

Corporate Medical Policy

Genetic Testing of Mitochondrial Disorders AHS – M2085

File Name: genetic_testing_of_mitochondrial_disorders
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Description of Procedure or Service

Description

Mitochondrial disease refers to a heterogeneous group of disorders caused by dysfunctional mitochondria, the organelles responsible for oxidative phosphorylation within the cell. Mitochondrial diseases are classified according to the primary genetic defect, including those affecting respiratory chain proteins or ancillary proteins, mitochondrial RNA translation defects, inner membrane lipid defects, mutations causing depletion of mitochondrial DNA, or mutations to mitochondrial dynamics. Tissues with high energy demands, such as brain, heart, and skeletal muscle, are most affected by mitochondrial diseases (O'Ferrall, 2019). As a result, mitochondrial encephalopathy and cardiomyopathy are the most prominent manifestations (Meyers, Basha, & Koenig, 2013).

Related Policies

General Genetic Testing, Germline Disorders AHS – M2145
General Genetic Testing, Somatic Disorders AHS – M2146

******Note: This Medical Policy is complex and technical. For questions concerning the technical language and/or specific clinical indications for its use, please consult your physician.***

Policy

BCBSNC will provide coverage for genetic testing of mitochondrial disorders when it is determined to be medically necessary because the medical criteria and guidelines shown below are met.

Benefits Application

This medical policy relates only to the services or supplies described herein. Please refer to the Member's Benefit Booklet for availability of benefits. Member's benefits may vary according to benefit design; therefore member benefit language should be reviewed before applying the terms of this medical policy.

When Genetic Testing of Mitochondrial Disorders is covered

1. Genetic testing to confirm the diagnosis of a mitochondrial disorder (Eg. MELAS, MERRF, CPEO, Kearns-Sayre syndrome, Leigh's syndrome) is considered medically necessary as an alternative to muscle biopsy when clinical signs and symptoms are consistent with a specific mitochondrial disorder, but the diagnosis cannot be made with certainty without genetic testing.

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2. In patients strongly suspected of having a mitochondrial disorder without symptomology associated with a specific mitochondrial condition, genomic sequencing and large deletion detection of the entire mitochondrial genome with heteroplasmy detection is considered medically necessary.
3. Quantification of mtDNA in tissue to diagnose mtDNA depletion syndrome is considered medically necessary.
4. Genetic counseling for mitochondrial disorder genetic testing is considered medically necessary.

When Genetic Testing of Mitochondrial Disorders is not covered

Combination testing of mitochondrial genome testing with WES with intronic variants testing and regulatory variants testing, sometimes referred to as whole exome plus testing, including but not limited to Genomic Unity® Exome Plus Analysis is considered not medically necessary.

Combination testing of mitochondrial genome testing with WGS with intronic variants testing and regulatory variants testing, sometimes referred to as Genomic Unity® Whole Genome Analysis is considered not medically necessary.

Genetic testing for mitochondrial disorders is considered investigational in all other situations.

Policy Guidelines

Background

Mitochondrial diseases are generally inherited and present with an elaborate genetic makeup (Lightowlers, Taylor, & Turnbull, 2015). Several different types of mitochondrial diseases and resulting ailments exist which include “mitochondrial encephalomyopathy, lactic acidosis, and stroke-like episodes (MELAS), myoclonic epilepsy and ragged-red-fibers (MERRF), chronic progressive external ophthalmoplegia (CPEO), Kearns-Sayre syndrome (KSS), neuropathy, ataxia, and retinitis pigmentosa (NARP), maternally inherited Leigh syndrome (MILS), and Leber hereditary optic neuropathy (LHON) (Hatakeyama & Goto, 2016).” These diseases can be caused by mutations in either nuclear DNA (nDNA) or mitochondrial DNA (mtDNA); many different mitochondrial disease mutations have been identified, but clinical symptoms are extremely variable and may even differ between patients carrying the same mtDNA mutation (Hatakeyama & Goto, 2016). Symptoms present in several areas of the body, including the central nervous system, cardiovascular system, gastrointestinal system, endocrine system, and neuromuscular system (Hatakeyama & Goto, 2016). Clinical differences depend on age of onset, affected organ or tissue, and disease progression. Phenotypic variability and severity can create challenges when diagnosing affected patients (O’Ferrall, 2019).

Pathogenic variants in more than 300 genes have been associated with mitochondria-related disorders (Thompson et al., 2019). For example, infantile onset of mitochondrial diseases with multiple mitochondrial respiratory chain defects result from mutation(s) in the Required for Meiotic Nuclear Division protein 1 (*RMND1*) gene (Ng et al., 2016). Further, a pathogenic variant in the ubiquinone biosynthesis protein (*COQ4*) gene has been affiliated with mitochondrial disease development (Lightowlers et al., 2015; Ling et al., 2019). Patients with mutations in the NADH dehydrogenase mitochondrial (*MT-ND1* and *NDUF*) genes share phenotypic and genotypic correlations in Leigh Syndrome (Sofou et al., 2018). The individual symptoms are nonspecific, and symptom patterns can overlap considerably. As a result, a patient often cannot be easily classified into one particular syndrome (Chinnery, 2014).

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Previously, the prevalence of mitochondrial diseases was considered low. With the advent of advanced genetic analysis tools, numerous studies now report a higher incidence of mitochondrial-associated mutations. A meta-analysis of the prevalence of the three primary mtDNA mutations that cause LHON in Europe shows a prevalence of approximately 1:45,000 (Mascialino, Leinonen, & Meier, 2012). A longitudinal study in Sweden reports an incidence of mitochondrial encephalomyopathies, in general, at 1:11,000, and an incidence of infantile mitochondrial myopathy with cytochrome C oxidase deficiency at 1:51,000. The authors conclude that “mitochondrial encephalomyopathies are relatively common neurometabolic disorders in childhood” (Darin, Oldfors, Moslemi, Holme, & Tulinius, 2001). A 2015 study in the United Kingdom reports that “the total prevalence of adult mitochondrial disease, including pathogenic mutations of both the mitochondrial and nuclear genomes (≈ 1 in 4,300), is among the commonest adult forms of inherited neurological disorders (Gorman et al., 2015).” An Australian study estimates a “minimum birth prevalence of 13.1/100 000 or 1/7634 for respiratory chain disorders with onset at any age (Skladal, Halliday, & Thorburn, 2003).”

The figure below (taken from (O’Brien, Cryan, Brett, Howley, & Farrell, 2014)) gives examples of classical phenotype mitochondrial diseases along with the clinical features and molecular genetics associated with each disorder.

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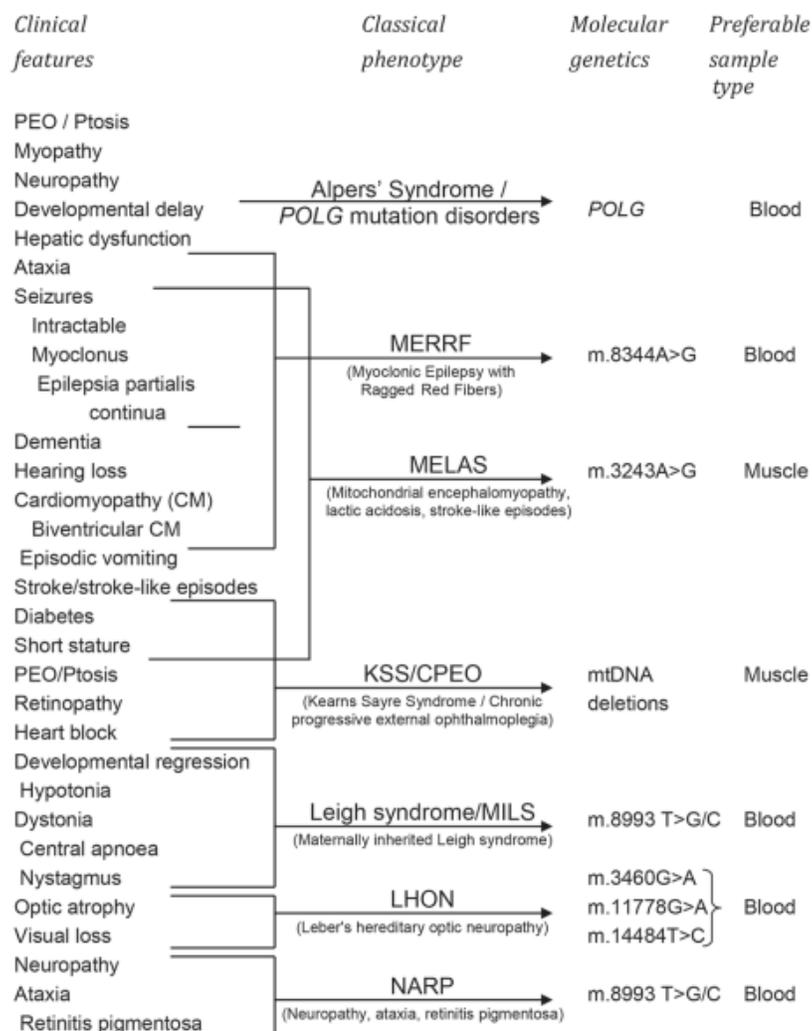


Figure 1. Algorithm for mitochondrial mutation analysis. Key clinical features, although not specific for each disease, can be used to select pertinent genetic tests and hence improve the efficiency of the analysis process.

The evaluation and diagnostic approach for a mitochondrial disorder varies according to age, clinical phenotype, and presumed inheritance pattern. Biochemical testing is indicated for patients who do not have a clear clinical picture of one specific disorder. Measurement of serum lactic acid is often used as a screening test, but the test is neither sensitive nor specific for mitochondrial disorders (Schon, DiMauro, & Hirano, 2012). “Identifying causative mutations underlying mitochondrial dysfunction is the ultimate gold standard for the diagnosis. Two mitochondrial diseases (MNGIE and coenzyme Q10 deficiency) are particularly important to identify because of potential treatments (O’Ferrall, 2019).”

Clinical Validity and Utility

Clinical utility is high for confirming the diagnosis of mitochondrial disorders in people who have clinical features consistent with a specific mitochondrial disease. In these patients, a positive result on genetic testing can avoid a muscle biopsy and eliminate the need for further clinical workup

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(Dimmock & Lawlor, 2017). Additionally, genetic testing may impact reproductive decision making when a defined mitochondrial disease is present in the family that is severe enough to cause impairment and/or disability. If genetic testing is used in this situation, there will be a decreased risk of a mitochondrial disorder in the offspring. Such testing includes whole-exome sequencing, whole-genome sequencing, and whole mitochondrial sequencing.

The most common first-line diagnostic test for a mitochondrial disease is massively parallel sequencing (MPS), also known as Next-Generation Sequencing (NGS); other accepted methods included targeted panels, whole-exome sequencing (WES) and whole-genome sequencing (WGS) (Horvath & Chinnery, 2019). Broad-based exome sequencing has been considered the first-line diagnostic tool for primary mitochondrial disease (PMD) (McCormick, Zolkipli-Cunningham, & Falk, 2018), and other researchers have used WES in tandem with rapid mitochondrial genome (mtDNA) sequencing for diagnoses (Akesson et al., 2019).

WES is likely to increase the detection rate but will also increase the rate of identifying a variant of uncertain significance (VUS). In one study from the U.K., 53 patients who had biochemical evidence of a mitochondrial disorder, but were negative on genetic testing of the primary mitochondrial disorder mutations, underwent whole exome sequencing. Probable pathogenic mutations causative of a mitochondrial disorder were identified in 28 patients (53%), and an additional four patients had variants that were possibly pathogenic (Taylor et al., 2014). “False negative rates vary by genomic region; therefore, genomic testing may not be as accurate as targeted single gene testing or multigene molecular genetic testing panels. Most laboratories confirm positive results using a second, well-established method (Chinnery, 2014).”

Expanded panels are defined as panels that include more genes than are associated with any specific disorder. When these panels are used in individuals with nonspecific signs and symptoms that are not consistent with a “classic” presentation of a mitochondrial disorder, the probability of finding a pathogenic mutation is considerably less. Conversely, the likelihood of a false-positive result and the number of VUS (a variant of uncertain significance) may be substantially increased (O'Brien et al., 2014). Table 1, below, lists examples of commercially available expanded genetic panels for mitochondrial disorders.

Table 1. Examples of Commercially Available Expanded Genetic Panels for Mitochondrial Disorders

Laboratory	Lab Test or Panel	Number of Genes Included on Panel
Gene Dx® (Gaithersburg, MD)	MitoXpanded Panel (GeneDX, 2018b)	~1800
	Combined Mito Genome Plus Mito Focused Nuclear Gene Panel (GeneDX, 2018a)	202
Transgenomic® (New Haven, CT)	Nuclear Mitome Test (Transgenomic, 2011)	>400
ARUP® (Salt Lake City, UT)	Mitochondrial Disorders Panel (ARUP, 2018)	>150
Baylor® Miraca Genetics Laboratories (Houston, TX)	Mitome Nuclear Genes (BMGL, 2015)	164
Medical Neurogenetics® (Atlanta, GA)	Mitochondrial Genome Sequencing & Deletion	>300

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	Analysis (Medical Neurogenetics, 2018)	
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Wood et al. (2019) recently compared the mtDNA sequencing results of the long-read sequencing technology Oxford Nanopore Technologies (ONT) MinION to the Illumina MiSeq, a next generation sequencing platform. A total of 12 patients participated in this study (three healthy controls and nine with known mtDNA deletion disorders). Both of these next-generation sequencing methods were more efficient than LR-PCR and/or Southern Blotting; further, MinION proved to be just as accurate as the Illumina MiSeq in this study, successfully identifying all mtDNA deletions (Wood et al., 2019). This tool may assist in making the mitochondrial disease diagnostic process more efficient and cost effective in the future.

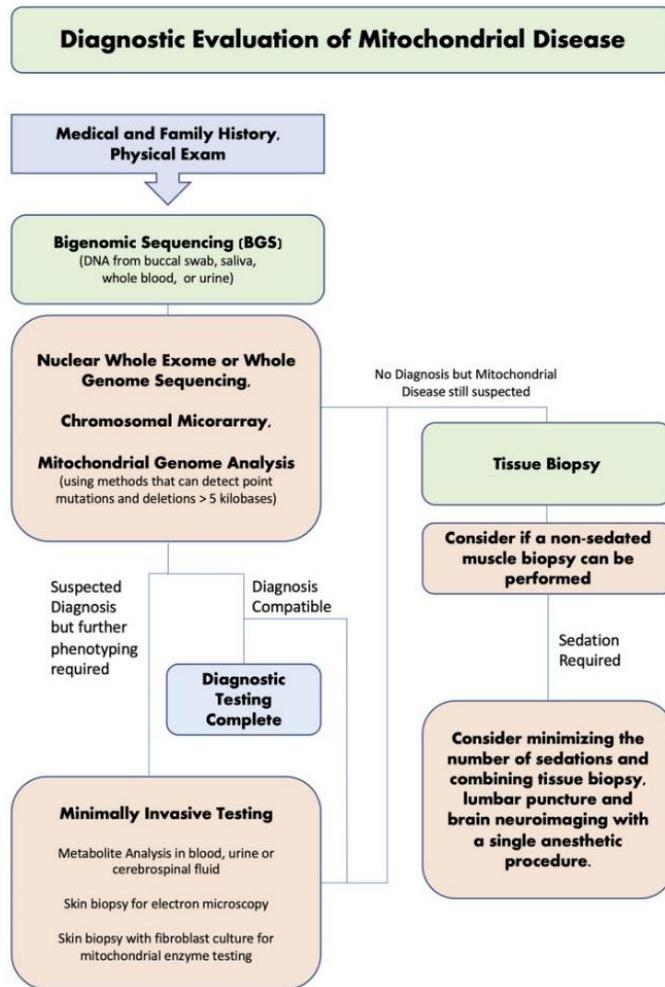
Wagner et al. (2019) researched the effectiveness of exome sequencing (ES) for mitochondrial disease diagnostics; data was used from 2111 clinical cases. The researchers stated that “ES identified known pathogenic mtDNA point mutations in 38 individuals, increasing the diagnostic yield by nearly 2%. Analysis of mtDNA variants by ES had a high recall rate ($96.2 \pm 5.6\%$) and excellent precision ($99.5 \pm 2.2\%$) when compared to the gold standard of targeted mtDNA next generation sequencing. (Wagner et al., 2019).” These results suggest that ES should be considered as a diagnostic tool for both nDNA and mtDNA testing.

Legati et al. (2016) suggest a two-tiered approach to genetic testing where targeted NGS is used first in cases of suspected mitochondrial disorders followed by WES in patients who have inconclusive results. “Importantly, WES on selected cases has unraveled the presence of pathogenic mutations in genes encoding non-mitochondrial proteins (e.g. the transcription factor E4F1), an observation that further expands the intricate genetics of mitochondrial disease and suggests a new area of investigation in mitochondrial medicine (Legati et al., 2016).”

Pronicka et al. (2016) suggest that whole-exome sequencing (WES) is a better diagnostic tool than NGS. A total of 113 pediatric Polish patients participated in this study; variants were identified in both nDNA and mtDNA (Pronicka et al., 2016). WES was able to identify “likely causative mutations” in 67 patients, with 50.5% of all detected genetic changes novel variants; further, “In 47 patients, changes in 31 MD-related genes (*ACAD9*, *ADCK3*, *AIFM1*, *CLPB*, *COX10*, *DLD*, *EARS2*, *FBXL4*, *MTATP6*, *MTFMT*, *MTND1*, *MTND3*, *MTND5*, *NAXE*, *NDUFS6*, *NDUFS7*, *NDUFV1*, *OPAI*, *PARS2*, *PC*, *PDHA1*, *POLG*, *RARS2*, *RRM2B*, *SCO2*, *SERAC1*, *SLC19A3*, *SLC25A12*, *TAZ*, *TMEM126B*, *VARA2*) were identified (Pronicka et al., 2016).”

In a study by Kerr et al. (2020), 390 patients were recruited and tested for mitochondrial disease (MD) through traditional diagnostic pathways (metabolite analysis, tissue neuropathology and respiratory chain enzyme activity) and new diagnostic approaches (next generation sequencing (NGS) and nuclear whole exome sequencing (nWES)). Testing through traditional diagnostic methods resulted in a mitochondrial diagnosis in 115 out of 390 patients (29.50%). In comparison, 116 out of 390 patients were recruited for NGS, which identified 36 patients (31%) with a mitochondrial diagnosis. To confirm diagnosis, patients were further tested through nuclear whole exome sequencing (nWES), which provided a secondary diagnosis in “two cases who already had a pathogenic variant in mtDNA, and a revised diagnosis (*GLUL*) in one case that had abnormal pathology but no pathogenic mtDNA variant” (Kerr et al., 2020). nWES also identified a mitochondrial diagnosis in one patient who tested negative from NGS. The author offers a diagnostic evaluation strategy, as shown in the figure below, and recommends that “a non-invasive, bigenomic sequencing (BGS) approach (using both a nWES and optimized mtDNA analysis to include large deletions) should be the first step in investigating for mitochondrial diseases. There may still be a role for tissue biopsy in unsolved cases or when the diagnosis is still not clear after NGS studies” (Kerr et al., 2020).

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Another study clearly demonstrates the heterogeneity of genetic mutations causing mitochondrial disorders. Of the 142 patients with childhood-onset mitochondrial disorders, researchers “identified 37 novel mutations in known mitochondrial disease genes and 3 mitochondria-related genes (*MRPS23*, *QRSL1*, and *PNPLA4*) as novel causative genes (Kohda et al., 2016).” These researchers utilized whole mtDNA and exome and chromosomal aberration analysis approaches to “enhance the ability to identify pathogenic gene mutations in patients” (Kohda et al., 2016).

A study by Fang et al. (2017) recruited 141 children with suspected mitochondrial disorders and used NGS to identify genetic characteristics. Forty children were gene confirmed with a known mitochondrial disease; 62.5% of those cases were due to a mtDNA mutation and 37.5% due to a nDNA mutation. This study found the most prevalent disorders to be Leigh Syndrome and MELAS (Fang et al., 2017).

Guidelines and Recommendations

Mitochondrial Medicine Society (Parikh et al., 2017; Parikh et al., 2015)

The Mitochondrial Medicine Society published the following consensus recommendations on genetic testing for mitochondrial disorders (Parikh et al., 2015):

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1. “Massively parallel sequencing/NGS of the mtDNA genome is the preferred methodology when testing mtDNA and should be performed in cases of suspected mitochondrial disease instead of testing for a limited number of pathogenic point mutations.
2. Patients with a strong likelihood of mitochondrial disease because of a mtDNA mutation and negative testing in blood, should have mtDNA assessed in another tissue to avoid the possibility of missing tissue-specific mutations or low levels of heteroplasmy in blood; tissue-based testing also helps assess the risk of other organ involvement and heterogeneity in family members and to guide genetic counseling.
3. Heteroplasmy analysis in urine can selectively be more informative and accurate than testing in blood alone, especially in cases of MELAS due to the common m. 3243A>G mutation.
4. mtDNA deletion and duplication testing should be performed in cases of suspected mitochondrial disease via NGS of the mtDNA genome, especially in all patients undergoing a diagnostic tissue biopsy.
 - a. If a single small deletion is identified using polymerase chain reaction–based analysis, then one should be cautious in associating these findings with a primary mitochondrial disorder.
 - b. When multiple mtDNA deletions are noted, sequencing of nuclear genes involved in mtDNA biosynthesis is recommended.
5. When a tissue specimen is obtained for mitochondrial studies, mtDNA content (copy number) testing via real-time quantitative polymerase chain reaction should strongly be considered for mtDNA depletion analysis because mtDNA depletion may not be detected in blood.
 - a. mtDNA proliferation is a nonspecific compensatory finding that can be seen in primary mitochondrial disease, secondary mitochondrial dysfunction, myopathy, hypotonia, and as a by-product of regular, intense exercise.
6. When considering nuclear gene testing in patients with likely primary mitochondrial disease, NGS methodologies providing complete coverage of known mitochondrial disease genes is preferred. Single-gene testing should usually be avoided because mutations in different genes can produce the same phenotype. If no known mutation is identified via known NGS gene panels, then whole exome sequencing should be considered.”

The Mitochondrial Medicine Society also commented on the set of mtDNA depletion syndromes, which are “characterized by a significant reduction in mtDNA copy number in affected tissues”. They note that diagnosis of these conditions “requires quantification of mtDNA content, typically in affected tissue, with identification of a significant decrease below the mean of normal age, gender, and tissue-specific control when normalized to nDNA tissue content”. Since NGS of the mtDNA genome does not identify mtDNA content, a separate quantitative real-time polymerase chain reaction must be used (Parikh et al., 2015).

The Mitochondrial Medicine Society in 2017 released their guidelines regarding patient care standards. Within this set of guidelines, they state, “Pregnancy in mitochondrial disease also elicits the concern of transmission of a genetic disorder. Appropriate preconception genetic counseling and discussion of options of prenatal testing are needed. A fetus affected by mitochondrial disease may also be at higher risk for prenatal morbidity. Finally, premature ovarian failure is a feature of several mitochondrial disorders and affected women should be referred for assisted reproductive technologies if they wish to have children (Parikh et al., 2017).”

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European Academy of Neurology (EAN) (Mancuso et al., 2020)

Regarding genetic testing for mitochondrial encephalopathy, lactic acidosis and stroke-like episodes (MELAS), the EAN recommends “Urgent genetic testing for MELAS should be considered in patients presenting with suspected SLE [stroke-like episode]. Search for the m.3243A>G variant (in urine where possible) and, if m.3243A>G variant is negative, POLG sequencing is required. Muscle biopsy should be considered after excluding m.3243A>G and POLG variants.” The EAN also notes that valproic acid is “contraindicated, mainly in patients with POLG variants” (Mancuso et al., 2020).

MNGIE International Network (Hirano et al., 2020)

The MNGIE [Mitochondrial neurogastrointestinal encephalomyopathy] International Network recommended *TYMP* sequencing to confirm a MNGIE diagnosis. If a variant of unknown significance or a wild-type variant is found, the Network recommends biochemical testing of thymidine (dThd) and deoxyuridine levels to determine thymidine phosphorylase (TP) activity. The Network also remarks on several treatment options (both short- and long-term), which focus on restoring the biochemical balance of the patient (Hirano et al., 2020).

Applicable Federal Regulations

A search of the FDA database on 10/27/2020 using the terms “mtDNA” and “mitochondrial disease” yielded 0 results. Many labs have developed specific tests that they must validate and perform in house. These laboratory-developed tests (LDTs) are regulated by the Centers for Medicare and Medicaid (CMS) as high-complexity tests under the Clinical Laboratory Improvement Amendments of 1988 (CLIA '88). As an LDT, the U. S. Food and Drug Administration has not approved or cleared this test; however, FDA clearance or approval is not currently required for clinical use.

Billing/Coding/Physician Documentation Information

This policy may apply to the following codes. Inclusion of a code in this section does not guarantee that it will be reimbursed. For further information on reimbursement guidelines, please see Administrative Policies on the Blue Cross Blue Shield of North Carolina web site at www.bcbsnc.com. They are listed in the Category Search on the Medical Policy search page.

Applicable service codes: 81401, 81403, 81440, 81460, 81465, 96040, S0265, 0212U, 0213U, 0214U, 0215U

BCBSNC may request medical records for determination of medical necessity. When medical records are requested, letters of support and/or explanation are often useful, but are not sufficient documentation unless all specific information needed to make a medical necessity determination is included.

Scientific Background and Reference Sources

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Policy Implementation/Update Information

- 1/1/2019 New policy developed. BCBSNC will provide coverage for genetic testing of mitochondrial disorders when it is determined to be medically necessary because criteria and guidelines are met. Medical Director review 1/1/2019. Policy noticed 1/1/2019 for effective date 4/1/2019. (jd)
- 4/16/2019 Description section and policy guidelines updated. When Covered section revised for clarity and removed criteria concerning prenatal testing as this is addressed in a separate policy. Policy intent unchanged. Added 96040 and S0265 for genetic counseling which was added as item #3 under the When Covered section. Medical Director review 4/2019(jd)
- 2/11/20 Annual review by Avalon 4th Quarter 2019 CAB. No revisions and no change to policy intent. Medical Director review 12/2019. (jd)
- 4/14/20 Specialty Matched Consultant Advisory Panel review 3/2020. Medical Director review 3/2020. (jd)
- 2/9/21 Annual review by Avalon 4th Quarter 2020 CAB. Related Policies added to description section. Item #3 added as follows to the When Covered section: “Quantification of mtDNA in tissue to diagnose mtDNA depletion syndrome is considered medically necessary.” The following statements were added to the When Not Covered section as follows: “Combination testing of mitochondrial genome testing with WES with intronic variants testing and regulatory variants testing, sometimes referred to as whole exome plus testing, including but not limited to Genomic Unity® Exome Plus Analysis is considered not medically necessary.”, and “Combination testing of mitochondrial genome testing with WGS with intronic variants testing and regulatory variants testing, sometimes referred to as Genomic Unity® Whole Genome Analysis is considered not medically necessary.” Policy guidelines and references updated. Removed code box and added codes 0212U-0215U to the Billing/Coding section. Medical Director review 1/2021. (jd)
- 3/31/21 Specialty Matched Consultant Advisory Panel review 3/2021. Medical Director review 3/2021. (jd)

Medical policy is not an authorization, certification, explanation of benefits or a contract. Benefits and eligibility are determined before medical guidelines and payment guidelines are applied. Benefits are determined by the group contract and subscriber certificate that is in effect at the time services are rendered. This document is solely provided for informational purposes only and is based on research of current medical literature and review of common medical practices in the treatment and diagnosis of disease. Medical practices and knowledge are constantly changing and BCBSNC reserves the right to review and revise its medical policies periodically.