Medical Policy

**MP 2.04.53**

**KRAS, NRAS, BRAF Variant Analysis (Including Liquid Biopsy) in Metastatic Colorectal Cancer**

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**POLICY**

**KRAS** variant analysis may be considered medically necessary for patients with metastatic colorectal cancer to predict nonresponse prior to planned therapy with anti-epidermal growth factor receptor monoclonal antibodies cetuximab or panitumumab.

**NRAS** variant may be considered medically necessary for patients with metastatic colorectal cancer to predict nonresponse prior to planned therapy with anti-epidermal growth factor receptor 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.

KRAS, NRAF, and BRAF variant analysis using circulating tumor DNA or circulating tumor cell testing (liquid biopsy) to guide treatment for patients with metastatic colorectal cancer is considered investigational.

**POLICY GUIDELINES**

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 \textit{BRAF} variant analysis to predict response to treatment.

\textbf{Genetics Nomenclature Update}

The Human Genome Variation Society 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). The Society's nomenclature is recommended by the Human Variome Project, the Human Genome Organization, and by the Human Genome Variation Society itself.

The American College of Medical Genetics and Genomics and the Association for Molecular Pathology standards and guidelines for interpretation of sequence variants represent expert opinion from both organizations, in addition to 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.

\textbf{Table PG1. Nomenclature to Report on Variants Found in DNA}

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

\textbf{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.

\textbf{BENEFIT APPLICATION}

\textbf{BLUECARD/NATIONAL ACCOUNT ISSUES}

Some Plans may have contract or benefit exclusions for genetic testing.

\textbf{BACKGROUND}

Cetuximab (Erbilux; 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. The Ras proteins are G proteins that cycle between active (RAS guanosine triphosphate) and inactive (RAS guanosine diphosphate) forms in response to stimulation from a cell surface receptor, such as EGFR, and they act as a binary switch between the cell surface EGFR and downstream signaling pathways. The \textit{KRAS} gene can harbor oncogenic variants that result in a constitutively activated protein, independent of EGFR ligand binding,
rendering antibodies to the upstream EGFR ineffective. Approximately 40% of colorectal cancers (CRCs) have KRAS variants in codons 12 and 13 in exon 2. Another proto-oncogene that acts downstream from KRAS-NRAS harbors oncogenic variants in codons 12, 13, or 61 that result in constitutive activation of the EGFR-mediated pathway. These variants are less common compared with KRAS, detected in 2% to 7% of CRC specimens. It is unclear whether NRAS variants predict poor response due 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; BRAF is also a principal downstream effector of KRAS. BRAF variants occur in fewer than 10% to 15% of CRCs and appear to be a marker of poor prognosis. KRAS and BRAF variants are considered to be mutually exclusive.

Cetuximab and panitumumab have marketing approval from the U.S. Food and Drug Administration (FDA) for the treatment of metastatic CRC in the refractory disease setting. The 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

**Detecting ctDNA and Circulating Tumor Cells**

Typically, the evaluation of RAS mutation status requires tissue biopsy. Circulating tumor DNA (ctDNA) testing is proposed as a non-invasive alternative.

Detection of ctDNA is challenging because ctDNA is diluted by nonmalignant circulating DNA and usually represents a small fraction (<1%) of total cfDNA. Therefore, more sensitive methods than the standard sequencing approaches (eg, Sanger sequencing) are needed.

Highly sensitive and specific methods have been developed to detect ctDNA, for both single nucleotide variants (eg BEAMing [which combines emulsion polymerase chain reaction with magnetic beads and flow cytometry] and digital polymerase chain reaction) and copy-number variants. Digital genomic technologies allow for enumeration of rare variants in complex mixtures of DNA.

Approaches to detecting ctDNA can be considered targeted, which includes the analysis of known genetic mutations from the primary tumor in a small set of frequently occurring driver mutations, which can impact therapy decisions or untargeted without knowledge of specific variants present in the primary tumor, and include array comparative genomic hybridization, next-generation sequencing, and whole exome and genome sequencing.

CTC assays usually start with an enrichment step that increases the concentration of CTCs, either by biologic properties (expression of protein markers) or physical properties (size, density, electric charge). CTCs can then be detected using immunologic, molecular, or functional assays.

A number of liquid biopsy tests related to targeted treatment of metastatic colorectal cancer have been developed (Table 1).

**Table 1. Examples of Liquid Biopsy Tests Related to Targeted Treatment of Metastatic Colorectal Cancer**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Test</th>
<th>Type of Liquid Biopsy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biocept</td>
<td>Target SElector ctDNA EGFR Kit</td>
<td>ctDNA</td>
</tr>
<tr>
<td>CellMax Life</td>
<td>CellMax-CRC Colorectal Cancer Early Detection Test</td>
<td>CTC</td>
</tr>
<tr>
<td>Cynvenio</td>
<td>ClearID Solid Tumor Panel</td>
<td>ctDNA and CTC</td>
</tr>
<tr>
<td>Foundation Medicine</td>
<td>FoundationOne Liquid (Previously FoundationAct)</td>
<td>ctDNA</td>
</tr>
</tbody>
</table>
Guardant Health Guardant360® ctD
IV Diagnostics Velox™ CTC
Pathway Genomics CancerIntercept® Detect ctD
Personal Genome Diagnostics PlasmaSELECT ctD
Sysmex Inostics OncoBEAM ctD
Circulogene Theranostics ctD

CTC: circulating tumor cell; ctDNA: circulating tumor DNA.

Regulatory Status

Approved Companion Diagnostic Tests for KRAS Variant Analysis to Select Cetuximab and Panitumumab in Metastatic Colorectal Cancer

Companion diagnostic tests for the selection of cetuximab and panitumumab have been approved by the FDA through the premarket approval process (Table 2):

Table 2. Companion Diagnostic Tests for the Selection of Cetuximab and Panitumumab for Metastatic Colorectal Cancer

<table>
<thead>
<tr>
<th>Diagnostic Name.</th>
<th>PMA/510(k)/HDE</th>
<th>Description</th>
<th>Approval Date</th>
<th>Diagnostic Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>FoundationOne CDx</td>
<td>P170019</td>
<td>Next Generation Sequencing Oncology Panel, Somatic Or Germline Variant Detection System</td>
<td>11/30/2017</td>
<td>Foundation Medicine, Inc.</td>
</tr>
<tr>
<td>Praxis Extended RAS Panel</td>
<td>P160038</td>
<td>Next Generation Sequencing Oncology Panel, Somatic Or Germline Variant Detection System</td>
<td>06/29/2017</td>
<td>Illumina, Inc.</td>
</tr>
<tr>
<td>cobas KRAS Mutation Test</td>
<td>P140023</td>
<td>Somatic Gene Mutation Detection System</td>
<td></td>
<td>Roche Molecular Systems, Inc</td>
</tr>
<tr>
<td>therascreen KRAS RGQ PCR Kit</td>
<td>P110030/P110027</td>
<td>Somatic Gene Mutation Detection System</td>
<td>5/23/2014</td>
<td>Qiagen Manchester, Ltd.</td>
</tr>
</tbody>
</table>

Source: U.S. Food and Drug Administration (2019)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, the FDA has chosen not to require any regulatory review of this test.

Liquid Biopsy

No liquid biopsy test is currently FDA approved to select treatment for patients with metastatic colorectal cancer.
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 29, 2019.

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 PICO(s) elements 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.

Patients with metastatic CRC are actively managed by oncologists.

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

Technically Reliable
Assessment of technical reliability focuses on specific tests and operators and requires a 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 CRC (Table 3). 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 a 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 four to eight 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 3, 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 3. *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>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>

Adapted from Amado et al (2008).4

BSC: best supportive care; CI: confidence interval; MT: mutated; P: panitumumab; WT: wild-type.

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 endpoints 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-fluorouracil, 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).6 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 polymerase chain reaction 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 eight 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 4.

Table 4. *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>ITTa</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</td>
<td>38.7</td>
<td>59.3</td>
</tr>
<tr>
<td></td>
<td>(42.9 to 51.0)</td>
<td>(34.8 to 66.7)</td>
<td>(51.6 to 66.7)</td>
</tr>
<tr>
<td>Median PFS, weeks</td>
<td>8.9</td>
<td>8.0</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Original Policy Date: October 2008
KRAS, NRAS, BRAF Variant Analysis (Including Liquid Biopsy) in Metastatic Colorectal Cancer

Table 5. 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% Cl), %</td>
<td>0.011</td>
<td>0.106</td>
</tr>
<tr>
<td>Odds ratio (95% Cl)</td>
<td>2.54 (1.24 to 5.23)</td>
<td>0.51 (0.22 to 1.15)</td>
</tr>
<tr>
<td>Median PFS, mo(^a)</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).\(^\text{2}\)

C: cetuximab; CI: confidence interval; F: FOLFIRI (folinic acid, 5-flouroacil, and irinotican); ITT: intention-to-treat; MT: mutated; PFS: progression-free survival; RR: response rate; WT: wild-type.

\(^a\) 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 capectabine, oxaliplatin, and bevacizumab (CB regimen, n=378), or to the same CB regimen plus cetuximab (n=377).\(^\text{8}\)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,
significant interactions between response rate (57.3% vs 39.7%; odds ratio [OR], 2.069; p<0.001) compared with FOLFIRI alone.

months; HR=0.796; p=0

with overall median duration of follow

e of 2007, and an associated overall median duration of

tumor

KRAS, Van Cutsem et al (2011) report with wild

The CRYSTAL trial (2009) demonstrated that the addition of cetuximab to FOLFIRI statistically

The updated OS analysis was carried out with a new

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).

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.® The patients had

advanced CRC had failed chemotherapy 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. The

primary endpoint was PFS; OS was a secondary endpoint. 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.® 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. The

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 endpoints. 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 endpoints 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 endpoints 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 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 CRYS`TAL 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 endpoints 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 three 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 KRAS tumors. Two of these single-arm studies have also reported differences in PFS and OS.

**Section Summary: Clinically Valid**

Evidence for the clinical validity of 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 KRAS variant predicts nonresponse to treatment while KRAS wild-type status predicts response to anti-EGFR monoclonal antibody therapy.

**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 KRAS 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, supports the use of the anti-EGFR monoclonal antibodies cetuximab and panitumumab for the treatment of patients with wild-type 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.

\textbf{NRAS VARIANT Testing to Guide Treatment for Metastatic CRC}

\textbf{Clinical Context and Test Purpose}

The purpose of \textit{NRAS} variant testing in individuals with metastatic CRC is to determine \textit{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 \textit{NRAS} variant testing improve health outcomes?

The following PICO\textit{s} elements were used to select literature to inform this review.

\textbf{Patients}

The relevant population of interest includes individuals with metastatic CRC.

\textbf{Interventions}

The test being considered is \textit{NRAS} variant testing.

Patients with metastatic CRC are actively managed by oncologists.

\textbf{Comparators}

The following test strategy is currently being used: no \textit{NRAS} variant testing to guide treatment.

\textbf{Outcomes}

The beneficial outcomes of interest include PFS and OS.

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

\textbf{Technically Reliable}

Assessment of technical reliability focuses on specific tests and operators and requires a 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.

\textbf{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.

\textbf{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 three 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. 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 endpoints 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 6 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 6. 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-flourouracil, 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 a 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. 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 a 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 FOLF4X (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 FOLF4X 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 polymerase chain reaction 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.
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.

**BRAF 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 PICOs elements 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.

Patients with metastatic CRC are actively managed by oncologists.

**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.

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

Technically Reliable
Assessment of technical reliability focuses on specific tests and operators and requires a 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 endpoint 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 (one study was a nonconcurrent analysis of response in a population previously randomized). Anti-EGFR therapy was given as first-line treatment in one study and as second-line or greater in the other ten. In two studies, the anti-EGFR monoclonal antibody was given as monotherapy, and in nine 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 of 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 three studies presented data on PFS and OS and, therefore, a 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 et al (2011) meta-analysis 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 four studies included only patients with wild-type KRAS. The primary endpoint 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 endpoints 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 two 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.

**Circulating Tumor DNA Testing (Liquid Biopsy) to Guide Treatment for Metastatic CRC**

Clinical Context and Test Purpose

One purpose of liquid biopsy testing of patients who have metastatic CRC is to inform a decision regarding treatment selection (eg, whether to select a targeted treatment or standard treatment).

The question addressed in this evidence review is: Does use of circulating tumor DNA (ctDNA) or circulating tumor cells (CTCs) testing to select treatment in patients with metastatic CRC improve the net health outcome compared with standard tissue testing?

The following PICOs elements were used to select literature to inform this review.

**Patients**
MP 2.04.53
KRAS, NRAS, BRAF Variant Analysis (Including Liquid Biopsy) in Metastatic Colorectal Cancer

The relevant population of interest includes individuals with metastatic CRC being considered for targeted therapy.

Patients with metastatic CRC are actively managed by oncologists.

Interventions

The test being considered is liquid biopsy using either ctDNA or CTCs. Both targeted polymerase chain reaction-based assays and broad next-generation sequencing-based approaches are available.

Comparators

In patients who are able to undergo a biopsy, molecular characterization of the tumor is performed using standard tissue biopsy samples. Patients unable to undergo a biopsy generally receive standard therapy.

Outcomes

True-positive liquid biopsy test results lead to the initiation of appropriate treatment (eg, targeted therapy) without a tissue biopsy. False-positive liquid biopsy test results lead to the initiation of inappropriate therapy, which could shorten progression-free survival.

In patients able to undergo a tissue biopsy, negative liquid biopsies reflex to tissue testing. In patients unable to undergo a tissue biopsy, a negative liquid biopsy result would not change empirical treatment. Therefore, health outcomes related to negative test results do not differ between liquid biopsy and tissue biopsy.

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

Technically Reliable

Assessment of technical reliability focuses on specific tests and operators and requires a 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).

Given the breadth of molecular diagnostic methodologies available to assess ctDNA and CTC, the clinical validity of each commercially available test must be established independently. Multiple high-quality studies are needed to establish the clinical validity of a test.

OncoBEAM RAS CRC Assay

The clinical validity of the OncoBEAM RAS CRC assay has been evaluated in several published studies of patients with metastatic CRC. Study characteristics and results are shown in Tables 7 and 8. Study relevance, design, and conduct limitations are described in Tables 11 and 12.

Table 7. Clinical Validity Studies of the OncoBEAM RAS Assay

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Population</th>
<th>Design</th>
<th>Reference Standard</th>
<th>Timing of Tissue Biopsy and Liquid Biopsy</th>
<th>Blinding of Assessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garcia</td>
<td>Patients with</td>
<td>Prospective</td>
<td>Analysis of Plasma collected</td>
<td>Not</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Patients</td>
<td>Sample Collection</td>
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</tr>
<tr>
<td>Foncillas et al (2018)&lt;sup&gt;42&lt;/sup&gt;</td>
<td>Metastatic CRC newly diagnosed or presenting with recurrent disease after resection and/or chemotherapy at 10 centers in Spain. Enrolled from November 2015 to October 2016.</td>
<td>Tissue using standard-of-care procedures validated by each hospital before any therapeutic intervention. OncoBEAM used when standard of care RAS result was discordant with RAS result. The same tissue block was used for re-analysis by OncoBEAM.</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vidal et al (2017)&lt;sup&gt;43&lt;/sup&gt;</td>
<td>Patients from Spain with histologically confirmed metastatic CRC. Anti-EGFR treatment-naïve. Enrolled from 2009 to 2016.</td>
<td>Retrospective-prospective Analysis of tissue samples conducted using institutional standard-of-care procedures</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schmiegel (2017)&lt;sup&gt;44&lt;/sup&gt;</td>
<td>Patients from Australia and Germany with newly diagnosed stage III/IV histologically confirmed CRC.</td>
<td>Prospective Analysis of tissue samples conducted using Sanger sequencing</td>
<td>Tissue collected immediately prior to tissue biopsy or resection.</td>
<td>Not stated</td>
<td></td>
</tr>
<tr>
<td>Grasselli (2017)&lt;sup&gt;45&lt;/sup&gt;</td>
<td>Patients from Spain with histologically confirmed metastatic CRC. Anti-EGFR treatment-naïve but majority treated with other systemic therapies.</td>
<td>Retrospective-prospective Analysis of tissue samples conducted using real-time PCR</td>
<td>Tissue collected before blood.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Normanno (2018)&lt;sup&gt;46&lt;/sup&gt;</td>
<td>Patients with metastatic CRC.</td>
<td>Retrospective-prospective Analysis of tissue</td>
<td>Unclear when tissue was collected.</td>
<td>Not stated</td>
<td></td>
</tr>
</tbody>
</table>
who KRAS exon-2 wild-type and received first-line etuximab plus FOLFIRI within the CAPRI-GOIM trial.

CRC: colorectal cancer; EGFR: epidermal growth factor receptor; NGS: next-generation sequencing; PCR: polymerase chain reaction.

Table 8. Clinical Validity Studies of the OncoBEAM RAS Assay-Results

<table>
<thead>
<tr>
<th>Study</th>
<th>Initial N</th>
<th>Final N</th>
<th>Excluded Samples</th>
<th>RAS Variant-Positive, %</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>PPV (95% CI)</th>
<th>NPV (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garcia-Foncillas et al (2018)</td>
<td>239</td>
<td>236</td>
<td>3 patients initially excluded because of total disease removal during primary surgery. RAS mutation status was evaluable in all 236 patients</td>
<td>55.5</td>
<td>86.3</td>
<td>92.4</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Vidal et al (2017)</td>
<td>NA</td>
<td>115</td>
<td>No description of samples excluded from comparison to tissue results</td>
<td>51</td>
<td>96 (87 to 100)</td>
<td>90 (79 to 96)</td>
<td>90 (79 to 96)</td>
<td>96 (88 to 100)</td>
</tr>
<tr>
<td>Schmiegel (2017)</td>
<td>102</td>
<td>98</td>
<td>N=3 (inadequate plasma DNA) N=1 (RAS mutation not confirmed in tissue when re-evaluated)</td>
<td>53</td>
<td>90 (79 to 96)</td>
<td>94 (82 to 98)</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Grasselli (2017)</td>
<td>157</td>
<td>146</td>
<td>N=11 (pre-analytical requirements or lack of tumor tissue availability)</td>
<td>59</td>
<td>89 (77 to 96)</td>
<td>90 (82 to 95)</td>
<td>84 (74 to 91)</td>
<td>93 (87 to 97)</td>
</tr>
<tr>
<td>Normanno (2018)</td>
<td>340</td>
<td>92</td>
<td>Tissue and plasma unavailable (not clear if tissue samples were</td>
<td>36</td>
<td>70 (51 to 84)</td>
<td>83 (71 to 92)</td>
<td>70 (56 to 81)</td>
<td>83 (74 to 89)</td>
</tr>
</tbody>
</table>
RC: colorectal cancer; NA: not available; NPV: negative predictive value; PPV: positive predictive value.  
a With tissue biopsy reference standard.  
b Values are percent with 95% confidence interval.  
b Confidence intervals not reported in publication; calculated from data provided.

**FoundationACT ctDNA Assay**

The FoundationACT ctDNA assay, the predecessor of FoundationOne Liquid, was compared to tissue biopsy using the FoundationOne assay in one manufacturer-sponsored study. (Li et al 2019)\(^{47}\) Study characteristics are shown in Table 9. The researchers reported results on the subset of 51 patients with KRAS, NRAS, and BRAF variants. These results are shown in Table 10. Positive percent agreement was 80% for all time points for short variants and increased to 90% for cases in which tissue and liquid biopsy were measured less than 270 days apart. Limitations of this study are described in Tables 11 and 12.

**Table 9. Clinical Validity Study of the FoundationACT ctDNA Assay**

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Population</th>
<th>Design</th>
<th>Reference Standard</th>
<th>Timing of Reference and Index Tests</th>
<th>Blinding of Assessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li et al (2019)(^{47})</td>
<td>Patients with CRC, 74% stage IV, 19% stage III, 7% stage II</td>
<td>Prospective and retrospective</td>
<td>Previously-collected tissue biopsy with FoundationOne assay</td>
<td>Liquid biopsy testing was done at the discretion of the clinician at variable time intervals after tissue sample collection (0–709 days).</td>
<td>Not stated</td>
</tr>
</tbody>
</table>

ctDNA: circulating tumor DNA; CRC: colorectal cancer.

**Table 10. Clinical Validity Study of the FoundationACT ctDNA Assay- Results**

<table>
<thead>
<tr>
<th>Study</th>
<th>Initial N</th>
<th>Final N</th>
<th>Excluded Samples</th>
<th>RAS Variant(^{\circ}) Positive, %</th>
<th>Positive Percent Agreement (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li et al (2019)(^{47})</td>
<td>96</td>
<td>73</td>
<td>22 samples did not have detectable ctDNA</td>
<td>51/74 (92%)</td>
<td>Overall (N=73) 79% Subset with KRAS, NRAS, and BRAF variants (N=51): 80% for all timepoints 90% for cases &lt;270 days between tissue and liquid</td>
</tr>
</tbody>
</table>
ctDNA: circulating tumor DNA.; PPV: positive predictive value.

Table 11. Relevance Limitations for Clinical Validity Studies of Liquid Biopsy in Metastatic Colorectal Cancer

<table>
<thead>
<tr>
<th>Study</th>
<th>Population(^a)</th>
<th>Intervention(^b)</th>
<th>Comparator(^c)</th>
<th>Outcomes(^d)</th>
<th>Duration of Follow-Up(^e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li et al (2019)(^42)</td>
<td>4.74% had metastatic disease</td>
<td></td>
<td>2. Reference standard was FoundationOne assay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garcia-Foncillas et al (2018)(^42)</td>
<td></td>
<td></td>
<td></td>
<td>3. PPV and NPV not reported</td>
<td></td>
</tr>
<tr>
<td>Vidal et al (2017)(^43)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schmiegel (2017)(^44)</td>
<td>2: Not clear if marketed version of test used</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grasselli (2017)(^45)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normanno (2018)(^46)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The study limitations stated in this table are those notable in the current review; this is not a comprehensive limitations assessment.

NPV: negative predictive value; PPV: positive predictive value.

\(^a\) Population key: 1. Intended use population unclear; 2. Clinical context is unclear; 3. Study population is unclear; 4. Study population not representative of intended use.

\(^b\) Intervention key: 1. Classification thresholds not defined; 2. Version used unclear; 3. Not intervention of interest.

\(^c\) Comparator key: 1. Classification thresholds not defined; 2. Not compared to credible reference standard; 3. Not compared to other tests in use for same purpose.

\(^d\) Outcomes key: 1. Study does not directly assess a key health outcome; 2. Evidence chain or decision model not explicated; 3. Key clinical validity outcomes not reported (sensitivity, specificity and predictive values); 4. Reclassification of diagnostic or risk categories not reported; 5. Adverse events of the test not described (excluding minor discomforts and inconvenience of venipuncture or noninvasive tests).

\(^e\) Follow-Up key: 1. Follow-up duration not sufficient with respect to natural history of disease (true positives, true negatives, false positives, false negatives cannot be determined).

Table 12. Study Design and Conduct Limitations for Clinical Validity Studies of OncoBEAM RAS Assay

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection(^a)</th>
<th>Blinding(^b)</th>
<th>Delivery of Test(^c)</th>
<th>Selective Reporting(^d)</th>
<th>Completeness of Follow-Up(^e)</th>
<th>Statistical(^f)</th>
</tr>
</thead>
</table>

Original Policy Date: October 2008
<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li et al (2019)</td>
<td>2. Inclusion required a previously performed FoundationACT assay; previous treatments varied</td>
</tr>
<tr>
<td>Garcia-Foncillas et al (2018)</td>
<td>1. Not clear whether samples were consecutive or convenience</td>
</tr>
<tr>
<td>Vidal et al (2017)</td>
<td>2. Timing of liquid biopsy and tissue biopsy varied (range 0-709 days)</td>
</tr>
<tr>
<td>Schmiegel (2017)</td>
<td>2. 20% of samples had no detectable ctDNA</td>
</tr>
<tr>
<td>Grasselli (2017)</td>
<td>1. Not clear whether samples were consecutive or convenience</td>
</tr>
<tr>
<td>Normanno (2018)</td>
<td>2. Blood collected approximately 1.5 m after tissue</td>
</tr>
<tr>
<td></td>
<td>1. Registration not described</td>
</tr>
<tr>
<td></td>
<td>1. Not clear whether there were samples that were insufficient for analysis or failed to produce results</td>
</tr>
<tr>
<td></td>
<td>1. CIs not reported but calculated based on data provided</td>
</tr>
</tbody>
</table>

The study limitations stated in this table are those notable in the current review; this is not a comprehensive limitations assessment.

CI: confidence interval; ctDNA: circulating tumor DNA.

Selection key: 1. Selection not described; 2. Selection not random or consecutive (ie, convenience).
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 liquid biopsy to guide treatment for patients with metastatic CRC.

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.

Section Summary: Clinically Useful

The clinical validity of the OncoBEAM RAS CRC Assay has been studied in multiple observational studies. When compared to tissue biopsy, sensitivity ranged from 70% (51% to 84%) to 96% (95% CI 87% to 100%) and specificity ranged from 83% (95% CI 71% to 92%) to 94% (82% to 98%). FoundationOne Liquid has been compared to tissue biopsy with the FoundationACT assay in one observational study; positive percent agreement was 80% overall and 90% when tissue and liquid biopsy were collected less than 270 days apart. Clinical validity studies were limited by unclear reporting of blinding, use of convenience rather than consecutive samples, and variation in the timing of sample collection. There are no published studies reporting clinical outcomes or clinical utility.

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. The relevant outcomes are OS, 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. The relevant outcomes are OS, 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 the 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 two meta-analyses of prospective and retrospective analyses of RCTs. The relevant outcomes are OS, 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.

For individuals with metastatic CRC who receive ctDNA or CTC testing (liquid biopsy) to guide treatment, the evidence includes observational studies. The relevant outcomes are OS, disease-specific survival, test validity, morbidity events, and medication use. Given the breadth of methodologies available to assess ctDNA and CTC, the clinical validity of each commercially available test must be established independently. The clinical validity of the OncoBEAM RAS CRC Assay has been studied in multiple observational studies. When compared to tissue biopsy, sensitivity ranged from 70% (51% to 84%) to 96% (95% CI 87% to 100%) and specificity ranged from 83% (95% CI 71% to 92%) to 94% (82% to 98%). FoundationOne Liquid has been compared to tissue biopsy with the FoundationACT assay in one observational study; positive percent agreement was 80% overall and 90% when tissue and liquid biopsy were collected less than 270 days apart. Clinical validity studies were limited by unclear reporting of blinding, use of convenience rather than consecutive samples, and variation in the timing of sample collection. There are no published studies reporting clinical outcomes or clinical utility. 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

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

Confidence Level That Clinical Use Expected to Provide Meaningful Clinical Benefit

<table>
<thead>
<tr>
<th>Respondent</th>
<th>Specialty</th>
<th>Identified by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Association for Molecular Pathology</td>
<td>Medical Oncology</td>
<td>American Society of Clinical Oncology</td>
</tr>
<tr>
<td>Dr. Allegra</td>
<td>Medical Oncology</td>
<td>Medical Oncology</td>
</tr>
<tr>
<td>Dr. Lieu</td>
<td>Medical Oncology</td>
<td>Medical Oncology</td>
</tr>
<tr>
<td>Dr. Smaglo and Dr. Chandar</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>
<td>Medical Oncology</td>
<td>Cancer Treatment Centers of America</td>
</tr>
<tr>
<td>Dr. Loaiza-Bonilla</td>
<td>Medical Oncology</td>
<td>Cancer Treatment Centers of America</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Pathology and Laboratory Medicine</td>
<td>Cancer Treatment Centers of America</td>
</tr>
<tr>
<td>Dr. Chowdhury</td>
<td>Medical Oncology</td>
<td>Cancer Treatment Centers of America</td>
</tr>
</tbody>
</table>

Confidence Level That Clinical Use is Consistent with Generally Accepted Medical Practice

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:
  o 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:

‘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 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 extend 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])
Variants Analysis (Including Liquid Biopsy) in Metastatic Colorectal Cancer

- "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 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 colorectal cancer 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

The National Comprehensive Cancer Network (v.2.2018) guidelines on the treatment of colon cancer recommend that tumor tissue should be genotyped for RAS (KRAS and NRAS) and BRAF variants, individually or as part of a next-generation sequencing panel, for all patients with metastatic colon cancer (v.2.2019). Testing should be performed on archived specimens of the primary tumor or 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.

The guidelines for colon cancer (v.2.2019) reference a paper on circulating tumor DNA in the discussion of adjuvant chemotherapy in stage II disease with the statement "Research into additional possible predictive markers may allow for more informed decision-making in the future."

American College of Medical Genetics and Genomics

An evidence review published by the American College of Medical Genetics and Genomics (2013) 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.

The American Society of Clinical Oncology along with American Society for Clinical Pathology, College of American Pathologists, Association for Molecular Pathology (2017) published guidelines on molecular biomarkers for the evaluation of colorectal cancer. Table 13 summarizes the relevant guidelines.

Table 13. Summary of Recommendations

<table>
<thead>
<tr>
<th>Guidelines</th>
<th>Type</th>
<th>SOE</th>
<th>QOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorectal carcinoma</td>
<td>Recommendatio</td>
<td>Convincing/ adequate, benefits</td>
<td>High/intermediat</td>
</tr>
</tbody>
</table>
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 of exon 4 ("expanded" or "extended" RAS).

<table>
<thead>
<tr>
<th>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</th>
<th>Recommendatio n</th>
<th>Adequate/inadequate, balance of benefits and harms</th>
<th>Intermediate/low</th>
</tr>
</thead>
<tbody>
<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 sporadic pathogenesis. The absence of BRAF mutation does not exclude risk of Lynch syndrome</td>
<td>Recommendatio n</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>Recommendatio n</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</td>
</tr>
</tbody>
</table>

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

The American Society of Clinical Oncology (2015) updated its provisional clinical opinion on extended RAS variant testing in metastatic colorectal cancer to predict response to anti-EGFR.
monoclonal antibody therapy.\textsuperscript{51} The opinion was based on evidence from 13 articles on \textit{KRAS} variants (11 systematic reviews, 2 health technology assessments) and 2 articles on \textit{NRAS} testing. The opinion stated that subgroup analyses of patients with any of the less common \textit{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 \textit{RAS} variant other than the exon 2 \textit{KRAS} variant. The Society considered the less common \textit{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 \textit{KRAS}.

\section*{U.S. Preventive Services Task Force Recommendations}
Not applicable.

\section*{Medicare National Coverage}
A March 2018 decision memo from the Centers for Medicare & Medicaid Services addressed next-generation sequencing for Medicare beneficiaries with advanced cancer.\textsuperscript{52} The memo states:

The Centers for Medicare & Medicaid Services has determined that Next Generation Sequencing (NGS) as a diagnostic laboratory test is reasonable and necessary and covered nationally when performed in a CLIA-certified laboratory, when ordered by a treating physician and when all of the following requirements are met:

1. Patient has:
   a. either recurrent, relapsed, refractory, metastatic, or advanced stages III or IV cancer; and
   b. either not been previously tested using the same NGS test for the same primary diagnosis of cancer or repeat testing using the same NGS test only when a new primary cancer diagnosis is made by the treating physician; and
   c. decided to seek further cancer treatment (e.g., therapeutic chemotherapy).

2. The diagnostic laboratory test using NGS must have:
   a. Food and Drug Administration approval or clearance as a companion in vitro diagnostic; and
   b. a Food and Drug Administration approved or cleared indication for use in that patient's cancer; and
   c. results provided to the treating physician for management of the patient using a report template to specify treatment options.

Regarding liquid biopsies, the memo states, "The NCD does not limit coverage to how to prepare a sample for performing a diagnostic laboratory test using NGS. Commenters submitted published articles on liquid biopsies (also referred to as circulating tumor DNA (ctDNA) or plasma cell-free DNA (cfDNA) tests). We reviewed and included in the evidence and analysis of four studies on liquid biopsies. At this time, liquid-based multi-gene sequencing panel tests are left to contractor discretion if certain patient criteria are met."\textsuperscript{52}

\section*{Ongoing and Unpublished Clinical Trials}
A currently unpublished trial that might influence this review is listed in Table 14.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|}
\hline
NCT No. & Trial Name & Planned Enrollment & Completion Date \\
\hline
\end{tabular}
\end{table}
ESSENTIAL HEALTH BENEFITS

The Affordable Care Act (ACA) requires fully insured non-grandfathered individual and small group benefit plans to provide coverage for ten categories of Essential Health Benefits (“EHBs”), whether the benefit plans are offered through an Exchange or not. States can define EHBs for their respective state. States vary on how they define the term small group. In Idaho, a small group employer is defined as an employer with at least two but no more than fifty eligible employees on the first day of the plan or contract year, the majority of whom are employed in Idaho. Large group employers, whether they are self-funded or fully insured, are not required to offer EHBs, but may voluntary offer them.

The Affordable Care Act requires any benefit plan offering EHBs to remove all dollar limits for EHBs.

REFERENCES


**CODES**

<table>
<thead>
<tr>
<th>Codes</th>
<th>Number</th>
<th>Description</th>
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<tbody>
<tr>
<td>CPT</td>
<td>81210</td>
<td>BRAF (B-Raf proto-oncogene, serine/threonine kinase) (eg, colon cancer, melanoma), gene analysis, V600 variant(s)</td>
</tr>
<tr>
<td>CPT</td>
<td>81275</td>
<td>KRAS (Kirsten rat sarcoma viral oncogene homolog) (eg, carcinoma) gene analysis; variants in exon 2 (eg, codons 12 and 13)</td>
</tr>
<tr>
<td>CPT</td>
<td>81276</td>
<td>KRAS (Kirsten rat sarcoma viral oncogene homolog) (eg, carcinoma) gene analysis; additional variant(s) (eg, codon 61, codon 146)</td>
</tr>
<tr>
<td>CPT</td>
<td>81311</td>
<td>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)</td>
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<tr>
<td>CPT</td>
<td>88363</td>
<td>Examination and selection of retrieved archival (ie, previously diagnosed) tissue(s) for molecular analysis (eg, KRAS mutational analysis)</td>
</tr>
<tr>
<td>0069U</td>
<td></td>
<td>Oncology (colorectal), microRNA, RT-PCR expression profiling of miR-31-3p, formalin-fixed paraffin-embedded tissue, algorithm reported as an expression score (new eff 10/1/18)</td>
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<tr>
<td>ICD-10-CM</td>
<td>C18.0-C18.9</td>
<td>Malignant neoplasm of colon code range</td>
</tr>
<tr>
<td>ICD-10-CM</td>
<td>C19</td>
<td>Malignant neoplasm of rectosigmoid junction</td>
</tr>
<tr>
<td>ICD-10-CM</td>
<td>C20</td>
<td>Malignant neoplasm of rectum</td>
</tr>
<tr>
<td>ICD-10-CM</td>
<td>C78.5</td>
<td>Secondary malignant neoplasm of large intestine and rectum</td>
</tr>
</tbody>
</table>

**POLICY HISTORY**

<table>
<thead>
<tr>
<th>Date</th>
<th>Action</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/11/14</td>
<td>Replace policy</td>
<td>Policy updated with literature review through September 30, 2014; references 20-24 and 38 were added. Title changed to indicate inclusion</td>
</tr>
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</table>
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.

<table>
<thead>
<tr>
<th>Date</th>
<th>Action</th>
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<tr>
<td>05/19/16</td>
<td>Replace policy</td>
<td>Policy updated with literature review through March 24, 2016; references 1, 21-22, 28, and 42-43 were added. 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.</td>
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<tr>
<td>06/01/17</td>
<td>Replace policy</td>
<td>Blue Cross of Idaho annual review; no change to policy.</td>
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<tr>
<td>11/30/17</td>
<td>Replace policy</td>
<td>Blue Cross of Idaho adopted changes to policy as noted Policy updated with literature review through June 2, 2017; reference 2-4 and 46 added. Policy revised with updated genetics nomenclature. Policy statements otherwise unchanged. Title changed to “KRAS, NRAS, and BRAF Variant Analysis in Metastatic Colorectal Cancer”.</td>
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<tr>
<td>07/25/18</td>
<td>Replace policy</td>
<td>Blue Cross of Idaho adopted changes as noted. Policy updated with literature review through May 10, 2018; no references added. Policy statements unchanged.</td>
</tr>
<tr>
<td>07/22/19</td>
<td>Replace policy</td>
<td>Blue Cross of Idaho adopted changes as noted, effective 10/21/2019. Policy updated with literature review through May 29, 2019; references added. Indication 4 (KRAS, NRAS, and BRAF variant analysis using circulating tumor DNA or circulating tumor cell testing [liquid biopsy] to guide treatment) removed from policy 2.01.141 and inserted here. Policy statement for Indication 4 added: &quot;KRAS, NRAS, and BRAF variant analysis using circulating tumor DNA or circulating tumor cell testing (liquid biopsy) to guide treatment for patients with metastatic colorectal cancer is considered investigational.&quot; Title changed to include liquid biopsy.</td>
</tr>
</tbody>
</table>

APPENDIX
APPENDIX 1: CLINICAL INPUT

Appendix Table 2. Respondent Profile

<table>
<thead>
<tr>
<th>Specialty Society</th>
<th>Clinical Specialty</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Name of Organization</td>
</tr>
<tr>
<td>1</td>
<td>Association for Molecular Pathology</td>
</tr>
</tbody>
</table>

Physician

<table>
<thead>
<tr>
<th>No.</th>
<th>Identified by Cancer Treatment Centers of America (CTCA)</th>
<th>Name</th>
<th>Degree</th>
<th>Institutional Affiliation</th>
<th>Clinical Specialty</th>
<th>Board Certification and Fellowship Training</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>Anonymous MD</td>
<td>Cancer Treatment Centers of America (CTCA)</td>
<td>Medical Oncologist</td>
<td>Internal Medicine and Medical Oncology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Eyal Meiri MD</td>
<td>Cancer Treatment Centers of America (CTCA)</td>
<td>Medical Oncology</td>
<td>Medical Oncology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Arturo Loaiza-Bonilla MD, MSEd</td>
<td>Cancer Treatment Centers of America (CTCA)</td>
<td>Medical Oncology, Gastrointestinal Oncology</td>
<td>ABIM certified in Internal Medicine, Medical Oncology and Hematology. Fellowship.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Anonymous MD</td>
<td>Cancer Treatment Centers of America (CTCA)</td>
<td>Pathology and Laboratory Medicine</td>
<td>American Board of Pathology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shahin Chowdhury DO</td>
<td>Cancer Treatment Centers of America (SERMC)</td>
<td>Medical Oncology</td>
<td>American College of Osteopathic Internists (ACOI)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Identified by Dan L Duncan Comprehensive Cancer Center, Baylor College of Medicine

<table>
<thead>
<tr>
<th>Identified by Dan L Duncan Comprehensive Cancer Center, Baylor College of Medicine</th>
<th>Name</th>
<th>Degree</th>
<th>Institutional Affiliation</th>
<th>Clinical Specialty</th>
<th>Board Certification and Fellowship Training</th>
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</table>

Identified by American Society of Clinical Oncology

<table>
<thead>
<tr>
<th>Identified by American Society of Clinical Oncology</th>
<th>Name</th>
<th>Degree</th>
<th>Institutional Affiliation</th>
<th>Clinical Specialty</th>
<th>Board Certification and Fellowship Training</th>
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<tbody>
<tr>
<td>8</td>
<td>Carmen J. Allegra MD</td>
<td>University of Florida</td>
<td>Medical Oncology</td>
<td>Internal Medicine and Oncology</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Christopher H. Lieu MD</td>
<td>University of Colorado</td>
<td>Medical Oncology</td>
<td>Medical Oncology -</td>
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</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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes/No</td>
<td>Explanation</td>
<td>Yes/No</td>
<td>Explanation</td>
</tr>
<tr>
<td>2</td>
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<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>No</td>
<td>No</td>
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</tr>
<tr>
<td>5</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>No</td>
<td>No</td>
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<tr>
<td>7</td>
<td>No</td>
<td>Yes (BGS)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No (MC)</td>
<td></td>
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</tr>
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<td>8</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASCO representative for colorectal cancer biomarkers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Individual Conflict of Interest Policy Statement

1. No conflict of interest

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>
</thead>
<tbody>
<tr>
<td>Individuals:</td>
<td>Interventions of interest are:</td>
<td>Comparators of interest are:</td>
<td>Relevant outcomes include:</td>
</tr>
<tr>
<td>• With metastatic colorectal cancer</td>
<td>• BRAF variant testing to guide treatment</td>
<td>• No BRAF variant testing to guide treatment</td>
<td>• Overall survival</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Disease-specific survival</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Change in disease status</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Medication use</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Treatment-related morbidity</td>
</tr>
</tbody>
</table>

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.

No. Response
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 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:
**MP 2.04.53**  
*KRAS, NRAS, BRAF Variant Analysis (Including Liquid Biopsy) in Metastatic Colorectal Cancer*

---

**No.**  
**Response**

• 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: “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. 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.”

• 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 V600E mutations showed resistance to anti-EGFR therapy.

3 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.

4 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.

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 have 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]


Patients with metastatic colorectal carcinoma who have been shown on testing to have variants of 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.

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.

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.

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...
No.  Response

(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 (FOLFOXIRI; 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 BRAF V600E 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 \textit{BRAF} V600E variant testing to guide treatment with \textit{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.

   \begin{center}
   \begin{tabular}{|c|c|c|c|c|}
   \hline
   \textbf{No.} & \textbf{Yes / No} & \textbf{Low Confidence} & \textbf{Intermediate Confidence} & \textbf{High Confidence} \\
   \hline
   1 & Yes & 1 & 2 & 3 \textbf{4} \textbf{5} \\
   2 & Yes & 1 & 2 & 3 \textbf{4} \\
   3 & Yes & 1 & 2 & 3 \textbf{4} \\
   4 & Yes & 1 & 2 & 3 \textbf{4} \\
   5 & Yes & 1 & 2 & 3 \textbf{4} \\
   6 & No & 1 & 2 & 3 \textbf{4} \\
   7 & Yes & 1 & 2 & 3 \textbf{4} \\
   8 & Yes & 1 & 2 & 3 \textbf{5} \\
   9 & Yes & 1 & 2 & 3 \textbf{5} \\
   10 & Yes & 1 & 2 & 3 \textbf{5} \\
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   \end{tabular}
   \end{center}

3. Based on the evidence and your clinical experience for \textit{BRAF} V600E variant testing to guide treatment with \textit{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.

   \begin{center}
   \begin{tabular}{|c|c|c|c|c|}
   \hline
   \textbf{No.} & \textbf{Yes / No} & \textbf{Low Confidence} & \textbf{Intermediate Confidence} & \textbf{High Confidence} \\
   \hline
   1 & Yes & 1 & 2 & 3 \textbf{4} \textbf{5} \\
   2 & Yes & 1 & 2 & 3 \textbf{4} \\
   3 & Yes & 1 & 2 & 3 \textbf{5} \\
   4 & Yes & 1 & 2 & 3 \textbf{5} \\
   5 & Yes & 1 & 2 & 3 \textbf{4} \\
   6 & No & 1 & 2 & 3 \textbf{4} \\
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<td>7</td>
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<td>10</td>
<td>Yes</td>
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</table>
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.

<table>
<thead>
<tr>
<th>No.</th>
<th>Additional Comments</th>
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<tbody>
<tr>
<td>1</td>
<td>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: • Gavin PG, Colangelo LH, Fumagalli D, et al. Mutation profiling and microsatellite instability in stage II and III colon cancer: an assessment of their prognostic and oxaliplatin predictive value. Clin Cancer Res. Dec 01 2012;18(23):6531-6541. PMID 23045248 • Xu Q, Xu AT, Zhu MM, et al. Predictive and prognostic roles of BRAF mutation in patients with metastatic colorectal cancer treated with anti-epidermal growth factor receptor monoclonal antibodies: a meta-analysis. J Dig Dis. Aug 2013;14(8):409-416. PMID 23615046 • Yuan ZX, Wang XY, Qin QY, et al. The prognostic role of BRAF mutation in metastatic colorectal cancer receiving anti-EGFR monoclonal antibodies: a meta-analysis. PLoS One. 2013;8(6):e65995. PMID 23776587 • Forbes SA, Bhamra G, Bamford S, et al. The Catalogue of Somatic Mutations in Cancer (COSMIC). Curr Protoc Hum Genet. Apr 2008;Chapter 10:Unit 10 11. PMID 18428421</td>
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<tr>
<td>2</td>
<td>None Listed</td>
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<tr>
<td>3</td>
<td>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.</td>
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Variant Analysis (Including Liquid Biopsy) in Metastatic Colorectal Cancer

No. Additional Comments

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

4 See above response in Question 1.
5 Testing using next gen sequencing has found several non-V600E mutations. Additional studies need to be done on these non-V600E mutations to determine its significance and effect on patient’s response to therapy.
6 I don’t use BRAF test to determine use of anti-EGFR therapy.
7 An important issue to consider for future use of BRAF testing is cost. One cycle of cetuximab at our institution would cost over $11,000 to administer, which in most instances would already surpass the cost of the BRAF mutational status testing. Thus, if the value of BRAF mutational testing as a predictor for or against anti-EGFR monoclonal antibody therapy is confirmed, cost/benefit would also be a key reason to quickly adopt its use.

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

No. Yes/No Citations of Missing Evidence

1 Yes Yes, in March 2017, the American Society for Clinical Pathology, College of American Pathologists, Association for Molecular Pathology, and American Society of Clinical Oncology 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. An expert panel was convened to develop an...
evidence-based guideline to establish standard molecular biomarker testing and guide therapies for patients with CRC. During this process, a comprehensive literature search that included more than 4,000 articles was conducted. The guideline is available for download here and is open access. A full citation is also provided below, for your convenience. http://dx.doi.org/10.1016/j.jmoldx.2016.11.001


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 RGQ 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 RGQ 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 RGQ 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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<th>No.</th>
<th>Yes/No</th>
<th>Citations of Missing Evidence</th>
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<tr>
<td>4</td>
<td>Yes</td>
<td>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 7%), 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]</td>
</tr>
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<td>5</td>
<td>No</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 vemurafenib in BRAF-mutant metastatic colorectal cancer (SWOG 1406) [abstract]. J Clin Oncol. 2017;35(4 Suppl):520.</td>
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<td>6</td>
<td>No</td>
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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 +</td>
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<tr>
<td>No.</td>
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<td>Citations of Missing Evidence</td>
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<td>8</td>
<td>Yes</td>
<td>As noted above in responses to #1 and 4</td>
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<td>10</td>
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<td>NR: no response.</td>
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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.