KRAS, NRAS, and BRAF Variant Analysis in Metastatic Colorectal Cancer

Policy Number: 2.04.53  Last Review: 5/2019

Policy
Blue Cross and Blue Shield of Kansas City (Blue KC) will provide coverage for KRAS variant analysis in metastatic colorectal cancer when it is determined to be medically necessary because the criteria shown below are met.

Note: Genetic testing may be excluded in some contracts. Verify benefits prior to review of Medical Necessity.

When Policy Topic is covered
KRAS mutation analysis may be considered medically necessary for patients with metastatic colorectal cancer to predict nonresponse prior to planned therapy with anti-EGFR monoclonal antibodies cetuximab or panitumumab.

NRAS mutation analysis may be considered medically necessary for patients with metastatic colorectal cancer to predict nonresponse prior to planned therapy with anti-EGFR monoclonal antibodies cetuximab or panitumumab.

BRAF variant analysis is considered medically necessary for patients with metastatic colorectal cancer who are found to be wild-type on KRAS and NRAS variant analysis to guide management decisions.

When Policy Topic is not covered
KRAS mutation analysis is considered investigational if the criterion is not met.

Considerations
There is support from the evidence and clinical input to use BRAF V600 variant testing for prognostic stratification. Clinical input suggests that patients who are positive for this variant may be considered for clinical trials.

It is uncertain whether the presence of a BRAF V600 variant in patients with metastatic colorectal cancer who are wild-type on KRAS and NRAS variant analysis
is predictive of response to anti-epidermal growth factor receptor therapy. Furthermore, there is mixed opinion in clinical guidelines and clinical input on the use of BRAF variant analysis to predict response to treatment.

Genetics Nomenclature Update
Human Genome Variation Society (HGVS) nomenclature is used to report information on variants found in DNA and serves as an international standard in DNA diagnostics. It is being implemented for genetic testing medical evidence review updates starting in 2017 (see Table PG1). HGVS nomenclature is recommended by HGVS, the Human Variome Project, and the HUman Genome Organization (HUGO).

The American College of Medical Genetics and Genomics (ACMG) and Association for Molecular Pathology (AMP) standards and guidelines for interpretation of sequence variants represent expert opinion from ACMG, AMP, and the College of American Pathologists. These recommendations primarily apply to genetic tests used in clinical laboratories, including genotyping, single genes, panels, exomes, and genomes. Table PG2 shows the recommended standard terminology—“pathogenic,” “likely pathogenic,” “uncertain significance,” “likely benign,” and “benign”—to describe variants identified that cause Mendelian disorders.

<table>
<thead>
<tr>
<th>Previous</th>
<th>Updated</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutation</td>
<td>Disease-associated variant</td>
<td>Disease-associated change in the DNA sequence</td>
</tr>
<tr>
<td></td>
<td>Variant</td>
<td>Change in the DNA sequence</td>
</tr>
<tr>
<td></td>
<td>Familial variant</td>
<td>Disease-associated variant identified in a proband for use in subsequent targeted genetic testing in first-degree relatives</td>
</tr>
</tbody>
</table>

Table PG2. ACMG-AMP Standards and Guidelines for Variant Classification

<table>
<thead>
<tr>
<th>Variant Classification</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathogenic</td>
<td>Disease-causing change in the DNA sequence</td>
</tr>
<tr>
<td>Likely pathogenic</td>
<td>Likely disease-causing change in the DNA sequence</td>
</tr>
<tr>
<td>Variant of uncertain significance</td>
<td>Change in DNA sequence with uncertain effects on disease</td>
</tr>
<tr>
<td>Likely benign</td>
<td>Likely benign change in the DNA sequence</td>
</tr>
<tr>
<td>Benign</td>
<td>Benign change in the DNA sequence</td>
</tr>
</tbody>
</table>

ACMG: American College of Medical Genetics and Genomics; AMP: Association for Molecular Pathology.

Coding
There are specific CPT codes for BRAF, KRAS, or NRAS variant analysis.

81210: **BRAF (B-Raf proto-oncogene, serine/threonine kinase)** (eg, colon cancer, melanoma), gene analysis, V600 variant(s)
81275: **KRAS (Kirsten rat sarcoma viral oncogene homolog)** (eg, carcinoma) gene analysis; variants in exon 2 (eg, codons 12 and 13)
81276: additional variant(s) (eg, codon 61, codon 146)
81311: NRAS (neuroblastoma RAS viral [v-ras] oncogene homolog) (eg, colorectal carcinoma), gene analysis, variants in exon 2 (eg, codons 12 and 13) and exon 3 (eg, codon 61).

There is also a CPT code for using archival tissue for molecular analysis:

88363: Examination and selection of retrieved archival (ie, previously diagnosed) tissue(s) for molecular analysis (eg, KRAS mutational analysis).

### Description of Procedure or Service

<table>
<thead>
<tr>
<th>Populations</th>
<th>Interventions</th>
<th>Comparators</th>
<th>Outcomes</th>
</tr>
</thead>
</table>
| Individuals:  
  o With metastatic colorectal cancer | Interventions of interest are:  
  o KRAS mutation testing to guide treatment | Comparators of interest are:  
  o No KRAS mutation testing to guide treatment | Relevant outcomes include:  
  o Overall survival  
  o Disease-specific survival  
  o Change in disease status  
  o Medication use  
  o Resource utilization  
  o Treatment-related morbidity |
| Individuals:  
  o With metastatic colorectal cancer | Interventions of interest are:  
  o NRAS mutation testing to guide treatment | Comparators of interest are:  
  o No NRAS mutation testing to guide treatment | Relevant outcomes include:  
  o Overall survival  
  o Disease-specific survival  
  o Change in disease status  
  o Medication use  
  o Resource utilization  
  o Treatment-related morbidity |
| Individuals:  
  o With metastatic colorectal cancer | Interventions of interest are:  
  o BRAF mutation testing to guide treatment | Comparators of interest are:  
  o No BRAF mutation testing to guide treatment | Relevant outcomes include:  
  o Overall survival  
  o Disease-specific survival  
  o Change in disease status  
  o Medication use  
  o Resource utilization  
  o Treatment-related morbidity |

The epidermal growth factor receptor (EGFR) is overexpressed in colorectal cancer (CRC). EGFR-targeted therapy combined with monoclonal antibodies cetuximab and panitumumab have shown a clear survival benefit in patients with metastatic CRC. However, this benefit depends on a lack of variants in certain genes in the signaling pathway downstream from the EGFR. It has been hypothesized that knowledge of tumor cell KRAS, NRAS, and BRAF variant status might be used to predict nonresponse to anti-EGFR monoclonal antibody therapy.

For individuals with metastatic CRC who receive KRAS variant testing to guide treatment, the evidence includes multiple systematic reviews including a TEC Assessment. Relevant outcomes are overall survival, disease-specific survival, change in disease status, medication use, resource utilization, and treatment-related morbidity. Variant testing of tumor tissue performed in prospective and retrospective analyses of randomized controlled trials has consistently shown that the presence of a KRAS variant predicts nonresponse to cetuximab and
panitumumab, either as monotherapy or in combination with other treatment regimens and supports the use of KRAS variant analysis of tumor DNA before considering a treatment regimen. The evidence is sufficient to determine that the technology results in a meaningful improvement in the net health outcome.

For individuals with metastatic CRC who receive NRAS variant testing to guide treatment, the evidence includes prospective-retrospective analyses of randomized controlled trials and retrospective cohort studies. Relevant outcomes are overall survival, disease-specific survival, change in disease status, medication use, resource utilization, and treatment-related morbidity. Pooled analyses have shown that NRAS variants (beyond the common KRAS exon 2 variants) predict nonresponse to cetuximab and panitumumab, and support the use of NRAS variant analysis of tumor DNA before considering a treatment regimen. In addition, there is strong support from the National Comprehensive Cancer Network and American Society of Clinical Oncology for NRAS and KRAS testing in patients with metastatic CRC. The evidence is sufficient to determine that the technology results in a meaningful improvement in the net health outcome.

For individuals with metastatic CRC who receive BRAF variant testing to guide treatment, the evidence includes 2 meta-analyses of prospective and retrospective analyses of randomized controlled trials. Relevant outcomes are overall survival, disease-specific survival, change in disease status, medication use, resource utilization, and treatment-related morbidity. The meta-analyses have shown that anti-EGFR monoclonal antibody therapy did not improve survival in patients with RAS wild-type or BRAF-mutated tumors; however, the individual studies have been small, and the results have been inconsistent. The evidence is insufficient to determine the effects of the technology on health outcomes.

Clinical input obtained in 2017 supports that the following indication provides a clinically meaningful improvement in net health outcome and is consistent with generally accepted medical practice.

- Use of BRAF V600E variant analysis in individuals with metastatic CRC who are found to be wild-type on KRAS and NRAS variant analysis to guide management decisions.

Thus, the above indication may be considered medically necessary considering the suggestive evidence and clinical input support.

**Background**

Cetuximab (Erbitux®, ImClone Systems) and panitumumab (Vectibix®, Amgen) are monoclonal antibodies that bind to the epidermal growth factor receptor (EGFR), preventing intrinsic ligand binding and activation of downstream signaling pathways vital for cancer cell proliferation, invasion, metastasis, and stimulation of neovascularization.

The RAS-RAF-MAP kinase pathway is activated in the EGFR cascade. RAS proteins are G proteins that cycle between active (RAS-GTP) and inactive (RAS-GDP)
forms, in response to stimulation from a cell surface receptor such as EGFR, and act as a binary switch between the cell surface EGFR and downstream signaling pathways. The KRAS gene can harbor oncogenic mutations that result in a constitutively activated protein, independent of EGFR ligand binding, rendering antibodies to the upstream EGFR ineffective. KRAS mutations are found in approximately 30% to 50% of CRC tumors and are common in other tumor types. Another proto-oncogene that acts downstream from KRAS–NRAS harbors oncogenic mutations in codons 12, 13, or 61 that result in constitutive activation of the EGFR mediated pathway. These mutations are relatively rare compared with KRAS, detected in perhaps 2% to 7% of CRC specimens. It is unclear whether NRAS mutations predict poor response to anti-EGFR monoclonal antibody therapy or are prognostic of poor CRC outcome in general. A third proto-oncogene, BRAF, encodes a protein kinase and is involved in intracellular signaling and cell growth and is a principal downstream effector of KRAS. BRAF mutations occur in less than 10% to 15% of CRCs and appear to be a marker of poor prognosis. KRAS and BRAF mutations are considered to be mutually exclusive.

Cetuximab and panitumumab have marketing approval from the U.S. Food and Drug Administration (FDA) for treatment of metastatic CRC in the refractory disease setting. FDA approval for panitumumab indicates that panitumumab is not indicated for the treatment of patients with KRAS or NRAS variant-positive disease in combination with oxaliplatin-based chemotherapy.1

**Regulatory Status**

**Approved Companion Diagnostic Tests for KRAS Variant Analysis**

Companion diagnostic tests for the selection of cetuximab and panitumumab have been approved by FDA through the premarket approval process, specifically:

“The cobas® KRAS Mutation Test, for use with the cobas® 4800 System, [which] is a real-time PCR [polymerase chain reaction] test for the detection of seven somatic mutations in codons 12 and 13 of the KRAS gene in DNA derived from formalin-fixed paraffin-embedded human colorectal cancer (CRC) tumor tissue. The test is intended to be used as an aid in the identification of CRC patients for whom treatment with Erbitux® (cetuximab) or with Vectibix® (panitumumab) may be indicated based on a no mutation detected result.”2

“The therascreen® KRAS RGQ PCR Kit is a real-time qualitative PCR assay used on the Rotor-Gene Q MDx instrument for the detection of seven somatic mutations in the human KRAS oncogene, using DNA extracted from formalin-fixed paraffin-embedded (FFPE), colorectal cancer (CRC) tissue. The therascreen KRAS RGQ PCR Kit is intended to aid in the identification of CRC patients for treatment with Erbitux (cetuximab) and Vectibix (panitumumab) based on a KRAS no mutation detected test result.”2
Laboratory-Developed Tests for *KRAS, NRAS,* and *BRAF* Variant Analysis
Clinical laboratories may develop and validate tests in-house and market them as a laboratory service; laboratory-developed tests must meet the general regulatory standards of the Clinical Laboratory Improvement Amendments. *KRAS, NRAS,* and *BRAF* variant analyses using polymerase chain reaction methodology are available under the auspices of the Clinical Laboratory Improvement Amendments. Laboratories that offer laboratory-developed tests must be licensed under the Clinical Laboratory Improvement Amendments for high-complexity testing. To date, FDA has chosen not to require any regulatory review of this test.

Rationale
This evidence review was created in October 2008 and has been updated regularly with searches of the MEDLINE and EMBASE databases. The most recent literature update was performed through May 10, 2018.

Evidence reviews assess whether a medical test is clinically useful. A useful test provides information to make a clinical management decision that improves the net health outcome. That is, the balance of benefits and harms is better when the test is used to manage the condition than when another test or no test is used to manage the condition.

The first step in assessing a medical test is to formulate the clinical context and purpose of the test. The test must be technically reliable, clinically valid, and clinically useful for that purpose. Evidence reviews assess the evidence on whether a test is clinically valid and clinically useful. Technical reliability is outside the scope of these reviews, and credible information on technical reliability is available from other sources.

A large body of literature has shown that metastatic colorectal cancer (CRC) tumors with a variant in exon 2 (codon 12 or 13) of the *KRAS* gene do not respond to cetuximab or panitumumab therapy. More recent evidence has shown that variants in *KRAS* outside exon 2, in exons 3 (codons 59 and 61) and exon 4 (codons 117 and 146), and variants in *NRAS* exon 2 (codons 12 and 13), exons 3 (codons 59 and 61), and exon 4 (codons 117 and 146) also predict a lack of response to these monoclonal antibodies. Variant testing of these exons outside the *KRAS* exon 2 is referred to as extended RAS testing.

*KRAS* VARIANT Testing to Guide Treatment for Metastatic CRC
Clinical Context and Test Purpose
The purpose of *KRAS* variant testing in individuals with metastatic CRC is to determine *KRAS* variant status to guide treatment decisions with epidermal growth factor receptor (EGFR)-targeted therapy with the monoclonal antibodies cetuximab and panitumumab.

The question addressed in this evidence review is: In individuals with metastatic CRC, does the use of *KRAS* variant testing improve health outcomes?
The following PICOTS were used to select literature to inform this review.

**Patients**
The relevant population of interest includes individuals with metastatic CRC.

**Interventions**
The test being considered is *KRAS* variant testing.

**Comparators**
The following test strategy is currently being used: no *KRAS* variant testing to guide treatment.

**Outcomes**
The beneficial outcomes of interest include progression-free survival (PFS) and overall survival (OS).

**Timing**
The time frame for outcomes measures varies from several months to several years.

**Setting**
Patients with metastatic CRC are actively managed by oncologists.

**Technically Reliable**
Assessment of technical reliability focuses on specific tests and operators and requires review of unpublished and often proprietary information. Review of specific tests, operators, and unpublished data are outside the scope of this evidence review and alternative sources exist. This evidence review focuses on the clinical validity and clinical utility.

**Clinically Valid**
A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

This evidence review has been informed, in part, by a TEC Assessment (2008). Additional evidence derives from systematic reviews, randomized controlled trials (RCTs), and single-arm studies, organized and outlined below.

**Randomized Controlled Trials**
RCTs have performed nonconcurrent subgroup analyses of the efficacy of EGFR inhibitors in patients with wild-type vs mutated *KRAS* in metastatic CRC. Data from these trials have consistently shown a lack of clinical response to cetuximab and panitumumab in patients with mutated *KRAS*, with tumor response and prolongation of PFS observed only in wild-type *KRAS* patients.

Amado et al (2008) performed a subgroup analysis of *KRAS* tumor variants in a patient population that had previously been randomized to panitumumab or to best supportive care as third-line therapy for chemotherapy-refractory metastatic...
The original study reported by Van Cutsem et al (2007), designed as a multicenter RCT, was not blinded because of expected skin toxicity related to panitumumab administration. Patients were randomized 1:1 to panitumumab or to best supportive care. Random assignment was stratified by Eastern Cooperative Oncology Group (ECOG) Performance Status (0 or 1 vs 2) and geographic region. Crossover from best supportive care to the panitumumab arm was allowed in patients who experienced disease progression. Of the 232 patients originally assigned to best supportive care alone, 176 crossed over to the panitumumab arm, at a median time to crossover of 7 weeks (range, 6.6-7.3 weeks).

Of the 463 patients in the original trial, 427 (92%) were included in the KRAS subgroup variant analysis. A central laboratory performed the KRAS variant analysis in a blinded fashion, using formalin-fixed, paraffin-embedded tumor sections and a validated KRAS variant kit (DxS) that identifies 7 somatic variants located in codons 12 and 13 using real-time polymerase chain reaction. KRAS variant status could not be determined in 36 patients because tumor samples were not available or DNA was of insufficient or of poor quality for analysis. Forty-three percent of the KRAS-evaluable patients had KRAS-mutated tumors, with a distribution similar to KRAS variant types between treatment arms.

Patient demographics and baseline characteristics were balanced between the wild-type and mutated groups for the panitumumab and best supportive care groups including patient age, sex, and ECOG Performance Status. The interaction between variant status and PFS was examined, controlling for randomization factors. PFS and tumor response rate were assessed radiographically every 4 to 8 weeks until disease progression using Response Evaluation Criteria in Solid Tumors criteria by blinded, central review. In the KRAS-assessable population, 20% of patients had a treatment-related grade 3 or 4 adverse events. As shown in Table 1, the relative effect of panitumumab on PFS was significantly greater among patients with wild-type KRAS than patients with mutated KRAS in whom no benefit from panitumumab was observed. No responders to panitumumab were identified in the mutated group, indicating a 100% positive predictive value for nonresponse in that group.

Table 1. KRAS Status and Efficacy of Panitumumab as Monotherapy in the Treatment of Chemotherapy-Refractory Metastatic Colorectal Cancer (N=427)

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>KRAS WT (n=243 [57%])</th>
<th>KRAS MT (n=184 [43%])</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P (n=124)</td>
<td>BSC (n=119)</td>
</tr>
<tr>
<td></td>
<td>P (n=84)</td>
<td>BSC (n=100)</td>
</tr>
<tr>
<td>Median progression-free survival, wk</td>
<td>12.3</td>
<td>7.3</td>
</tr>
<tr>
<td>Hazard ratio (95% CI)</td>
<td>0.45 (0.34 to 0.59)</td>
<td>0.99 (0.73 to 1.36)</td>
</tr>
<tr>
<td>Response rate, %</td>
<td>17</td>
<td>0</td>
</tr>
</tbody>
</table>


Given the crossover trial design and the fact that most of the best supportive care patients crossed over to the panitumumab arm early in the trial, conclusions on the effect of KRAS variant status on PFS and tumor response rate end points are...
limited. However, of the 168 best supportive care patients who crossed over to panitumumab after disease progression (119 with wild-type KRAS, 77 with mutated KRAS), PFS was significantly longer among patients with wild-type KRAS (median PFS: 16.4 weeks for wild-type vs 7.9 weeks for mutated; hazard ratio [HR], 0.32; 95% confidence interval [CI], 0.22 to 0.45).

After completion of the CRYSTAL trial (detailed below), in which 1198 patients with metastatic CRC were randomized to cetuximab in combination with folinic acid (leucovorin), 5-florouracil, and irinotecan (FOLFIRI) or to FOLFIRI alone for first-line treatment, a subgroup analysis of response rate and PFS by KRAS variant status was performed by Van Cutsem et al (2009). The original trial design consisted of a central stratified permuted block randomization procedure with geographic regions and ECOG Performance Status as randomization strata. Two interim assessments of safety data were conducted by an independent data safety monitoring board.

Of the original 1198 patients, 540 had KRAS-evaluable, archival material. KRAS testing was performed using genomic DNA isolated from archived formalin-fixed, paraffin-embedded tissue, using quantitative PCR to detect the KRAS variant status of codons 12 and 13. It was not stated whether the KRAS variant analysis was performed blinded. KRAS variants were present in 192 (35.6%) patients. No differences were found in patient demographics or baseline characteristics between the mutated and wild-type populations, including age, sex, ECOG Performance Status, involved disease sites, and liver-limited disease. PFS and tumor response rate were assessed by a blinded, independent review committee using computed tomography scans every 8 weeks. A multivariate analysis performed for PFS by patient characteristics showed a trend for PFS favoring the cetuximab plus FOLFIRI combination. The patients with wild-type KRAS who received cetuximab plus FOLFIRI showed a statistically significant improvement in median PFS and tumor response rate, whereas the mutated KRAS population did not, as summarized in Table 2.

Table 2. KRAS Status and Efficacy in the First-Line Therapy of Metastatic Colorectal Cancer Treated With FOLFIRI With or Without Cetuximab (CRYSTAL Trial) (N=540)

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>ITT a</th>
<th>KRAS WT (n=348 [64%] b)</th>
<th>KRAS MT (n=192 [36%] b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C+F</td>
<td>F</td>
<td>C+F</td>
</tr>
<tr>
<td>n</td>
<td>599</td>
<td>599</td>
<td>172</td>
</tr>
<tr>
<td>RR (95% CI), %</td>
<td>46.9 (42.9 to 51.0)</td>
<td>38.7 (34.8 to 42.8)</td>
<td>59.3 (51.6 to 66.7)</td>
</tr>
<tr>
<td></td>
<td>0.68 (p=0.017)</td>
<td>1.07 (p=0.47)</td>
<td></td>
</tr>
<tr>
<td>Median PFS, mo c</td>
<td>8.9</td>
<td>8.0</td>
<td>9.9</td>
</tr>
<tr>
<td>Hazard ratio</td>
<td></td>
<td></td>
<td>7.6</td>
</tr>
</tbody>
</table>

Adapted from Van Cutsem et al (2009). a C: cetuximab; CI: confidence interval; F: FOLFIRI (folinic acid, 5-florouracil, and irinotecan); HR: hazard ratio; ITT: intention-to-treat; MT: mutated; PFS: progression-free survival; RR: response rate; WT: wild-type.
ITT in the original CRYSTAL trial assessing C+F vs F alone as first-line therapy for metastatic colorectal cancers.

540 patients had available archival pathology material for the KRAS variant subset analysis.

Confidence intervals for median PFS were not provided in the presentation slides.

In a third trial, the phase 2 OPUS trial, the intention-to-treat (ITT) population consisted of 337 patients randomized to cetuximab and folinic acid (leucovorin), 5-flourouracil, and oxaliplatin (FOLFOX) or to FOLFOX alone in the first-line treatment of metastatic CRC. A 10% higher response rate (assessed by independent reviewers) was observed in the population treated with cetuximab, but no difference in PFS was seen between groups. Researchers then reevaluated the efficacy in the 2 treatment arms based on the KRAS variant status of patients’ tumors. Of the original ITT population, 233 subjects had evaluable material for KRAS testing, and 99 (42%) were KRAS variants. The demographics or baseline characteristics were similar between the wild-type and mutated groups, including patient age, sex, ECOG Performance Status, involved disease sites, and liver-limited disease. The trial showed that the addition of cetuximab to FOLFOX resulted in a significant improvement in response rate and PFS only in the wild-type KRAS group. Table 3 summarizes study findings.

**Table 3. KRAS Status and Efficacy in the First-Line Therapy of Metastatic Colorectal Cancer Treated With FOLFOX With or Without Cetuximab (OPUS Study) (N=233)**

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>KRAS WT (n=134 [58%])</th>
<th>KRAS MT (n=99 [42%])</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C+Fx</td>
<td>Fx</td>
</tr>
<tr>
<td>n (KRAS-evaluable)</td>
<td>61</td>
<td>73</td>
</tr>
<tr>
<td>RR (95% CI), %</td>
<td>60.7 (47.3 to 72.9)</td>
<td>37.0 (26.0 to 49.1)</td>
</tr>
<tr>
<td>p</td>
<td>0.011</td>
<td>0.106</td>
</tr>
<tr>
<td>Odds ratio (95% CI)</td>
<td>2.54 (1.24 to 5.23)</td>
<td>0.51 (0.22 to 1.15)</td>
</tr>
<tr>
<td>Median PFS, moa</td>
<td>7.7</td>
<td>7.2</td>
</tr>
<tr>
<td>p</td>
<td>0.016</td>
<td>0.019</td>
</tr>
<tr>
<td>Hazard ratio</td>
<td>0.57</td>
<td>1.83</td>
</tr>
</tbody>
</table>

Adapted from Bokemeyer et al (2009). C: cetuximab; CI: confidence interval; Fx: FOLFOX (folinic acid, 5-flourouracil, and oxaliplatin); MT: mutated; PFS: progression-free survival; RR: response rate; WT: wild-type.

Confidence intervals for median PFS were not provided in presentation slides.

In the CAIRO2 study, Tol et al (2009) analyzed tumor samples from 528 of 755 previously untreated patients with metastatic CRC who were randomized to capecitabine, oxaliplatin, and bevacizumab (CB regimen, n=378), or to the same CB regimen plus cetuximab (n=377). KRAS variant was found in 40% of tumors (108 from patients in the CB group, 98 from the CB plus cetuximab group). Patients with KRAS variants treated with cetuximab had a significantly shorter PFS (8.1 months) than the wild-type KRAS patients who received cetuximab (10.5 months; p=0.04). In addition, patients who had mutated KRAS tumors who received cetuximab had a significantly shorter PFS and OS than patients with mutated KRAS tumors who did not receive cetuximab (PFS: 8.1 months vs 12.5 months, respectively, p=0.003; OS: 17.2 months vs 24.9 months, respectively, p=0.03). For patients with wild-type tumors, no significant PFS differences were reported between groups. Overall, patients treated with cetuximab who had
tumors with a mutated KRAS gene had significantly decreased PFS compared with cetuximab-treated patients with wild-type KRAS tumors or patients with mutated KRAS tumors in the CB group.

Karapetis et al (2008) analyzed tumor samples from 394 (69%) of 572 patients with CRC who were randomized to cetuximab plus best supportive care (n=287) or to best supportive care alone (n=285) for KRAS variants and assessed whether variant status was associated with survival.9 The patients had advanced CRC and had no other standard anticancer therapy available. Of the tumors evaluated (198 from the cetuximab group, 196 from the best supportive care group), 41% and 42% had a KRAS variant, respectively, and these groups reported a median OS of 9.5 months and 4.8 months, respectively (HR for death, 0.55; 95% CI, 0.41 to 0.74; p<0.001) and a median PFS of 3.7 months and 1.9 months, respectively (HR for progression to death, 0.40; 95% CI, 0.30 to 0.54; p<0.001). For patients with mutated KRAS tumors, no significant differences were reported between those treated with cetuximab and best supportive care alone with respect to OS (HR=0.98, p=0.89) or PFS (HR=0.99, p=0.96).

Douillard et al (2010) reported on the results of a multicenter, phase 3 trial in which patients with no prior chemotherapy for metastatic CRC, ECOG Performance Status of 0 to 2, and available tissue for biomarker testing were randomized 1:1 to panitumumab plus FOLFOX4 or to FOLFOX4.10 The primary end point was PFS; OS was a secondary end point. Results were prospectively analyzed on an ITT basis by tumor KRAS status. KRAS results were available for 93% of the 1183 patients randomized. In the wild-type KRAS group, panitumumab plus FOLFOX4 significantly improved PFS compared with FOLFOX4 alone (median PFS, 9.6 months vs 8.0 months, respectively; HR=0.80; 95% CI, 0.66 to 0.97; p=0.02). A nonsignificant increase in OS was also observed for panitumumab plus FOLFOX4 vs FOLFOX4 (median OS, 23.9 months vs 19.7 months, respectively; HR=0.83; 95% CI, 0.67 to 1.02; p=0.072). In the mutant KRAS group, PFS was significantly reduced in the panitumumab plus FOLFOX4 arm compared with the FOLFOX4 arm (HR=1.29; 95% CI, 1.04 to 1.62; p=0.02), and median OS was 15.5 months vs 19.3 months, respectively (HR=1.24; 95% CI, 0.98 to 1.57; p=0.068). Adverse event rates were generally comparable across arms with the exception of toxicities known to be associated with anti-EGFR therapy. The trial demonstrated that panitumumab plus FOLFOX4 was well-tolerated and significantly improved PFS in patients with wild-type KRAS tumors.

The CRYSTAL trial (2009) demonstrated that the addition of cetuximab to FOLFIRI statistically significantly reduced the risk of disease progression and increased the chance of response in patients with wild-type KRAS metastatic CRC compared with chemotherapy alone.6 In an updated analysis of CRYSTAL, Van Cutsem et al (2011) reported on longer follow-up and more patients evaluable for tumor KRAS status and considered the clinical significance of the BRAF variant tumor status in the expanded population of patients with wild-type KRAS tumors.11 Subsequent to the initial published analysis, which reported an OS cutoff of December 2007, and an associated overall median duration of follow-up of 29.7 months, additional tumor analysis allowed for the typing of another 523 tumors.
for KRAS variant status, representing an increase in the ascertainment rate from 45% of ITT population patients in the original analysis to 89% (540 to 1063) in the current analysis, with variants detected in 37% of tumors. The updated OS analysis was carried out with a new cutoff date of May 2009, giving an overall median duration of follow-up of 46 months. The addition of cetuximab to FOLFIRI in patients with wild-type KRAS disease resulted in significant improvements in OS (median, 23.5 months vs. 20.0 months; HR=0.796; p=0.009), PFS (median, 9.9 months vs 8.4 months; HR=0.696; p=0.001), and response rate (57.3% vs 39.7%; odds ratio [OR], 2.069; p<0.001) compared with FOLFIRI alone. Significant interactions between KRAS status and treatment effect were noted for all key efficacy end points. KRAS variant status was confirmed as a powerful predictive biomarker for the efficacy of cetuximab plus FOLFIRI. BRAF V600E variants were detected in 60 (6%) of 999 tumor samples evaluable for both BRAF and KRAS. In all but a single case, BRAF variants were identified in tumors wild-type for KRAS. The impact of BRAF tumor variant status in relation to the efficacy of cetuximab plus FOLFIRI was examined in the population of patients with wild-type KRAS disease (n=625). No evidence was reported for an independent treatment interaction by tumor BRAF variant status. The trialists concluded that BRAF variant status was not predictive of treatment effects of cetuximab plus FOLFIRI but that BRAF tumor variant was a strong indicator of poor prognosis for all efficacy end points compared with those whose tumors were wild-type.

Peeters et al (2010) reported on the results of a phase 3 study in which 1186 patients with metastatic CRC were randomized to panitumumab plus FOLFIRI or to FORFIRI alone as a second-line treatment. The trial end points were PFS and OS, which were independently tested and prospectively analyzed by KRAS status. KRAS status was available for 91% of patients: 597 (55%) had wild-type KRAS tumors and 486 (45%) had mutated KRAS tumors. In the wild-type KRAS subpopulation, when panitumumab was added to chemotherapy, a significant improvement in PFS was observed (HR=0.73; 95% CI, 0.59 to 0.90; p=0.004); median PFS was 5.9 months for panitumumab plus FOLFIRI and 3.9 months for FOLFIRI. A nonsignificant trend toward increased OS was observed; median OS for panitumumab plus FOLFIRI was 14.5 months while median OS for FOLFIRI alone was 12.5 months (HR=0.85, 95% CI, 0.70 to 1.04; p=0.12). Response rates improved with the addition of panitumumab to the FOLFIRI regimen. In patients with mutated KRAS, no difference was reported in efficacy. Adverse events were comparable across arms. The trialists concluded that panitumumab plus FOLFIRI significantly improved PFS and was well-tolerated as second-line treatment in patients with wild-type KRAS metastatic CRC.

Maughan et al (2011) reported on the results of a phase 3, multicenter trial (MRC COIN trial), which randomized patients with advanced CRC who had not received previous chemotherapy to oxaliplatin plus fluoropyrimidine chemotherapy (arm A) or to the same combination plus cetuximab (arm B). The comparison between arms A and B (for which the primary outcome was OS) was in patients with wild-type KRAS tumors. Baseline characteristics were well-balanced between groups. The analysis was by ITT and treatment allocation was not masked. A total of 1630 patients were randomized to treatment groups (815 to standard therapy, 815 to
the addition of cetuximab). Tumor samples from 1316 (81%) of patients were used for somatic variant analyses; 43% had KRAS variants. In patients with wild-type KRAS tumors, OS did not differ between treatment groups (median survival, 17.9 months in the control group vs 17.0 months in the cetuximab group; HR=1.04; 95% CI, 0.87 to 1.23; p=0.67). BRAF variants were detected in 8% of patients; BRAF did not show any evidence of a benefit from the addition of cetuximab. Contrary to other trials that have studied the benefit of adding cetuximab to the regimen of wild-type KRAS patients, this trial did not show a benefit of adding cetuximab to oxaliplatin-based chemotherapy.

**Systematic Reviews**
Qiu et al (2010) conducted a meta-analysis of 22 studies on the predictive and prognostic value of KRAS variants in metastatic CRC patients treated with cetuximab. The overall KRAS variant rate was 38% (829/2188 patients). Meta-analytic results were consistent with previous studies on the use of cetuximab and KRAS variant status, in that patients with tumors harboring mutant-type KRAS were more likely to have a worse response, PFS, and OS when treated with cetuximab than those with wild-type KRAS.

Dahabreh et al (2011) conducted a systematic review of RCTs that assessed the use of KRAS variant testing as a predictive biomarker for treatment of advanced CRC with cetuximab and panitumumab. Reviewers concluded that, compared with patients who had wild-type KRAS, KRAS variants were consistently associated with reduced OS and PFS and increased treatment failure rates among patients with advanced CRC who are treated with anti-EGFR antibodies.

In a pooled analysis of wild-type KRAS tumors from the CRYSTAL and OPUS trials, Bokemeyer et al (2012) assessed extended survival data and enhancement in the ascertainment rate of KRAS and BRAF tumor variant status. Pooled individual patient data from each trial were analyzed for OS, PFS, and best objective response rate (ORR) in patients evaluable for KRAS and BRAF variant status. In 845 patients with wild-type KRAS tumors, adding cetuximab to chemotherapy led to significant improvements in OS (HR=0.81; p=0.006), PFS (HR=0.66; p<0.001), and ORR (OR=2.16; p<0.001). BRAF variants were detected in 70 (8.8%) of 800 evaluable tumors. No significant differences were found in outcomes between treatment groups. However, the prognosis was worse in each treatment arm for patients with BRAF tumors, and OPUS trials confirmed the consistency of the benefit obtained from all efficacy end points from adding cetuximab to first-line chemotherapy in patients with wild-type KRAS metastatic CRC. It further suggested that BRAF variants do not appear to be predictive biomarkers in this setting, but are markers of poor prognosis.

**Single-Arm Studies**
In addition to the 3 randomized trials discussed, a number of single-arm studies have retrospectively evaluated KRAS variant status and treatment response in patients with metastatic CRC. Overall they have shown similar nonresponse rates to anti-EGFR monoclonal antibodies (cetuximab, panitumumab)
in patients with mutated \textit{KRAS} tumors. Two of these single-arm studies have also reported differences in PFS and OS. \cite{18,21}.

\textbf{Section Summary: Clinically Valid}

Evidence for the clinical validity of \textit{KRAS} variants in predicting nonresponse to anti-EGFR monoclonal antibody therapy consists of multiple systematic reviews, including a TEC Assessment, and RCTs. The evidence has demonstrated that the presence of a \textit{KRAS} variant predicts nonresponse to treatment while \textit{KRAS} wild-type status predicts response to anti-EGFR monoclonal antibody therapy.

\textbf{Clinically Useful}

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

\textbf{Direct Evidence}

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified on the clinical utility of \textit{KRAS} variant testing to predict nonresponse to anti-EGFR monoclonal antibody therapy.

\textbf{Chain of Evidence}

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

A chain of evidence, based on clinical validity, supports the use of the anti-EGFR monoclonal antibodies cetuximab and panitumumab for the treatment of patients with wild-type \textit{KRAS} metastatic CRC. Cetuximab and panitumumab are not indicated for the treatment of patients when \textit{KRAS} variants are present or when \textit{KRAS} variant status is unknown.

\textbf{Section Summary: Clinically Useful}

Direct evidence for the clinical validity of \textit{KRAS} variant testing includes RCTs. RCTs supporting Food and Drug Administration approvals for cetuximab and panitumumab have demonstrated that the presence of \textit{KRAS} variants is predictive of nonresponse to anti-EGFR monoclonal antibody therapy. Documentation of \textit{KRAS} wild-type status is required before patients are eligible for treatment with cetuximab or panitumumab.

\textit{NRAS} VARIANT Testing to Guide Treatment for Metastatic CRC
Clinical Context and Test Purpose
The purpose of NRAS variant testing in individuals with metastatic CRC is to determine NRAS variant status to guide treatment decisions with EGFR-targeted therapy with the monoclonal antibodies cetuximab and panitumumab.

The question addressed in this evidence review is: In individuals with metastatic CRC, does the use of NRAS variant testing improve health outcomes?

The following PICOTS were used to select literature to inform this review.

Patients
The relevant population of interest includes individuals with metastatic CRC.

Interventions
The test being considered is NRAS variant testing.

Comparators
The following test strategy is currently being used: no NRAS variant testing to guide treatment.

Outcomes
The beneficial outcomes of interest include PFS and OS.

Timing
The time frame for outcomes measures varies from several months to several years.

Setting
Patients with metastatic CRC are actively managed by oncologists.

Technically Reliable
Assessment of technical reliability focuses on specific tests and operators and requires review of unpublished and often proprietary information. Review of specific tests, operators, and unpublished data are outside the scope of this evidence review and alternative sources exist. This evidence review focuses on the clinical validity and clinical utility.

Clinically Valid
A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

Systematic Reviews
A systematic review by Therkildsen et al (2014) evaluated the predictive value of NRAS variants on clinical outcomes of anti-EGFR therapy in CRC. The meta-analysis included data from 3 studies described below. Reviewers suggested that the pooled analyses showed a trend toward a poor OR based on 17 events.
but significant effects on PFS (HR=2.30; 95% CI, 1.30 to 4.07) and OS (HR=1.85; 95% CI, 1.23 to 2.78) among patients with wild-type KRAS. These results are limited by the small pool of variants, permitting no conclusions whether NRAS variants have an effect on anti-EGFR therapy.

**Prospective-Retrospective Analyses of Randomized Controlled Trials**

RCTs have analyzed nonconcurrent subgroups for the efficacy of EGFR inhibitors in patients with wild-type and mutated RAS genes in metastatic CRC.

Peeters et al (2015) reported on the influence of RAS variant status in a prospective-retrospective analysis of a randomized, multicenter phase 3 trial comparing panitumumab plus FOLFIRI with FOLFIRI alone as second-line therapy in patients with metastatic CRC.26 If a tumor was classified as wild-type KRAS exon 2, extended RAS variant testing beyond KRAS exon 2 was performed (KRAS exons 3 and 4; NRAS exons 2, 3, and 4; BRAF exon 15). Primary end points were PFS and OS. RAS variants were obtained in 85% of the specimens from the original trial; 18% of wild-type KRAS exon 2 tumors harbored other RAS variants. Table 4 summarizes the PFS and OS HRs for panitumumab plus FOLFIRI vs FOLIRI alone. The HRs more strongly favored panitumumab in the wild-type RAS population.

**Table 4. Hazard Ratios of Panitumumab Plus FOLFIRI vs FOLFIRI Alone Based on RAS Status**

<table>
<thead>
<tr>
<th>RAS Status</th>
<th>PFS HR (95% CI)</th>
<th>p</th>
<th>OS HR (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wild-type RAS</td>
<td>0.70 (0.54 to 0.91)</td>
<td>0.007</td>
<td>0.81 (0.63 to 1.03)</td>
<td>0.08</td>
</tr>
<tr>
<td>Wild-type KRAS exon 2</td>
<td>0.73 (0.59 to 0.90)</td>
<td>0.004</td>
<td>0.85 (0.70 to 1.04)</td>
<td>0.12</td>
</tr>
</tbody>
</table>

CI: confidence interval; FOLFIRI: (folinic acid, 5-florouracil, and irinotecan); HR: hazard ratio; OS: overall survival; PFS: progression-free survival.

For RAS wild-type patients, the ORR was 41% when patients were treated with panitumumab plus FOLFIRI vs 10% when treated with FOLFIRI alone. Therefore, RAS wild-type status predicted likely response to panitumumab and overall benefit from treatment. In contrast, the presence of RAS variants predicted nonresponse to panitumumab and unlikely benefit from treatment.

Van Cutsem et al (2015) reported on results of a prospective-retrospective extended RAS variant analysis of tumor samples from the randomized phase 3 CRYSTAL trial, which compared FOLFIRI with FOLFIRI plus cetuximab in wild-type KRAS exon 2 patients.27 Variant status was available in 430 (64.6%) of 666 patients from the trial. A pooled analysis of RAS variants, other than KRAS exon 2, found a lack of benefit from the addition of cetuximab to FOLFIRI for median PFS (7.4 months vs 7.5 months; p=0.47) and median OS (16.4 months vs 17.7 months; p=0.64). Patients with tumors without RAS variants experienced significant benefit in median PFS (9.9 months vs 8.4 months; p<0.05) and median OS (23.5 months vs 20 months; p<0.05) with the addition of cetuximab to chemotherapy.
Douillard et al (2013) performed a prospective-retrospective analysis of RAS variants (KRAS, NRAS) in tumor samples from patients enrolled in the Panitumumab Randomized Trial in Combination with Chemotherapy for Metastatic Colorectal Cancer to Determine Efficacy RCT. A total of 108 (17%) of 641 tumor specimens that did not harbor exon 2 KRAS variants had variants in other RAS exons, including NRAS (exons 2 or 4) and KRAS(exons 3 and 4). For patients with a wild-type KRAS exon 2 variant (n=656), OS was significantly better with panitumumab plus FOLFOX4 (n=325; median, 23.8 months) than with FOLFOX4 alone (n=331; median, 19.4 months; p=0.03). For patients with no KRAS exon 2 variant but with 1 type of RAS variant, median OS with panitumumab plus FOLFOX4 was shorter (n=51; median, 17.1 months) than with FOLFOX4 alone (n=57; median, 17.8 months; p=0.01). These data would suggest variants in a RAS gene exon other than KRAS exon 2 negatively affect anti-EGFR therapy. However, the investigators did not discriminate between specific types of RAS variants, so it is not possible to relate NRAS to these results. Furthermore, the numbers of patients involved were very small, further limiting conclusions.

Tumor specimens (288 of 320) from an RCT by Van Cutsem et al (2007) were analyzed by Peeters et al (2013) using next-generation sequencing to investigate whether EGFR pathway variants would predict response to monotherapy with panitumumab compared with best supportive care. This 2013 analysis showed that NRAS had mutated in 14 (5%) of 282 samples with available data. Among patients with wild-type KRAS (codons 12, 13, and 61) and wild-type NRAS (n=138), treatment with panitumumab was associated with improved PFS (HR=0.39; 95% CI, 0.27 to 0.56; p<0.001) compared with best supportive care. Among those with wild-type KRAS but mutated NRAS (n=11), treatment with panitumumab was no longer associated with longer PFS (HR=1.94; 95% CI, 0.44 to 8.44; p=0.379). A treatment interaction analysis was suggestive but not significantly indicative of an interaction between the presence of mutated NRAS and poorer outcome (p=0.076). The authors suggested their data were consistent with the hypothesis that NRAS variants may limit the efficacy of anti-EGFR therapy. However, because the prevalence of NRAS variants was low, the degree of predictive or prognostic value is more uncertain.

Retrospective Cohort Studies
A retrospective consortium analysis by De Roock et al (2010) reported on results of centrally performed high-throughput mass spectrometric variant profiling of CRC specimens gathered from 11 centers in 7 European countries. Patients had been treated with panitumumab alone, cetuximab alone, or cetuximab plus chemotherapy. Among 747 of 773 samples with data, KRAS had mutated in 299 (40%), including codons 12, 13, 61, and 146. By contrast, NRAS variants were identified in 17 (2.6%) of 644 samples with data, primarily in codon 61. KRAS and NRAS variants were mutually exclusive. Among wild-type KRAS samples from patients treated with cetuximab plus chemotherapy, the NRAS variant was associated with an ORR of 7.7% (1/13) compared with 38% for the wild-type NRAS (p=0.013). However, there were no significant differences between NRAS mutant and wild-type genes in median PFS (14 weeks vs 26 weeks, p=0.055) or OS (38 weeks vs 50 weeks, p=0.051). Similar to results previously reported, the
results of this analysis showed a very low prevalence of NRAS variants and were inconclusive as to whether NRAS variants are predictive of nonresponse to anti-EGFR therapy or are prognostic indicators of poor outcomes of CRC.

The rarity of NRAS variants reported in the studies discussed was also shown in a study by Irahara et al (2010) that used PCR and pyrosequencing (Qiagen) to assess tumor samples from individuals who developed CRC and were identified within the databases of 2 prospective cohort studies: the Nurses’ Health Study and the Health Professionals Follow-Up Study. Among 225 CRC specimens, NRAS variants were identified in 5 (2.2%). Because of the low frequency of NRAS variants, they were not associated with any clinical or pathologic features or with patient survival.

Section Summary: Clinically Valid
Evidence for the clinical validity of NRAS variants in predicting nonresponse to anti-EGFR monoclonal antibody therapy includes prospective-retrospective analyses of RCTs. Subgroup analyses of KRAS wild-type patients who did not respond to anti-EGFR monoclonal antibody therapy have suggested that NRAS variants are predictive of nonresponse. However, because of the low prevalence of NRAS variants, the predictive value of NRAS variants is uncertain.

Clinically Useful
A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

Direct Evidence
Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified on the clinical utility of NRAS variant testing to predict nonresponse to anti-EGFR monoclonal antibody therapy.

Chain of Evidence
Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Documentation of KRAS wild-type status is required prior to treatment with cetuximab or panitumumab.

A chain of evidence, based on clinical validity, supports the use of the anti-EGFR monoclonal antibodies cetuximab and panitumumab for the treatment of patients with wild-type NRAS metastatic CRC. Documentation of NRAS variant status is not required but has been recommended to identify patients who are predicted to be nonresponders to anti-EGFR monoclonal antibody therapy.
Section Summary: Clinically Useful
Direct evidence for the clinical utility of NRAS variant testing includes prospective-retrospective analyses of RCTs and retrospective cohort studies. NRAS variant testing has potential clinical utility in predicting nonresponse to anti-EGFR monoclonal antibody therapy in patients with documented KRAS wild-type status. However, the direct evidence is limited for NRAS variant testing due to low prevalence NRAS variants in CRC.

bраф VARIANT Testing to Guide Treatment for Metastatic CRC

Clinical Context and Test Purpose
The purpose of BRAF variant testing in individuals with metastatic CRC is to determine BRAF variant status to guide treatment.

The question addressed in this evidence review is: In individuals with metastatic CRC, does the use of BRAF variant testing improve health outcomes?

The following PICOTS were used to select literature to inform this review.

Patients
The relevant population of interest includes individuals with metastatic CRC who are found to be wild-type on KRAS and NRAS variant analysis.

Interventions
The test being considered is BRAF variant testing.

Comparators
The following test strategy is currently being used: no BRAF variant testing to guide management.

Outcomes
The beneficial outcomes of interest include PFS and OS.

Timing
The time frame for outcomes measures varies from several months to several years.

Setting
Patients with metastatic CRC are actively managed by oncologists.

Technically Reliable
Assessment of technical reliability focuses on specific tests and operators and requires review of unpublished and often proprietary information. Review of specific tests, operators, and unpublished data are outside the scope of this evidence review and alternative sources exist. This evidence review focuses on the clinical validity and clinical utility.
Clinically Valid
A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

Systematic Reviews
A meta-analysis by Pietrantonio et al (2015) identified 9 phase 3 trials that compared cetuximab or panitumumab with standard therapy or best supportive care. The analysis included 463 patients with metastatic CRC and BRAF variants. The addition of an EGFR inhibitor did not improve PFS (HR=0.88; 95% CI, 0.67 to 1.14; p=0.33) or ORR (RR=1.31; 95% CI, 0.83 to 2.08; p=0.25) compared with the control arms.

A meta-analysis by Mao et al (2011) assessed BRAF variants and resistance to anti-EGFR monoclonal antibodies in patients with metastatic CRC. The primary end point of eligible studies was ORR, defined as the sum of complete and partial tumor response. Eleven studies reported sample sizes ranging from 31 to 259 patients. All were conducted retrospectively (1 study was a nonconcurrent analysis of response in a population previously randomized). Anti-EGFR therapy was given as first-line treatment in 1 study and as second-line or greater in the other 10. In 2 studies, the anti-EGFR monoclonal antibody was given as monotherapy, and in 9 studies, patients received various chemotherapies. Seven studies were performed in unselected patients (ie, unknown KRAS variant status) totaling 546 patients, for whom 520 were assessable for tumor response. In the unselected population, a BRAF variant was detected in 8.8% of patients, and the ORR for patients with mutant BRAF was 29.2% (14/48) and for wild-type BRAF was 33.5% (158/472; p=0.048). Four studies were performed in patients with wild-type KRAS metastatic CRC. BRAF variant status was performed on 376 wild-type KRAS tumors. BRAF variant was detected in 10.6% (n=40) of primary tumors. Among the 376 analyzed, all patients were assessable for tumor response. The ORR of patients with a mutant BRAF gene was 0% (0/40), whereas the ORR of patients with wild-type BRAF was 36.3% (122/336). Only 3 studies presented data on PFS and OS and, therefore, pooled analysis was not performed. Reviewers concluded that, although the meta-analysis provided evidence that BRAF variants were associated with lack of response to anti-EGFR monoclonal antibodies in wild-type KRAS metastatic CRC, the number of studies and number of patients analyzed were relatively small and that large studies would be needed to confirm the meta-analytic results using homogenous metastatic CRC patients with assessors blinded to the clinical data.

Mao’s meta-analysis (2011) also assessed BRAF V600E variant and resistance to anti-EGFR monoclonal antibodies in patients with metastatic CRC. The same 11 studies were selected. Seven included unselected patients, and 4 studies included only patients with wild-type KRAS. The primary end point was ORR. In the 7 studies with unselected patients, BRAF variant status was performed successfully on 546 metastatic CRC. BRAF variants were detected in 8.8% of primary tumors. The ORR of metastatic CRC patients with mutant BRAF was 29.2% and 33.5% in patients with wild-type BRAF. In the 4 studies that included patients with wild-type KRAS, BRAF variant status was performed successfully on 376 wild-type KRAS.
metastatic CRC. *BRAF* variants were detected in 10.6% of primary tumors. The ORR of patients with mutant *BRAF* genes was 0.0%, whereas it was 36.3% in patients with wild-type. Reviewers concluded that their results provided evidence that the *BRAF* variant is associated with lack of response in wild-type *KRAS* metastatic CRC treated with anti-EGFR monoclonal antibodies.

**Retrospective Studies**

Di Nicolantonio et al (2008) retrospectively analyzed 113 patients with metastatic CRC who had received cetuximab or panitumumab. None of the *BRAF*-mutated tumors (0/11) responded to treatment, whereas 32.4% (22/68) of the wild-type *BRAF* did. Loupakis et al (2009) retrospectively assessed 87 patients receiving irinotecan and cetuximab. Of the 87 patients in the study, *BRAF* was mutated in 13 patients, and none of whom responded to chemotherapy, compared with 32% (24/74) of patients with wild-type *BRAF* who did. In the CAIRO2 study, Tol et al (2009) retrospective analyzed *BRAF* variants in 516 available tumors from patients previously randomized to the CB regimen or to the CB plus cetuximab regimen. A *BRAF* variant was found in 8.7% (n=45) of the tumors. Patients with a *BRAF* variant had a shorter median PFS and OS compared with wild-type *BRAF* tumors in both treatment arms. The authors concluded that a *BRAF* variant was a negative prognostic marker in patients with metastatic CRC and that this effect, unlike *KRAS* variants, was not restricted to the outcome of cetuximab treatment. In the CRYSTAL trial, Van Cutsem et al (2009) randomized 1198 patients with untreated metastatic CRC to FOLFIRI with or without cetuximab. Analysis of *BRAF* variants in this patient population and the influence of *BRAF* variant status by Peeters et al (2014) showed that for the wild-type, *KRAS*-, and *BRAF*-mutated patients, OS for cetuximab plus FOLFIRI was 14.1 months and 10.3 months with FOLFIRI (p=0.744). Although this difference was not statistically significant, it suggested a trend toward improved OS, PFS, and response, and that wild-type *KRAS*- and *BRAF*-mutant patients might benefit from anti-EGFR therapy.

De Roock et al (2010) reported on the effects of 4 variants, including *BRAF*, on the efficacy of cetuximab and chemotherapy in chemotherapy-refractory metastatic CRC in 773 primary tumor samples. Tumor samples were from fresh frozen or formalin-fixed, paraffin-embedded tissue, and the variant status was compared with retrospectively collected clinical outcomes including ORR, PFS, and OS. *BRAF* variants were found in 36 (4.7%) of 761 tumors. In patients with wild-type *KRAS*, carriers of *BRAF* variants had a significantly lower response rate (8.3% [2/24] patients) than wild-type *BRAF* (38.0% [124/326] patients; OR=0.15; 95% CI, 0.02 to 0.51; p=0.001). PFS for *BRAF*-mutated vs wild-type patients was a median of 8 weeks vs 26 weeks, respectively (HR=3.74; 95% CI, 2.44 to 5.75; p<0.001), and median OS was 26 weeks vs 54 weeks, respectively (HR=3.03; 95% CI, 1.98 to 4.63; p<0.001).

In an updated analysis of the CRYSTAL trial, Van Cutsem et al (2011) reported on longer follow-up and more patients with evaluable for *KRAS* tumor status and considered the clinical significance of *BRAF* tumor variant status in the expanded population of patients with wild-type *KRAS* tumors. The impact of *BRAF* tumor
variant status on the efficacy of cetuximab plus FOLFIRI was examined in the population with wild-type KRAS disease (N=625). No evidence was reported for an independent treatment interaction by BRAF tumor variant status. The authors concluded that BRAF variant status was not predictive of the treatment effects of cetuximab plus FOLFIRI but that BRAF tumor variant was a strong indicator of poor prognosis for all efficacy end points compared with those whose tumors were wild-type.

Section Summary: Clinically Valid
Evidence for the clinical validity of BRAF variants in predicting nonresponse to anti-EGFR monoclonal antibody therapy includes 2 meta-analyses of prospective and retrospective analyses of RCTs. Subgroup analyses of KRAS wild-type and NRAS wild-type patients who did not respond to anti-EGFR monoclonal antibody therapy suggested that BRAF variants might be predictive of nonresponse. However, because of the low prevalence of BRAF variants, the true predictive value of BRAF variants is unclear.

Clinically Useful
A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

Direct Evidence
Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified on the clinical utility of BRAF variant testing to predict nonresponse to anti-EGFR monoclonal antibody therapy.

Chain of Evidence
Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

A chain of evidence, based on clinical validity, cannot be constructed to support the use of the anti-EGFR monoclonal antibodies cetuximab and panitumumab for the treatment of patients with wild-type BRAF metastatic CRC.

Documentation of KRAS wild-type status is required prior to treatment with cetuximab or panitumumab. Documentation of BRAF variant status is not required but has been suggested to identify patients who are predicted to be nonresponders to anti-EGFR monoclonal antibody therapy.

Section Summary: Clinically Useful
Direct evidence for the clinical validity of BRAF variant testing includes meta-analyses of prospective and retrospective analyses of RCTs. BRAF variant testing
has potential clinical utility in predicting nonresponse to anti-EGFR monoclonal antibody therapy in patients with documented KRAS wild-type and NRAS wild-type status. However, the direct evidence is limited for BRAF variant testing due to the low prevalence BRAF variants in CRC.

**Summary of Evidence**

For individuals with metastatic CRC who receive KRAS variant testing to guide treatment, the evidence includes multiple systematic reviews including a TEC Assessment. Relevant outcomes are overall survival, disease-specific survival, change in disease status, medication use, resource utilization, and treatment-related morbidity. Variant testing of tumor tissue performed in prospective and retrospective analyses of RCTs has consistently shown that the presence of a KRAS variant predicts nonresponse to cetuximab and panitumumab, either as monotherapy or in combination with other treatment regimens and supports the use of KRAS variant analysis of tumor DNA before considering a treatment regimen. The evidence is sufficient to determine that the technology results in a meaningful improvement in the net health outcome.

For individuals with metastatic CRC who receive NRAS variant testing to guide treatment, the evidence includes prospective-retrospective analyses of RCTs and retrospective cohort studies. Relevant outcomes are overall survival, disease-specific survival, change in disease status, medication use, resource utilization, and treatment-related morbidity. Pooled analyses have shown that NRAS variants (beyond the common KRAS exon 2 variants) predict nonresponse to cetuximab and panitumumab, and support the use of NRAS variant analysis of tumor DNA before considering a treatment regimen. In addition, there is strong support from the National Comprehensive Cancer Network and American Society of Clinical Oncology for NRAS and KRAS testing in patients with metastatic CRC. The evidence is sufficient to determine that the technology results in a meaningful improvement in the net health outcome.

For individuals with metastatic CRC who receive BRAF variant testing to guide treatment, the evidence includes 2 meta-analyses of prospective and retrospective analyses of RCTs. Relevant outcomes are overall survival, disease-specific survival, change in disease status, medication use, resource utilization, and treatment-related morbidity. The meta-analyses have shown that anti-EGFR monoclonal antibody therapy did not improve survival in patients with RAS wild-type or BRAF-mutated tumors; however, the individual studies have been small, and the results have been inconsistent. The evidence is insufficient to determine the effects of the technology on health outcomes.

**CLINICAL INPUT**

In 2017, clinical input was sought to help determine whether testing for BRAF V600E variant status for individuals with metastatic colorectal cancer (CRC) would provide a meaningful clinical benefit, defined as avoidance of anti-epidermal growth factor receptor (EGFR) targeted therapies that are unlikely to result in an objective tumor response in patients, and whether this use is consistent with generally accepted medical practice.
Respondents
Clinical input was provided by the following specialty societies and physician members identified by a specialty society or clinical health system:

- Association for Molecular Pathology
- Carmen J. Allegra, MD, Medical Oncology; identified by American Society of Clinical Oncology
- Christopher H. Lieu, MD, Medical Oncology; identified by American Society of Clinical Oncology
- Brandon G. Smaglo, MD, Gastrointestinal Oncology, and Manisha Chandar, DO, Hematology/Oncology; identified by Dan L Duncan Comprehensive Cancer Center, Baylor College of Medicine
- Anonymous, MD, Medical Oncology; identified by Catholic Health Initiatives
- Arturo Loaiza-Bonilla, MD, MSEd, Medical Oncology, Gastrointestinal Oncology; identified by Cancer Treatment Centers of America (CTCA)
- Eyal Meiri, MD, Medical Oncology; identified by CTCA
- Shahin Chowdhury, DO, Medical Oncology; identified by CTCA
- Anonymous, MD, Medical Oncologist; identified by CTCA
- Anonymous, MD, Pathology and Laboratory Medicine; identified by CTCA

*a* Indicates that information on conflicts of interest related to the topic where clinical input is being sought were disclosed by this respondent (see Appendix 1).

Clinical input provided by the specialty society at an aggregate level is attributed to the specialty society. Clinical input provided by a physician member designated by the specialty society or health system is attributed to the individual physician and is not a statement from the specialty society or health system. Specialty society and physician respondents participating in the Evidence Street® clinical input process provide a review, input, and feedback on topics being evaluated by Evidence Street. However, participation in the clinical input process by a special society and/or physician member designated by the specialty society or health system does not imply an endorsement or explicit agreement with the Evidence Opinion published by BCBSA or any Blue Plan.

Clinical Input Responses
Figure 1
**Clinical Indication:**
Testing for \( BRFV600E \) variant status for individuals with metastatic colorectal cancer to guide treatment with EGFR-targeted therapy

<table>
<thead>
<tr>
<th>Respondent</th>
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<tbody>
<tr>
<td>Association for Molecular Pathology</td>
<td>Molecular Pathology</td>
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<tr>
<td>Dr. Allegra</td>
<td>Medical Oncology</td>
<td>American Society of Clinical Oncology</td>
</tr>
<tr>
<td>Dr. Lieu</td>
<td>Medical Oncology</td>
<td>American Society of Clinical Oncology</td>
</tr>
<tr>
<td>Dr. Smagio and Dr. Chander</td>
<td>Gastrointestinal Oncology and Hematology/Oncology</td>
<td>Baylor College of Medicine</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Medical Oncology</td>
<td>Catholic Health Initiatives</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Medical Oncology</td>
<td>Cancer Treatment Centers of America</td>
</tr>
<tr>
<td>Dr. Meiri</td>
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<td>Cancer Treatment Centers of America</td>
</tr>
<tr>
<td>Dr. Lozada-Bonilla</td>
<td>Medical Oncology, Gastrointestinal Oncology</td>
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<td>Anonymous</td>
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<tr>
<td>Dr. Chewdhury</td>
<td>Medical Oncology</td>
<td>Cancer Treatment Centers of America</td>
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</table>

**Additional Comments**

- “In March 2017, the American Society for Clinical Pathology (ASCP), College of American Pathologists (CAP), Association for Molecular Pathology (AMP), and American Society of Clinical Oncology (ASCO) published an updated guideline on Molecular Biomarkers for the Evaluation of Colorectal Cancer. This is an evidence-based guideline recommendation, which was constructed through a systematic review of the literature to establish standard molecular biomarker testing of CRC tissue to guide EGFR therapies and conventional chemotherapy regimens. We recommend review and incorporation of these guidelines into your evidence review and summaries for colorectal cancer. Our comments in this clinical input reflect recommendations within the guideline. The guideline supports extended RAS testing along with the following recommendations:

  - While \( BRAF \) status does not directly inform about response to anti-EGFR therapies, it is a poor prognostic indicator in high stage cancers and has important value generally in informing therapeutic decision making for those patients. Specifically, the ASCP/CAP/AMP/ASCO guideline states that \( BRAF \) V600 position mutational status is recommended for prognostic stratification in selected patients with CRC (Recommendation 2a) and that there is insufficient evidence to recommend \( BRAF \) pV600 mutational status as a predictive molecular biomarker for response to anti-EGFR inhibitors (Recommendation 4).

Briefly, the guidelines state:

\( BRF \) activating mutations occur in about 8% of advanced disease patients with CRC and in approximately 14% of patients with localized stage II and III CRC. As such, mutations in \( BRAF \) constitute a substantial subset of patients with CRC. Four systematic reviews and three systematic reviews that included meta-analyses pertaining to the prognostic and predictive value of \( BRAF \) mutations in patients with CRC were identified through our systematic review process. These studies
revealed that patients with advanced CRC who possess a BRAF mutation have significantly poorer outcomes as measured by PFS and OS and have a decreased response rate to anti-EGFR therapy relative to those with nonmutated BRAF. Poorer OS was also demonstrated for those patients with earlier stage II and III CRC having a BRAF mutation; however, the poorer outcome appears to be primarily the result of decreased OS after relapse in these patients rather than a harbinger of an increased rate of relapse. Finally, while outcomes in advanced disease patients with BRAF mutations were poorer relative to nonmutation patients, the data were consistent with a modest beneficial impact from the use of anti-EGFR agents relative to those patients whose tumors contained a RAS mutation. In summary, patients with CRC that contains a BRAF mutation have a worse outcome relative to nonmutation patients. Selected patients for BRAF mutation testing include patients with metastatic disease, since these patients have particularly poor outcomes. It is important to know the BRAF c.1799 (p.V600) mutation status of a patient's CRC since standard therapy is not adequate for patients with metastatic disease and BRAF mutation. For these patients, some studies suggest the use of FOLFIRINOX [folinic acid (leucovorin calcium), 5-fluorouracil, irinotecan hydrochloride, and oxaliplatin] as first-line therapy, followed by enrollment in a clinical trial.” (Association for Molecular Pathology [AMP])

- “The utilization and importance of BRAF V600 variant testing in patients with metastatic colon cancer extends beyond guiding treatment with EGFR-targeted therapy. Thus we recommend that Evidence Street expand the meaningful clinical benefit for BRAF in the evidence summary beyond selecting a specific targeted treatment. AMP has high confidence that BRAF V600 variant testing is clinically beneficial for these patients. BRAF V600 variant testing should not be denied for these patients solely on the basis of EGFR treatment selection.” (Association for Molecular Pathology [AMP])
- “The role for BRAF V600E testing as a predictive marker for anti-EGFR monoclonal antibody therapy effectiveness in the treatment of metastatic colorectal cancer is not yet clearly defined. The evidence available does lean to suggest that such antibody therapies are unlikely to be effective in patients whose tumors harbor such a mutation. The meta-analysis from Pietrantonio and colleagues did conclude that BRAF mutation should be considered as a factor against the use of an anti-EGFR monoclonal antibody therapy. Separately, however, the meta-analysis performed by Rowland and colleagues found the evidence for selection for or against an anti-EGFR monoclonal antibody based upon BRAF mutation insufficient. The updated recommendation from the ASCO in 2017 similarly states that the evidence for BRAF testing in this indication is insufficient. There is sparse prospective data to address this issue, and this will be necessary in order to determine if BRAF testing is requisite to the selection of anti-EGFR monoclonal antibody use in metastatic colorectal cancer. We cannot cite personal clinical experiences in a meaningful way, as the instances when we have known the BRAF status of a patient’s tumor in this context is quite limited, given that the testing is not routinely assessed. Thus, at present BRAF testing should not be routinely assessed as a biomarker for anti-EGFR selection. Future studies on par with the data establishing RAS testing as such
a biomarker (CRYSTAL, OPUS, etc.), could change this, and a similar level of
evidence and demonstrated benefit as established the role for RAS testing
would be necessary to impart this distinction onto BRAF.

Concerning sequences of testing, the value of identifying mutant KRAS in exon 2
in order to predict for or against the use of an anti-EGFR monoclonal antibody for
the treatment of metastatic colorectal cancer pre-dates the similar knowledge for
the value of mutational status of KRAS exons 3 and 4, NRAS, and, theoretically,
BRAF. Additionally, of these mutations, KRAS exon 2 mutations are by far the
most common. Prior to understanding the relevance of extended RAS testing,
many institutions had developed internal tests for the KRAS exon 2 mutations.
Rather than develop additional internal testing for the rest of the extended panel,
many institutions still assess KRAS exon 2 internally, as it is the most common. If
this turns out to be wildtype, internal practice is then to refer the specimen out for
commercial testing of the remainder of the panel. Given the likelihood of the
mutation being within KRAS exon 2, this practice seems reasonable. Should BRAF
ultimately be added to the panel of routinely testing mutations for anti-EGFR
monoclonal eligibility, or otherwise be assessed, assessing KRAS exon 2 in a
similar fashion is appropriate.” (Drs. Smaglo and Chandar, identified by Dan L
Duncan Comprehensive Cancer Center, Baylor College of Medicine)

“Pooled analysis and meta-analysis presented in summary report is self-
explanatory. BRAF V600E mutations are a predictor of poor response to anti-EGFR
therapy and in general represent a poor prognostic category of patients. Upon
testing for RAS variants, should no mutations for RAS be found, BRAF mutations
analysis should be obtained... I believe that there is reasonably good data now on
the value proposition of including BRAF mutation analysis on all metastatic
specimens RAS wild. Should a mutation be found for BRAF in a RAS wild patient,
alternative treatment options need to be considered.” (Eyal Meiri, MD, CTCA)

See Appendices 1 and 2 for details of the clinical input.

SUPPLEMENTAL INFORMATION

Clinical Input From Physician Specialty Societies and Academic Medical
Centers
While the various physician specialty societies and academic medical centers may
collaborate with and make recommendations during this process, through
the provision of appropriate reviewers, input received does not represent an
endorsement or position statement by the physician specialty societies or
academic medical centers, unless otherwise noted.

2017 Input
In response to requests, clinical input on use of BRAF V600E variant analysis in
individuals with metastatic CRC who are found to be wild-type on KRAS and NRAS
variant analysis to guide management decisions was received from 11
respondents, including 2 specialty society-level response, 1 physician from the
academic center, and 6 physicians from 2 health systems, while this policy was under review in 2017.

Based on the evidence and independent clinical input, the clinical input supports that the following indication provides a clinically meaningful improvement in the net health outcome and is consistent with generally accepted medical practice:

- Use of BRAF V600E variant analysis in individuals with metastatic colorectal cancer who are found to be wild-type on KRAS and NRAS variant analysis to guide management decisions.

Practice Guidelines and Position Statements

National Comprehensive Cancer Network
National Comprehensive Cancer Network guidelines on the treatment of colon cancer recommend that tumor tissue should be genotyped for RAS (KRAS and NRAS) and BRAF variants for all patients with metastatic colon cancer (v.2.2018). Testing should be performed on archived specimens of primary tumor or a metastasis at the time of diagnosis of metastatic disease. The guidelines indicate that cetuximab and panitumumab are appropriate only for patients with a tumor that expresses wild-type KRAS and NRAS genes. Individuals with KRAS variant in exons 2, 3, or 4, or with NRAS variant in exons 2, 3, or 4, are not eligible for treatment with cetuximab or panitumumab. The guidelines also state that the presence of the BRAF V600E variant makes a response to panitumumab and cetuximab highly unlikely. However, the concurrent administration of a BRAF inhibitor may make a response to these treatments more likely.

American College of Medical Genetics and Genomics
An evidence review published in 2013 by the American College of Medical Genetics and Genomics has stated that evidence is insufficient to support the clinical validity or utility of testing colorectal cancer specimens for NRAS variants to guide patient management. That same review further found no guidelines on NRAS testing from any other U.S. group.

American Society of Clinical Oncology
In 2017, American Society of Clinical Oncology along with American Society for Clinical Pathology, College of American Pathologists, Association for Molecular Pathology published guidelines on molecular biomarkers for the evaluation of colorectal cancer. Table 3 summarizes the relevant guidelines.

Table 5. Summary of Recommendations

<table>
<thead>
<tr>
<th>Guidelines</th>
<th>Type Recommendation</th>
<th>SOE</th>
<th>QOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorectal carcinoma patients being considered for anti-EGFR therapy must receive RAS mutational testing. Mutational analysis should include KRAS and NRAS codons 12, 13 of exon 2; 59, 61 of exon 3; and 117 and 146</td>
<td>Convincing/ adequate, benefits outweigh harms</td>
<td>High/intermediate</td>
<td></td>
</tr>
<tr>
<td>Guidelines</td>
<td>Type</td>
<td>SOE</td>
<td>QOE</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>--------------</td>
<td>------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>of exon 4 (“expanded” or “extended” RAS)</td>
<td></td>
<td></td>
<td>Intermediate/low</td>
</tr>
<tr>
<td>BRAF p.V600 (BRAF c. 1799 (p.V600)) mutational analysis should be performed in colorectal cancer tissue in patients with colorectal carcinoma for prognostic stratification</td>
<td>Recommendation</td>
<td>Adequate/inadequate, balance of benefits and harms</td>
<td>Intermediate/low</td>
</tr>
<tr>
<td>BRAF p.V600 mutational analysis should be performed in deficient MMR tumors with loss of MLH1 to evaluate for Lynch Syndrome risk. Presence of a BRAF mutation strongly favors a sporadic pathogenesis. The absence of BRAF mutation does not exclude risk of Lynch syndrome</td>
<td>Recommendation</td>
<td>Adequate/inadequate, balance of benefits and harms</td>
<td>Intermediate/low</td>
</tr>
<tr>
<td>Clinicians should order mismatch repair status testing in patients with colorectal cancers for the identification of patients at high risk for Lynch syndrome and/or prognostic stratification</td>
<td>Recommendation</td>
<td>Adequate/inadequate, balance of benefits and harms</td>
<td>Intermediate/low</td>
</tr>
<tr>
<td>There is insufficient evidence to recommend BRAF c.1799 p.V600 mutational status as a predictive molecular biomarker for response to anti-EGFR inhibitors</td>
<td>No recommendation</td>
<td>Insufficient, benefits/harms balance unknown</td>
<td>Insufficient balance unknown</td>
</tr>
</tbody>
</table>

EGFR: epidermal growth factor receptor; QOE: quality of evidence; SOE: strength of evidence.

The American Society of Clinical Oncology updated its provisional clinical opinion (2015) on extended RAS variant testing in metastatic colorectal cancer to predict response to anti-EGFR monoclonal antibody therapy. The opinion was based on evidence from 13 articles on KRAS variants (11 systematic reviews, 2 health technology assessments) and 2 articles on NRAS testing. The opinion stated that subgroup analyses of patients with any of the less common RAS variants were small, and there was inadequate evidence to provide a definitive opinion on the lack of benefit for the use of anti-epidermal growth factor receptor antibodies for patients whose cancer harbors any specific RAS variant other than the exon 2 KRAS variant. The Society considered the less common RAS variants as a group, and a pooled analysis suggested the same lack of benefit with anti-epidermal growth factor receptor therapy as seen with the more common variants in exon 2 of KRAS.

**U.S. Preventive Services Task Force Recommendations**

Not applicable.
Medicare National Coverage
There is no national coverage determination. In the absence of a national coverage determination, coverage decisions are left to the discretion of local Medicare carriers.

Ongoing and Unpublished Clinical Trials
A search of ClinicalTrials.gov in June 2018 did not identify any ongoing or unpublished trials that would likely influence this review.

REFERENCES
3. Blue Cross and Blue Shield Association Technology Evaluation Center (TEC). KRAS mutations and epidermal growth factor receptor inhibitor therapy in metastatic colorectal cancer. TEC Assessments 2008;Volume 23:Tab 6. PMID


Billing Coding/Physician Documentation Information

81210 BRAF (v-raf murine sarcoma viral oncogene homolog B1) (eg, colon cancer), gene analysis, V600E variant
81275 KRAS (v-Ki-ras2 Kirsten rat sarcoma viral oncogene) (eg, carcinoma) gene analysis, variants in codons 12 and 13
81276 KRAS (Kirsten rat sarcoma viral oncogene homolog) (eg, carcinoma) gene analysis; additional variant(s) (eg, codon 61, codon 146) (new code 1/1/2016)
81311 NRAS (neuroblastoma RAS viral [v-ras] oncogene homolog) (eg, colorectal carcinoma), gene analysis, variants in exon 2 (eg, codons 12 and 13) and exon 3 (eg, codon 61) (new code 1/1/2016)
81403 Molecular pathology procedure, Level 4 (eg, analysis of single exon by DNA sequence analysis, analysis of > 10 amplicons using multiplex PCR in 2 or more independent reactions, mutation scanning or
duplication/deletion variants of 2-5 exons) ABL1 (c-abl oncogene 1, receptor tyrosine kinase) (eg, acquired imatinib tyrosine kinase inhibitor resistance), variants in the kinase domain DAZ/SRY (deleted in azoospermia and sex determining region Y) (eg, male infertility), common deletions (eg, AZFa, AZFb, AZFc, AZFd) GJB1 (gap junction protein, beta 1) (eg, Charcot-Marie-Tooth X-linked), full gene sequence JAK2 (Janus kinase 2) (eg, myeloproliferative disorder), exon 12 sequence and exon 13 sequence, if performed KRAS (v-Ki-ras2 Kirsten rat sarcoma viral oncogene) (eg, carcinoma), gene analysis, variant(s) in exon 2 MPL (myeloproliferative leukemia virus oncogene, thrombopoietin receptor, TPOR) (eg, myeloproliferative disorder), exon 10 sequence VHL (von Hippel-Lindau tumor suppressor) (eg, von Hippel-Lindau familial cancer syndrome), deletion/duplication analysis VWF (von Willebrand factor) (eg, von Willebrand disease types 2A, 2B, 2M), targeted sequence analysis (eg, exon 28)

81404 Molecular pathology procedure, Level 5 (eg, analysis of 2-5 exons by DNA sequence analysis, mutation scanning or duplication/deletion variants of 6-10 exons, or characterization of a dynamic mutation disorder/triplet repeat by Southern blot analysis)

88363 Examination and selection of retrieved archival (ie, previously diagnosed) tissue(s) for molecular analysis (eg, KRAS mutational analysis)

ICD10 Codes
C18.0- Malignant neoplasm of colon code range
C18.9
C19 Malignant neoplasm of rectosigmoid junction
C20 Malignant neoplasm of rectum
C78.5 Secondary malignant neoplasm of large intestine and rectum

Additional Policy Key Words
N/A

Policy Implementation/Update Information
1/1/11 New policy; may be considered medically necessary
5/1/11 No policy statement changes.
5/1/12 Title changed to indicate inclusion of BRAF testing to the policy; BRAF testing policy statement added as investigational to predict nonresponse to anti-EGFR monoclonal antibodies cetuximab and panitumumab in the treatment of metastatic colorectal cancer; KRAS policy statement unchanged.
5/1/13 No policy statement changes.
5/1/14 No policy statement changes.
5/1/15 Title changed to indicate inclusion of NRAS testing to the policy; NRAS testing policy statement added as investigational to predict nonresponse to anti-EGFR monoclonal antibodies cetuximab and panitumumab in the treatment of metastatic colorectal cancer. KRAS testing not meeting criteria changed from not medically necessary to investigational.
5/1/16  No policy statement changes.
12/1/16  Policy statement revised to indicate that NRAS testing policy statement added as medically necessary to predict nonresponse to anti-EGFR monoclonal antibodies cetuximab and panitumumab in the treatment of metastatic colorectal cancer.
5/1/17  No policy statement changes.
5/1/18  BRAF variant analysis is considered medically necessary for patients with metastatic colorectal cancer who are found to be wild-type on KRAS and NRAS variant analysis to guide management decisions. Title changed to “KRAS, NRAS, and BRAF Variant Analysis in Metastatic Colorectal Cancer”. Removed BRAF mutation analysis is considered investigational to predict nonresponse to anti-EGFR monoclonal antibodies cetuximab and panitumumab in the treatment of metastatic colorectal cancer.
5/1/19  No policy statement changes.

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APPENDIX

Appendix Table 1. Categories of Genetic Testing Addressed in 2.04.53

<table>
<thead>
<tr>
<th>Category</th>
<th>Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Testing of an affected individual’s germline to benefit the individual</td>
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<tr>
<td>1a. Diagnostic</td>
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</tr>
<tr>
<td>1b. Prognostic</td>
<td></td>
</tr>
<tr>
<td>1c. Therapeutic</td>
<td></td>
</tr>
<tr>
<td>2. Testing cancer cells from an affected individual to benefit the individual</td>
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</tr>
<tr>
<td>2a. Diagnostic</td>
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</tr>
<tr>
<td>2b. Prognostic</td>
<td>X</td>
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<tr>
<td>2c. Therapeutic</td>
<td>X</td>
</tr>
<tr>
<td>3. Testing an asymptomatic individual to determine future risk of disease</td>
<td></td>
</tr>
<tr>
<td>4. Testing of an affected individual’s germline to benefit family members</td>
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</tr>
<tr>
<td>5. Reproductive testing</td>
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</tr>
<tr>
<td>5a. Carrier testing: preconception</td>
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</tr>
<tr>
<td>5b. Carrier testing: prenatal</td>
<td></td>
</tr>
<tr>
<td>5c. In utero testing: aneuploidy</td>
<td></td>
</tr>
<tr>
<td>5d. In utero testing: familial variants</td>
<td></td>
</tr>
<tr>
<td>5e. In utero testing: other</td>
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</tr>
<tr>
<td>5f. Preimplantation testing with in vitro fertilization</td>
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</table>

APPENDIX 1: CLINICAL INPUT

Appendix Table 2. Respondent Profile

<table>
<thead>
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<th>Specialty Society</th>
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</tr>
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<tbody>
<tr>
<td>Association for Molecular Pathology</td>
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<td>Cancer Treatment Centers of America (CTCA)</td>
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</tr>
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<td>8</td>
<td>University of Florida</td>
</tr>
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<td>Cancer Treatment Centers of America (CTCA)</td>
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</tbody>
</table>

### Appendix Table 3. Respondent Conflict of Interest Disclosure

<table>
<thead>
<tr>
<th>No.</th>
<th>1. Research support related to the topic where clinical input is being sought</th>
<th>2. Positions, paid or unpaid, related to the topic where clinical input is being sought</th>
<th>3. Reportable, more than $1,000, health care–related assets or sources of income for myself, my spouse, or my dependent children related to the topic where clinical input is being sought</th>
<th>4. Reportable, more than $350, gifts or travel reimbursements for myself, my spouse, or my dependent children related to the topic where clinical input is being sought</th>
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<tr>
<td></td>
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<td>7</td>
<td>No</td>
<td>Yes (BGS)</td>
<td>BGS: Speaker's bureau for TAIHO oncology for the colorectal cancer drug Lonsurf</td>
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<td>ASCO representative for colorectal cancer biomarkers</td>
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<tr>
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</tbody>
</table>

**Conflict of Interest Policy Statement**

Individual physician respondents answered at individual level. Specialty Society respondents provided aggregate information that may be relevant to the group of clinicians who provided input to the Society-level response.

NR: not reported.
APPENDIX 2: CLINICAL INPUT RESPONSES

Objective
The epidermal growth factor receptor (EGFR) is overexpressed in colorectal cancer (CRC). EGFR-targeted therapy, with monoclonal antibodies cetuximab and panitumumab, has shown a clear survival benefit in patients with metastatic CRC. However, this benefit depends on a lack of variants in certain genes in the signaling pathway downstream from the EGFR. It has been hypothesized that knowledge of tumor cell KRAS, NRAS, and BRAF variant status might be used as a predictor of nonresponse to anti-EGFR monoclonal antibody therapy.

The following PICO applies to this indication.

<table>
<thead>
<tr>
<th>Populations</th>
<th>Interventions</th>
<th>Comparators</th>
<th>Outcomes</th>
</tr>
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<td>Individuals:</td>
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<td>o With metastatic colorectal cancer</td>
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<td>Interventions of interest are:</td>
<td>Comparators of interest are:</td>
<td>Relevant outcomes include:</td>
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<td>o BRAF variant testing to guide treatment</td>
<td>o No BRAF variant testing to guide treatment</td>
<td>o Overall survival</td>
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<td>o Disease-specific survival</td>
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<td>o Change in disease status</td>
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<td>o Medication use</td>
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<td>o Treatment-related morbidity</td>
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Clinical input is sought to help determine whether testing for BRAF V600E variant status for individuals with metastatic colorectal cancer would provide a meaningful clinical benefit, defined as avoidance of anti-EGFR targeted therapies that are unlikely to result in an objective tumor response in patients, and whether this use is consistent with generally accepted medical practice.

Responses
1. Based on the evidence and your clinical experience, please describe the clinical context that may offer clinical benefit associated with testing for BRAF V600E variant status for individuals with metastatic colorectal cancer to guide treatment with EGFR-targeted therapy. Please comment on what predictive value of testing for BRAF V600E variant status would be needed for a clinically meaningful benefit from avoiding anti-EGFR targeted therapies. Also include any sequencing considerations with other evaluation and testing. Please include supporting rationale and relevant references to support your clinical input.

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| 1  | In March 2017, the American Society for Clinical Pathology (ASCP), College of American Pathologists (CAP), Association for Molecular Pathology (AMP), and American Society of Clinical Oncology (ASCO) published an updated guideline on Molecular Biomarkers for the Evaluation of Colorectal Cancer. This is an evidence-based guideline recommendation, which was constructed through a systematic review of the literature to establish standard molecular biomarker testing of CRC tissue to guide EGFR therapies and conventional chemotheraphy regimens. We recommend review and incorporation of these guidelines into your evidence review and summaries for colorectal cancer. Our comments in this clinical input reflect recommendations within the guideline. The guideline supports extended RAS testing along with the following recommendations:
- While BRAF status does not directly inform about response to anti-EGFR therapies, it is a poor prognostic indicator in high stage cancers and has important value generally in informing therapeutic decision making for those patients. Specifically, the ASCP/CAP/AMP/ASCO guideline states that Braf V600 position mutational status is recommended for prognostic stratification in selected patients with CRC (Recommendation 2a) and that there is insufficient evidence to recommend Braf pV6000 mutational status as a predictive molecular biomarker for response to anti-EGFR inhibitors (Recommendation 4).

Briefly, the guidelines state: “BRAF activating mutations occur in about 8% of advanced disease patients with CRC and in approximately 14% of patients with localized stage II and III CRC. As such, mutations in BRAF constitute a substantial subset of patients with CRC. Four systematic reviews and three systematic reviews that included meta-analyses pertaining to the prognostic and predictive value of BRAF mutations in patients with CRC were identified through our systematic review process. These studies revealed that patients with advanced CRC who possess a BRAF mutation have significantly poorer outcomes as measured by PFS and OS and have a decreased response rate to anti-EGFR therapy relative to those with nonmutated BRAF. Poorer OS was also demonstrated for those patients with earlier stage II and III CRC having a BRAF mutation; however, the poorer outcome appears to be primarily the result of decreased OS after relapse in these patients rather than a harbinger of an increased rate of relapse. Finally, while outcomes in advanced disease patients with BRAF mutations were poorer relative to nonmutation patients, the data were consistent with a modest beneficial impact from the use of anti-EGFR agents relative to those patients whose tumors contained a RAS mutation. In summary, patients with CRC that contains a BRAF mutation have a worse outcome relative to nonmutation patients. Selected patients for Braf mutation testing include patients with metastatic disease, since these patients have particularly poor outcomes. It is important to known the BRAF c.1799 (p.V600) mutation status of a patient’s CRC since standard therapy is not adequate for patients with metastatic disease and BRAF mutation. For these patients, some studies suggest the use of FOLFIRINOX [folinic acid (leucovorin calcium), 5-fluorouracil, irinotecan hydrochloride, and oxaliplatin] as first-line therapy, followed by enrollment in a clinical trial.”
- Further, clinicians should order mismatch repair status testing in patients with colorectal cancers for the identification of patients at high risk for Lynch syndrome and/or prognostic stratification (Recommendation 3), a recommendation which is supported in Evidence Summary 2.04.08 “Genetic Testing for Lynch Syndrome and Other Inherited Colon Cancer Syndromes.”

2 | BRAF V600E occurs in less than 10% of sporadic colorectal carcinoma. There is a strong negative prognostic marker for both early and late stage colorectal carcinoma especially in the non–MSI-H tumors. MSI-H tumors which have BRAF mutation may not have the same adverse prognostic responses. BRAF V 600E mutations showed resistance to anti EGFR therapy.
KRAS, NRAS, and BRAF Variant Analysis in Metastatic Colorectal Cancer 2.04.53

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<td>3</td>
<td>Pooled analysis and meta-analysis presented in summary report is self-explanatory. BRAF V600E mutations are a predictor of poor response to anti-EGFR therapy and in general represent a poor prognostic category of patients. Upon testing for RAS variants, should no Ramos for RAS be found, BRAF mutations analysis should be obtained.</td>
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<td>4</td>
<td>Overall, the presence of BRAF mutation is an indicator of poor prognosis and a potential target for clinical trials, currently testing combinations of BRAF inhibitor, MEK inhibitor and EGFR inhibitor. As such, the only clinical benefit of testing BRAF variant to guide treatment would be to consider an earlier introduction of clinical trial with combination targeted therapy, given the poor prognosis of these patients.</td>
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Only one meta-analysis provided evidence that BRAF V600E mutation is associated with lack of response in wild-type KRAS mCRC treated with anti-EGFR MoAbs [1]. More recent analysis has failed to demonstrated a negative predictive response to EGFR inhibitors in BRAF mutated colorectal cancer; however BRAF is a well described poor prognostic factor [2]. Overall, the hazard ratios of patients treated with EGFR-blocking antibodies (cetuximab or panitumumab) were not dependent on the BRAF mutation status for overall survival (interaction test P-value: 0.43) but were close to significance for progression-free survival (interaction test P-value: 0.07). [3] The authors concluded that the BRAF mutation was not predictive of benefits provided by anti-EGFR therapies. Similarly, another meta-analysis [4] reported that EGFR-blocking antibodies did not increase the efficacy of standard chemotherapy in BRAF-mutant patients [4]. |


5 | Patients with metastatic colorectal cancer who harbor both KRAS and BRAF V600E mutations have variant BRAF mutational status. BRAF V600E mutations have been found to have poor overall response to anti-EGFR therapy as compared to patients with wild-type. It is critical that only patients with BRAF V600E wild type receive anti-EGFR therapy. An example of this is in one study by Mao et al, the ORR was 29.2% for patients with mutant BRAF compared to 33.5% on wild-type BRAF. BRAF mutational status is a strong predictor for overall survival not only in the metastatic setting but also in earlier stage diagnosis. Studies using the FDA-approved and newer developed LDT tests have found adequate evidence that KRAS mutation analysis reliably and accurately detects common BRAF mutations. Results from RT-PCR testing are comparable to next gen sequencing. Testing using immunohistochemical stain (clone VE1) for BRAF V600Ein colon carcinoma needs more data. Some studies have reported near to complete concordance, but there is a report that it is not a useful surrogate for genotyping in colorectal carcinoma. |


6 | I routinely request KRAS, NRAS and BRAF testing in all my stage IV colorectal cancer patients, and consider anti-EGFR therapy in wild-type KRAS and NRAS tumors. At this point, I am not basing my decision to use anti-EGFR agent based on BRAF mutation (although I recognize it portends a poorer prognosis) since I reserve anti-EGFR therapy for 2nd line therapy. |

7 | The role for BRAF V600E testing as a predictive marker for anti-EGFR monoclonal antibody therapy effectiveness in the treatment of metastatic colorectal cancer is not yet clearly defined. The evidence available does lean to suggest that such antibody therapies are unlikely to be effective in patients whose tumors harbor such a mutation. The meta-analysis from Pietrantonio and colleagues did conclude that BRAF mutation should be considered as a factor against the use of an anti-EGFR monoclonal antibody therapy. Separately, however, the meta-analysis performed by Rowland and colleagues found the evidence for selection for or against an anti-EGFR monoclonal antibody based upon BRAF mutation insufficient. The updated recommendation from the ASCO in 2017 similarly states that the evidence for BRAF testing in this indication is insufficient. There is sparse prospective data to address this issue, and this will be necessary in order to determine if BRAF testing is requisite to the selection of anti-EGFR monoclonal antibody use in metastatic colorectal cancer. We cannot cite personal clinical experiences in a meaningful way, as the instances when we have known the BRAF status of a patient’s tumor in this context is quite limited, given that the testing is not routinely assessed. Thus, at present BRAF testing should not be routinely assessed as a biomarker for anti-EGFR selection. Future studies on par with the data establishing RAS testing as such a biomarker (CRYSTAL, OPUS, etc.), could change this, and a similar level of evidence and demonstrated benefit as established the role for RAS testing would be necessary to impart this distinction onto BRAF. Concerning sequences of testing, the value of identifying mutant KRAS in exon 2 in order to predict for or against the use of an anti-EGFR monoclonal antibody for the treatment of metastatic colorectal cancer pre-dates the similar knowledge for the value of mutational status of KRAS exons 3 and 4, NRAS, and, theoretically, BRAF. Additionally, of these mutations, KRAS exon 2 mutations are by far the most common. Prior to understanding the relevance of extended RAS testing, many institutions had developed internal tests for the KRAS exon 2 mutations. Rather than develop additional internal testing for the rest of the extended panel, many institutions still assess KRAS exon 2 internally, as it is the most common. If this turns out to be wildtype, internal practice is then to refer the specimen out for commercial testing of the remainder of the panel. Given the likelihood of the mutation being within KRAS exon 2, this practice seems reasonable. Should BRAF ultimately be added to the panel of routinely testing mutations for anti-EGFR monoclonal eligibility, or otherwise be assessed, assessing KRAS exon 2 in a similar fashion is appropriate. |

- Rowland A, Dias MM, Wiese MD, et al. Meta-analysis of BRAF mutation as a predictive biomarker of benefit from anti-EGFR monoclonal
antibody therapy for RAS wild-type metastatic colorectal cancer. Br J Cancer. Jun 09 2015;112(12):1888-1894. PMID 25989278

8 The data concerning the prognostic value of BRAF testing is very clear in that patients whose tumor harbors a BRAF mutation have a much poorer outcome compared to those with wild type BRAF. The predictive value of BRAF testing relative to anti-EGFR therapy is less clear primarily due to the small sample sizes of most clinical trials where this question has been addressed. A recent meta-analysis (Rowland A, Dias MM, Wiese MD, et al. Meta-analysis of BRAF mutation as a predictive biomarker of benefit from anti-EGFR monoclonal antibody therapy for RAS wild-type metastatic colorectal cancer. Br J Cancer. Jun 09 2015;112(12):1888-1894. PMID 25989278) concluded that the data concerning BRAF mutational status in patients with metastatic CRC was insufficient to conclude that benefit from anti-EGFR therapy varied by mutational status of BRAF. However, despite the lack of statistical significance, the data supports a substantial reduction in benefit associated with the use of anti-EGFR therapy in patients with BRAF mutant CRC. Poor prognosis coupled with the reduced benefit associated with the use of anti-EGFR therapy makes knowledge of the BRAF status in patients with metastatic CRC of paramount importance. Given the toxicities and expense associated with the use of anti-EGFR therapy, having knowledge of the BRAF mutational status would help with the clinical decision to use anti-EGFR therapy. In addition, given the relative lack of benefit associated with the use of standard CRC regimens, emerging data support the benefit of either triple therapy (FOLFIRI, Cremolini C, Loupakis F, Antoniotti C, et al. FOLFOXIRI plus bevacizumab versus FOLFIRI plus bevacizumab as first-line treatment of patients with metastatic colorectal cancer: updated overall survival and molecular subgroup analyses of the open-label, phase 3 TRIBE study. Lancet Oncol. Oct 2015;16(13):1306-1315. PMID 26338525) or the combination of anti-EGFR plus irinotecan plus a BRAF inhibitor for patients with BRAF mutant CRC (Kopetz S, McDonough SL, Lenz H-J, et al. Randomized trial of irinotecan and cetuximab with or without vemurafenib in BRAF-mutant metastatic colorectal cancer (SWOG S1406) [abstract]. J Clin Oncol. 2017;35(15 Suppl):3505). Taken together, these data support the value of BRAF mutational analysis in clinical decision making.

9 There is evidence that patients with metastatic colorectal cancer with BRAF V600E variants do not benefit from treatment with EGFR inhibitors. While V600E BRAF is a known prognostic factor, we also know that response rates to almost any of our standard therapies are low, and this includes EGFR inhibitors. Frontline, phase III, randomized metastatic CRC studies showing this are listed below:


I agree with the NCCN assertion that patients with BRAF mutated tumors are highly unlikely to respond to anti-EGFR therapy.

10 • BRAF mutations associated with low probability response to epidermal growth factor receptor (EGFR) inhibitors.
• BRAF V600E associated with worse prognosis.
  - High microsatellite instability (MSI), could be candidate for immunotherapy.
• Non V600E BRAF associated with better prognosis. All these are important for prognosis and treatment of patients with colorectal cancer.

2. Based on the evidence and your clinical experience for BRAF V600E variant testing to guide treatment with EGFR-targeted therapy in individuals with metastatic colorectal cancer:
   a. Respond YES or NO whether the intervention would be expected to provide a clinically meaningful benefit in the net health outcome.
   b. Use the 1 to 5 scale outlined below to indicate your level of confidence that there is adequate evidence that supports your conclusions.

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<thead>
<tr>
<th>No.</th>
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<td>10</td>
<td>Yes</td>
<td>3</td>
<td>3</td>
<td>5</td>
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3. Based on the evidence and your clinical experience for BRAF V600E variant testing to guide treatment with EGFR-targeted therapy in individuals with metastatic colorectal cancer:
   a. Respond YES or NO for each indication whether this intervention is consistent with generally accepted medical practice.
   b. Use the 1 to 5 scale outlined below to indicate your level of confidence in your conclusions.
4. Additional comments and/or any citations supporting your clinical input on the use of BRAF V600E variant testing to guide treatment with EGFR-targeted therapy in individuals with metastatic colorectal cancer.

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<th>Additional Comments</th>
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| 1   | The utilization and importance of BRAF V600 variant testing in patients with metastatic colon cancer extends beyond guiding treatment with EGFR-targeted therapy. Thus we recommend that Evidence Street expand the meaningful clinical benefit for BRAF in the evidence summary beyond selecting a specific targeted treatment. AMP has high confidence that BRAF V600 variant testing is clinically beneficial for these patients. BRAF V600 variant testing should not be denied for these patients solely on the basis of EGFR treatment selection. We disagree with the evidence summary that evidence is insufficient to determine the effects of BRAF variant testing on health outcomes. As mentioned above, the ASCP/CAP/AMP/ASCO guideline conducted four systematic reviews and three systematic reviews that included meta-analyses pertaining to the prognostic and predictive value of BRAF mutations in patients with CRC were identified through a systematic review process. See Table 8 and Supplemental Table 14 in the guidelines. These studies revealed that patients with advanced CRC who possess a BRAF mutation have significantly poorer outcomes as measured by PFS and OS and have a decreased response rate to anti-EGFR therapy relative to those with nonmutated BRAF. Thus, knowledge of a patient's BRAF mutation status is important since these patients have particularly poor prognosis and any therapies should be correspondingly aggressive. Further, molecular testing for BRAF variants is also supported by NCCN guidelines. The evidence summary states on page 17 that direct evidence is limited for BRAF variant testing due to the low prevalence of BRAF mutations in CRC. This is not the case, in fact BRAF activating mutations occur in about 8% of advanced disease patients with CRC and in approximately 14% of patients with localized stage II and III CRC. As such, mutations in BRAF constitute a substantial subset of patients with CRC. Evidence to support his statement:


Table 8 and Supplemental Table 14 in the guidelines. These studies reveal that patients with advanced CRC who possess a BRAF mutation have significantly poorer outcomes as measured by PFS and OS and have a decreased response rate to anti-EGFR therapy relative to those with nonmutated BRAF. Thus, knowledge of a patient's BRAF mutation status is important since these patients have particularly poor prognosis and any therapies should be correspondingly aggressive. Further, molecular testing for BRAF variants is also supported by NCCN guidelines. The evidence summary states on page 17 that direct evidence is limited for BRAF variant testing due to the low prevalence of BRAF mutations in CRC. This is not the case, in fact BRAF activating mutations occur in about 8% of advanced disease patients with CRC and in approximately 14% of patients with localized stage II and III CRC. As such, mutations in BRAF constitute a substantial subset of patients with CRC. Evidence to support his statement:


2 | None Listed

3 | Treating metastatic colorectal cancer is becoming increasingly individualized. Individuals with BRAF V600E mutations represent 5 to 10% of patients in various series. There is yet a critical mass of data to be definitive, but in my practice, we do not utilize anti-EGFR therapy in this subgroup of patients. Current data indicates BRAF V600E variants having a more aggressive course with lack of response to anti-EGFR therapy. Nevertheless, data does exist as presented by Kopetz et al at ASCO that combining anti-EGFR therapy (Cetuximab with MEK inhibitor vemurafenib) and irinotecan improved progression free survival. Similar trials with other agents are also under way. The analogy here may well be similar to Her-2 testing in the past with its associated poor prognosis until development of anti-Her-2 therapy. I believe that there is reasonably good data now on the value proposition of including BRAF mutation analysis on all metastatic specimens RAS wild. Should a mutation be found for BRAF in a RAS wild patient, alternative treatment options need to be considered.

- Tabernero J, Van Geel R, Guren TK, et al. Phase 2 results: Encorafenib (ENCO) and cetuximab (CETUX) with or without alpelisib (ALP) in patients with advanced BRAF-mutant colorectal cancer (BRAFm CRC) [abstract]. *J Clin Oncol.* 2016;34(15 Suppl):3544

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5. Is there any evidence missing from the attached draft review of evidence that demonstrates clinical benefit?

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<th>No.</th>
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<th>Citations of Missing Evidence</th>
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<tr>
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<td>Yes</td>
<td><a href="http://dx.doi.org/10.1016/j.jmoldx.2016.11.001">http://dx.doi.org/10.1016/j.jmoldx.2016.11.001</a></td>
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The evidence summary states that no published studies are available demonstrating the analytic validity of LDTs for KRAS variants, but only for the FDA approved therascreen KRAS RQG PCR Kit and Cobas KRAS Mutation Test. Evidence that KRAS mutation status was predictive of response to anti-EGFR therapies first emerged around 2008. Those studies utilized LDTs as have virtually all subsequent clinical studies. FDA approved assays specific for KRAS codons 12 and 13 did not become available until 2012. In the interim, KRAS testing was performed by LDTs as regulated under CLIA without evidence of inadequacy. An FDA approved assay for expanded RAS testing did not become available until June 2017. Further, it’s important to note that the clinical studies that established expanded RAS testing clinically did not use FDA approved assays. Thus, it is inaccurate to state in the summary that there is a lack of published evidence on the analytic validity to detect RAS variants. Below are a few examples of published evidence:


Further, the evidence summary lists two FDA-approved tests for KRAS variant analysis, the Cobas KRAS mutation test and the therascreen KRAS RQG PCR kits. In June 2017, FDA granted market approval to the Praxis Extended RAS Panel and should be included as an approved companion diagnostic tests for KRAS and NRAS variant analysis. It should also be noted in the evidence summary that the cobas KRAS mutation test and the therascreen KRAS RQG PCR kits do not detect all the variants for KRAS and NRAS recommended by current guidelines.

https://www.fda.gov/drugs/informationondrugs/approveddrugs/ucm565785.htm

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| 4   | Yes    | Results of the phase II Southwest Oncology Group (SWOG) 1406 trial presented at the ASCO Gastrointestinal Cancer Symposium in January 2017 reported that in patients with metastatic colorectal cancer who have mutations in BRAF V600, the addition of the BRAF inhibitor vemurafenib (Zelboraf) to cetuximab (Erbitux) and irinotecan significantly improved progression-free survival. The trial met its primary endpoint, improving median progression-free survival from 2.0 months with cetuximab/irinotecan to 4.4 months with the addition of vemurafenib (HR = 0.42, P = 0.0002). Grade 3/4 adverse events were significantly higher in the experimental arm and included neutropenia (28% vs 15%), anemia (13% vs 0%), and nausea (15% vs 0%). Arthralgias (a known side effect of vemurafenib) were numerically increased. There was no increase in skin toxicity or fatigue with the addition of vemurafenib. Treatment discontinuation due to adverse events occurred in 18% of the experimental arm and 8% of the control arm. Almost 50% of patients in the control arm crossed over at the time of disease progression. Overall survival and efficacy at crossover data remain immature.[1]

Moreover, results from the Phase 3 BEACON CRC study evaluating binimetinib, a MEK inhibitor, encorafenib, a BRAF inhibitor and
Erbitux® (cetuximab), an anti-EGFR antibody, in patients with BRAF-mutant colorectal cancer (CRC) whose disease has progressed after one or two prior regimens in the metastatic setting were presented at ESMO 2017 in September. There was a 41% confirmed ORR for patients on combination of binimetinib, encorafenib and cetuximab. In the safety lead-in, the triplet combination was generally well-tolerated. The most common grade 3 or 4 adverse events (AEs) seen in at least 10% of patients were nausea (10%), vomiting (10%), increased blood creatine kinase (10%) and urinary tract infection (10%). Three patients discontinued treatment due to AEs with only one considered related to treatment. At the time of the analysis, 76% of patients remain on study treatment after a median duration of treatment of 5.6 months (range 1.0 - 9.3 months). [2]

2. Huijberts S, Schellens JHM, Fakih M, et al. BEACON CRC (binimetinib [BINI], encorafenib [ENCO], and cetuximab [CTX] combined to treat BRAF-mutant metastatic colorectal cancer [mCRC]): A multicenter, randomized, open-label, three-arm phase III study of ENCO plus CTX plus or minus BINI vs irinotecan (IRI)/CTX or infusional 5-fluorouracil/folinic acid/IRI (FOLFIRI)/CTX with a safety lead-in of ENCO + BINI + CTX in patients (Pts) with BRAFV600E mCRC [abstract]. J Clin Oncol. 2017;35(15 Suppl).

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<th>Citations of Missing Evidence</th>
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<td>7</td>
<td>Yes</td>
<td>There may be benefit to patients via RAF inhibition. Data has been presented evaluating the combination of irinotecan and cetuximab with or without the RAF-inhibitor vemurafenib in the treatment of patients with BRAF-mutant colorectal cancer. This phase II clinical trial enrolled 106 patients with metastatic colorectal cancer whose tumors harbored a BRAF V600E mutation. Patients were randomized to receive either cetuximab + irinotecan or cetuximab + irinotecan + vemurafenib. PFS was improved with the addition of vemurafenib in this population (4.4 months vs. 2.0 months) as was disease control rate (67% vs. 22%). The conclusions of this study suggest that adding a BRAF inhibitor to irinotecan + cetuximab (resulting in simultaneous BRAF and EGFR inhibition) is effective in these patients. This option for treatment is being actively investigated and, if validated, would certainly change the value of BRAF testing on a routine basis for these patients.</td>
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<td>8</td>
<td>Yes</td>
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NR: no response.