

Phase II study of the dual EGFR/HER3 inhibitor duligotuzumab (MEHD7945A) versus cetuximab in combination with FOLFIRI in second line RAS wild-type metastatic colorectal cancer

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Abstract

Purpose: Duligotuzumab is a dual-action antibody directed against EGFR and HER3.

Experimental design: mCRC patients with *KRAS* ex2 wild-type received duligotuzumab or cetuximab and FOLFIRI until progression or intolerable toxicity. Mandatory tumor samples underwent mutation and biomarker analysis. Efficacy analysis was conducted in patients with *RAS* exon 2/3 wild-type tumors.

Results: Of 134 randomized patients, 98 were *RAS* ex2/3 wild-type. Duligotuzumab provided no PFS or OR benefit compared to cetuximab; though there was a trend for lower ORR in the duligotuzumab arm. No relationship was seen between PFS or ORR and ERBB3, NRG1, or AREG expression. There were fewer skin rash events for duligotuzumab but more diarrhea. Although the incidence of grade ≥ 3 AEs was similar, the frequency of serious AEs was higher for duligotuzumab.

Conclusions: Duligotuzumab plus FOLFIRI did not appear to improve the outcomes in patients with *RAS* exon 2/3 wild-type mCRC compared to cetuximab + FOLFIRI.

Statement of translational relevance

Duligotuzumab, a dual-action antibody to EGFR and HER3, shows preclinical efficacy in EGFR-dependent CRC cell lines refractory to EGFR inhibition. We evaluated duligotuzumab compared to cetuximab in combination with FOLFIRI as second-line therapy in patients with *RAS* exon 2/3 wild-type metastatic CRC and found no advantage to duligotuzumab.

Introduction

EGFR is a growth factor receptor with tyrosine kinase activity implicated in both colorectal (CRC) tumorigenesis and tumor progression, and its overexpression (found in 65%-70% of human CRC) has been associated with advanced disease (1). Anti-EGFR monoclonal antibodies (mAbs) are established in the treatment of metastatic CRC (mCRC), either as single agent or in combination with chemotherapy (2-4). While the benefit was initially thought to be restricted to patients lacking hot spot mutations in *KRAS* exon 2, codons 12 and 13, a more recent retrospective analysis of Phase III studies with anti-EGFR mAbs either in first or second line mCRC identified additional mutations in *KRAS* or *NRAS* exons 2, 3, 4 as negative predictive biomarkers for EGFR inhibition (5-9). Consequently, the ESMO clinical practice guidelines for the treatment of mCRC were updated to recommend additional testing for *KRAS* mutations in exons 3 and 4, and *NRAS* mutations in exons 2-4 as a prerequisite for anti-EGFR antibody therapy (10). Similarly, NCCN guidelines now recommend against treating patients with known *KRAS* (exon 2 or non-exon 2) or *NRAS* mutation with either cetuximab or panitumumab (11).

Nonclinical and preliminary clinical data suggest a role for HER3 in acquired resistance to EGFR inhibitors (12-14). Yonesaka and coworkers (15) reported amplification of the HER2 gene and/or increased concentrations of neuregulin (NRG1) the ligand for HER3 in cetuximab-resistant clones of colorectal and lung cancers. Further analysis suggested that aberrant HER2 signaling, through either HER2/HER2 dimers associated with gene amplification or HER2/HER3 dimer activation through autocrine expression of neuregulin led to persistent ERK signaling and consequently to cetuximab resistance. Interestingly, a retrospective review of data from mCRC patients treated with cetuximab as a single agent or in combination with irinotecan (also reported in 15) found that those patients with a partial response had significantly lower baseline expression of NRG1 in plasma or tumor samples than patients with a best response of stable or progressive disease. Furthermore, patients with lower baseline plasma NRG1 levels had

significantly longer progression-free (PFS) and overall survival (OS) when compared with those with higher levels.

Clinical trial reports on the evaluation of therapeutics that inhibit HER3 dependent signaling are relatively rare, as are HER3-related biomarker studies that aim to identify clinically meaningful patient subsets. This is in part due to the attenuated enzymatic activity of HER3 that renders HER3 activity dependent on critical protein-protein interactions. Innovative methods for inhibiting activity often focus on these interactions and moreover, biomarkers of HER3 activity often include these interaction partners independent of HER3 expression. HER3 activity can be enhanced by elevated ligand or heterodimer expression or in some cases, activity is driven by multiple binding sites for signalling partners (i.e., PI3K). In addition, there is evidence for controlled HER3 feedback HER3 including altered transcription of HER3 itself. This was most clearly shown in a randomized Phase II trial of pertuzumab (a monoclonal antibody that targets HER2 and therefore inhibits heterodimerization of HER2 and HER3) in patients with platinum refractory ovarian cancer, those patients with low expression of HER3 in tumors (measured by quantitative reverse transcriptase polymerase chain reaction (qRT-PCR) had a statistically significant improvement in PFS and numerically improved response rate and OS (16). These results, together with preclinical observations that activation of the HER2/HER3 signaling pathway by ligand stimulation leads to down regulation of HER3 through negative feedback modulation (17), as well the cumulative mechanisms of HER3 activation independent of enhance HER3 expression may suggest that even low tumor expression of HER3 may be indicative of pathway activation and consequently sensitivity to HER3 blocking agents.

Duligotuzumab (MEHD7945A) is a novel humanized phage-derived, dual-action antibody that blocks ligand binding to EGFR and HER3, with either antigen-binding fragment (Fab). When bound to these receptors, duligotuzumab blocks ligand binding (K_d huHER3 = 0.39 nM; K_d hu EGFR = 1.9 nM), resulting in inhibition of ligand-driven signaling from EGFR/EGFR, EGFR/HER2, EGFR/HER3, and HER2/HER3 dimer pairs. As an IgG1 antibody, duligotuzumab

is also able to bind to Fc γ receptors and has demonstrated antibody-dependent cell-mediated cytotoxicity (ADCC) in *in vitro* models (18). *In vivo*, duligotuzumab shows activity in CRC *KRAS* wild-type xenograft models equal or superior to cetuximab, no effect in *KRAS* mutated models, and is additive in combination with chemotherapy (19). In CRC cell lines, standard chemotherapy may modulate the HER3/NRG network. These properties provided the rationale for investigating duligotuzumab for the treatment of patients with mCRC.

Methods

Study design

This open-label, randomized Phase II study enrolled patients with *KRAS* exon 2 wild-type mCRC who progressed on/after oxaliplatin-containing chemotherapy. The primary objectives of this study were to 1) evaluate the efficacy of duligotuzumab + FOLFIRI vs. cetuximab + FOLFIRI in *KRAS* wild-type mCRC patients, and 2) evaluate the efficacy of duligotuzumab + FOLFIRI vs. cetuximab + FOLFIRI in *KRAS* wild-type mCRC patients whose tumors express low levels of HER3. The secondary objectives included evaluating the safety and tolerability of duligotuzumab vs. cetuximab in combination with FOLFIRI in *KRAS* exon 2 wild-type mCRC patients, assess the effect of concomitant FOLFIRI on the pharmacokinetics (PK) of duligotuzumab and vice versa, and evaluate the incidence and impact of anti-duligotuzumab antibodies.

Eligible patients were randomized in a 1:1 ratio and received duligotuzumab at a fixed dose of 1100 mg IV every 2 weeks (q2w) (Arm A). Patients in Arm B received cetuximab administered according to the prescribing label, with a loading dose of 400 mg/m² IV on Day 1 of Cycle 1, followed by weekly doses of 250 mg/m² IV (2 x per cycle). No dose reductions were allowed for duligotuzumab and for cetuximab were limited to reductions for rash in accordance to its prescribing information. FOLFIRI chemotherapy was administered q2w (every cycle) starting on Day 1 of Cycle 1. FOLFIRI consisted of irinotecan (180 mg/m²), 5-FU (bolus and 46

hour infusional doses of 400 mg/m² and 2400 mg/m², respectively), and leucovorin (racemic, 400 mg/m² or L-isomer form, 200 mg/m²). Recommendations for chemotherapy dose reductions were in accordance to standard clinical practice. Dosing continued until progression or intolerable toxicity. An early per-protocol interim safety analysis occurred after an initial 6 and then 20 patients in each treatment arm received 2 cycles of treatment.

Patients

Eligible patients age \geq 18 years with histologically or cytologically confirmed adenocarcinoma of the colon and/or rectum, *KRAS* exon 2 wild-type status based on local assessment (EGFR expression status was not required for enrollment) and progressive disease on or after a first-line oxaliplatin-containing chemotherapy regimen for mCRC were enrolled into the study. Eastern Cooperative Oncology group (ECOG) performance status of 0-1, adequate hematologic and end organ function, and evaluable or measurable disease per modified RECIST v1.1 was required. Main exclusion criteria included prior treatment with irinotecan, HER-targeted agents, dihydropyrimidine dehydrogenase deficiency or current severe uncontrolled systemic disease.

The protocol was approved by Institutional Review Boards prior to patient recruitment and was conducted in accordance with International Conference on Harmonization E6 Guidelines for Good Clinical Practice. Written informed consent was obtained for all patients prior to performing study-related procedures in accordance with federal and institutional guidelines.

Safety assessments

Safety assessments consisted of recording protocol-defined adverse events (AEs) and serious AEs (SAEs); measurement of protocol specified hematology, clinical chemistry, and urinalysis variables; measurement of protocol specified vital signs; and other tests deemed

critical to the safety evaluation of the study drug(s). Safety was assessed by the incidence, nature, severity and relatedness of AEs, which were graded for severity according to the National Cancer Institute Common Terminology Criteria for Adverse Events, v4.0. All patients who received ≥ 1 dose of study treatment were included in the safety evaluation. Protocol-defined Adverse Events of Special Interest included grade ≥ 3 events associated with infusion related reactions (defined as AEs occurring within 24 hours of infusion and attributed to treatment), grade ≥ 3 rash, grade ≥ 3 diarrhea, and grade ≥ 2 GI hemorrhage.

Pharmacokinetic assessments

Serum samples for PK analysis were collected on Day 1 of each cycle. PK parameters were derived from non-compartmental analysis (Phoenix WinNonlin version 6.2) from the plasma concentration-time profile of duligotuzumab. A validated ELISA with a lower limit of quantitation of 150 ng/mL was used to measure the concentration of duligotuzumab in serum samples. All study samples were analyzed at Genentech. Plasma concentrations of 5-FU, irinotecan, and SN-38 were measured using validated liquid chromatography tandem mass spectrometry methods. Serum samples were assayed for the presence ATAs to duligotuzumab using a validated bridging ELISA.

Activity outcomes

Per protocol, the primary efficacy outcome measure for this study was PFS in all patients with *KRAS* exon 2 wild-type mCRC and later restricted to *RAS* wild-type mCRC, and among patients whose tumors expressed low levels of HER3. PFS was defined as the time from study treatment initiation to the first occurrence of disease progression was determined by investigator review of tumor assessments with use of the modified RECIST v1.1, or death, whichever occurred first. Objective response by investigator assessment, duration of response, and overall survival were secondary efficacy outcome measures. Objective response was

defined as a complete or partial response according to modified RECIST v1.1; confirmed ≥ 4 weeks after the initial response. Duration of objective response was defined as the time from first occurrence of a documented objective response until the time of relapse or death from any cause. OS was defined as the time from study treatment initiation to death from any cause. Time to treatment failure was defined as time from randomization to discontinuation of treatment for any reason, including disease progression, treatment toxicity, and death.

Biomarker assessments

Tumor samples were mandatory and biomarker expression analysis focused on ERBB3 and its ligand NRG1, as well as on EGFR and its ligands AREG and EREG, by qRT-PCR. IHC was used to determine protein expression and localization of HER3. Pre-cut tissue sections were stained for HER3 for analysis by IHC using the Ventana BenchMark® XT staining platform (Ventana Medical Systems, Inc., Tucson, AZ). Hematoxylin and eosin previously stained slides or images were reviewed to assess tissue quality and presence of tumor. IHC was performed in the TDx CAP/CLIA laboratory of VMSI using assays developed and validated in the Translational Diagnostics Laboratories of VMSI. Immunostaining was assessed by a board-certified pathologist.

qRT-PCR was assessed using the fluidigm platform using an allele-specific PCR mutation panel that detects mutations in *KRAS* and *NRAS* in exon 2 (G12 and G13), exon 3 (Q61), and exon 4 (K117 and A146) as previously described (20).

Statistical methods

This Phase II trial was designed to make a preliminary comparison of the safety and efficacy of FOLFIRI + duligotuzumab versus FOLFIRI + cetuximab in patients with *KRAS* wild-type mCRC and in those patients with low HER3 levels in their tumors. In particular, it was designed to obtain informative estimates of the PFS hazard ratios in the overall patient

population and the HER3-low patient population to enable further decision making. This trial is hypothesis generating and was not intended to detect the minimal clinically meaningful benefit.

Results

Patient characteristics

A total of 68 patients were enrolled in the duligotuzumab + FOLFIRI arm (78% *RAS* wild type), and 66 in the cetuximab + FOLFIRI arm (68% *RAS* wild type), from 22 Oct 2012 to 24 December 2013 at 43 sites. The last patient's final visit was completed on 26 November 2014; this date serving as the clinical data cutoff for the analyses. The baseline characteristics of the patient population are shown in **Table 1** and were well balanced between treatment arms with the exception of a slight imbalance in sex, ECOG PS, *RAS* wt and *PIK3CA* mutation status. Of 134 randomized patients, 98 were *RAS* exon 2/3 wild-type (n=53 in the duligotuzumab arm); *BRAF* and *PIK3CA* mutations were present in 15% and 12% of all patients enrolled. Sixty-five percent of patients were triple wild-type (*RAS*, *BRAF*, and *PIK3CA*). Most patients (77%) had progressed on first-line oxaliplatin within 6 months.

Safety and tolerability

There were 67 and 63 patients in the duligotuzumab and cetuximab arms, respectively, who were evaluable for safety (**Table 2**). The most common AEs of any grade were rash (84%), diarrhea (79%), fatigue (62%), and nausea (50%). There were fewer rash events of any grade in the duligotuzumab arm but more diarrhea.

The incidence of grade ≥ 3 AEs was similar between arms (All AEs: 85% and 89%; related AEs 46% and 60%); overall, neutropenia (23%) was the most common AE of grade ≥ 3 intensity, regardless of attribution. The frequency of SAEs was higher in the cetuximab arm (56% vs. 48% for duligotuzumab). AEs of special interest included grade ≥ 3 diarrhea that was

higher in the duligotuzumab arm (18%) compared to the cetuximab arm (14%), and grade ≥ 3 infusion-related reactions (8% vs. 2%) and grade ≥ 3 rash (22% vs. 8%) were higher in the cetuximab arm.

AEs that led to a fatal outcome were reported in 3 patients on the duligotuzumab + FOLFIRI arm (pneumonia, respiratory failure, and one unknown cause of death), and 2 patients on the cetuximab arm (*Campylobacter* infection and lung infection).

SAEs occurred in 54% and 56% of patients on duligotuzumab vs. cetuximab arm. The SAEs regardless of attribution, occurring in $\geq 5\%$ of patients were pyrexia (7%), diarrhea and pulmonary embolism (5% each).

Treatment discontinuation of mAbs due to AEs was comparable in the duligotuzumab (14%) and cetuximab (16%) arms. However, cumulative dose intensity of FOLFIRI chemotherapy components was lower on the duligotuzumab vs. cetuximab arm (irinotecan: 66 [24–100] vs. 75 [32–100]; 5-FU infusion 67 [24–99] vs. 74 [32–107]). In the duligotuzumab arm, select gastrointestinal (GI) toxicities (diarrhea, mucosal inflammation, and stomatitis) occurring at relatively high frequency led to disproportionately more frequent dose changes for irinotecan and 5-FU. For example, 52% of the stomatitis events occurring in the duligotuzumab arm led to chemotherapy dose modifications, while in the cetuximab arm, 8% of stomatitis events led to chemotherapy modifications. Furthermore, AEs leading to chemotherapy dose modifications, as a whole, occurred earlier in the duligotuzumab arm compared to the cetuximab arm. The median time of onset to first AEs for which irinotecan or 5-FU was modified (dose reduced, drug interrupted, or drug withdrawn) was 22 days in the duligotuzumab arm vs. 35 days in the cetuximab arm, of safety-evaluable patients.

Pharmacokinetic analysis

In the duligotuzumab arm, mean peak and trough (\pm SD) serum concentrations of duligotuzumab were 299 $\mu\text{g/mL}$ (\pm 66.3) and 39.5 $\mu\text{g/mL}$ (\pm 43.7), respectively, in Cycle 1, and

the trough serum concentration was 76.0 (\pm 42.6) $\mu\text{g/mL}$ in Cycle 9 (Cycle 10, Day 1 [predose]). The data were comparable with previously reported serum duligotuzumab concentration data (equivalent dose of 14 mg/kg q2w IV) in the Phase I study (21).

There was no apparent effect of 5-FU and irinotecan co-administration on duligotuzumab PK. From an assessment of mean observed serum duligotuzumab trough concentration (69.4 $\mu\text{g/mL}$) from Cycle 3 (Cycle 4, Day 1 [predose]) onwards, there appeared to be minimal accumulation of duligotuzumab during the treatment period.

There was no evidence of trends in PFS or OS with duligotuzumab exposure, based on exposure-response analyses; indicating that dose was close or at the top of exposure-response curve.

The baseline prevalence of anti-therapeutic antibodies (ATAs) was 0% in the overall study population (0/70 patients). None of the 59 post-baseline evaluable patients treated with duligotuzumab had positive ATA results.

Clinical activity

Efficacy results (**Table 3A**) show no benefit of duligotuzumab + FOLFIRI compared to cetuximab + FOLFIRI in *RAS* wild-type patients. Patients in the duligotuzumab arm did not show improved PFS by investigator assessment (**Figure 1**). In the *RAS* wild-type subgroup, median PFS was 7.3 vs. 5.7 months for duligotuzumab vs. cetuximab (stratified HR 1.21, 90% CI 0.81-1.81). In HER3-low *RAS* wild-type randomized patients (based on the median ERBB3 qRT-PCR expression; [n=54]), the HR for PFS was 1.34 (90% CI, 0.80–2.25).

OS data were immature with 45% of OS events having occurred on the duligotuzumab and 49% on the cetuximab arm at the time to data cutoff (HR 1.00, 90% CI 0.61-1.66). Median OS was 14.0 months for duligotuzumab, and 13.1 months for cetuximab. Time to treatment failure was longer in the cetuximab arm compared to duligotuzumab.

The objective response rate (ORR) was numerically lower in duligotuzumab-receiving patients (19%) compared to cetuximab (33%), (OR 0.47, 90% CI 0.21-1.01). Best overall response rates in the duligotuzumab arm consisted of 12 (23%) PR, as compared to 2 (4%) CR and 19 (42%) PR in the cetuximab arm. The waterfall plot for best CT response in **Figure 2A** shows the corresponding degree of tumor shrinkage in cetuximab vs. the duligotuzumab arm. Overall time on study treatment was lower on duligotuzumab vs. cetuximab (**Figure 3**).

Biomarker analysis

By qRT-PCR, ERBB3 expression was in the range of 0.75-9.96 relative expression units ($2^{-\Delta\text{dCT}}$), and membranous staining of HER3 protein measured by IHC was observed with H-scores ranging from 100-245. Neither HER3 protein levels nor relative gene expression based on RNA (ERBB3) showed a relationship with tumor shrinkage (**Figure 2A**) or PFS (**Figure 2B**). While no nuclear staining was observed, there was evidence for cytoplasmic staining. Comprehensive H-scores including both membranous and cytoplasmic staining patterns did not show benefit based on tumor response.

HER3 and EGFR ligand expression was also evaluated. NRG1 expression was in the range of 0.008-17.53 relative expression units ($2^{-\Delta\text{dCT}}$) in biopsy specimens but also failed to discriminate for response based on tumor shrinkage (22). Similarly, there was no clear relationship between AREG and EREG and best CT response or degree of tumor shrinkage. However, AREG and EREG, which were significantly correlated, showed a trend towards benefit in the cetuximab arm. EGFR levels showed no difference (22).

Evaluation of KRAS mutation status showed that 3.7% of samples exhibited mutations at codons 12 and 13 (exon 2, possibly undetected at screening), 0% with mutations at codon 61 in exon 3, and 117 (0.9%) and 146 (2.8%) in exon 4. Mutations in NRAS were detected at codons 12 and 13 (1.9%) in exon 2, and 61 (1.9%) in exon 3; no mutations were detected in exon 4 at codons 117 and 146. Additionally, mutations in BRAF were observed in 15% of patients at

codon 600 (exon 15), but not in exon 11. Both NRAS and BRAF mutations were balanced between treatment arms. The majority of patients harboring mutations in KRAS exon 2 or 4, or BRAF, did not respond to either treatment arm (**Table 3B**), however, limited responses were observed in patients with mutations in NRAS (3 PRs, 2 cetuximab, 1 duligotuzumab arm).

Discussion

HER3 is thought to have a functional role in CRC tumorigenesis (23). Although normal colonic tissue has little to no HER3 expression, HER3 is expressed in a significant proportion of colorectal tumors (24-29). Indeed, CRC tumors express high levels of NRG1 and several EGFR ligands, suggesting that these tumors use both the EGFR and HER3 pathways to sustain proliferation (22).

Given the limited sample size no definitive conclusions can be drawn with respect to efficacy, however, a large clinical benefit was excluded. Furthermore, HER3 protein or gene expression levels did not select for benefit with duligotuzumab, nor did NRG1 or AREG expression. The mean peak and trough serum concentrations of duligotuzumab in the duligotuzumab + FOLFIRI arm were comparable to those previously reported (equivalent dose of 14 mg/kg q2w IV) in the Phase I study (21), indicating that there was no apparent effect of 5-FU and irinotecan co-administration on the duligotuzumab PK.

Duligotuzumab in combination with FOLFIRI has an acceptable safety profile. The combination of duligotuzumab was overall well-tolerated with no unexpected safety findings. The overall incidence of AEs, SAEs, deaths, and withdrawal from the study due to AEs, dose modification/interruption due to AEs was comparable between the duligotuzumab and cetuximab arms. In the duligotuzumab arm there was less rash consistent with the Phase I study (21) and IRRs, however, more frequent all grades selected GI toxicities including diarrhea.

A number of factors could have contributed to lower ORR in the duligotuzumab arm. For one, select GI toxicities (diarrhea, mucosal inflammation, and stomatitis) occurred at relatively high frequency and led to disproportionately more frequent and earlier dose changes for irinotecan and 5-FU. The more frequent occurrences of diarrhea and mucosal inflammation were associated with shorter duration and reduced dose intensity of the chemo backbone. The 5-FU bolus was preferentially reduced to the lowest dose intensity in an attempt to counter these AEs. In addition, no severe imbalances were seen in overall incidence of grade 3-5 AEs, and the overall percentage of patients in whom irinotecan or 5-FU was modified due to a grade 3-5 AE was similar between the arms. Therefore, it was mainly, and often multiple, grade 1-2 AEs accounting for the disproportionately more frequent irinotecan and 5-FU dose modifications in the duligotuzumab arm.

The role of HER3 appears limited in the mCRC EGFR inhibitor naïve setting since there was no additional benefit of inhibiting HER3 in addition to EGFR. Expression of HER3 measured by RNA or protein did not correlate with response suggesting a minor role for HER3 in this disease. Conversely, the EGFR ligands AREG and EREG did show a trend towards improved survival in the cetuximab arm consistent with published data demonstrating stratified responses to antibody-based EGFR inhibitors (30). In the context of chemotherapy, it is difficult to discriminate specific differences between the two regimens but these data may suggest more potent EGFR clinical inhibitory activity by cetuximab ($K_d = 0.2$ nM, 31). The affinity of duligotuzumab is almost 1 log higher for HER3 than for EGFR (K_d huHER3 = 0.39 nM; K_d huEGFR = 1.9 nM; 32), which may in part explain the lack of additional benefit of duligotuzumab compared to cetuximab in this setting. Abrogation of dual HER3/EGFR signaling may explain the higher incidence of diarrhea and mucosal inflammation in the duligotuzumab arm, which has been seen with other HER3 inhibitors, and the lower affinity for EGFR could translate in a lower EGFR-signaling down regulation that may be the cause of the lower frequency of cutaneous

toxicities observed in the duligotuzumab-containing arm given the binding affinity of each compound.

Whether dual EGFR/HER3 inhibition could restore sensitivity once tumors have failed initial EGFR inhibition is something that we cannot rule out due to the design of this study. Receptor expression based on HER3 protein and gene expression analysis did not select for benefit with duligotuzumab. Similarly, the expression of the ligands, NRG1 and AREG also do not select for benefit. Unlike SCCHN, no relationship between NRG1 and EGFR ligands was noted (33-34).

In light of this and another randomized Phase 2 study in SCCHN showing no benefit for the dual inhibition of EGFR and HER3 over EGFR alone, neither in all randomized patients nor in biomarker selected subsets, we conclude that the role of dual HER3/HER1 inhibition remains not well understood in patients not previously treated with EGFR inhibitors. Further development of duligotuzumab has been stopped.

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Disclaimer

The authors take full responsibility for the design of the study, the collection of the data, the analysis and interpretation of the data, the decision to submit the article for publication, and the writing of the article.

Author's contributions

Conception and design: Pirzkall, Penuel, Tabernero, McCall.

Development of methodology: Pirzkall, Penuel, Tabernero, McCall.

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Writing, review, and/or revision of the manuscript: all authors.

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Study supervision: Pirzkall, McCall, Tabernero, Coveler.

Other (study conduction): Tabernero, Coveler.

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Tables

Table 1.

| | Duligotuzumab + FOLFIRI | | Cetuximab + FOLFIRI | | All Patients | |
|---|-------------------------|--------------------|---------------------|--------------------|--------------|---------------|
| | All (n=68) | RAS WT (n=53, 78%) | All (n=66) | RAS WT (n=45, 68%) | All (N=134) | RAS WT (N=98) |
| Age (years), median (range) | 61 (21–85) | 62 (21–85) | 62 (26–82) | 65 (39–82) | 62 (21–85) | 63 (21–85) |
| Sex (male) | 36 (53%) | 27 (51%) | 46 (70%) | 34 (76%) | 82 (61%) | 61 (62%) |
| Race (white) | 60 (88%) | 46 (87%) | 59 (89%) | 42 (93%) | 119 (89%) | 88 (90%) |
| ECOG PS (0) | 30 (45%) | 24 (45%) | 39 (62%) | 25 (57%) | 69 (53%) | 49 (51%) |
| <i>BRAF</i> mutation ^a | 8 (12%) | 8 (15%) | 8 (12%) | 8 (18%) | 16 (12%) | 16 (16%) |
| <i>PIK3CA</i> mutation ^a | 11 (20%) | 9 (17%) | 6 (12%) | 4 (9%) | 17 (16%) | 13 (13%) |
| Triple WT (<i>RAS</i> , <i>BRAF</i> and <i>PIK3CA</i>) ^a | 36 (64%) | 36 (68%) | 33 (65%) | 33 (73%) | 69 (65%) | 69 (70%) |
| Received prior bevacizumab | 32 (47%) | 23 (44%) | 31 (48%) | 18 (40%) | 63 (47%) | 41 (42%) |
| Time to PD on first-line oxaliplatin-based chemo (≤ 6 months) | 53 (78%) | 38 (72%) | 50 (76%) | 34 (76%) | 103 (77%) | 72 (74%) |
| Primary tumor location | | | | | | |
| Left colon | 22 (42%) | - | 18 (40%) | - | 40 (41%) | - |
| Right colon | 12 (23%) | - | 11 (24%) | - | 23 (24%) | - |
| Rectum | 19 (36%) | - | 14 (31%) | - | 33 (34%) | - |
| Unknown | 0 | - | 2 (4%) | - | 2 (2%) | - |

WT = wild-type; ECOG = Eastern Cooperative Oncology Group; PD = progressive disease.

^a The denominator for the all-randomized population is the number of patients with mutation data.

Table 2.

| MedDRA Preferred Term | Duligotuzumab + FOLFIRI (n=67) | | Cetuximab + FOLFIRI (n=63) | |
|--|--------------------------------|-----------------|----------------------------|-----------------|
| | Any Grade | ≥ Grade 3 | Any Grade | ≥ Grade 3 |
| All | 67 (100%) | 57 (85%) | 63 (100%) | 56 (89%) |
| Rash and related terms ^a | 53 (79%) | 5 (8%) | 56 (89%) | 14 (22%) |
| Diarrhea | 61 (91%) | 12 (18%) | 42 (67%) | 9 (14%) |
| Fatigue | 43 (64%) | 6 (9%) | 37 (59%) | 10 (16%) |
| Nausea | 33 (49%) | 3 (5%) | 32 (50%) | 2 (3%) |
| Mucosal inflammation | 26 (38%) | 7 (10%) | 23 (37%) | 3 (5%) |
| Stomatitis | 21 (31%) | 6 (9%) | 26 (41%) | 4 (6%) |
| Alopecia | 18 (27%) | - | 22 (35%) | 1 (2%) |
| Neutropenia | 18 (27%) | 14 (21%) | 21 (33%) | 16 (25%) |
| Paronychia | 21 (31%) | 2 (3%) | 18 (29%) | 1 (2%) |
| Hypokalemia | 25 (37%) | 4 (6%) | 13 (21%) | 4 (6%) |
| Abdominal pain | 13 (19%) | 1 (2%) | 22 (35%) | 4 (6%) |
| Decreased appetite | 16 (24%) | 2 (3%) | 14 (22%) | 2 (3%) |
| Dry skin | 17 (25%) | - | 13 (21%) | - |
| Infusion-related reaction ^b | 13 (19%) | 1 (2%) | 17 (27%) | 5 (8%) |
| Vomiting | 17 (25%) | 4 (6%) | 12 (19%) | 3 (5%) |
| Hand-foot syndrome | 13 (19%) | 1 (2%) | 13 (21%) | 2 (3%) |

^a Rash and related MedDRA terms = rash dermatitis acneiform, rash maculo-papular, acne, dermatitis, rash macular, rash erythematous, rash pruritic, dermatitis atopic, dermatitis bullous, dermatitis exfoliative, rash generalized, rash papular, and rash pustular.

^b Any AE occurring during infusion or within 24 hours and suspected to be caused by duligotuzumab or cetuximab.

Table 3.
 A.

| All randomized <i>RAS</i> WT patients | Duligotuzumab + FOLFIRI (n=53) | Cetuximab + FOLFIRI (n=45) | Hazard Ratio^a or Odds Ratio (90% CI) |
|--|---------------------------------------|-----------------------------------|--|
| PFS events | 41 (77%) | 35 (78%) | 1.21 (0.81, 1.81) |
| Median PFS, mo (90% CI) | 7.3 (5.3, 8.1) | 5.7 (5.5, 7.7) | |
| OS events | 24 (45%) | 22 (49%) | 1.00 (0.61, 1.66) |
| Median OS, mo (90% CI) | 14.0 (12.0, NE) | 13.1 (10.2, NE) | |
| ORR, % (90% CI) | 10 (19%; 11, 29) | 15 (33%; 22, 46) | 0.47 (0.21, 1.01) |
| Complete response | - | 2 (4%) | |
| Partial response | 12 (23%) | 19 (42%) | |
| Stable disease | 27 (51%) | 19 (42%) | |
| Progressive disease | 8 (15%) | 4 (9%) | |
| Missing/unevaluable | 6 (11%) | 1 (2%) | |

B.

| All randomized <i>KRAS</i> exon 2 WT patients | Duligotuzumab + FOLFIRI (n=68) | Cetuximab + FOLFIRI (n=66) | Hazard Ratio^a or Odds Ratio (90% CI) |
|--|---------------------------------------|-----------------------------------|--|
| PFS events | 54 (79%) | 50 (76%) | 1.30 (0.93, 1.82) |
| Median PFS, mo (90% CI) | 5.4 (3.8, 7.5) | 5.6 (5.3, 7.5) | |
| OS events | 34 (50%) | 33 (50%) | 0.97 (0.64, 1.46) |
| Median OS, mo (90% CI) | 14.0 (11.0, 20.3) | 12.4 (10.2, NE) | |
| ORR, % (90% CI) | 11 (16%; 10, 24) | 21 (32%; 22, 42) | 0.41 (0.21, 0.83) |
| Complete response | - | 2 (3%) | |
| Partial response | 15 (22%) | 25 (38%) | |
| Stable disease | 34 (50%) | 27 (41%) | |
| Progressive disease | 9 (13%) | 6 (9%) | |
| Missing/unevaluable | 10 (15%) | 6 (9%) | |

PFS = progression-free survival; OS = overall survival; ORR: objective response rate (note that not all responses were confirmed)]; CI=confidence interval; NE=not estimated, WT = wild-type.

^a Stratified hazard ratio.

Table legends

Table 1. Patient baseline and disease characteristics.

Table 2. All AEs regardless of attribution in $\geq 20\%$ of patients.

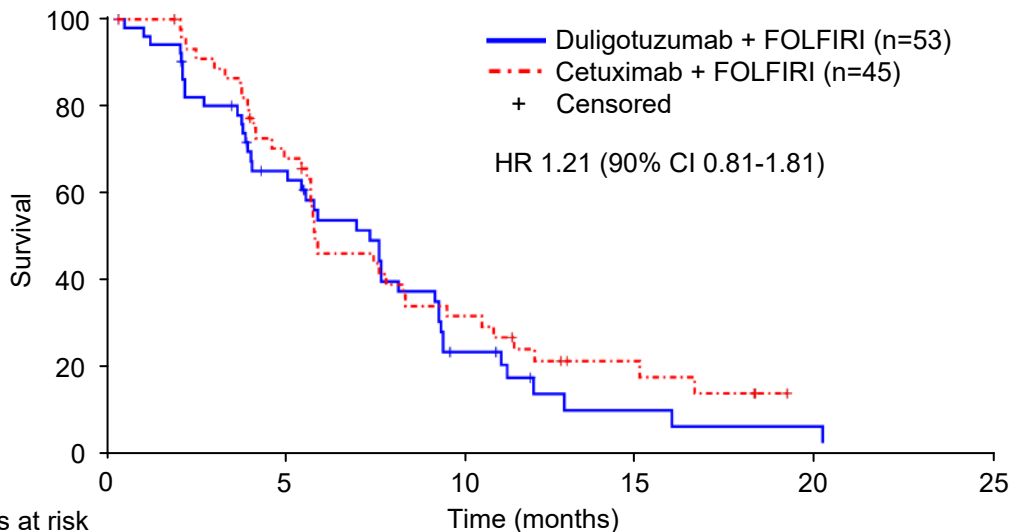
Table 3. Summary outcomes in (A) all randomized *RAS* WT patients and (B) all randomized *KRAS* exon 2 WT patients.

Figure legends

Figure 1. Progression-free survival and number of patients at risk by duligotuzumab and cetuximab treatment arms.

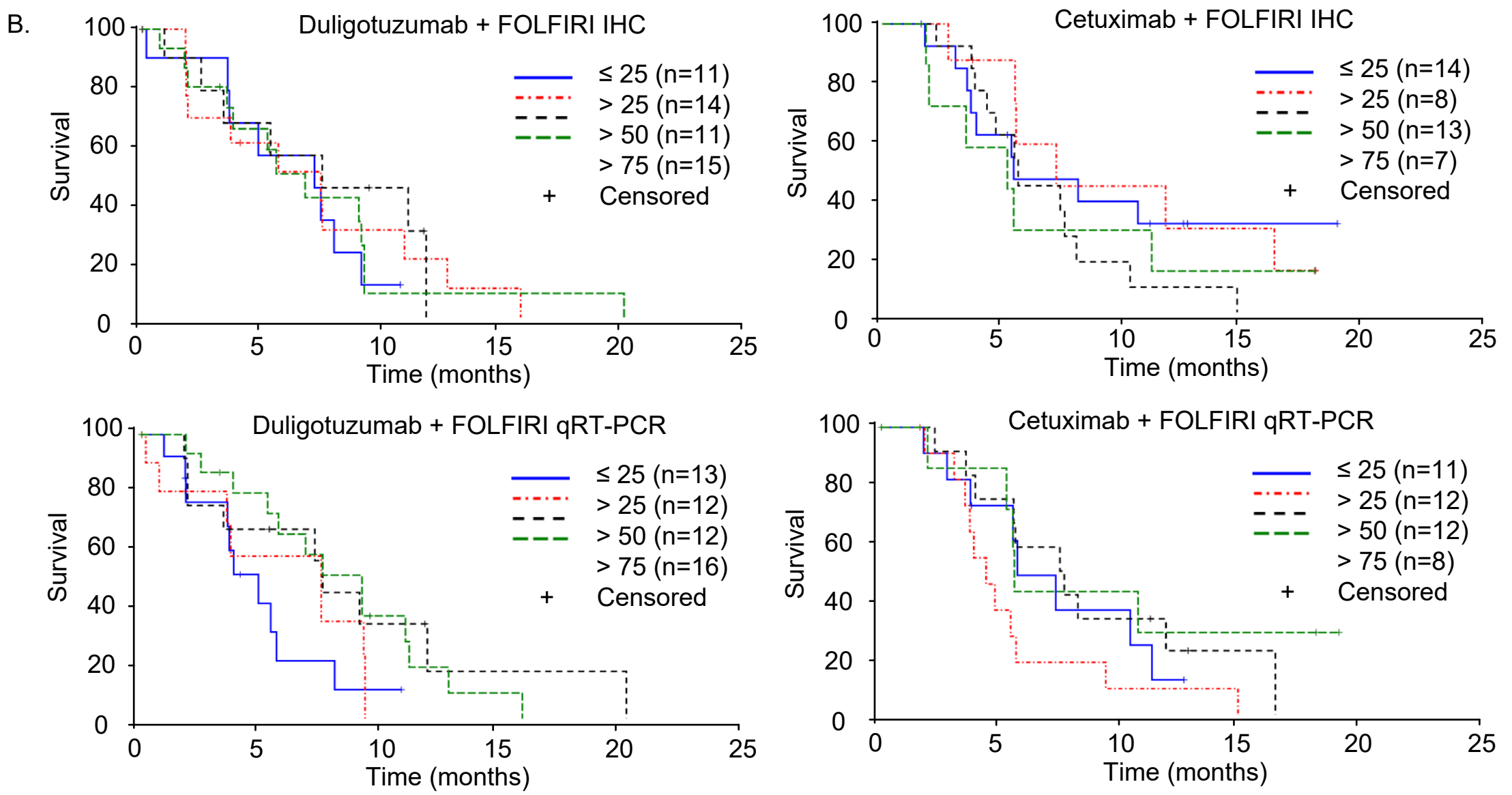
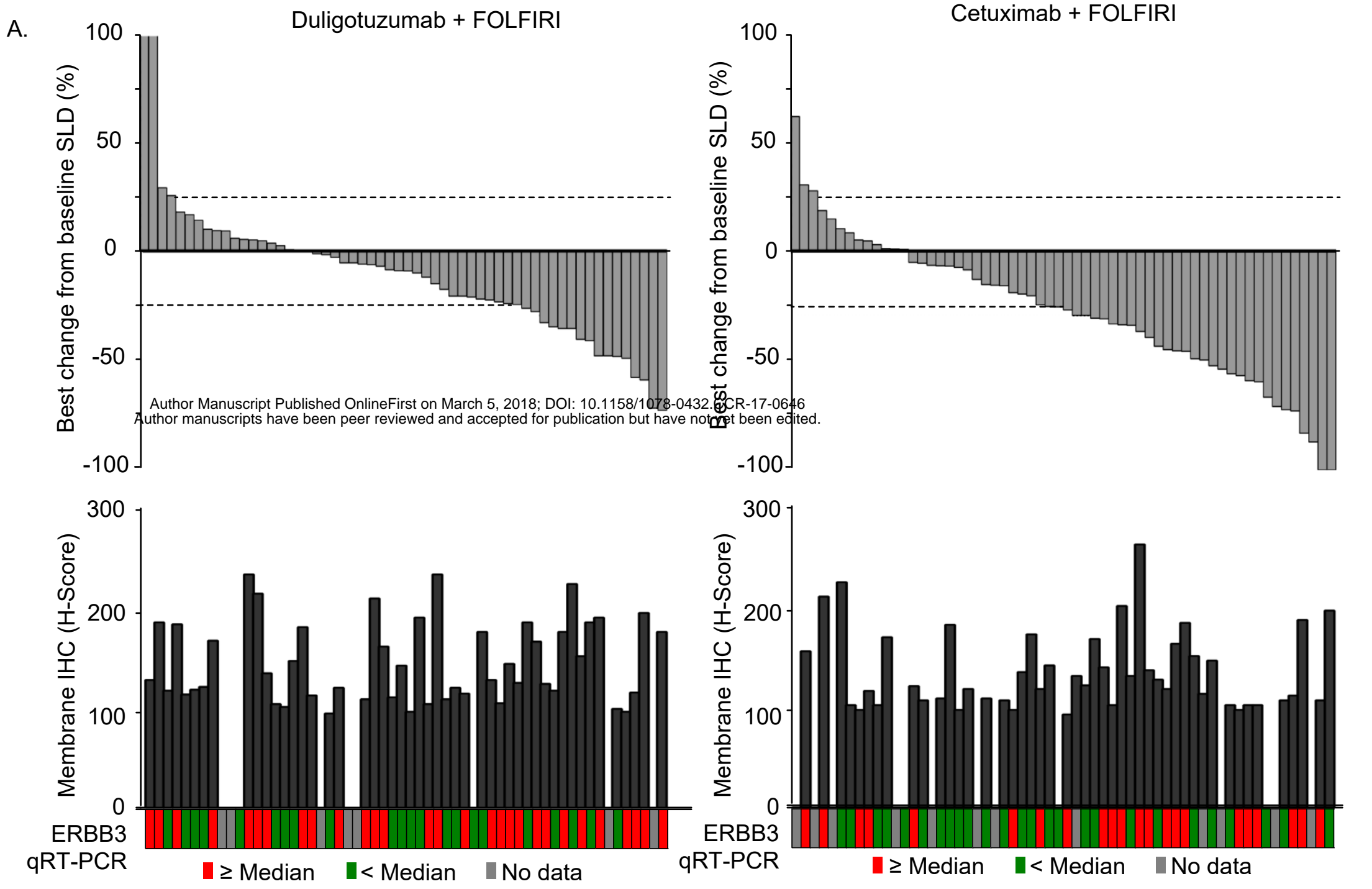
Figure 2. (A) Best response in duligotuzumab and cetuximab treatment arms in all randomized patients with *RAS* wildtype tumors with corresponding HER expression by membrane IHC H-score and *ERBB3* qRT-PCR. (B) Progression-free survival by duligotuzumab or cetuximab arm by membranous H-score and *ERBB3* qRT-PCR quartile.

Figure 3. Time on study treatment for duligotuzumab and cetuximab treatment arms.

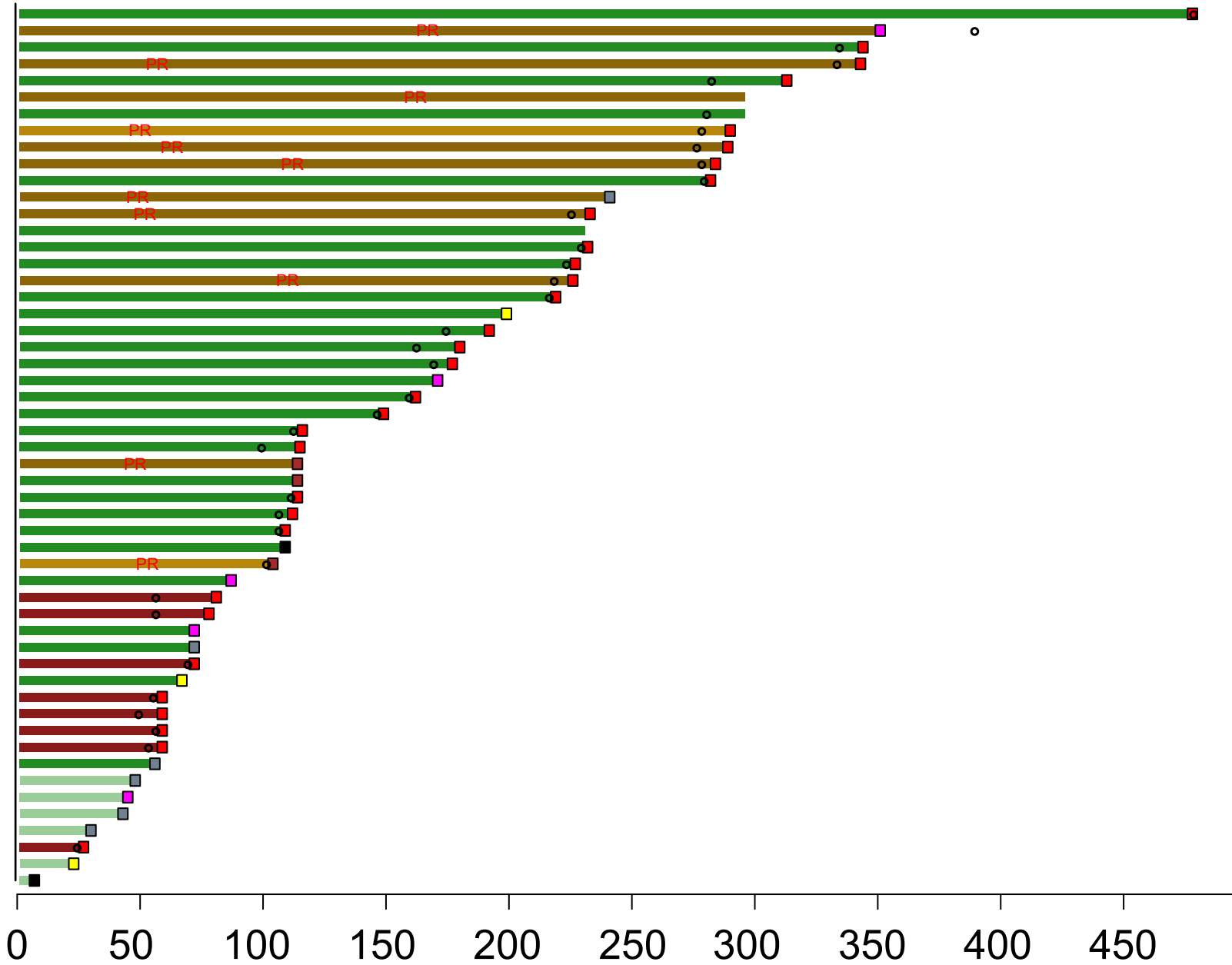


No. patients at risk

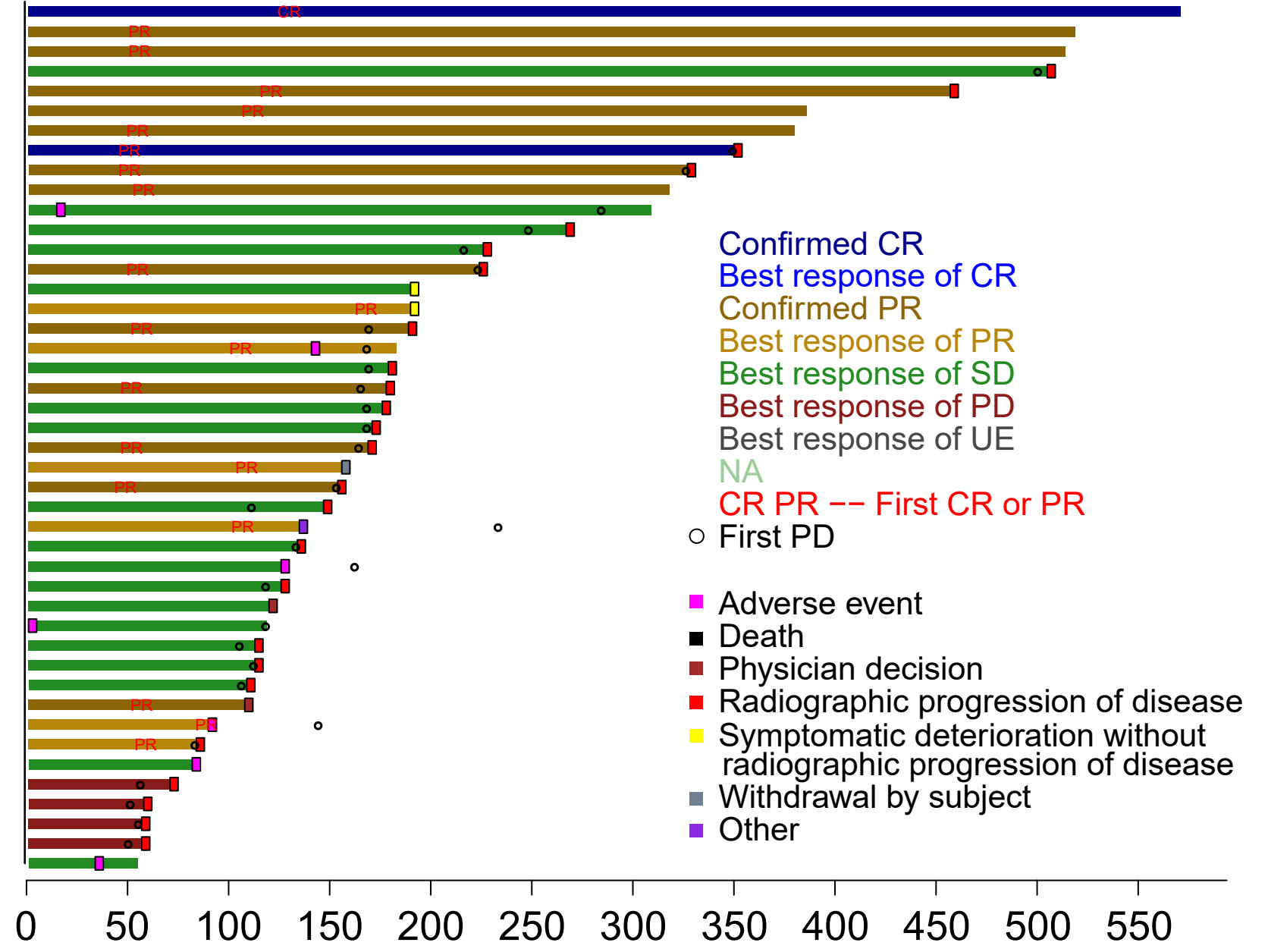
| | | | | | |
|-------------------------|----|----|----|---|---|
| Duligotuzumab + FOLFIRI | 53 | 27 | 8 | 2 | 1 |
| Cetuximab + FOLFIRI | 45 | 28 | 12 | 5 | |



Duligotuzumab + FOLFIRI



Cetuximab + FOLFIRI



Study day

Study day

Clinical Cancer Research

Phase II study of the dual EGFR/HER3 inhibitor duligotuzumab (MEHD7945A) vs. cetuximab in combination with FOLFIRI in RAS wild-type metastatic colorectal cancer

Andrew Graham Hill, Michael Findlay, Matthew Burge, et al.

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