of the high expression group have no 2RG allele and they include heterozygous tumors in which due to LOH, the allele 2RG was deleted. Medium expression group includes the heterozygous tumors with three USF-1 binding sites (one in the 2RG and two in the 3RG), resulting in one more than the low expression and one less than the high expression group. Also in this group, we included tumors with only one 2R allele as LOH eliminates the 3R allele. Although they have less than three USF-1 binding sites, the LOH situation bears a loss of genetic material from chromosome 18q that, in ways not fully understood, adversely affects survival[54].

The low expression group of 3’UTR polymorphism contains the homozygous deletion of the 6bp insertion leading to destabilization of *TYMS* mRNA, resulting in reduced translation and eventually reduced TYMS activity. The high expression group has only ins alleles, homozygous or in combination with LOH, that impart stability to *TYMS* mRNA and thus, by increasing TYMS production/activity, increases the risk of poor response or development of resistance[18,19]. Tumors in the medium expression group have an allele with deletion, which coexists with either ins allele or LOH, that have been associated with increased risk of relapse[54].

On the basis of previous studies, *TYMS* 5’UTR may be linked to survival outcomes[41,55]. Contrary to these, in the multivariate Cox regression analysis of our data the groups of 5’UTR polymorphisms did not emerge as factors of survival outcome. However, the 3’UTR polymorphisms’ groups, was identified as an independent factor of disease progression and death.

More specifically, the high expression group was identified as an independent risk factor of disease progression and death compared to the medium/low-risk groups (Table 5). Similar to our findings, a previous study showed that mCRC patients with del/del genotype treated with 5FU/oxaliplatin had significantly longer OS[31]. The ins allele, present in high-risk genotypes (ins/ins and ins/LOH) has been associated with higher *TYMS* mRNA stability and TYMS protein expression[18]. It is logical to assume that the mRNA stability has a more significant role in TYMS protein production than the number of transcripts. Hence, even if *TYMS* 5’UTR has a 3RG polymorphism leading to higher mRNA production, the complete absence of ins allele in *TYMS* 3’UTR could cause *TYMS* mRNA instability and therefore decreased TYMS translation. On the contrary, in theory the final outcome of decreased mRNA production of 2R cases combined with ins/ins genotype could be an increase of protein production due to the stability of transcribed mRNA and translational efficacy.

Tumors with 2R/3RLOH genotype have been shown to be expressing significantly lower levels of TYMS protein than those with 2RLOH/3R[56]. Also patients with mCRC bearing 2R/3RLOH genotype have been shown to have better survival than those with 2RLOH/3R[12]; although in the later study the SNP G>C was not taken into consideration. LOH is as likely to lead to altered genotypes, either with high or low TYMS protein expression (2RLOH/3RG and 2R/3RGLOH respectively). But the loss of chromosomal material from 18q, the cause of LOH, has been shown to act as a molecular marker of adverse prognosis[29], even if combined with low-risk 2R allele. This is in agreement with our results as LOH remained in the Cox proportional hazards model as a factor that associates with disease progression with marginal statistical significance (HR = 1.674, 95%CI: 0.912-3.071, *P <* 0.1). This association was not observed for risk of death, probably due to the numerous factors that affect this outcome, such as the additional chemotherapy lines.

It has been previously shown that patients with *KRAS* mutant tumors had significantly lower *TYMS* mRNA levels, especially in proximal colon tumors[57]. In our study, we were able to identify an association of *KRAS* wild type only with polymorphism 3RG/3RC (RR = 1.753 95%CI: 1.156-2.657, *P <* 0.04), a member of high TYMS protein expression group.

The addition of bevacizumab in the fluoropyrimidine-based 1st line chemotherapy for mCRC did not emerge, in the Cox model, as a factor affecting survival outcome in our study. To date, no prospectively validated biomarkers have emerged to include or exclude patients from anti-VEGF therapy[58]. Pander *et al*[59] have shown that there is a genetic interaction between the polymorphisms in the *TYMS* enhancer region (5’UTR) and VEGF +405g>c polymorphisms as a predictor of the efficacy of capecitabine / oxaliplatin / bevacizumab in mCRC patients, but only for PFS. Also. Watanabe *et al*[60] have found that higher TYMS levels are associated with an adverse response to bevacizumab therapy. In this context, it could be proposed that in studies applying anti-VEGF and targeted therapy, *TYMS* polymorphisms should be considered. Overall, there is great need for a prognostication model that would include all these polymorphisms with *RAS* mutations for treatment tailoring.

In our study, we did not examine TYMS protein expression, as this could be affected by a plentiful of factors[47,48,50] and altered in the course of the disease. For example, it has been found discordance in *TYMS* mRNA expression and TYMS protein levels between primary and secondary tumors[33,61,62]. Also, in an autoregulatory manner, the binding of TYMS protein to its own mRNA, as well as the binding of TYMS to p53 mRNA, causes translational repression[13,63,64].

Some limitations of this study should be addressed. The plethora of genotypes resulting from the polymorphisms occurring in the UTRs of *TYMS* is difficult to be analyzed with a small patient group. Moreover, previous exposure to adjuvant therapy with fluoropyrimidines, that could associate with resistance to fluoropyrimidines, was not taken into consideration. The allocation of *TYMS* polymorphisms into groups was based on published research but the conflicting results observed in these studies and ours highlight the need for further analysis on larger scale datasets. Also, we did not examine the TYMS protein expression and activity. Finally, due to the retrospective nature of this analysis we could not correlate these findings to the treatment toxicity.

 After taking into account the SNP G>C and LOH, only the polymorphisms in the *TYMS* 3’UTR, affecting the stability of mRNA, independently influenced survival outcome for patients with mCRC treated with fluoropyrimidines-based chemotherapy. Genotypes that include del alleles, linked to *TYMS* mRNA instability, had better survival outcome. *KRAS* mutation was associated with high risk of disease progression. Combinations that included irinotecan were associated with lower risk of disease progression and death. Future studies should focus on gathering large samples and carefully select batteries of biomarkers to be examined in multivariate analysis. For the more complete assessment of *TYMS*-gene polymorphisms’ effect, LOH should be considered. Further prospective studies are needed to elucidate the role of *TYMS* polymorphisms in tailoring treatment of patients with mCRC.

**COMMENTS**

***Background***

Metastatic colorectal cancer (mCRC) remains a significant cause of cancer-related death worldwide, althouht important improvements have been achieved in the last decades. It has been found that large variation exists in individual patient prognosis and response to chemotherapy, caused by molecular heterogeneity. Around 32%-40% of CRC harbor a *KRAS* mutation which is a predictor of response to anti-EGFR treatment, while *BRAF* is a *KRAS* downstream abnormally activated kinase that has been shown to have similar adverse effects on treatment response. Several polymorphisms of the thymidylate synthase(*TYMS*) gene have been connected to variable TYMS protein leves and therapeutic outcome in relation to 5-FU, while loss of heterozygosity (LOH) is included in potential resistance mechanisms to fluoropyrimidines. This study aims to investigate the associations of *TYMS* polymorphisms, LOH, *KRAS / BRAF* mutations and clinicopathologic characteristics with the survival outcome of patients with mCRC treated with 1st line fluoropyrimidine-based chemotherapy.

***Research frontiers***

To the best of our knowledge, this is the first study that analyzes the extensive number of *TYMS* polymorphisms, their combination with LOH and *KRAS* and *BRAF* mutationsin relation to the chemotherapy treatment and the survival outcome of patients with mCRC. Additionally, for the first time, we classified the polymorphisms of each untranslated region (UTR) region into three groups according to the level of *TYMS* expression. The results of this study contribute to clarifying the significance of *TYMS* polymorphisms for patients with mCRC.

***Innovations and breakthroughs***

In this study, the groups of *TYMS* 5’UTRpolymorphisms did not emerge as factors of survival outcome. However, the 3’UTR polymorphisms’ groups, were identified as an independent factor of disease progression and death. Genotypes that included del alleles, linked to *TYMS* mRNA instability, had better survival outcome.

***Applications***

This study suggests that *TYMS* 3’UTR polymorphisms independently influence survival outcome for patients with mCRC treated with fluoropyrimidines-based chemotherapy. Genotypes that include del alleles may benefit from flyoropyrimidines-based chemotherapy. Future studies should gather large samples and carefully select the biomarkers to be examined in multivariate analysis, taking into consideration LOH.

***Terminology***

UTR: regions of the mRNA that are not translated into protein but, among others, affect the post-transcriptional regulation of gene expression. Upstream stimulatory factor (USF): Factors that enhance the gene promoter and leads to increased gene expression.

***Peer-review***

Good overview of the role of TYMS in the treatment protocol. Will be of interest to the readership.

**REFERENCES**

1 **Ferlay J**, Steliarova-Foucher E, Lortet-Tieulent J, Rosso S, Coebergh JW, Comber H, Forman D, Bray F. Cancer incidence and mortality patterns in Europe: estimates for 40 countries in 2012. *Eur J Cancer* 2013; **49**: 1374-1403 [PMID: 23485231 DOI: 10.1016/j.ejca.2012.12.027]

2 **Siegel RL**, Miller KD, Jemal A. Cancer statistics, 2016. *CA Cancer J Clin* 2016; **66**: 7-30 [PMID: 26742998 DOI: 10.3322/caac.21332]

3 **Rossi A**, Torri V, Garassino MC, Porcu L, Galetta D. The impact of personalized medicine on survival: comparisons of results in metastatic breast, colorectal and non-small-cell lung cancers. *Cancer Treat Rev* 2014; **40**: 485-494 [PMID: 24112813 DOI: 10.1016/j.ctrv.2013.09.012]

4 **Peeters M**, Price T. Biologic therapies in the metastatic colorectal cancer treatment continuum--applying current evidence to clinical practice. *Cancer Treat Rev* 2012; **38**: 397-406 [PMID: 21899955 DOI: 10.1016/j.ctrv.2011.08.002]

5 **Sinicrope FA**, Okamoto K, Kasi PM, Kawakami H. Molecular Biomarkers in the Personalized Treatment of Colorectal Cancer. *Clin Gastroenterol Hepatol* 2016; **14**: 651-658 [PMID: 26872400 DOI: 10.1016/j.cgh.2016.02.008]

6 **Cubillo A**, Rodriguez-Pascual J, López-Ríos F, Plaza C, García E, Álvarez R, de Vicente E, Quijano Y, Hernando O, Rubio C, Perea S, Sanchez G, Hidalgo M. Phase II Trial of Target-guided Personalized Chemotherapy in First-line Metastatic Colorectal Cancer. *Am J Clin Oncol* 2016; **39**: 236-242 [PMID: 24517959 DOI: 10.1097/COC.0000000000000045]

7 **Adjei AA**. Blocking oncogenic Ras signaling for cancer therapy. *J Natl Cancer Inst* 2001; **93**: 1062-1074 [PMID: 11459867 DOI: 10.1093/jnci/93.14.1062]

8 **De Roock W**, De Vriendt V, Normanno N, Ciardiello F, Tejpar S. KRAS, BRAF, PIK3CA, and PTEN mutations: implications for targeted therapies in metastatic colorectal cancer.*Lancet Oncol* 2011; **12**: 594-603 [PMID: 21163703 DOI: 10.1016/S1470-2045(10)70209-6]

9 **Allegra CJ**, Jessup JM, Somerfield MR, Hamilton SR, Hammond EH, Hayes DF, McAllister PK, Morton RF, Schilsky RL. American Society of Clinical Oncology provisional clinical opinion: testing for KRAS gene mutations in patients with metastatic colorectal carcinoma to predict response to anti-epidermal growth factor receptor monoclonal antibody therapy. *J Clin Oncol* 2009; **27**: 2091-2096 [PMID: 19188670 DOI: 10.1200/JCO.2009.21.9170]

10 **Van Cutsem E**, Köhne CH, Láng I, Folprecht G, Nowacki MP, Cascinu S, Shchepotin I, Maurel J, Cunningham D, Tejpar S, Schlichting M, Zubel A, Celik I, Rougier P, Ciardiello F. Cetuximab plus irinotecan, fluorouracil, and leucovorin as first-line treatment for metastatic colorectal cancer: updated analysis of overall survival according to tumor KRAS and BRAF mutation status. *J Clin Oncol* 2011; **29**: 2011-2019 [PMID: 21502544 DOI: 10.1200/JCO.2010.33.5091]

11 **Wang TL**, Diaz LA Jr, Romans K, Bardelli A, Saha S, Galizia G, Choti M, Donehower R, Parmigiani G, Shih IeM, Iacobuzio-Donahue C, Kinzler KW, Vogelstein B, Lengauer C, Velculescu VE. Digital karyotyping identifies thymidylate synthase amplification as a mechanism of resistance to 5-fluorouracil in metastatic colorectal cancer patients. *Proc Natl Acad Sci U S A* 2004; **101**: 3089-3094 [PMID: 14970324 DOI: 10.1073/pnas.0308716101]

12 **Uchida K**, Hayashi K, Kawakami K, Schneider S, Yochim JM, Kuramochi H, Takasaki K, Danenberg KD, Danenberg PV. Loss of heterozygosity at the thymidylate synthase (TS) locus on chromosome 18 affects tumor response and survival in individuals heterozygous for a 28-bp polymorphism in the TS gene. *Clin Cancer Res* 2004; **10**: 433-439 [PMID: 14760062 DOI: 10.1158/1078-0432.CCR-0200-03]

13 **Chu E**, Koeller DM, Casey JL, Drake JC, Chabner BA, Elwood PC, Zinn S, Allegra CJ. Autoregulation of human thymidylate synthase messenger RNA translation by thymidylate synthase. *Proc Natl Acad Sci U S A* 1991; **88**: 8977-8981 [PMID: 1924359 DOI: 10.1073/pnas.88.20.8977]

14 National Center for Biotechnology Information USNLoM. 2017. Available from: URL: https://www.ncbi.nlm.nih.gov/pubmed

15 **Kawakami K**, Salonga D, Park JM, Danenberg KD, Uetake H, Brabender J, Omura K, Watanabe G, Danenberg PV. Different lengths of a polymorphic repeat sequence in the thymidylate synthase gene affect translational efficiency but not its gene expression. *Clin Cancer Res* 2001; **7**: 4096-4101 [PMID: 11751507]

16 **Marsh S**. Thymidylate synthase pharmacogenetics. *Invest New Drugs* 2005; **23**: 533-537 [PMID: 16267625 DOI: 10.1007/s10637-005-4021-7]

17 **Mandola MV**, Stoehlmacher J, Muller-Weeks S, Cesarone G, Yu MC, Lenz HJ, Ladner RD. A novel single nucleotide polymorphism within the 5' tandem repeat polymorphism of the thymidylate synthase gene abolishes USF-1 binding and alters transcriptional activity. *Cancer Res* 2003; **63**: 2898-2904 [PMID: 12782596]

18 **Mandola MV**, Stoehlmacher J, Zhang W, Groshen S, Yu MC, Iqbal S, Lenz HJ, Ladner RD. A 6 bp polymorphism in the thymidylate synthase gene causes message instability and is associated with decreased intratumoral TS mRNA levels. *Pharmacogenetics* 2004; **14**: 319-327 [PMID: 15115918 DOI: 10.1097/00008571-200405000-00007]

19 **Ulrich CM**, Bigler J, Velicer CM, Greene EA, Farin FM, Potter JD. Searching expressed sequence tag databases: discovery and confirmation of a common polymorphism in the thymidylate synthase gene. *Cancer Epidemiol Biomarkers Prev* 2000; **9**: 1381-1385 [PMID: 11142426]

20 **Lecomte T**, Ferraz JM, Zinzindohoué F, Loriot MA, Tregouet DA, Landi B, Berger A, Cugnenc PH, Jian R, Beaune P, Laurent-Puig P. Thymidylate synthase gene polymorphism predicts toxicity in colorectal cancer patients receiving 5-fluorouracil-based chemotherapy. *Clin Cancer Res* 2004; **10**: 5880-5888 [PMID: 15355920 DOI: 10.1158/1078-0432.ccr-04-0169]

21 **Spathis A**, Georgoulakis J, Foukas P, Kefala M, Leventakos K, Machairas A, Panayiotides I, Karakitsos P. KRAS and BRAF mutation analysis from liquid-based cytology brushings of colorectal carcinoma in comparison with formalin-fixed, paraffin-embedded tissue. *Anticancer Res* 2010; **30**: 1969-1975 [PMID: 20651341 DOI: 30/6/1969]

22 **Popat S**, Matakidou A, Houlston RS. Thymidylate synthase expression and prognosis in colorectal cancer: a systematic review and meta-analysis. *J Clin Oncol* 2004; **22**: 529-536 [PMID: 14752076 DOI: 10.1200/JCO.2004.05.064]

23 **Wang Y**, Shen L, Xu N, Wang JW, Jiao SC, Liu ZY, Xu JM. UGT1A1 predicts outcome in colorectal cancer treated with irinotecan and fluorouracil. *World J Gastroenterol* 2012; **18**: 6635-6644 [PMID: 23236239 DOI: 10.3748/wjg.v18.i45.6635]

24 **Hur H**, Kang J, Kim NK, Min BS, Lee KY, Shin SJ, Keum KC, Choi J, Kim H, Choi SH, Lee MY. Thymidylate synthase gene polymorphism affects the response to preoperative 5-fluorouracil chemoradiation therapy in patients with rectal cancer. *Int J Radiat Oncol Biol Phys* 2011; **81**: 669-676 [PMID: 20932673 DOI: 10.1016/j.ijrobp.2010.06.049]

25 **Kawakami K**, Watanabe G. Identification and functional analysis of single nucleotide polymorphism in the tandem repeat sequence of thymidylate synthase gene. *Cancer Res*2003; **63**: 6004-6007 [PMID: 14522928]

26 **Stoehlmacher J**, Goekkurt E, Mogck U, Aust DE, Kramer M, Baretton GB, Liersch T, Ehninger G, Jakob C. Thymidylate synthase genotypes and tumour regression in stage II/III rectal cancer patients after neoadjuvant fluorouracil-based chemoradiation. *Cancer Lett* 2008; **272**: 221-225 [PMID: 18722050 DOI: 10.1016/j.canlet.2008.07.008]

27 **Qiu LX**, Tang QY, Bai JL, Qian XP, Li RT, Liu BR, Zheng MH. Predictive value of thymidylate synthase expression in advanced colorectal cancer patients receiving fluoropyrimidine-based chemotherapy: evidence from 24 studies. *Int J Cancer* 2008; **123**: 2384-2389 [PMID: 18729195 DOI: 10.1002/ijc.23822]

28 **Panczyk M**. Pharmacogenetics research on chemotherapy resistance in colorectal cancer over the last 20 years. *World J Gastroenterol* 2014; **20**: 9775-9827 [PMID: 25110414 DOI: 10.3748/wjg.v20.i29.9775]

29 **Azzoni C**, Bottarelli L, Cecchini S, Ziccarelli A, Campanini N, Bordi C, Sarli L, Silini EM. Role of topoisomerase I and thymidylate synthase expression in sporadic colorectal cancer: associations with clinicopathological and molecular features. *Pathol Res Pract* 2014; **210**: 111-117 [PMID: 24332575 DOI: 10.1016/j.prp.2013.11.004]

30 **Graziano F**, Ruzzo A, Loupakis F, Santini D, Catalano V, Canestrari E, Maltese P, Bisonni R, Fornaro L, Baldi G, Masi G, Falcone A, Tonini G, Giordani P, Alessandroni P, Giustini L, Vincenzi B, Magnani M. Liver-only metastatic colorectal cancer patients and thymidylate synthase polymorphisms for predicting response to 5-fluorouracil-based chemotherapy. *Br J Cancer* 2008; **99**: 716-721 [PMID: 18728661 DOI: 10.1038/sj.bjc.6604555]

31 **Kumamoto K**, Ishibashi K, Okada N, Tajima Y, Kuwabara K, Kumagai Y, Baba H, Haga N, Ishida H. Polymorphisms of <i>GSTP1</i>, <i>ERCC2</i> and <i>TS</i>-3'UTR are associated with the clinical outcome of mFOLFOX6 in colorectal cancer patients. *Oncol Lett* 2013; **6**: 648-654 [PMID: 24137384 DOI: 10.3892/ol.2013.1467]

32 **Grimminger PP**, Shi M, Barrett C, Lebwohl D, Danenberg KD, Brabender J, Vigen CL, Danenberg PV, Winder T, Lenz HJ. TS and ERCC-1 mRNA expressions and clinical outcome in patients with metastatic colon cancer in CONFIRM-1 and -2 clinical trials. *Pharmacogenomics J* 2012; **12**: 404-411 [PMID: 21788964 DOI: 10.1038/tpj.2011.29]

33 **Kumamoto K**, Kuwabara K, Tajima Y, Amano K, Hatano S, Ohsawa T, Okada N, Ishibashi K, Haga N, Ishida H. Thymidylate synthase and thymidine phosphorylase mRNA expression in primary lesions using laser capture microdissection is useful for prediction of the efficacy of FOLFOX treatment in colorectal cancer patients with liver metastasis. *Oncol Lett* 2012; **3**: 983-989 [PMID: 22783377 DOI: 10.3892/ol.2012.598]

34 **Abdallah EA**, Fanelli MF, Buim ME, Machado Netto MC, Gasparini Junior JL, Souza E Silva V, Dettino AL, Mingues NB, Romero JV, Ocea LM, Rocha BM, Alves VS, Araújo DV, Chinen LT. Thymidylate synthase expression in circulating tumor cells: a new tool to predict 5-fluorouracil resistance in metastatic colorectal cancer patients. *Int J Cancer* 2015; **137**: 1397-1405 [PMID: 25721610 DOI: 10.1002/ijc.29495]

35 **Paré L**, Marcuello E, Altés A, del Rio E, Sedano L, Barnadas A, Baiget M. Transcription factor-binding sites in the thymidylate synthase gene: predictors of outcome in patients with metastatic colorectal cancer treated with 5-fluorouracil and oxaliplatin? *Pharmacogenomics J* 2008; **8**: 315-320 [PMID: 17684476 DOI: 10.1038/sj.tpj.6500469]

36 **Yamagishi S**, Shimada H, Ishikawa T, Fujii S, Tanaka K, Masui H, Yamaguchi S, Ichikawa Y, Togo S, Ike H. Expression of dihydropyrimidine dehydrogenase, thymidylate synthase, p53 and p21 in metastatic liver tumor from colorectal cancer after 5-fluorouracil-based chemotherapy. *Anticancer Res* 2005; **25**: 1237-1242 [PMID: 15865071]

37 **Hosokawa A**, Yamada Y, Shimada Y, Muro K, Hamaguchi T, Morita H, Araake M, Orita H, Shirao K. Prognostic significance of thymidylate synthase in patients with metastatic colorectal cancer who receive protracted venous infusions of 5-fluorouracil. *Int J Clin Oncol* 2004; **9**: 388-392 [PMID: 15549590 DOI: 10.1007/s10147-004-0425-1]

38 **Johnston PG**, Benson AB 3rd, Catalano P, Rao MS, O'Dwyer PJ, Allegra CJ. Thymidylate synthase protein expression in primary colorectal cancer: lack of correlation with outcome and response to fluorouracil in metastatic disease sites. *J Clin Oncol* 2003; **21**: 815-819 [PMID: 12610179 DOI: 10.1200/JCO.2003.07.039]

39 **Umekita N**, Tanaka S, Abe H, Kitamura M. [Thymidylate synthase and dihydropyrimidine dehydrogenase activity in a metastatic liver tumor from colorectal cancer]. *Gan To Kagaku Ryoho* 2000; **27**: 1883-1885 [PMID: 11086436]

40 **Chen Y**, Yi C, Liu L, Li B, Wang Y, Wang X. Thymidylate synthase expression and prognosis in colorectal cancer: a meta-analysis of colorectal cancer survival data. *Int J Biol Markers* 2012; **27**: e203-e211 [PMID: 23015402 DOI: 10.5301/JBM.2012.9584]

41 **Dotor E**, Cuatrecases M, Martínez-Iniesta M, Navarro M, Vilardell F, Guinó E, Pareja L, Figueras A, Molleví DG, Serrano T, de Oca J, Peinado MA, Moreno V, Germà JR, Capellá G, Villanueva A. Tumor thymidylate synthase 1494del6 genotype as a prognostic factor in colorectal cancer patients receiving fluorouracil-based adjuvant treatment. *J Clin Oncol* 2006;**24**: 1603-1611 [PMID: 16575011 DOI: 10.1200/JCO.2005.03.5253]

42 **Edler D**, Glimelius B, Hallström M, Jakobsen A, Johnston PG, Magnusson I, Ragnhammar P, Blomgren H. Thymidylate synthase expression in colorectal cancer: a prognostic and predictive marker of benefit from adjuvant fluorouracil-based chemotherapy. *J Clin Oncol* 2002; **20**: 1721-1728 [PMID: 11919227 DOI: 10.1200/JCO.2002.07.039]

43 **Etienne-Grimaldi MC**, Bennouna J, Formento JL, Douillard JY, Francoual M, Hennebelle I, Chatelut E, Francois E, Faroux R, El Hannani C, Jacob JH, Milano G. Multifactorial pharmacogenetic analysis in colorectal cancer patients receiving 5-fluorouracil-based therapy together with cetuximab-irinotecan. *Br J Clin Pharmacol* 2012; **73**: 776-785 [PMID: 22486600 DOI: 10.1111/j.1365-2125.2011.04141.x]

44 **Johnston PG**, Lenz HJ, Leichman CG, Danenberg KD, Allegra CJ, Danenberg PV, Leichman L. Thymidylate synthase gene and protein expression correlate and are associated with response to 5-fluorouracil in human colorectal and gastric tumors. *Cancer Res* 1995; **55**: 1407-1412 [PMID: 7882343]

45 **Koumarianou A**, Tzeveleki I, Mekras D, Eleftheraki AG, Bobos M, Wirtz R, Fountzilas E, Valavanis C, Xanthakis I, Kalogeras KT, Basdanis G, Pentheroudakis G, Kotoula V, Fountzilas G. Prognostic markers in early-stage colorectal cancer: significance of TYMS mRNA expression. *Anticancer Res* 2014; **34**: 4949-4962 [PMID: 25202077]

46 **Ichikawa W**, Uetake H, Shirota Y, Yamada H, Nishi N, Nihei Z, Sugihara K, Hirayama R. Combination of dihydropyrimidine dehydrogenase and thymidylate synthase gene expressions in primary tumors as predictive parameters for the efficacy of fluoropyrimidine-based chemotherapy for metastatic colorectal cancer. *Clin Cancer Res* 2003; **9**: 786-791 [PMID: 12576451]

47 **Nief N**, Le Morvan V, Robert J. Involvement of gene polymorphisms of thymidylate synthase in gene expression, protein activity and anticancer drug cytotoxicity using the NCI-60 panel. *Eur J Cancer* 2007; **43**: 955-962 [PMID: 17317154 DOI: 10.1016/j.ejca.2006.12.012]

48 **Yoo BK**, Gredler R, Vozhilla N, Su ZZ, Chen D, Forcier T, Shah K, Saxena U, Hansen U, Fisher PB, Sarkar D. Identification of genes conferring resistance to 5-fluorouracil. *Proc Natl Acad Sci U S A* 2009; **106**: 12938-12943 [PMID: 19622726 DOI: 10.1073/pnas.0901451106]

49 **Rosmarin D**, Palles C, Church D, Domingo E, Jones A, Johnstone E, Wang H, Love S, Julier P, Scudder C, Nicholson G, Gonzalez-Neira A, Martin M, Sargent D, Green E, McLeod H, Zanger UM, Schwab M, Braun M, Seymour M, Thompson L, Lacas B, Boige V, Ribelles N, Afzal S, Enghusen H, Jensen SA, Etienne-Grimaldi MC, Milano G, Wadelius M, Glimelius B, Garmo H, Gusella M, Lecomte T, Laurent-Puig P, Martinez-Balibrea E, Sharma R, Garcia-Foncillas J, Kleibl Z, Morel A, Pignon JP, Midgley R, Kerr D, Tomlinson I. Genetic markers of toxicity from capecitabine and other fluorouracil-based regimens: investigation in the QUASAR2 study, systematic review, and meta-analysis. *J Clin Oncol* 2014; **32**: 1031-1039 [PMID: 24590654 DOI: 10.1200/JCO.2013.51.1857]

50 **Vignoli M**, Nobili S, Napoli C, Putignano AL, Morganti M, Papi L, Valanzano R, Cianchi F, Tonelli F, Mazzei T, Mini E, Genuardi M. Thymidylate synthase expression and genotype have no major impact on the clinical outcome of colorectal cancer patients treated with 5-fluorouracil. *Pharmacol Res* 2011; **64**: 242-248 [PMID: 21536130 DOI: 10.1016/j.phrs.2011.04.006]

51 **Joerger M**, Huitema AD, Boot H, Cats A, Doodeman VD, Smits PH, Vainchtein L, Rosing H, Meijerman I, Zueger M, Meulendijks D, Cerny TD, Beijnen JH, Schellens JH. Germline TYMS genotype is highly predictive in patients with metastatic gastrointestinal malignancies receiving capecitabine-based chemotherapy. *Cancer Chemother Pharmacol* 2015; **75**: 763-772 [PMID: 25677447 DOI: 10.1007/s00280-015-2698-7]

52 **Fernández-Contreras ME**, Sánchez-Hernández JJ, González E, Herráez B, Domínguez I, Lozano M, García De Paredes ML, Muñoz A, Gamallo C. Combination of polymorphisms within 5' and 3' untranslated regions of thymidylate synthase gene modulates survival in 5 fluorouracil-treated colorectal cancer patients. *Int J Oncol* 2009; **34**: 219-229 [PMID: 19082493]

53 **Etienne-Grimaldi MC**, Milano G, Maindrault-Goebel F, Chibaudel B, Formento JL, Francoual M, Lledo G, André T, Mabro M, Mineur L, Flesch M, Carola E, de Gramont A. Methylenetetrahydrofolate reductase (MTHFR) gene polymorphisms and FOLFOX response in colorectal cancer patients. *Br J Clin Pharmacol* 2010; **69**: 58-66 [PMID: 20078613 DOI: 10.1111/j.1365-2125.2009.03556.x]

54 **Watanabe T**, Wu TT, Catalano PJ, Ueki T, Satriano R, Haller DG, Benson AB 3rd, Hamilton SR. Molecular predictors of survival after adjuvant chemotherapy for colon cancer. *N Engl J Med* 2001; **344**: 1196-1206 [PMID: 11309634 DOI: 10.1056/NEJM200104193441603]

55 **Etienne MC**, Chazal M, Laurent-Puig P, Magné N, Rosty C, Formento JL, Francoual M, Formento P, Renée N, Chamorey E, Bourgeon A, Seitz JF, Delpero JR, Letoublon C, Pezet D, Milano G. Prognostic value of tumoral thymidylate synthase and p53 in metastatic colorectal cancer patients receiving fluorouracil-based chemotherapy: phenotypic and genotypic analyses. *J Clin Oncol* 2002; **20**: 2832-2843 [PMID: 12065560 DOI: 10.1200/JCO.2002.09.091]

56 **Kawakami K**, Ishida Y, Danenberg KD, Omura K, Watanabe G, Danenberg PV. Functional polymorphism of the thymidylate synthase gene in colorectal cancer accompanied by frequent loss of heterozygosity. *Jpn J Cancer Res* 2002; **93**: 1221-1229 [PMID: 12460463]

57 **Maus MK**, Hanna DL, Stephens CL, Astrow SH, Yang D, Grimminger PP, Loupakis F, Hsiang JH, Zeger G, Wakatsuki T, Barzi A, Lenz HJ. Distinct gene expression profiles of proximal and distal colorectal cancer: implications for cytotoxic and targeted therapy. *Pharmacogenomics J* 2015; **15**: 354-362 [PMID: 25532759 DOI: 10.1038/tpj.2014.73]

58 **Strickler JH**, Hurwitz HI. Bevacizumab-based therapies in the first-line treatment of metastatic colorectal cancer. *Oncologist* 2012; **17**: 513-524 [PMID: 22477726 DOI: 10.1634/theoncologist.2012-0003]

59 **Pander J**, Wessels JA, Gelderblom H, van der Straaten T, Punt CJ, Guchelaar HJ. Pharmacogenetic interaction analysis for the efficacy of systemic treatment in metastatic colorectal cancer. *Ann Oncol* 2011; **22**: 1147-1153 [PMID: 21048041 DOI: 10.1093/annonc/mdq572]

60 **Watanabe T**, Kobunai T, Yamamoto Y, Matsuda K, Ishihara S, Nozawa K, Iinuma H, Ikeuchi H. Gene expression of vascular endothelial growth factor A, thymidylate synthase, and tissue inhibitor of metalloproteinase 3 in prediction of response to bevacizumab treatment in colorectal cancer patients. *Dis Colon Rectum* 2011; **54**: 1026-1035 [PMID: 21730794 DOI: 10.1097/DCR.0b013e31821c44af]

61 **Aschele C**, Debernardis D, Tunesi G, Maley F, Sobrero A. Thymidylate synthase protein expression in primary colorectal cancer compared with the corresponding distant metastases and relationship with the clinical response to 5-fluorouracil. *Clin Cancer Res* 2000; **6**: 4797-4802 [PMID: 11156237]

62 **Marsh S**, McKay JA, Curran S, Murray GI, Cassidy J, McLeod HL. Primary colorectal tumour is not an accurate predictor of thymidylate synthase in lymph node metastasis. *Oncol Rep* 2002; **9**: 231-234 [PMID: 11836585 DOI: 10.3892/or.9.2.231]

63 **Liu Q**, Yu Z, Xiang Y, Wu N, Wu L, Xu B, Wang L, Yang P, Li Y, Bai L. Prognostic and predictive significance of thymidylate synthase protein expression in non-small cell lung cancer: a systematic review and meta-analysis. *Cancer Biomark* 2015; **15**: 65-78 [PMID: 25524944 DOI: 10.3233/CBM-140432]

64 **Chu E**, Voeller DM, Jones KL, Takechi T, Maley GF, Maley F, Segal S, Allegra CJ. Identification of a thymidylate synthase ribonucleoprotein complex in human colon cancer cells. *Mol Cell Biol* 1994; **14**: 207-213 [PMID: 8264588]

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**Figure 1 Agarose gel with PCR products for the TYMS 5’UTR 28bp insertion.** A DNA ladder of repeated 50bp fragments was use (M 50bp). All potential genotypes (2R 241bp and 3R 242bp) are depicted as well as a sample with LOH for 3R (Lane 3).



**Figure 2 Polyacrylamide gel for the 12G>C substitution in the 5’UTR after digestion.** Expected bands are 12bp, 44bp, 45bp, and 47bp for all genotypes. Digestion of a sample with 2R or 3R12G genotype results in production of two bands of 66bp and 28bp, while in 3R12C genotypes those two fragments are left undigested in a single 94bp fragment.



**Figure 3 Polyacrylamide gel of the 3’UTR products.** Expected bands are 104bp and 110bp.In heterozygotes a second band of approximately 200bp was observed due to heteroduplex mismatches.

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**Figure 4 Kaplan-Meier survival curve.** A: Kaplan-Meier curve for PFS according to *TYMS* 3’UTR Groups; B: Kaplan-Meier curve for OS according to *TYMS* 3’UTR Groups. Comparisons were made using the long-rank tests.

**Table 1 *TYMS* polymorphisms’ groups per untranslated region**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Low expression** | **Medium expression** | **High expression** |
| *TYMS* 3’UTR | del/del | ins/del | ins/ins |
|  |  | del/LOH | ins/LOH |
|  |  |  |  |
| *TYMS* 5’UTR | 2RG | 2RG/3RG | 3RG |
|  | 2RG/3RC | 2RG/3RG | 3RG/3RC |
|  | 3RC | 2RG/3RCLOH | 2RGLOH/3RG |
|  |  | 2RG/3RGLOH |  |
|  |  | 2RGLOH/3RC |  |

**Table 2 Clinicopathologic data for patients with** metastatic colorectal cancer ***n* (%)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Clinicopathologic data** | **Relapses** | ***De novo* metastatic** | **Total** |
|  | 48 (53.9) | 41 (46.1) | 89 (100) |
| Median Age (range) | 65 (40 – 84.1) | 64 (27 – 86) | 65 (27 – 86) |
| Male | 34 (70.8) | 23 (56.1) | 57 (64.8) |
| Primary site |  |  |  |
| Colon | 20 (41.7) | 26 (63.4) | 46 (51.7) |
| Rectum | 28 (58.3) | 15 (36.6) | 43 (48.3) |
| Histological grade |  |  |  |
| I + II | 27 (56.3) | 28 (68.3) | 55 (61.8) |
| III+IV | 21 (43.7) | 13 (31.7) | 34 (38.2) |
| *KRAS* mutation | 22 (45.8) | 18 (43.9) | 40 (44.9) |
| *BRAF* V600E mut | 2 (4.2) | 3 (7.3) | 5 (5.6) |
| *TYMS* LOH | 15 (31.3) | 11 (26.8) | 26 (29.2) |
| Fluoropyrimidine-Based CT |  |  |  |
| Monotherapy or with | 5 (10.4) | 5 (12.2) | 10 (11.2) |
| Irinotecan | 18 (37.5) | 10 (24.4) | 28 (31.4) |
| Oxaliplatin | 22 (45.8) | 22 (53.7) | 44 (49.4) |
| Oxaliplatin and Irinotecan | 3 (6.3) | 3 (7.3) | 6 (6.7) |
| Bevacizumab | 31 (64.6) | 30 (73.2) | 61 (68.5) |
| No Chemotherapy | 0 (0.0) | 1 (2.4) | 1 (1.1) |
| Overall survival  |  |  |  |
| Deaths  | 30 (62.5) | 33 (80.5) | 63 (70.8) |
| Median time mos (95%CI)  | 21.4 (12.2 – 30.6) | 18.2 (14.3 – 22.0) | 19.8 (15.8 – 23.9) |
| Progression-free survival |  |  |  |
| Events  | 44 (91.7) | 41 (100.0) | 85 (95.5) |
| Median time mos (95%CI) | 10.8 (9.0 – 12.5) | 9.9 (7.0 – 12.8) | 10.6 (8.8 – 12.5) |
| Median follow up mo (range) | 14.2 (0 – 72.5) | 17.0 (0.8 – 119.8) | 14.8 (0 – 119.8) |

CT: Chemotherapy.

**Table 3 Association between *TYMS* polymorphisms and patients characteristics**

|  |  |  |  |
| --- | --- | --- | --- |
| **Polymorphism** | **Patients Characteristic** | **RR (95%CI)** | ***P* value** |
| 2R | Age < 65 years old | 1.708 (1.158-2.520) | 0.090 |
| 2RG/3RG | Grade 1-2 | 1.449 (1.077-1.948) | 0.044 |
| 2RG/3RC | Female | 1.943 (1.152-3.275) | 0.036 |
| ins/ins | *KRAS* G12D | 3.563 (1.163-10.912) | 0.045 |
| 3RG/3RC | *KRAS* wild type | 1.753 (1.156-2.657) | 0.031 |

**Table 4 Risk Groups of *TYMS* Polymorphisms *n* (%)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Groups** | **Relapsed** | **De novo metastatic** | **Total** |
| *TYMS* 5’UTR |  |  |  |
| Low expression |  |  |  |
|  2RG | 2 (4.2) | 6 (14.6) | 8 (9.0) |
|  2RG/3RC | 8 (16.7) | 3 (7.3) | 11 (12.4) |
|  3RC | 6 (12.5) | 5 (12.2) | 11 (12.4) |
|  |  |  |  |
| Medium expression |  |  |  |
|  2RG/3RG | 4 (8.3) | 4 (9.8) | 8 (9) |
|  2RG/3RCLOH | 7 (14.6) | 3 (7.3) | 10 (11.2) |
|  2RG/3RGLOH | 3 (6.3) | 2 (4.9) | 5 (5.6) |
|  2RGLOH/3RC | 1 (2.1) | 2 (4.9) | 3 (3.4) |
|  |  |  |  |
| High expression |  |  |  |
|  3RG | 4 (8.3) | 4 (9.8) | 8 (9.0) |
|  3RG/3RC | 9 (18.8) | 8 (19.5) | 17 (19.1) |
|  2RGLOH/3RG | 4 (8.3) | 4 (9.8) | 8 (9.0) |
|  |  |  |  |
| *TYMS* 3’UTR |  |  |  |
| Low expression del/del | 6 (12.5) | 7 (17.1) | 13 (14.6) |
| Medium expression |  |  |  |
|  ins/del | 19 (39.6) | 10 (24.4) | 29 (32.6) |
|  del/LOH | 1 (2.1) | 3 (7.3) | 4 (4.5) |
| High expression  |  |  |  |
|  ins/ins | 8 (16.7) | 13 (31.7) | 21 (23.6) |
|  ins/LOH  | 14 (29.2) | 8 (19.5) | 22 (24.7) |

LOH: Loss of heterozygosity.

**Table 5 Univariate Cox regression analysis for clinicopathological features and genotype**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **PFS** |  |  |  | **OS** |  |
| **Variable** | **HR** | **95%CI** | ***P* value** |  | **HR** | **95%CI** | ***P* value** |
| *KRAS* Mutated | 1.390 | 0.895 – 2.164 | 0.142 |  | 1.669 | 0.996-2.797 | **0.052** |
| *BRAF* V600E | 0.884 | 0.356 – 2.196 | 0.791 |  | 1.514 | 0.545-4.207 | 0.426 |
| LOH | 1.013 | 0.632-1.624 | 0.957 |  | 1.020 | 0.592-1.758 | 0.944 |
| *TYMS* 5’UTR |  |  | 0.561 |  |  |  | 0.845 |
|  2R | 1 |  |  |  | 1 |  |  |
|  2R/3R | 1.243 | 0.616-2.508 | 0.543 |  | 1.276 | 0.556-2.928 | 0.565 |
|  3R | 0.974 | 0.474-2.003 | 0.944 |  | 1.239 | 0.535-2.870 | 0.616 |
| *TYMS* 5’UTR |  |  | 0.887 |  |  |  | 0.486 |
|  2RG | 1 |  |  |  | 1 |  |  |
|  2RG/3RC | 1.151 | 0.535-2.475 | 0.720 |  | 0.978 | 0.388-2.468 | 0.963 |
|  2RG/3RG | 1.351 | 0.625-2.921 | 0.444 |  | 1.688 | 0.689-4.132 | 0.252 |
|  3RC | 1.038 | 0.428-2.517 | 0.935 |  | 0.876 | 0.293-2.620 | 0.813 |
|  3RG/3RC | 0.883 | 0.391-1.995 | 0.764 |  | 1.648 | 0.660-4.113 | 0.284 |
|  3RG | 1.107 | 0.433-2.832 | 0.832 |  | 1.054 | 0.348-3.189 | 0.926 |
| *TYMS* 5’UTR |  |  | 0.726 |  |  |  | 0.562 |
|  2R | 1 |  |  |  | 1 |  |  |
|  2RG/3RC | 1.864 | 0.738-4.713 | 0.188 |  | 1.678 | 0.546-5.160 | 0.366 |
|  2RG/3RCLOH | 0.783 | 0.300-2.044 | 0.617 |  | 1.044 | 0.328-3.323 | 0.942 |
|  2RG/3RG | 1.058 | 0.372-3.014 | 0.916 |  | 1.869 | 0.537-6.504 | 0.325 |
|  2RG/3RGLOH | 1.936 | 0.630-5.948 | 0.248 |  | 3.875 | 1.019-14.740 | 0.047 |
|  2RGLOH/3RC | 1.155 | 0.301-4.441 | 0.834 |  | 1.091 | 0.126-9.412 | 0.937 |
|  2RGLOH/3RG | 1.656 | 0.617-4.442 | 0.317 |  | 1.745 | 0.546-5.576 | 0.348 |
|  3RC | 1.096 | 0.428-2.806 | 0.848 |  | 1.070 | 0.325-3.521 | 0.912 |
|  3RG | 1.163 | 0.432—3.134 | 0.765 |  | 1.281 | 0.385-4.270 | 0.687 |
|  3RG/3RC | 1.001 | 0.413-2.426 | 0.998 |  | 2.144 | 0.758-6.064 | 0.151 |
| *TYMS* 5’UTR groups |  |  | 0.812 |  |  |  | 0.489 |
| Low expression | 1.063 | 0.633-1.784 | 0.818 |  | 0.696 | 0.384-1.261 | 0.232 |
| Medium expression | 0.888 | 0.518-1.523 | 0.667 |  | 0.851 | 0.460-1.572 | 0.606 |
| High expression | 1 |  |  |  | 1 |  |  |
| *TYMS* 3’UTR |  |  | 0.295 |  |  |  | 0.340 |
| del/del | 0.602 | 0.305-1.190 | 0.144 |  | 0.563 | 0.259-1.224 | 0.147 |
| ins/del | 0.764 | 0.475-1.228 | 0.267 |  | 0.910 | 0.522-1.587 | 0.739 |
| ins/ins | 1 |  |  |  | 1 |  |  |
| *TYMS* 3’UTR |  |  | **0**.**067** |  |  | 1 | **0.095** |
| del/del | 0.421 | 0.194-0.912 | **0**.**028** |  | 0.311 | 0.125-0.772 | **0.012** |
| del/LOH | 0.784 | 0.263-2.334 | 0.662 |  | 0.773 | 0.175-3.417 | 0.734 |
| ins/del | 0.438 | 0.240-0.802 | **0**.**007** |  | 0.459 | 0.230-0.918 | **0.028** |
| ins/LOH | 0.516 | 0.274-0.973 | **0**.**041** |  | 0.488 | 0.233-1.020 | **0.057** |
| ins/ins | 1 |  |  |  | 1 |  |  |
| *TYMS* 3’UTR groups |  |  | 0.225 |  |  |  | 0.187 |
| Low expression | 0.639 | 0.323-1.263 | 0.198 |  | 0.503 | 0.230-1.102 | 0.086 |
| Medium expression  | 0.435 | 0.435-1.118 | 0.135 |  | 0.738 | 0.426-1.279 | 0.279 |
| High expression | 1 |  |  |  | 1 |  |  |

CT: Chemotherapy.

**Table 6 Multivariate Cox regression analysis**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Progression Free Survival** |  | **Overall Survival** |
|  | **HR** | **95%CI** | ***P* value** |  | **HR** | **95%CI** | ***P* value** |
| *KRAS* mutated | 1.600 | 1.011-2.531 | **0.045** |  |  |  |  |
| LOH | 1.674 | 0.912-3.071 | 0.096 |  |  |  |  |
|  |  |  |  |  |  |  |  |
| **Fluoropyrimidine-Based CT** |  |  |  |  |  |  |  |
| With irinotecan | 0.600 | 0.372-0.969 | **0.037** |  | 0.352 | 0.164-0.757 | **0.007** |
| Without irinotecan | 1 |  |  |  | 1 |  |  |
|  |  |  |  |  |  |  |  |
| With oxaliplatin |  |  |  |  | 1 |  |  |
| Without oxaliplatin |  |  |  |  | 2.702 | 1.273-5.738 | **0.010** |
|  |  |  |  |  |  |  |  |
| ***TYMS* 3’UTR groups** |  |  | **0.043** |  |  |  | **0.027** |
| Low expression | 0.432 | 0.198-0.946 | **0.036** |  | 0.366 | 0.162-0.827 | **0.016** |
| Medium expression  | 0.513 | 0.287-0.919 | **0.025** |  | 0.559 | 0.309-1.013 | 0.055 |
| High expression  | 1 |  |  |  | 1 |  |  |
|  |  |  |  |  |  |  |  |
| **Gender** |  |  |  |  |  |  |  |
| Males |  |  |  |  | 1.580 | 0.916-2.724 | 0.100 |

CT: Chemotherapy.