

Chromosome Microarray Testing (Non-Oncology Conditions) (for New Jersey Only)

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[Instructions for Use](#)

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Related Policies
<ul style="list-style-type: none"> Molecular Oncology Testing for Cancer Diagnosis, Prognosis, and Treatment Decisions (for New Jersey Only) Preimplantation Genetic Testing (for New Jersey Only)

Application

This Medical Policy only applies to the state of New Jersey.

Coverage Rationale

Genome-wide comparative genomic hybridization microarray testing or single nucleotide polymorphism (SNP) chromosomal microarray analysis is proven and medically necessary for the following:

- Evaluation of an embryo/fetus in the following cases:
 - Women undergoing invasive prenatal testing (i.e., amniocentesis, chorionic villus sampling or fetal tissue sampling)
 - Testing the products of conception following pregnancy loss
 - [Intrauterine Fetal Demise or Stillbirth](#)
- Evaluation of individuals with one or more of the following:
 - Multiple anomalies not specific to a [Well-Delineated Genetic Syndrome](#) and cannot be identified by a clinical evaluation alone
 - Non-syndromic [Developmental Delay/Intellectual Disability](#)
 - Autism spectrum disorder
 - Isolated severe congenital heart disease
- Evaluation of biological parent of a fetus or child with an equivocal chromosome microarray result

Genome-wide comparative genomic hybridization microarray testing or SNP chromosomal microarray analysis is unproven and not medically necessary for all other populations and conditions due to insufficient evidence of efficacy. This includes but is not limited to epilepsy.

Note: Genome-wide comparative genomic hybridization microarray testing or SNP chromosomal microarray analysis for the following are addressed in other Medical Policies:

- The evaluation of cancer is addressed in the Medical Policy titled [Molecular Oncology Testing for Cancer Diagnosis Prognosis, and Treatment Decisions](#).
- Preimplantation genetic testing (PGT) is addressed in the Medical Policy titled [Preimplantation Genetic Testing \(for New Jersey Only\)](#).

Definitions

Developmental Delay: Developmental Delay may be used to describe children younger than 5 years of age who present with delays in the attainment of developmental milestones at the expected age (Moeschler and Shevell, 2014).

Intellectual Disability: Intellectual Disability may be used to describe persons 5 years of age and older (when standardized measures of intelligence become reliable and valid) who exhibit deficits in intelligence (IQ), adaptive behavior, and systems of support (Moeschler and Shevell, 2014).

Intrauterine Fetal Demise or Stillbirth: Fetal death at or after 20 weeks gestation (ACOG, 2009, reaffirmed 2016).

Prenatal Diagnosis: A laboratory test performed on fetal DNA or chromosomes before birth to determine if a fetus has a genetic or chromosomal disorder (American College of Obstetricians and Gynecologists, 2016a).

Well-Delineated Genetic Syndrome: A syndrome is a collection of recognizable traits or abnormalities that tend to occur together and are associated with a specific disease. Distinguishing characteristics, such as specific facial features or other physical traits, lab tests, or family history can be used to identify a genetic syndrome (Genetics Home Reference, National Library of Medicine, 2020; Genetics Glossary, National Genome Institute, 2019).

Applicable Codes

The following list(s) of procedure and/or diagnosis codes is provided for reference purposes only and may not be all inclusive. Listing of a code in this policy does not imply that the service described by the code is a covered or non-covered health service. Benefit coverage for health services is determined by federal, state, or contractual requirements and applicable laws that may require coverage for a specific service. The inclusion of a code does not imply any right to reimbursement or guarantee claim payment. Other Policies and Guidelines may apply.

CPT Code	Description
0209U	Cytogenomic constitutional (genome-wide) analysis, interrogation of genomic regions for copy number, structural changes and areas of homozygosity for chromosomal abnormalities
81228	Cytogenomic (genome-wide) analysis for constitutional chromosomal abnormalities; interrogation of genomic regions for copy number variants, comparative genomic hybridization [CGH] microarray analysis
81229	Cytogenomic (genome-wide) analysis for constitutional chromosomal abnormalities; interrogation of genomic regions for copy number and single nucleotide polymorphism (SNP) variants, comparative genomic hybridization (CGH) microarray analysis
81349	Cytogenomic (genome-wide) analysis for constitutional chromosomal abnormalities; interrogation of genomic regions for copy number and loss-of-heterozygosity variants, low-pass sequencing analysis
81479	Unlisted molecular pathology procedure

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HCPCS Code	Description
S3870	Comparative genomic hybridization (CGH) microarray testing for developmental delay, autism spectrum disorder and/or intellectual disability

Diagnosis Code	Description
F70	Mild intellectual disabilities
F71	Moderate intellectual disabilities
F72	Severe intellectual disabilities
F73	Profound intellectual disabilities
F78.A1	SYNGAP1-related intellectual disability
F78.A9	Other genetic related intellectual disability
F79	Unspecified intellectual disabilities
F80.0	Phonological disorder
F80.1	Expressive language disorder
F80.2	Mixed receptive-expressive language disorder
F80.4	Speech and language development delay due to hearing loss
F80.81	Childhood onset fluency disorder
F80.82	Social pragmatic communication disorder
F80.89	Other developmental disorders of speech and language
F80.9	Developmental disorder of speech and language, unspecified
F81.0	Specific reading disorder
F81.2	Mathematics disorder
F81.81	Disorder of written expression
F81.89	Other developmental disorders of scholastic skills
F81.9	Developmental disorder of scholastic skills, unspecified
F82	Specific developmental disorder of motor function
F84.0	Autistic disorder
F84.3	Other childhood disintegrative disorder
F84.5	Asperger's syndrome
F84.8	Other pervasive developmental disorders
F84.9	Pervasive developmental disorder, unspecified
F88	Other disorders of psychological development
F89	Unspecified disorder of psychological development
F90.8	Attention-deficit hyperactivity disorder, other type
H93.25	Central auditory processing disorder
N96	Recurrent pregnancy loss
O02.1	Missed abortion
O03.4	Incomplete spontaneous abortion without complication
O03.9	Complete or unspecified spontaneous abortion without complication
O09.511	Supervision of elderly primigravida, first trimester
O09.512	Supervision of elderly primigravida, second trimester
O09.513	Supervision of elderly primigravida, third trimester
O09.519	Supervision of elderly primigravida, unspecified trimester
O09.521	Supervision of elderly multigravida, first trimester
O09.522	Supervision of elderly multigravida, second trimester
O09.523	Supervision of elderly multigravida, third trimester

Diagnosis Code	Description
O09.529	Supervision of elderly multigravida, unspecified trimester
O26.0	Pregnancy care for patient with recurrent pregnancy loss, unspecified trimester
O26.1	Pregnancy care for patient with recurrent pregnancy loss, first trimester
O26.2	Pregnancy care for patient with recurrent pregnancy loss, second trimester
O26.3	Pregnancy care for patient with recurrent pregnancy loss, third trimester
O28.0	Abnormal hematological finding on antenatal screening of mother
O28.1	Abnormal biochemical finding on antenatal screening of mother
O28.2	Abnormal cytological finding on antenatal screening of mother
O28.3	Abnormal ultrasonic finding on antenatal screening of mother
O28.4	Abnormal radiological finding on antenatal screening of mother
O28.5	Abnormal chromosomal and genetic finding on antenatal screening of mother
O28.8	Other abnormal findings on antenatal screening of mother
O28.9	Unspecified abnormal findings on antenatal screening of mother
O35.0XX0	Maternal care for (suspected) central nervous system malformation in fetus, not applicable or unspecified
O35.0XX1	Maternal care for (suspected) central nervous system malformation in fetus, fetus 1
O35.0XX2	Maternal care for (suspected) central nervous system malformation in fetus, fetus 2
O35.0XX3	Maternal care for (suspected) central nervous system malformation in fetus, fetus 3
O35.0XX4	Maternal care for (suspected) central nervous system malformation in fetus, fetus 4
O35.0XX5	Maternal care for (suspected) central nervous system malformation in fetus, fetus 5
O35.0XX9	Maternal care for (suspected) central nervous system malformation in fetus, other fetus
O35.1XX0	Maternal care for (suspected) chromosomal abnormality in fetus, not applicable or unspecified
O35.1XX1	Maternal care for (suspected) chromosomal abnormality in fetus, fetus 1
O35.1XX2	Maternal care for (suspected) chromosomal abnormality in fetus, fetus 2
O35.1XX3	Maternal care for (suspected) chromosomal abnormality in fetus, fetus 3
O35.1XX4	Maternal care for (suspected) chromosomal abnormality in fetus, fetus 4
O35.1XX5	Maternal care for (suspected) chromosomal abnormality in fetus, fetus 5
O35.1XX9	Maternal care for (suspected) chromosomal abnormality in fetus, other fetus
O35.2XX0	Maternal care for (suspected) hereditary disease in fetus, not applicable or unspecified
O35.2XX1	Maternal care for (suspected) hereditary disease in fetus, fetus 1
O35.2XX2	Maternal care for (suspected) hereditary disease in fetus, fetus 2
O35.2XX3	Maternal care for (suspected) hereditary disease in fetus, fetus 3
O35.2XX4	Maternal care for (suspected) hereditary disease in fetus, fetus 4
O35.2XX5	Maternal care for (suspected) hereditary disease in fetus, fetus 5
O35.2XX9	Maternal care for (suspected) hereditary disease in fetus, other fetus
O35.8XX0	Maternal care for other (suspected) fetal abnormality and damage, not applicable or unspecified
O35.8XX1	Maternal care for other (suspected) fetal abnormality and damage, fetus 1
O35.8XX2	Maternal care for other (suspected) fetal abnormality and damage, fetus 2
O35.8XX3	Maternal care for other (suspected) fetal abnormality and damage, fetus 3
O35.8XX4	Maternal care for other (suspected) fetal abnormality and damage, fetus 4
O35.8XX5	Maternal care for other (suspected) fetal abnormality and damage, fetus 5

Diagnosis Code	Description
O35.8XX9	Maternal care for other (suspected) fetal abnormality and damage, other fetus
O36.4XX0	Maternal care for intrauterine death, not applicable or unspecified
O36.4XX1	Maternal care for intrauterine death, fetus 1
O36.4XX2	Maternal care for intrauterine death, fetus 2
O36.4XX3	Maternal care for intrauterine death, fetus 3
O36.4XX4	Maternal care for intrauterine death, fetus 4
O36.4XX5	Maternal care for intrauterine death, fetus 5
O36.4XX9	Maternal care for intrauterine death, other fetus
P02.9	Newborn affected by abnormality of membranes, unspecified
P95	Stillbirth
Q20.8	Other congenital malformations of cardiac chambers and connections
Q20.9	Congenital malformation of cardiac chambers and connections, unspecified
Q21.8	Other congenital malformations of cardiac septa
Q21.9	Congenital malformation of cardiac septum, unspecified
Q24.0	Dextrocardia
Q24.1	Levocardia
Q24.2	Cor triatriatum
Q24.3	Pulmonary infundibular stenosis
Q24.4	Congenital subaortic stenosis
Q24.5	Malformation of coronary vessels
Q24.6	Congenital heart block
Q24.8	Congenital heart block
Q24.9	Congenital malformation of heart, unspecified
Q89.7	Multiple congenital malformations, not elsewhere classified
Q89.8	Other specified congenital malformations
Q89.9	Congenital malformation, unspecified
Q90.0	Trisomy 21, nonmosaicism (meiotic nondisjunction)
Q90.1	Trisomy 21, mosaicism (mitotic nondisjunction)
Q90.2	Trisomy 21, translocation
Q90.9	Down syndrome, unspecified
Q91.0	Trisomy 18, nonmosaicism (meiotic nondisjunction)
Q91.1	Trisomy 18, mosaicism (mitotic nondisjunction)
Q91.2	Trisomy 18, translocation
Q91.3	Trisomy 18, unspecified
Q91.4	Trisomy 13, nonmosaicism (meiotic nondisjunction)
Q91.5	Trisomy 13, mosaicism (mitotic nondisjunction)
Q91.6	Trisomy 13, translocation
Q91.7	Trisomy 13, unspecified
Q92.0	Whole chromosome trisomy, nonmosaicism (meiotic nondisjunction)
Q92.1	Whole chromosome trisomy, mosaicism (mitotic nondisjunction)
Q92.2	Partial trisomy

Diagnosis Code	Description
Q92.5	Duplications with other complex rearrangements
Q92.61	Marker chromosomes in normal individual
Q92.62	Marker chromosomes in abnormal individual
Q92.7	Triploidy and polyploidy
Q92.8	Other specified trisomies and partial trisomies of autosomes
Q92.9	Trisomy and partial trisomy of autosomes, unspecified
Q93.0	Whole chromosome monosomy, nonmosaicism (meiotic nondisjunction)
Q93.1	Whole chromosome monosomy, mosaicism (mitotic nondisjunction)
Q93.2	Chromosome replaced with ring, dicentric or isochromosome
Q93.3	Deletion of short arm of chromosome 4
Q93.4	Deletion of short arm of chromosome 5
Q93.7	Deletions with other complex rearrangements
Q93.51	Angelman syndrome
Q93.59	Other deletions of part of a chromosome
Q93.81	Velo-cardio-facial syndrome
Q93.82	Williams syndrome
Q93.88	Other microdeletions
Q93.89	Other deletions from the autosomes
Q93.9	Deletion from autosomes, unspecified
Q95.2	Balanced autosomal rearrangement in abnormal individual
Q95.3	Balanced sex/autosomal rearrangement in abnormal individual
Q99.8	Other specified chromosome abnormalities
Q99.9	Chromosomal abnormality, unspecified
R48.0	Dyslexia and alexia
R62.0	Delayed milestone in childhood
R62.50	Unspecified lack of expected normal physiological development in childhood
R62.51	Failure to thrive (child)
R62.59	Other lack of expected normal physiological development in childhood
R89.8	Other abnormal findings in specimens from other organs, systems and tissues
Z14.1	Cystic fibrosis carrier
Z14.8	Genetic carrier of other disease
Z36.0	Encounter for antenatal screening for chromosomal anomalies
Z37.1	Single stillbirth
Z37.3	Twins, one liveborn and one stillborn
Z37.4	Twins, both stillborn
Z37.60	Multiple births, unspecified, some liveborn
Z37.61	Triplets, some liveborn
Z37.62	Quadruplets, some liveborn
Z37.63	Quintuplets, some liveborn
Z37.64	Sextuplets, some liveborn
Z37.69	Other multiple births, some liveborn

Diagnosis Code	Description
Z37.7	Other multiple births, all stillborn
Z87.74	Personal history of (corrected) congenital malformations of heart and circulatory system

Description of Services

Genetic counseling is strongly recommended prior to genome-wide comparative genomic hybridization microarray testing or SNP chromosomal microarray analysis in order to inform persons being tested about the advantages and limitations of the test as applied to their unique situation.

Chromosome abnormalities are a well-established cause of congenital anomalies, dysmorphic features, Developmental Delay, Intellectual Disability and other neurodevelopmental disorders. Two chromosome microarray genetic tests that are being evaluated for detection of chromosomal abnormalities are array comparative genomic hybridization (CGH) and single nucleotide polymorphism (SNP). These tests analyze multiple sequences of deoxyribonucleic acid (DNA) by identifying multiple deletions and duplications across the genome simultaneously. The microarray may be targeted in nature, assaying certain regions of the genome known to be associated with a specific syndrome or phenotype, or may be genome-wide (Shaffer et al., 2007). Currently, most clinical applications of chromosome microarray testing are being investigated for the diagnosis of chromosomal abnormalities in fetuses and newborns, and in children with developmental disorders. For prenatal testing, chromosome microarray testing requires an invasive procedure (e.g., amniocentesis or chorionic villous sampling) for the collection of fetal cells.

Chromosomal microarray analysis (CMA) includes both CGH and SNP arrays. CGH microarray testing, also known as array comparative genomic hybridization (aCGH), is a technology that can be used for the detection of genomic copy number variations (CNVs). CNVs are alterations that include deletion and/or duplication of one or more sections of DNA. This method allows the detection of chromosome imbalances that can provide more information than detected by conventional chromosome analysis [e.g., standard karyotype or fluorescence in situ hybridization (FISH)]. The array CGH approach compares patient DNA extracted from skin, blood or fetal cells to a control or reference DNA from a normal individual. These are labelled separately with different colored fluorescent dyes and then mixed together and allowed to combine or hybridize to an array containing known DNA sequences called probes. The amount of hybridization is measured by the amount and color of light emitted from each spot. Computer analysis of the fluorescent signals is used to read and interpret the findings. Areas of unequal hybridization, mostly large deletions and duplications, signify a DNA alteration. CNVs may be benign, with no effect on clinical phenotype, or may be pathogenic and result in a variety of phenotypic abnormalities (Kearney et al., 2011). If an unknown CNV is detected, a genomic database is used to determine if the abnormality has been previously reported and if it has been associated with a benign or proposed pathogenic condition. The disadvantages of array CGH testing include the detection of a large number of variants of unknown clinical significance, potential false positives results that will require further testing, and the inability to detect certain anomalies such as those with balanced rearrangements where there is no net gain or loss of the chromosomes (Fruhman and Van den Veyver 2010; Bui 2011).

SNP arrays are sequence variants in which a single base pair differs from a specified reference sequence. For each SNP, a person generally has two alleles, one inherited from each parent. The absence of one allele in multiple contiguous SNPs indicates the presence of a chromosomal deletion, while an increase in SNP copy number indicates the presence of a chromosomal duplication. SNP microarrays are being studied as a way to evaluate the pattern of SNPs in a particular individual. Particular patterns of SNPs can be used as markers for inherited disease susceptibility or for detecting loss of heterozygosity of particular genetic alleles in tumor DNA. Like aCGH, SNP microarrays offer a cytogenetic evaluation at a significantly higher resolution than a standard karyotype analysis, as well as the ability to look for genomic imbalances throughout the genome in a single assay. The main challenge with microarray testing, including SNP microarray analysis, is the identification of CNVs of unknown clinical significance.

Use in Obstetrics

Routine chromosome analysis has been used historically to identify chromosome abnormalities during pregnancy when risk factors are present, such as advanced maternal age and chromosome abnormalities. Chromosome microarray analysis (CMA) does not require cell culture or dividing cells, so it provides an advantage in turn-around time for time sensitive analysis, as is often the case during pregnancy. In addition, CMA can identify smaller chromosomal abnormalities than a routine chromosome analysis and is able to identify chromosomal breakpoints that are unbalanced but may appear balanced on a conventional karyotype. CMA does have limitations; in that it cannot detect totally balanced chromosomal material or low-level mosaicism. Some arrays may not detect triploidy. Clinicians may use CMA as a first line test, or only when fetal abnormalities are identified (Society for Maternal-Fetal Medicine 2016).

Prenatal Diagnosis

Analytical Validity

Pauta et al. (2017) performed a systemic review of the literature and meta-analysis to determine the utility of CMA by either aCGH or SNP-microarray, when compared to traditional karyotyping in early pregnancy loss. In twenty-three studies, 5520 pregnancies losses up to 20 weeks gestational age were reviewed. CMA provided informative results on 95% of cases compared to 67% with karyotyping, and CMA provided a 2% greater yield of pathogenic CNV. The authors concluded that CMA resulted in diagnostic information in early pregnancy loss in significantly more cases when compared to conventional chromosome analysis.

Clinical Validity

In a large cohort study, Maya et al. (2018) evaluated the frequency of penetrance of copy number variations (CNVs) in low and high risk prenatal and postnatal samples. The cohort was grouped according to chromosome microarray analysis (CMA) indication with group I being low-risk, prenatal women as the control group; group II being high risk prenatal women with fetuses that had congenital malformations; and group III being post-natal individuals with a variety of genetic based conditions. Within this cohort, 21,594 CMAs were performed and the frequency of high penetrance CNVs was 0.1% in group I, 0.9% in group II, and 2.6% in group III. CNV frequency of moderate-penetrance was 0.3%, 0.6%, and 1.2%, respectively, and these differences were statistically significant. The frequency of low-penetrance CNVs was not significantly different among groups: 0.6%, 0.9%, and 1.0%, respectively. The study concluded that high penetrance CNVs may be a factor in heritability of various anomalies, however low penetrance CNVs do not seem to contribute.

Peng et al. (2017) assessed chromosomal and sub chromosomal anomalies in small for gestational age (SGA) fetuses with no additional anomalies. A retrospective review of 128 SGA fetuses had both karyotyping and CMA. Analysis was performed and anomalies were identified in 6 (4.7%) SGA fetuses and pathogenic sub chromosomal anomalies in 4 (3.1%) by CMA. The researchers concluded that there was a 3.3% incremental yield of sub chromosomal anomalies in CMA above karyotyping in SGA fetuses.

Parchem et al. (2018) evaluated the association of CNVs with perinatal outcomes in fetuses that had sonographic abnormalities. This retrospective studied reviewed anomalous fetuses that had CMA testing. There were abnormal CMA results in 60 (21.4%) of the 280 fetuses in the study. Of these 60, 21 (35%) were considered to be pathogenic and 39 (65%) were variants of uncertain significance (VUS). Perinatal death was also studied as a part of this evaluation and among 212 (75.7%) of the continued pregnancies, abnormal CMA was not associated with increased risk of perinatal death.

Jin et al. (2018) investigated the use of CMA for prenatal diagnosis of orofacial clefts. The institution evaluated 143 fetuses with oral clefts that were detected by ultrasonography. The cases were separated into four groups: isolated cleft lip (CL) (CL only), isolated cleft palate (CP only), isolated cleft lip and palate (CLP) (CLP only), and syndromic CLP (combined with other malformations). CMA was performed for all cases and a total of 11 fetuses had pathogenic CNVs (7.7%), including isolated CP (1/143, 0.7%), isolated CLP (5/143, 3.5%), and syndromic CLP (5/143, 3.5%). Compared with the CMA results, five fetuses had an abnormal karyotype (5/139, 3.6%). The researchers concluded that CMA is a diagnostic tool for identification of chromosomal abnormalities in the prenatal diagnosis for oral clefts.

A French multicenter study by Egloff et al. (2018) evaluated CMA in a large cohort of fetuses with increased nuchal translucency thickness (NT). In this retrospective study, 720 fetuses were analyzed by rapid aneuploidy test and those identified as euploid underwent CMA. An aneuploidy involving chromosome 13, 18 or 21 was detected by rapid aneuploidy test in 121 (16.8%) fetuses. The remaining 599 fetuses were euploid. Of these 599 cases, 53 (8.8%) had a CNV detected by CMA: 16 (2.7%) had a pathogenic CNV (11 were considered cryptic or not visible by karyotyping); 7 (1.2%) were CNVs that are known to predispose one to neurodevelopmental disorders; 8 (1.3%) were VUS; 1 was unrelated or an incidental finding; and 21 were benign CNVs. This study demonstrated the benefit of CMA in the diagnosis of fetuses with isolated increased NT. An additional finding was that most (69%) pathogenic CNVs were cryptic.

A 2018 study evaluated CMA copy number variations (CNVs) and prenatal posterior fossa anomalies (PFAs), especially cerebellar hypoplasia (CH) (Zou et al., 2018). The researchers analyzed 77 pregnancies with PFAs who underwent CMA and also compared the data to karyotype analysis. Chromosomal aberrations (pathogenic and VUS) were detected in 31.2% (24/77) of all cases by CMA and in 18.5% (12/65) in fetuses with normal karyotypes. There was a high detection rate of clinically significant CNVs in this group of fetuses including those with CH (54.6%, 6/11), vermian hypoplasia (33.3%, 1/3), and Dandy-Walker malformation (25%, 3/12). The study also compared those fetuses with and without other anomalies and determined that cases with CH and additional malformations had a higher detection rate in CMA (33.3% compared to 88.9%). This analysis allowed the researchers to conclude that CMA detected the most frequent aberrations with CH.

A study by Sagi-Dain et al. (2018) examined CMA results in pregnancies with ultrasonographic abnormalities. A retrospective review was performed, and CMA of amniocenteses performed as a result of fetal ultrasound anomalies. In an analysis of 5,750 pregnancies, clinically significant CMA aberrations were detected in 272 (4.7%). Of these 272 cases, 115 (2%) were karyotype detectable and 157 (2.7%) were submicroscopic. The most common CNV was detected in 22q11.21 deletion. This study demonstrated that the rate of abnormal results from CMA was twice that of karyotyping in this set of pregnancies with abnormal fetal ultrasound findings.

Prenatal diagnosis of congenital heart disease (CHD) was studied using CMA in a study by Wang et al. (2018). The aim of the study was to evaluate the clinical utility of this approach and the study evaluated 602 prenatal cases of CHD. Using CMA, pathogenic abnormalities were identified in 125 (20.8%) of these cases of CHD and 52.0% of these were numerical chromosomal abnormalities. The detection rates of likely pathogenic copy number variations and variants of uncertain significance were 1.3% and 6.0%, respectively. The researchers concluded that CMA was a reliable technology for this type of prenatal diagnosis of CHD.

Gliem et al. (2017) studied the use of CMA for the testing of products of conception (POCs) to provide information about the cause of fetal loss. Using CMA may help determine the recurrence risk of future losses and chromosome abnormalities for subsequent pregnancies. This institution used fluorescent in situ hybridization (FISH) testing to identify specific chromosome aneuploidy in formalin-fixed paraffin-embedded (FFPE) samples. Twenty-five archived FFPE POC specimens were evaluated by CMA using the Affymetrix OncoScan FFPE Assay. The previous FISH results (five normal, 12 trisomy, six triploidy, two monosomy) were compared to the CMA results. Of the five normal samples, four had no clinically relevant CMA findings, and one sample was found to have trisomy 9, which was not detectable by the FISH test. Of the abnormal FISH results samples (n=20), the CMA detected all FISH reported abnormalities along with additional findings including additional trisomies in samples. This small study verified the performance characteristics of CMA on FFPE POC samples.

In a systematic review, Grande et al. (2015) estimated the incremental yield of detecting copy number variants (CNVs) by genomic microarray over karyotyping in fetuses with increased nuchal translucency (NT) diagnosed by first-trimester ultrasound. Seventeen studies met the inclusion criteria for analysis. Meta-analysis indicated an incremental yield of 5.0% for the detection of CNVs using microarray when pooling results. Stratified analysis of microarray results demonstrated a 4.0% incremental yield in cases of isolated NT and 7.0% when other malformations were present. The pooled prevalence for variants of uncertain significance was 1%. The authors concluded that the use of genomic microarray provides a 5.0% incremental yield of detecting CNVs in fetuses with increased NT and normal karyotype.

Dhillon et al. (2014) evaluated whether CMA testing on the products of conception following miscarriage provides better diagnostic information compared with conventional karyotyping in a systematic review and meta-analysis that included 9 studies. There was agreement between CMA and karyotyping in 86.0% of cases. CMA detected 13% additional chromosome abnormalities over conventional full karyotyping. In addition, traditional, full karyotyping detected 3% additional abnormalities

over CMA. The incidence of a variant of unknown significance (VOUS) being detected was 2%. The authors concluded that compared with karyotyping, there appears to be an increased detection rate of chromosomal abnormalities when CMA is used to analyze the products of conception; however, some of these abnormalities are VOUS, and this information should be provided when counseling women following miscarriage and when taking consent for the analysis of miscarriage products by CMA.

In a systematic review and meta-analysis, Hillman et al. (2011) evaluated whether array CGH testing in the prenatal population provides diagnostic information over that available from conventional karyotyping. Studies were selected if array CGH was used on prenatal samples or if array CGH was used on postnatal samples following termination of pregnancy for structural abnormalities that were detected on an ultrasound scan. Of the 135 potential articles, 10 were included in this systematic review and eight were included in the meta-analysis. The pooled rate of extra information detected by array CGH when the prenatal karyotype was normal was meta-analyzed using a random-effects model. The pooled rate of receiving an array CGH result of unknown significance was also meta-analyzed. Array CGH detected 3.6% additional genomic imbalances when conventional karyotyping was 'normal', regardless of referral indication. This increased to 5.2% more than karyotyping when the referral indication was a structural malformation on ultrasound. The authors concluded that there appears to be an increased detection rate of chromosomal imbalances, compared with conventional karyotyping, when array CGH techniques are employed in the prenatal population. However, some are copy number imbalances that are not clinically significant. Therefore, maternal anxiety may be generated by an abnormal test result that has little clinical significance.

de Wit et al. (2014) conducted a systematic review to evaluate the diagnostic and prognostic value of genomic array testing in pregnancies with fetuses with a structural ultrasound anomaly (restricted to one anatomical system) and a normal karyotype. Combined data of the reviewed studies (n=18) indicated that fetuses with an ultrasound anomaly restricted to one anatomical system (n=2220) had a 3.1-7.9% chance of carrying a causative submicroscopic CNV, depending on the anatomical system affected. This chance increased to 9.1% for fetuses with multiple ultrasound anomalies (n=1139). According to the authors, this review indicates that 3.1-7.9% of fetuses with a structural ultrasound anomaly restricted to one anatomical system and a normal karyotype will show a submicroscopic CNV, which explains its phenotype and provides information for fetal prognosis. The authors concluded that microarray has considerable diagnostic and prognostic value in these pregnancies.

Papoulidis et al. (2015) evaluated the diagnostic yield of comparative genomic hybridization microarrays (aCGH) and compare it with conventional karyotype analysis of standard >5-Mb resolution. A total of 1763 prenatal samples were analyzed by aCGH (CytoChip Focus Constitutional microarrays, BlueGnome, Cambridge). The diagnostic yield of chromosomal abnormalities detected by aCGH was assessed, compared with conventional karyotype analysis. The result was pathogenic/unknown penetrance in 125 cases (7.1%), and a variant of unknown significance (VOUS) was detected in 13 cases (0.7%). Out of the 125 cases with abnormal findings, 110 were also detected by conventional karyotype analysis. The aCGH increment in diagnostic yield was 0.9% (15/1763) and 1.6% when VOUS were included. Stratifying the sample according to indications for prenatal invasive testing, the highest values of diagnostic yield increment were observed for patients positive for second-trimester sonographic markers (1.5%) and for the presence of fetal structural anomalies (1.3%). In contrast, the incremental yield was marginal in patients with fetus with increased nuchal translucency (0.5%). The authors concluded that the routine implementation of aCGH offers an incremental yield over conventional karyotype analysis, which is also present in cases with 'milder' indications, further supporting its use as a first-tier test.

Srebniak et al. (2016) evaluated the diagnostic value of single-nucleotide polymorphism (SNP) array testing in 1033 fetuses with ultrasound anomalies by investigating the prevalence and genetic nature of pathogenic findings. Pathogenic findings were classified into three categories: causative findings; unexpected diagnoses (UD); and susceptibility loci (SL) for neurodevelopmental disorders. After exclusion of trisomy 13, 18, 21, sex-chromosomal aneuploidy and triploidies, in 76/1033 (7.4%) fetuses a pathogenic chromosome abnormality was detected by genomic SNP array: in 19/1033 cases (1.8%) a microscopically detectable abnormality was found and in 57/1033 (5.5%) fetuses a pathogenic submicroscopic chromosome abnormality was detected. 58% (n=44) of all these pathogenic chromosome abnormalities involved a causative finding, 35% (n=27) a SL for neurodevelopmental disorder, and 6% (n=5) a UD of an early-onset untreatable disease. In 0.3% of parental samples an incidental pathogenic finding was encountered. According to the authors, these results confirm that a genomic array should be the preferred first-tier technique in fetuses with ultrasound anomalies.

Rosenfeld et al. (2015) determined the frequency of clinically significant chromosomal abnormalities identified by chromosomal microarray in pregnancy losses at any gestational age and compared microarray performance with that of traditional

cytogenetic analysis when testing pregnancy losses. Among 535 fetal demise specimens of any gestational age, clinical microarray-based comparative genomic hybridization (aCGH) was performed successfully on 515, and a subset of 107 specimens underwent additional single nucleotide polymorphism (SNP) analysis. Overall, clinically significant abnormalities were identified in 12.8% (64/499) of specimens referred with normal or unknown karyotypes. Detection rates were significantly higher with earlier gestational age. In the subset with normal karyotype, clinically significant abnormalities were identified in 6.9% (20/288). This detection rate did not vary significantly with gestational age, suggesting that, unlike aneuploidy, the contribution of submicroscopic chromosomal abnormalities to fetal demise does not vary with gestational age. In the 107 specimens that underwent aCGH and SNP analysis, seven cases (6.5%) had abnormalities of potential clinical significance detected by the SNP component, including female triploidy. aCGH failed to yield fetal results in 8.3%, which is an improvement over traditional cytogenetic analysis of fetal demise specimens. The authors concluded that both the provision of results in cases in which karyotype fails and the detection of abnormalities in the presence of a normal karyotype demonstrate the increased diagnostic utility of microarray in pregnancy loss. According to the authors, chromosomal microarray testing is a preferable, robust method of analyzing cases of pregnancy loss to better delineate possible genetic etiologies, regardless of gestational age.

Clinical Utility

A retrospective study was performed to evaluate the use of CMA versus chromosome analysis for prenatal diagnosis of ventricular septal defects (VSDs) (Cai et al., 2018). The researchers analyzed 151 VSD cases (79 had an isolated defect and 72 had an additional anomaly) that were diagnosed by fetal ultrasonography. Chromosome karyotype testing identified 16 chromosomal abnormalities. CMA identified 14 cases that were consistent with the karyotype analysis and identified an additional 20 cases (13.2%) of abnormal copy number variations (CNVs), of which 13 were pathogenic CNVs, 5 were variations of uncertain significance (VUS) and 2 were benign CNVs. The detection rate of pathogenic CNVs was also compared between the two groups of VSD subjects. They determined that in non-isolated-VSDs this rate was significantly higher than that in isolated-VSDs (36.1% (26/72) vs. 1.3% (1/79)). The researchers concluded that CMA in combination with cytogenetics may be effective in the identification of VSDs. In addition, the CMA results that indicated a pathogenic variant had an effect on obstetrical outcomes.

Another study also compared the utility of single-nucleotide polymorphism (SNP) arrays in fetuses with VSDs and normal karyotypes and with or without other structural anomalies (Fu et al., 2017). The researchers analyzed 144 fetuses with VSDs and normal karyotypes using Affymetrix CytoScan HD arrays. Twelve fetuses (8.3%) demonstrated clinically significant CNVs with the most common to be a 22q11.2 deletion (4/144; 2.8%). Other well-known microdeletion or microduplication syndromes were also identified in six cases. These researchers found no significant difference in pathogenic CNVs in fetuses with or without other structural anomalies. The conclusion was that high-resolution SNP arrays are valuable in identifying submicroscopic chromosomal abnormalities for prenatal VSD diagnosis.

Shaffer et al. (2012b) evaluated the diagnostic utility of comparative genomic hybridization (CGH)-based microarrays for pregnancies with abnormal ultrasound findings. The authors conducted a retrospective analysis of 2858 pregnancies with abnormal ultrasounds and normal karyotypes (when performed) tested in their laboratory using CGH microarrays targeted to known chromosomal syndromes with later versions providing backbone coverage of the entire genome. Abnormalities were stratified according to organ system involvement. Detection rates for clinically significant findings among these categories were calculated. Clinically significant genomic alterations were identified in cases with a single ultrasound anomaly (n=99/1773, 5.6%), anomalies in two or more organ systems (n=77/808, 9.5%), isolated growth abnormalities (n=2/76, 2.6%), and soft markers (n=2/77, 2.6%). The following anomalies in isolation or with additional anomalies had particularly high detection rates: holoprosencephaly (n=9/85, 10.6%), posterior fossa defects (n=21/144, 14.6%), skeletal anomalies (n=15/140, 10.7%), ventricular septal defect (n=14/132, 10.6%), hypoplastic left heart (n=11/68, 16.2%), and cleft lip/palate (n=14/136, 10.3%). The authors concluded that microarray analysis identified clinically significant genomic alterations in 6.5% of cases with one or more abnormal ultrasound findings; the majority was below the resolution of karyotyping. The authors stated that for most informed medical management, pregnancies with ultrasound anomalies undergoing invasive testing should be tested by microarray to identify all clinically significant copy number alterations (CNAs).

Brady et al. (2013) evaluated the clinical utility of chromosomal microarrays for prenatal diagnosis by a prospective study of fetuses with abnormalities detected on ultrasound. Patients referred for prenatal diagnosis due to ultrasound anomalies underwent analysis by array comparative genomic hybridization as the first-tier diagnostic test. A total of 383 prenatal samples underwent analysis by array comparative genomic hybridization. Array analysis revealed causal imbalances in a total of 9.6% of

patients (n=37). Submicroscopic copy-number variations were detected in 2.6% of patients (n=10/37), and arrays added valuable information over conventional karyotyping in 3.9% of patients (n=15/37). Variants of uncertain significance were revealed in 1.6% of patients (n=6/383). The authors concluded that there was added value of chromosomal microarrays for prenatal diagnosis in the presence of ultrasound anomalies.

Maya et al. (2010) described the clinical utility of aCGH in the prenatal testing of fetuses with an increased risk of a chromosome disorder based on maternal age, maternal serum screening, ultrasound findings, or family history. The study involved a retrospective review of 269 cases, including 243 who had an amniocentesis and 16 who had a CVS (and 10 with an unknown specimen type). Of the 269 samples, 236 were tested with a BAC microarray and 19 were tested with an oligonucleotide microarray. Conventional cytogenetic testing identified 254 fetuses with a normal karyotype and 15 with an abnormal karyotype of unknown clinical significance. Array-based CGH identified submicroscopic imbalances categorized as pathogenic in 3 of the 254 (1.2%) fetuses with a normal karyotype, and in 4 of the 15 (26.7%) fetuses with an abnormal karyotype. No duplications or deletions were identified in the remaining 11 (73.3%) fetuses with abnormal karyotypes. All 7 of the pregnancies with a genomic imbalance detected by aCGH were terminated based on these findings and all 262 with normal aCGH results were continued, suggesting that some patients may utilize this testing for reproductive decision making.

Clinical Practice Guidelines

American College of Obstetricians and Gynecologists (ACOG)

In a 2016 Committee Opinion on Microarrays and Next-Generation Sequencing Technology (American College of Obstetricians and Gynecologists, 2016a), ACOG and SMFM make the following recommendations and conclusions for the use of chromosomal microarray analysis and newer genetic technologies in prenatal diagnosis (AGOG, Committee Opinion, 2016):

- Most genetic changes identified by chromosomal microarray analysis that typically are not identified on standard karyotype are not associated with increasing maternal age; therefore, the use of this test can be considered for all women, regardless of age, who undergo prenatal diagnostic testing.
- Prenatal chromosomal microarray analysis is recommended for a patient with a fetus with one or more major structural abnormalities identified on ultrasonographic examination and who is undergoing invasive prenatal diagnosis. This test typically can replace the need for fetal karyotype.
- In a patient with a structurally normal fetus who is undergoing invasive prenatal diagnostic testing, either fetal karyotyping or a chromosomal microarray analysis can be performed.
- Chromosomal microarray analysis of fetal tissue (i.e., amniotic fluid, placenta, or products of conception) is recommended in the evaluation of intrauterine fetal death or stillbirth when further cytogenetic analysis is desired because of the test's increased likelihood of obtaining results and improved detection of causative abnormalities.
- Comprehensive patient pretest and posttest genetic counseling from an obstetrician-gynecologist or other health care provider with genetics expertise regarding the benefits, limitations, and results of chromosomal microarray analysis is essential. Chromosomal microarray analysis should not be ordered without informed consent, which should include discussion of the potential to identify findings of uncertain significance, non-paternity, consanguinity, and adult-onset disease.

In a 2016 Practice Bulletin (American College of Obstetricians and Gynecologists, 2016b) on prenatal diagnostic testing for genetic disorders, ACOG and the Society for Maternal-Fetal Medicine (SMFM) recommend the following based on good and consistent scientific evidence (Level A):

- Chromosome microarray analysis should be made available to any patient choosing to undergo invasive diagnostic testing.
- Chromosome microarray analysis should be the primary test (replacing conventional karyotype) for patients undergoing prenatal diagnosis for the indication of a fetal structural abnormality detected by ultrasound.

The 2016 Practice Bulletin further stated that prenatal diagnostic testing for genetic disorders makes the following recommendation based on limited or inconsistent scientific evidence (Level B):

- Chromosomal microarray analysis can be used to confirm an abnormal FISH test.

Society for Maternal-Fetal Medicine (SMFM)

In an SMFM Consult Series publication (2016) on the use of chromosomal microarray for prenatal diagnosis, SMFM makes the following recommendations:

- Chromosomal microarray analysis (CMA) should be offered when genetic analysis is performed in cases with fetal structural anomalies and/or stillbirth and replaces the need for fetal karyotype in these cases (GRADE 1A).
- Providers should discuss the benefits and limitations of CMA and conventional karyotype with patients who are considering amniocentesis and chorionic villus sampling (CVS) and that both options be available to women who choose to undergo diagnostic testing (GRADE 1B).
- The use of CMA is not recommended as a first-line test to evaluate first trimester pregnancy losses due to limited data (GRADE 1C).
- Pre- and posttest counseling should be performed by trained genetic counselors, geneticists or other providers with expertise in the complexities of interpreting CMA results (Best practice).

Use in Pediatrics

Developmental Disorders

Analytical Validity

Baldwin et al. (2008) described the validation of an oligonucleotide array with approximately 43,000 probes spaced an average of 75 kb across the genome, a resolution of 500 kb overall, and a resolution of 50 kb in targeted regions. Initially, 10 patients with known chromosome abnormalities, including 2 supernumerary marker chromosomes, 5 telomere deletions, 2 unbalanced translocations, and a 15q11 to q13 microdeletion, were tested with the array. The array correctly identified all 10 (100%) anomalies and identified additional complex rearrangements in 2 (20%) of the cases. Another 20 patient samples, including 14 cases with abnormalities and 6 with normal cytogenetic findings, were subsequently analyzed in a blinded manner. As with the previous group of samples, the concordance rate between the aCGH results and previous cytogenetic testing was 100%.

Clinical Validity

Ellison et al. (2012) tested the hypothesis that chromosomal microarray analysis frequently identifies conditions that require specific medical follow-up and that referring physicians respond appropriately to abnormal test results. A total of 46,298 postnatal patients were tested by chromosomal microarray analysis for a variety of indications, most commonly intellectual disability/developmental delay, congenital anomalies, dysmorphic features, and neurobehavioral problems. The frequency of detection of abnormalities associated with actionable clinical features was tallied, and the rate of physician response to a subset of abnormal tests results was monitored. A total of 2088 diagnoses were made of more than 100 different disorders that have specific clinical features that warrant follow-up. The detection rate for these conditions using high-resolution whole-genome microarrays was 5.4%, which translates to 35% of all clinically significant abnormal test results identified in the laboratory. In a subset of cases monitored for physician response, appropriate clinical action was taken more than 90% of the time as a direct result of the microarray finding. The authors concluded that the disorders diagnosed by chromosomal microarray analysis frequently have clinical features that need medical attention, and physicians respond to the diagnoses with specific clinical actions, thus arguing that microarray testing provides clinical utility for a significant number of patients tested.

Miller et al. (2010) assessed the clinical validity of chromosomal microarray testing as a first-tier analysis in the evaluation of patients with unexplained DD, ID, ASD, and/or MCA (postnatal only). A review of 33 studies involving 21,698 patients was performed to evaluate the sensitivity of microarrays in the detection of deletions and duplications. The analysis of data from all 33 studies, including those that involved BAC or oligonucleotide microarrays (aCGH), showed that chromosomal microarray analysis in general had a diagnostic yield of approximately 15% to 20%. In addition, it was determined that, although balanced rearrangements and low-level mosaicism were generally not detectable by microarray analysis, these anomalies were rare causes of DD/ID/MCA (< 1%). As a result, the ISCA stated that the evidence supports the use of chromosomal microarray testing as a first-tier test in the clinical evaluation of infants, children, or adults with DD, ID, ASD, and/or MCA.

Battaglia et al. (2013) evaluated the usefulness of CMA, as a first-tier tool in detecting the etiology of unexplained intellectual disability/autism spectrum disorders (ID/ASDs) associated with dysmorphic features in a large cohort of pediatric patients. The study included 349 individuals; 223 males, 126 females, aged 5 months-19 years. Blood samples were analyzed with CMA at a resolution ranging from 1 Mb to 40 Kb. The imbalance was confirmed by FISH or qPCR. Copy number variants (CNVs) were considered causative if the variant was responsible for a known syndrome, encompassed gene/s of known function, occurred de novo or, if inherited, the parent was variably affected, and/or the involved gene/s had been reported in association with ID/ASDs in dedicated databases. A total of 91 CNVs were detected in 77 (22.06%) patients: 5 (6.49%) of those presenting with borderline cognitive impairment, 54 (70.13%) with a variable degree of DD/ID, and 18/77 (23.38%) with ID of variable degree

and ASDs. The CNVs caused the phenotype in 57/77 (74%) patients; 12/57 (21.05%) had ASDs/ID, and 45/57 (78.95%) had DD/ID. The authors concluded that this study provided further evidence of the high diagnostic yield of CMA for genetic testing in children with unexplained ID/ASDs who had dysmorphic features.

Bremer et al. (2011) used high-resolution whole genome array-based comparative genomic hybridization (array-CGH) to screen 223 Autism spectrum disorder (ASD) patients for gene dose alterations associated with susceptibility for autism. Clinically significant copy number variations (CNVs) were identified in 18 individuals (8%), of which 9 cases (4%) had de novo aberrations. In addition, 20 individuals (9%) were shown to have CNVs of unclear clinical relevance. Among these, 13 cases carried rare but inherited CNVs that may increase the risk for developing ASDs, while parental samples were unavailable in the remaining seven cases. Classification of all patients into different phenotypic and inheritance pattern groups indicated the presence of different CNV patterns in different patient groups. Clinically relevant CNVs were more common in syndromic cases compared to non-syndromic cases. Rare inherited CNVs were present in a higher proportion of ASD cases having first- or second-degree relatives with an ASD-related neuropsychiatric phenotype in comparison with cases without reported heredity. The authors concluded that rare CNVs, encompassing potential candidate regions for ASDs, increase the susceptibility for the development of ASDs and related neuropsychiatric disorders giving further insight into the complex genetics underlying ASDs.

Bartnik et al. (2014) evaluated the application of array Comparative Genomic Hybridization (CGH) in clinical diagnostics of developmental delay/ intellectual disability in 112 children. The authors identified 37 copy number variants (CNVs) with the size ranging from 40 kb to numerical chromosomal aberrations, including unbalanced translocations and chromosome Y disomy, receiving an overall diagnostic yield of 33%. Known pathogenic changes were identified in 21.4% of the cases. Among patients with pathogenic CNVs identified by array CGH, 41.7% had a previously normal karyotype analysis. According to the authors, this study provides more insight into the benefits derived by using chromosomal microarray analysis and demonstrates the usefulness of array CGH as a first-tier clinical setting test in patients with intellectual disability.

Nicholl et al. (2014) prospectively evaluated the frequency of pathogenic chromosomal microdeletions and microduplications in a large group of referred patients with developmental delay (DD), intellectual disability (ID) or autism spectrum disorders (ASD) within a genetic diagnostic service. First tier testing was applied using a standardized oligo-array comparative genomic hybridization (CGH) platform, replacing conventional cytogenetic testing that would have been used in the past. Copy number variants (CNVs) found to be responsible for the clinical condition on the request form could all be subdivided into 3 groups: well established pathogenic microdeletion/microduplication/aneuploidy syndromes, predicted pathogenic CNVs as interpreted by the laboratory, and recently established pathogenic disease susceptibility CNVs. Totalled from these three groups, with CNVs of uncertain significance excluded, detection rates were: DD (13.0%), ID (15.6%), ASD (2.3%), ASD with DD (8.2%), ASD with ID (12.7%) and unexplained epilepsy with DD, ID and ASD (10.9%). According to the authors, the greater diagnostic sensitivity arising from routine application of array CGH, compared with previously used conventional cytogenetics, outweighs the interpretative issues for the reporting laboratory and referring clinician arising from detection of CNVs of uncertain significance. The authors stated that precise determination of any previously hidden molecular defect responsible for the patient's condition is translated to improved genetic counselling.

McCormack et al. (2016) examined the utility of aCGH to replace karyotype in 5369 pre- and post-natal patients with an unexplained phenotype. In this cohort, 28% of those tested had a deletion or duplication. Ninety seven percent of cases with a CNV that was less than 5 kilobases in size would not have been detected by routine chromosome analysis, eight hundred and forty-two 15.7% had a variant of unknown significance. About 5% of the cohort met the criteria for a known syndrome. Using microarray as a primary analysis tool significantly increased the detection of CNV abnormalities, with 1 syndromic case identified per 20 referrals.

Szczaluba et al. (2016) studied the value of aCGH in newborns with multiple congenital anomalies. A group of 54 neonates with two or more birth defects were evaluated with an OGT Cytosure 8x60 K microarray. Ten newborns were found to have rearrangements detected by aCGH. One was a recurrent syndromic microdeletion, but the others were unique. Five could be seen on routine cytogenetics, but one was sub-microscopic. The other four were copy number variants that were likely pathogenic and could explain the phenotype.

Geddes et al. (2017) evaluated a protocol to direct genetic testing, including karyotyping, 22q deletion analysis, and CMA, on infants with critical congenital heart disease. In a retrospective review of data of 733 infants prior to implementing the genetic testing protocol, 433 had at least one of included genetic tests. 66% of these patients had more than one genetic test, and the

rate of diagnosis was 26%. A genetic testing protocol was identified that aligned genetic testing with clinical presentation. For example, infants that were likely to have Trisomy 21 or Turner syndrome were first tested with routine chromosome analysis. Conotruncal heart lesion patients were evaluated by 22q analysis, and all others had a chromosome microarray as a first test. The protocol was implemented in January 2015 and evaluated through June 2016. In the post protocol period, 158 patients were evaluated, and 121 patients had at least one genetic test. The rate of genetic testing increased to 77%, and only 24% of patients had more than one genetic test. The rate of diagnosis was 36%. Overall, in the post-protocol period, infants were less likely to undergo multiple genetic tests, and were more likely to get a genetic diagnosis. Diagnostic yield varied between pre- and post-protocol tests as well. For karyotyping, the pre-protocol yield was 18%, and post-protocol was 76%. 22q analysis pre-protocol diagnostic yield was 24% and 26% post-protocol. There was no significant difference in the diagnostic yield of CMA at 22% pre-protocol and 22% post-protocol. There were no results in this cohort detected by karyotype or 22q deletion analysis that was not detectable by CMA.

Clinical Utility

Grünblatt et al. (2017) evaluated the use of CMA in 121 pediatric obsessive-compulsive disorder (OCD) cases compared to 124 controls to help identify rare and small CNVs which may contribute to early onset OCD. After analysis, the researchers determined that the frequency and size of the observed rare CNVs did not differ statistically between the subject groups, however there was a significant higher frequency of rare CNVs that affect brain related genes in the patient group (OR=1.98). They also determined that there was a significant cluster of predefined genes that are involved in brain related functional pathways that existed in the patient group and not in the control group. The study was able to conclude that these small, rare CNVs may be seen as a susceptibility factor for pediatric OCD.

Bassett et al. (2017) studied genetic factors by CMA and schizophrenia. Schizophrenia has been associated with the 22q11.2 deletion syndrome (22q11.2DS). DNA samples were obtained from 329 psychiatrically phenotyped subjects with 22q11.2DS. CMA and other methods that assess CNV were used to compare the genome outside of the 22q11.2 deletion. Rare CNVs were found that overlapped genes. Six of 19 gene-sets were found in this group and showed interactions with the 22q11.2 deletion region. The results demonstrated that there are additional rare CNVs overlapping genes outside of the 22q11.2 deletion region that may contribute to schizophrenia risk in 22q11.2DS. This supports a multi-genic hypothesis for schizophrenia.

A study by Rambo-Martin et al. (2017) assessed Down syndrome (DS) patients with atrioventricular septal defect (AVSD) who were evaluated with CMA to determine CNV to better understand why AVSD has a higher incidence in this population. This study tested 198 case individuals with DS+AVSD, and 211 control individuals with DS and a normal heart, using a custom microarray with dense probes tiled on chromosome 21 for array CGH (aCGH). The researchers found that neither an individual chromosome 21 CNV nor any individual gene intersected by a CNV was associated with AVSD in DS. This added to the literature that AVSD in Down syndrome is heterogeneous.

CMA is well known as a first-tier test for developmental disabilities (DD) and congenital anomalies. One study of a Turkish population by Ozyilmaz et al. (2017) evaluated 971 patient and 301 parent samples. Of the 971 patient samples, 133 (13.6%) had pathogenic variants. These results lead the researchers to conclude that there is high potential for using CMA in single gene disorders or novel gene-phenotype associations and CNVs.

A study of neonates with congenital heart disease (CHD) was performed to identify possible CHD genes by comparing CNVs in the institution's CHD population compared with those in the literature (Shanshen et al., 2018). Over ten years of neonatal records were reviewed and 307 neonates with CHD had CMA. Of these 25% (77 patients) had CNVs containing 832 unique genes, 16% (49 patients) had isolated CHD with 353 genes of which many were previously reported. The findings demonstrated a high incidence of abnormal genes.

A pediatric CMA study was performed to identify recurrent pathogenic CNVs in patients with idiopathic short stature (Homma et al., 2018). The study researchers selected 229 children that did not have a well-recognized syndrome but had short stature and dysmorphic features, developmental delay, and/or intellectual disability. CMA was used for evaluation of the patients and the study targeted pathogenic CNVs that were associated with short stature. In the 229 patients, 32 pathogenic or likely pathogenic CNVs were identified. The study also reviewed the literature and selected additional cohorts of patients with short stature to create a larger cohort of 671 patients. In total, CNVs were identified in 87 (13%) of patients with seven recurrent CNVs (22q11.21, 15q26, 1p36.33, Xp22.33, 17p13.3, 1q21.1, 2q24.2) that were identified as responsible for 40% of all genomic imbalances in this population.

Sys et al. (2018) evaluated CMA as a diagnostic tool for patients with autism spectrum disorders (ASD) with a variety of clinical characteristics. The researchers stated that this tool may be restricted to patients that had specific characteristics or comorbidities. A retrospective review of the files of 311 children diagnosed with ASD was performed and the following clinical characteristics were captured: intellectual disability, major congenital anomalies, epilepsy, prematurity, familial history of ASD, electroencephalography, and brain MRI findings. Next, the results of any genetic analyses were evaluated in conjunction with the clinical data. CMA had been performed in 79 patients and was normal in 55 (group 1) and abnormal in 23 (group 2). There was no significant difference between the two groups regarding the presence of clinical characteristics. Additionally, the researchers determined that the diagnostic yield of CMA (8.9%) was higher than karyotyping (1.6%) and other genetic tests (3.8%).

CMA and fragile X syndrome analysis is currently recommended as a first-tier approach for testing of males with intellectual disabilities/learning delay (ID/LD) and ASD (Weinstein et al., 2017). The study analyzed 310 male patients with ID/LD or ASD. Abnormalities were detected by CMA in 29% of males with ID/LD and 9% of males with ASD. The study concluded that this detection rate of CMA in males with ID/LD was higher than that reported in the literature (10-20%).

A study by Cuccaro et al. (2018) evaluated CNVs and mutations in Alzheimer's disease (AD). The researchers used the NeuroArray which was a custom CMA for screening patients with confirmed or suspected AD. The study design evaluated 641 genes and 9118 exons that have been linked to AD. The NeuroArray demonstrated the presence of amplifications in several AD associated genes. This study concluded that this approach may be a helpful tool in clinical diagnosis of AD.

Hussein et al. (2018) studied the role of CMA for diagnosis of congenital heart defects (CHDs) in neonates. It is known that chromosomal abnormalities or single-gene defects cause a small proportion of CHDs, however many CHDs are unable to be linked to genetic causes due to conventional techniques. The use of CMA can detect pathogenic CNVs or imbalances that other methods cannot. The researchers investigated 94 patients with CHDs that were associated with developmental delay or other malformations. They used a high-density array-CGH 2 x 400K for 41 patients and CGH/SNP microarray 2 x 400k for 53 patients. In certain cases, confirmation was performed using Fluorescent in situ hybridization or qPCR. In 21 of 94 patients (22%) using both conventional cytogenetics and CMA, abnormalities were detected in trisomy 18, 13, 21, microdeletions: del22q11.2, del7q11.23, del18 (p11.32; p11.21), tetrasomy 18p, trisomy 9p, del11q24-q25, add 15p, add (18) (q21.3), and der 9, 15 (q34.2; q11.2). In 15 of 73 cases (20.5%), cryptic chromosomal abnormalities and pathogenic variants were detected. CMA was able to detect loss of heterozygosity in chromosomes in 10 of 25 patients. Cryptic chromosomal anomalies and pathogenic variants were detected in 15/73 (20.5%) cases.

Pfundt et al. (2016) assessed the diagnostic yield and potential clinical utility of a high-density chromosomal microarray (CMA) of CytoScan Dx Assay in 960 patients with developmental delay or intellectual disability. Eighty-six percent of the subjects were assessed using a microarray as part of historical routine patient care (RPC). The rate of pathogenic findings was similar between RPC (13.3%) and the CytoScan Dx Assay (13.8%). Among the 138 patients who did not receive microarray as RPC, the diagnostic yield for CytoScan Dx Assay was 23.9% as compared with 14.5%, indicating a 9.4% improvement when using higher-resolution methods. Thirty-five percent of patients with abnormal findings had predicted clinical management implications that may improve health outcomes. The authors concluded that the assay's diagnostic yields are similar to those found in other studies of CMAs.

Fry et al. (2016) evaluated the range of rare Copy number variants (CNVs) found in 80 Welsh patients with intellectual disability (ID) or developmental delay (DD), and childhood-onset epilepsy. Molecular cytogenetic testing by single nucleotide polymorphism array or microarray-based comparative genome hybridization was performed. 8.8% (7/80) of the patients had at least one rare CNVs that was considered to be pathogenic or likely pathogenic. The CNVs involved known disease genes (EHMT1, MBD5 and SCN1A) and imbalances in genomic regions associated with neurodevelopmental disorders (16p11.2, 16p13.11 and 2q13). Prompted by the observation of two deletions disrupting SCN1A the authors undertook further testing of this gene in selected patients. This led to the identification of four pathogenic SCN1A mutations in the cohort. Five rare de novo deletions were identified, and the authors confirmed the clinical utility of array analysis in patients with ID/DD and childhood-onset epilepsy.

Shen et al. (2010) evaluated a cohort of 933 patients who received clinical genetic testing for a diagnosis of autism spectrum disorders (ASD). Clinical genetic testing included G-banded karyotype, fragile X testing, and chromosomal microarray (CMA) to

test for submicroscopic genomic deletions and duplications. Diagnostic yield of clinically significant genetic changes was compared. Karyotype yielded abnormal results in 19 of 852 patients. Fragile X testing was abnormal in 4 of 861 and CMA identified deletions or duplications in 154 of 848 patients. CMA results for 59 of 848 patients were considered abnormal, which includes variants associated with known genomic disorders or variants of possible significance. CMA results were normal in 10 of 852 patients (1.2%) with abnormal karyotype due to balanced rearrangements or unidentified marker chromosome. CMA with whole-genome coverage and CMA with targeted genomic regions detected clinically relevant copy-number changes in 7.3% and 5.3% of patients, respectively, both higher than karyotype. With the exception of recurrent deletion and duplication of chromosome 16p11.2 and 15q13.2q13.3, most copy-number changes were unique or identified in only a small subset of patients. The authors concluded that CMA had the highest detection rate among clinically available genetic tests for patients with ASD. Interpretation of microarray data is complicated by the presence of both novel and recurrent copy-number variants of unknown significance. The authors stated that despite these limitations, CMA should be considered as part of the initial diagnostic evaluation of patients with ASD.

In a clinical guideline for the recognition, referral and diagnosis of children and young people with autism, the National Institute for Health and Care Excellence (NICE) recommends that genetic tests only be done in patients who have either dysmorphic features and/or intellectual disability because these are the cases where the rate of genetic abnormalities are definitely increased above general population levels. According to the guideline, most research to date has focused on the rate and type of definite abnormalities rather than the impact of testing on children/young people with autism and their families. The authors of the guideline state that further research using CGH array would lead to a stronger evidence base to inform key decision-makers as to whether wider use of genetic testing is appropriate or not when this guideline is updated. It would also alert practitioners to any negative consequences that might occur as a result of testing (NICE 2011).

In a technology report, the Blue Cross Blue Shield Association (2015) stated that the ability to detect pathogenic CNVs underlying global developmental delay/intellectual disability (GDD/ID) and autism spectrum disorder (ASD) is improving. This improvement is likely due to higher chromosomal microarray (CMA) resolution along with increasingly extensive data for copy number variant (CNV) pathogenicity and associated phenotypes. Professional societies recommended CMA testing as first-line evaluation when genetic evaluation is desired as opposed to first obtaining a karyotype. According to the report, there is consistent evidence that the diagnostic yield obtained from CMA testing is higher than with karyotyping in children with GDD/ID or ASD, with or without congenital anomalies. (Blue Cross Blue Shield Association 2015)

Clinical Practice Guidelines

American Academy of Pediatrics (AAP)

In a 2014 clinical report, the Committee on Genetics AAP stated that chromosome microarray is designated as a first-line test and replaces the standard karyotype and fluorescent in situ hybridization subtelomere tests for the child with intellectual disability of unknown etiology. The authors recommend that chromosomal microarray should be performed in all children with intellectual disability (ID) or global developmental delays (GDDs). (Moeschler and Shevell, 2014)

In a guidance for the identification and evaluation of autism spectrum disorders (ASDs), the AAP stated that microarray aCGH is a promising tool that may become standard of care in the future, but this technique has not been evaluated systematically in children with ASDs (Johnson et al. 2007, Reaffirmed September 2010).

American Academy of Neurology (AAN)

In a model coverage policy for chromosomal microarray analysis for intellectual disabilities, the AAN recommends the following inclusion criteria for microarray testing:

- In children with developmental delay/intellectual disability (DD/ID) or an autism spectrum disorder (ASD) according to accepted Diagnostic and Statistical Manual of Mental Disorders-IV criteria;
- If warranted by the clinical situation, biochemical testing for metabolic diseases has been performed and is negative;
- Targeted genetic testing, (for example: FMR1 gene analysis for Fragile X), if or when indicated by the clinical and family history, is negative;
- The results for the testing have the potential to impact the clinical management of the patient;
- Face-to-face genetic counseling with an appropriately trained and experienced healthcare professional has been provided to the patient (or legal guardian(s) if a minor child). Patient or legal guardians have given their consent for testing. Cognitively competent adolescent patients have given their assent for testing as well.

The AAN model coverage policy states that the following circumstances limit the value of microarray testing:

- Absence of an appropriate and informed consent from the patient, a parent (in case of minors) or a guardian (in persons with cognitive impairment) is necessary prior to testing.
- Inadequacy of knowledge about the test and the actions required to address the results of the test.
- A lack of clear value for chromosomal microarray analysis in all instances other than those delineated above. Under these circumstances the test is considered investigational.
- Chromosomal microarray analysis would not be considered medically necessary when a diagnosis of a disorder or syndrome is readily apparent based on clinical evaluation alone.

The AAN model coverage policy indicates the presence of major and minor congenital malformations and dysmorphic features should be considered evidence that microarray testing will be more likely to yield a diagnosis. However, dysmorphic and syndromic features are not required for testing (AAN, 2015).

The Quality Standards Subcommittee of the American Academy of Neurology and the Practice Committee of the Child Neurology Society systematically reviewed the evidence concerning the diagnostic yield of genetic and metabolic evaluation of children with global developmental delay or intellectual disability (GDD/ID). Relevant literature was reviewed, abstracted, and classified according to the 4-tiered American Academy of Neurology classification of evidence scheme. The authors concluded that in patients with GDD/ID, microarray testing is diagnostic on average in 7.8% (Class III), G-banded karyotyping is abnormal in at least 4% (Class II and III), and subtelomeric fluorescence in situ hybridization is positive in 3.5% (Class I, II, and III). The authors state that currently, microarray testing can identify only unbalanced copy number changes and is insufficiently sensitive for detecting genetic disorders caused by inversions, balanced insertions, reciprocal translocations, polyploidy, low-level mosaicism (less than 20%–25%), rearrangements in repeat sequences, point mutations, or duplications/deletions that are undetectable at the test's resolution level. According to the authors, there is consensus among clinical geneticists that microarrays should be considered first-line cytogenetic tests, preferred over subtelomeric fluorescence in situ hybridization (StFISH) testing and karyotyping, with karyotyping reserved for patients having signs of a specific chromosomal syndrome (e.g., Down syndrome), a family history of a chromosomal rearrangement, or a parent with a history of multiple miscarriages. In recommendations for future research, the authors state that research is sorely lacking on the medical, social, and financial benefits of having an accurate etiologic diagnosis. It may be that testing for relatively rare in-born errors of metabolism has a more substantial impact on families and society than testing for genetic syndromes, given how often the diagnosis directly influences patient treatment and outcome. The authors state that the ability to rate diagnostic tests on the basis of factors other than diagnostic yield, such as the availability of effective treatment, would have a positive influence on clinical practice (Michelson et al. 2011).

American College of Medical Genetics (ACMG)

The ACMG published a guideline in 2010 that focused on when CGH should be used. The specific recommendations listed in the 2010 guideline are as follows (Manning and Hudgins, 2010):

- Cytogenetic microarray (CMA) testing for copy number variation (CNV) is recommended as a first-line test in the initial postnatal evaluation of individuals with the following:
 - Multiple anomalies not specific to a well-delineated genetic syndrome
 - Apparently non-syndromic developmental delay/intellectual disability
 - Autism spectrum disorders
- Further determination of the use of CMA testing for the evaluation of the child with growth retardation, speech delay, and other less-well studied indications is recommended, particularly via prospective studies and aftermarket analysis.
- Appropriate follow up is recommended in cases of chromosome imbalance identified by CMA, to include cytogenetic/FISH (fluorescence in situ hybridization) studies of the patient, parental evaluation, and clinical genetic evaluation and counseling.

This guideline did not address testing for prenatal gene mutations. These guidelines also do not specify what type of microarray platform should be used (i.e., microarray-based CGH versus SNP microarray), although they do state that any ordering physician should be aware of the information generated and the limitations of the particular test performed.

The 2013 ACMG guideline for identifying the etiology of autism spectrum disorders (ASDs) lists chromosomal microarray (array-comparative genomic hybridization or single-nucleotide polymorphism arrays) as a first-tier diagnostic test for the evaluation of

ASDs. According to the ACMG, many recognizable syndromes (i.e., Fragile X syndrome, Rett syndrome) have a firmly documented association with ASDs. For these conditions, further investigation into the etiology of the ASD is unnecessary (Schaefer, 2013).

ACMG Practice Guidelines regarding the interpretation and reporting of microarray results in postnatal clinical settings were published in 2011 and include recommendations regarding how to define the various types of CNVs (pathogenic versus benign versus uncertain significance), the confirmation of abnormal results, the information that should be included in laboratory reports, and how to handle unanticipated or ambiguous results. Of importance, it is noted that if a CMA is identified that has unknown clinical significance, the parents of the proband should be tested to determine if the copy number variant is de novo or inherited, which may allow the clinician to determine the clinical significance of the result (Kearney et al. 2011).

Epilepsy

Berg et al. (2017) examined the utility of various genetic testing methodologies when used in children with early life epilepsy. The study took place at 17 US based pediatric hospitals from 2012-2015. 795 families were recruited, and 775 agreed to participate. The median age of onset of symptoms was 7.5 months, and there were 397 girls and 408 boys. 95 had acquired brain injuries. Of the remaining 680 patients, 327 had various forms of genetic testing. 132 had pathogenic variants identified. Diagnostic yield was greatest for epilepsy gene panels (29%), whole exome sequencing (28%) and least for CMA (8%).

D'Orsi et al. (2017) retrospectively investigated 61 adult patients with epilepsy and intellectual disability or other neurodevelopmental disorders by CMA to determine pathogenic CNVs. High resolution CMA was analyzed to detect clinically relevant chromosomal microdeletions and microduplications. CMA identified CNVs in 33 patients analyzed: 11 had an established pathogenic microdeletion/microduplication and 22 were carriers of CNVs of unknown clinical significance. The researchers concluded that high resolution CMA should be evaluated in adult patients with intellectual disability and epilepsy with peculiar clinical features.

U.S. Food and Drug Administration (FDA)

This section is to be used for informational purposes only. FDA approval alone is not a basis for coverage.

A search of the FDA website identified an approval (K042279) for the Affymetrix Genechip Microarray Instrumentation System on December 23, 2004. Refer to the following for more information:

http://www.accessdata.fda.gov/cdrh_docs/pdf4/K042279.pdf. (Accessed January 17, 2019)

The CytoScan[®] DX Assay (Affymetrix, Inc.) was cleared for marketing under the FDA's 510(k) process in January 2014. The FDA classifies the devices a Type II postnatal chromosomal copy number variation detection system. According to documents filed with FDA, CytoScan Dx Assay is a qualitative assay intended for the postnatal detection of copy number variations (CNV) in genomic DNA obtained from peripheral whole blood in patients referred for chromosomal testing based on clinical presentation. CytoScan Dx Assay is intended for the detection of CNVs associated with developmental delay, intellectual disability, congenital anomalies, or dysmorphic features. The CytoScan DX Assay is a microarray that works with Affymetrix's existing GeneChip technology platform to perform comparative whole-genome hybridization. This device is not intended to be used for standalone diagnostic purposes, preimplantation or prenatal testing or screening, population screening, or for the detection of, or screening for, acquired or somatic genetic aberrations. The FDA's review of the CytoScan Dx Assay included an analytic evaluation of the test's ability to accurately detect numerous chromosomal variations of different types, sizes, and genome locations when compared with several analytically validated test methods. FDA found that the CytoScan Dx Assay could analyze a patient's entire genome and adequately detect chromosome variations in regions of the genome associated with intellectual and developmental disabilities. Refer to the following for more information:

- http://www.accessdata.fda.gov/cdrh_docs/pdf13/K130313.pdf
- http://www.accessdata.fda.gov/cdrh_docs/reviews/k130313.pdf

(Accessed January 17, 2019)

Genetic tests are regulated under the Clinical Laboratory Improvement Amendments (CLIA) of 1988. All laboratories offering microarray testing have current CLIA certifications, including Ambry Genetics Corp., ARUP Laboratories, Baylor College of Medicine Medical Genetics Laboratories, GeneDx Inc., LabCorp, Quest Diagnostics Inc., and Signature Genomic Laboratories.

Refer to the following website for more information:

<http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/IVDRegulatoryAssistance/ucm124105.htm>.

(Accessed January 17, 2019)

Additional Products

180K Oligo Array and SNP+CGH Array (Ambry Genetics Corp.); Cytogenomic SNP Microarray (2003414), Cytogenomic SNP Microarray, Prenatal (2002366), and Cytogenomic SNP Microarray, Products of Conception (2005633) (ARUP Laboratories); Chromosomal Microarray Analysis – HR (Test #8655), Chromosomal Microarray Analysis HR + SNP Screen (Test #8665), Chromosomal Microarray Analysis – CytoScan HD SNP Array – Non-Tumor (Test #8650), Targeted Chromosomal Microarray Analysis – Prenatal (Test #8656 [Amniocentesis] or #8657 [CVS]), and Expanded Chromosomal Microarray Analysis – Prenatal (Test #8670 [Amniocentesis] or #8671 [CVS]) (Baylor College of Medicine Medical Genetics Laboratories); Whole-Genome Chromosomal Microarray (GenomeDx), Whole-Genome Chromosomal Microarray, Prenatal, and Whole-Genome Chromosomal Microarray, Products of Conception (GeneDx Inc.); Reveal SNP Microarray- Pediatric; Reveal SNP Microarray – Prenatal, and Reveal SNP Microarray – POC (Integrated Genetics); Chromosomal Microarray, Postnatal, Clarisure Oligo-SNP (Test 16478), Chromosomal Microarray, Prenatal, Clarisure Oligo-SNP (Test 90927), and Chromosomal Microarray, POC, Clarisure Oligo-SNP (Test 90929) (Quest Diagnostics Inc.); Signature ChipOS, Signature ChipOS + SNP, Signature PrenatalChipOS, Signature PrenatalChipOS + SNP, Signature PrenatalChipTE, and Signature PrenatalChipTE + SNP (Signature Genomic Laboratories LLC)

References

- American Academy of Neurology (AAN). Model Coverage Policy. Chromosomal microarray analysis for intellectual disabilities. March 2015. Available at: https://www.aan.com/siteassets/home-page/tools-and-resources/practicing-neurologist-administrators/billing-and-coding/model-coverage-policies/15microarrayanalysismodel_tr.pdf. Accessed January 17, 2019.
- American College of Obstetricians and Gynecologists (ACOG). ACOG Practice Bulletin #102. Management of Stillbirth. March 2009. Reaffirmed 2016. Available at: <http://starlegacyfoundation.org/wp-content/uploads/acog-management-of-stillbirth1.pdf>. Accessed January 17, 2019.
- American College of Obstetricians and Gynecologists (ACOG). ACOG Committee Opinion #682. Microarrays and Next-Generation Sequencing Technology: The Use of Advanced Genetic Diagnostic Tools in Obstetrics and Gynecology. December 2016a. Available at: <https://www.acog.org/-/media/Committee-Opinions/Committee-on-Genetics/co682.pdf?dmc=1&ts=20170705T0003145503>. Accessed January 17, 2019.
- American College of Obstetricians and Gynecologists (ACOG). ACOG Practice Bulletin #162. Prenatal Diagnostic Testing for Genetic Disorders. May 2016b. Available at: <https://s3.amazonaws.com/cdn.smfm.org/publications/223/download-f5260f3bc6686c15e4780f8100c74448.pdf>. Accessed January 17, 2019.
- Baldwin EL, Lee JY, Blake DM, et al. Enhanced detection of clinically relevant genomic imbalances using a targeted plus whole genome oligonucleotide microarray. *Genet Med*. 2008;10(6):415-429.
- Bartnik M, Wiśniowiecka-Kowalnik B, Nowakowska B, et al. The usefulness of array comparative genomic hybridization in clinical diagnostics of intellectual disability in children. *Dev Period Med*. 2014 Jul-Sep;18(3):307-17.
- Bassett AS, Lowther C, Merico D, et al. Rare genome-wide copy number variation and expression of Schizophrenia in 22q11.2 Deletion Syndrome. *Am J Psychiatry*. 2017;174(11):1054-1063.
- Battaglia A, Doccini V, Bernardini L, et al. Confirmation of chromosomal microarray as a first-tier clinical diagnostic test for individuals with developmental delay, intellectual disability, autism spectrum disorders and dysmorphic features. *Eur J Paediatr Neurol*. 2013 Nov;17(6):589-99.
- Berg AT, Coryell J, Saneto RP, et al. Early-life epilepsies and the emerging role of genetic testing. *JAMA Pediatr*. 2017 Sep 1;171(9):863-871.
- Blue Cross Blue Shield Association. Special Report: Chromosomal Microarray for the Genetic Evaluation of Patients With Global Developmental Delay, Intellectual Disability, and Autism Spectrum Disorder. *Technol Eval Cent Assess Program Exec Summ*. 2015 Aug;30(2):1-4.

Brady PD, Delle Chiaie B, Christenhusz G, et al. A prospective study of the clinical utility of prenatal chromosomal microarray analysis in fetuses with ultrasound abnormalities and an exploration of a framework for reporting unclassified variants and risk factors. *Genet Med*. 2013 Oct 31.

Bremer A, Giacobini M, Eriksson M, et al. Copy number variation characteristics in subpopulations of patients with autism spectrum disorders. *Am J Med Genet B Neuropsychiatr Genet*. 2011 Mar;156(2):115-24. doi: 10.1002/ajmg.b.31142.

Bruno DL, Ganesamoorthy D, Schoumans J, et al. Detection of cryptic pathogenic copy number variations and constitutional loss of heterozygosity using high resolution SNP microarray analysis in 117 patients referred for cytogenetic analysis and impact on clinical practice. *J Med Genet*. 2009;46(2):123-131.

Bui TH, Vetro A, Zuffardi O, et al. Current controversies in prenatal diagnosis 3: is conventional chromosome analysis necessary in the post-array CGH era? *Prenat Diagn*. 2011 Mar;31(3):235-43. doi: 10.1002/pd.2722.

Cai M, Huang H, Su L, et al. Chromosomal abnormalities and copy number variations in fetal ventricular septal defects. *Mol Cytogenet*. 2018;11:58.

Cuccaro D, Guarnaccia M, Iemolo R, et al. NeuroArray, A custom CGH microarray to decipher copy number variants in Alzheimer's Disease. *Curr Genomics*. 2018 Sep;19(6):499-504. de Wit MC, Srebniak MI, Govaerts LC, et al. Additional value of prenatal genomic array testing in fetuses with isolated structural ultrasound abnormalities and a normal karyotype: a systematic review of the literature. *Ultrasound Obstet Gynecol*. 2014 Feb;43(2):139-46.

Dhillon R, Hillman S, Morris R, et al. Additional information from chromosomal microarray analysis (CMA) over conventional karyotyping when diagnosing chromosomal abnormalities in miscarriage: a systematic review and meta-analysis. *BJOG*. 2014 Jan;121(1):11-21.

d'Orsi G, Martino T, Palumbo O, et al. The epilepsy phenotype in adult patients with intellectual disability and pathogenic copy number variants. *Seizure*. 2017 Dec;53:86-93.

Egloff M, Hervé B, Quibel T, et al. Diagnostic yield of chromosomal microarray analysis in fetuses with isolated increased nuchal translucency: a French multicenter study. *Ultrasound Obstet Gynecol*. 2018 Dec;52(6):715-721.

Ellison JW, Ravnán JB, Rosenfeld JA, et al. Clinical utility of chromosomal microarray analysis. *Pediatrics*. 2012 Nov;130(5):e1085-95.

Fruhman G, Van den Veyver IB. Applications of array comparative genomic hybridization in obstetrics. *Obstet Gynecol Clin North Am*. 2010 Mar;37(1):71-85.

Fry AE, Rees E, Thompson R, et al. Pathogenic copy number variants and SCN1A mutations in patients with intellectual disability and childhood-onset epilepsy. *BMC Med Genet*. 2016 Apr 26;17(1):3.

Fu F, Deng Q, Lei TY, et al. Clinical application of SNP array analysis in fetuses with ventricular septal defects and normal karyotypes. *Arch Gynecol Obstet*. 2017 Nov;296(5):929-940.

Geddes GC, Basel D, Frommelt P, et al. Genetic testing protocol reduces costs and increases rate of genetic diagnosis in infants with congenital heart disease. *Pediatric Cardiology*. 2017;38(7):1465-1470.

Genetics Glossary (Syndrome). National Genome Institute. 2019. Available at: <https://www.genome.gov/search?terms=syndrome>. Accessed June 5, 2019.

Genetics Home Reference, National Library of Medicine. How are Genetic Conditions Diagnosed? May 2019. Available at: https://ghr.nlm.nih.gov/primer/consult/diagnosis?_ga=2.107334282.928673881.1559156694-1234460177.1559156694. Accessed June 5, 2019.

Gliem TJ, Aypar U. Development of a chromosomal microarray test for the detection of abnormalities in formalin-fixed, paraffin-embedded products of conception specimens. *J Mol Diagn*. 2017 Nov;19(6):843-847.

Grande M, Jansen FA, Blumenfeld YJ, et al. Genomic microarray in fetuses with increased nuchal translucency and normal karyotype: a systematic review and meta-analysis. *Ultrasound Obstet Gynecol*. 2015 Dec;46(6):650-8.

Grünblatt E, Oneda B, Ekici AB, et al. High-resolution chromosomal microarray analysis in paediatric obsessive-compulsive disorder. *BMC Med Genomics*. 2017;10(1):68.

Hillman, SC, Pretlove, S, Coomarasamy, A, et al. Additional information from array comparative genomic hybridization technology over conventional karyotyping in prenatal diagnosis: a systematic review and meta-analysis. *Ultrasound Obstet Gynecol.* 2011;37(1):6-14.

Homma TK, Krepischi ACV, Furuya TK, et al. Recurrent copy number variants associated with syndromic short stature of unknown cause. *Horm Res Paediatr.* 2018;89(1):13-21.

Hussein IR, Bader RS, Chaudhary AG, et al. Identification of De Novo and rare inherited copy number variants in children with syndromic congenital heart defects. *Pediatr Cardiol.* 2018 Jun;39(5):924-940.

Jin H, Yingqiu C, Zequn L, et al. Chromosomal microarray analysis in the prenatal diagnosis of orofacial clefts: Experience from a single medical center in mainland China. *Medicine (Baltimore).* 2018;97(34):e12057.

Johnson CP, Myers SM; American Academy of Pediatrics Council on Children with Disabilities. Identification and evaluation of children with autism spectrum disorders. *Pediatrics.* 2007 Nov;120(5):1183-215. Reaffirmed September 2010.

Kearney HM, Thorland EC, Brown KK, et al.; Working Group of the American College of Medical Genetics Laboratory Quality Assurance Committee. American College of Medical Genetics standards and guidelines for interpretation and reporting of postnatal constitutional copy number variants. *Genet Med.* 2011;13(7):680-685.

Manning M, Hudgins L. Use of array-based technology in the practice of medical genetics. *Genet Med.* 2007;9(9):650-653.

Manning M, Hudgins L; Professional Practice and Guidelines Committee. Array-based technology and recommendations for utilization in medical genetics practice for detection of chromosomal abnormalities. *Genet Med.* 2010 Nov;12(11):742-5.

Maya I, Davidov B, Gershovitz L, et al. Diagnostic utility of array-based comparative genomic hybridization (aCGH) in a prenatal setting. *Prenat Diagn.* 2010 Dec;30(12-13):1131-7.

Maya I, Sharony R, Yacobson S, et al. When genotype is not predictive of phenotype: implications for genetic counseling based on 21,594 chromosomal microarray analysis examinations. *Genet Med.* 2018 Jan;20(1):128-131.

Mc Cormack A, Claxton K, Ashton F, et al. Microarray testing in clinical diagnosis: an analysis of 5,300 New Zealand patients. *Molecular Cytogenetics.* 2016;9:29.

Michelson DJ, Shevell MI, Sherr EH, et al. Evidence report: Genetic and metabolic testing on children with global developmental delay: report of the Quality Standards Subcommittee of the American Academy of Neurology and the Practice Committee of the Child Neurology Society. *Neurology.* 2011 Oct 25;77(17):1629-35. Reaffirmed on August 9, 2014.

Miller DT, Adam MP, Aradhya S, et al. Consensus statement: chromosomal microarray is a first-tier clinical diagnostic test for individuals with developmental disabilities or congenital anomalies. *Am J Hum Genet.* 2010;86(5):749-764.

Moeschler JB, Shevell M; Committee on Genetics. Comprehensive evaluation of the child with intellectual disability or global developmental delays. *Pediatrics.* 2014 Sep;134(3):e903-18.

National Institute for Health and Care Excellence (NICE). Autism in under 19s: recognition, referral and diagnosis. September 2011.

Nicholl J, Waters W, Mulley JC, et al.; Array Referral Consortium, Friend K, Bain SM, Yu S. Cognitive deficit and autism spectrum disorders: prospective diagnosis by array CGH. *Pathology.* 2014 Jan;46(1):41-5.

Ozyilmaz B, Kirbiyik O, Koc A, et al. Experiences in microarray-based evaluation of developmental disabilities and congenital anomalies. *Clin Genet.* 2017 Oct;92(4):372-379.

Parchem JG, Sparks TN, Gosnell K, et al. Utility of chromosomal microarray in anomalous fetuses. *Prenat Diagn.* 2018 Jan;38(2):140-147.

Pauta M, Grande M, Rodriguez-Revenga L, et al. Added value of Chromosomal Microarray Analysis (CMA) over karyotyping in Early Pregnancy Loss - a Systematic Review and Meta-Analysis. *Ultrasound Obstet Gynecol.* 2017 Oct 21.

Papoulidis I, Sotiriadis A, Siomou E, et al. Routine use of array comparative genomic hybridization (aCGH) as standard approach for prenatal diagnosis of chromosomal abnormalities. Clinical experience of 1763 prenatal cases. *Prenat Diagn.* 2015 Dec;35(13):1269-77.

Peng R, Yang J, Xie HN, et al. Chromosomal and sub chromosomal anomalies associated to small for gestational age fetuses with no additional structural anomalies. *Prenat Diagn.* 2017 Dec;37(12):1219-1224.

Pfundt R, Kwiatkowski K, Roter A, et al. Clinical performance of the CytoScan Dx Assay in diagnosing developmental delay/intellectual disability. *Genet Med*. 2016 Feb;18(2):168-73.

Rambo-Martin BL, Mulle JG, Cutler DJ, et al. Analysis of copy number variants on chromosome 21 in Down Syndrome-associated congenital heart defects. *G3 (Bethesda)*. 2017;8(1):105-111.

Rosenfeld JA, Tucker ME, Escobar LF, et al. Diagnostic utility of microarray testing in pregnancy loss. *Ultrasound Obstet Gynecol*. 2015 Oct;46(4):478-86.

Sagi-Dain L, Maya I, Reches A, et al. Chromosomal microarray analysis results from pregnancies with various ultrasonographic anomalies. *Obstet Gynecol*. 2018 Dec;132(6):1368-1375.

Schaefer GB, Mendelsohn NJ; Professional Practice and Guidelines Committee. Clinical genetics evaluation in identifying the etiology of autism spectrum disorders: 2013 guideline revisions (reaffirmed March 2014). *Genet Med*. 2013 May;15(5):399-407.

Schoolcraft WB, Fragouli E, Stevens J, et al. Clinical application of comprehensive chromosomal screening at the blastocyst stage. *Fertil Steril*. 2010 Oct;94(5):1700-6.

Shaffer LG, Beaudet AL, Brothman AR, et al. Microarray analysis for constitutional cytogenetic abnormalities. *Genet Med*. 2007;9(9):654-662.

Shaffer LG, Rosenfeld JA, Dabell MP, et al. Detection rates of clinically significant genomic alterations by microarray analysis for specific anomalies detected by ultrasound. *Prenat Diagn*. 2012b Oct;32(10):986-95.

Shanshen E, Rosenberg J, Van Bergen AH. Identification of novel congenital heart disease candidate genes using chromosome microarray. *Pediatr Cardiol*. 2018 Jan;39(1):148-159.

Shen, Y, Dies, KA, Holm, IA, et al. Clinical genetic testing for patients with autism spectrum disorders. *Pediatrics*. 2010;125(4):e727-e735.

Society for Maternal-Fetal Medicine (SMFM). Dugoff L, Norton ME, Kuller JA. The use of chromosomal microarray for prenatal diagnosis. *Am J Obstet Gynecol*. 2016 Oct;215(4):B2-9.

Srebniak MI, Diderich KE, Joosten M, et al. Prenatal SNP array testing in 1000 fetuses with ultrasound anomalies: causative, unexpected and susceptibility CNVs. *Eur J Hum Genet*. 2016 May;24(5):645-51.

Sys M, van den Bogaert A, Roosens B, et al. Can clinical characteristics be criteria to perform chromosomal microarray analysis in children and adolescents with autism spectrum disorders? *Minerva Pediatr*. 2018 Jun;70(3):225-232.

Szczałuba K, Nowakowska B, Sobecka K, et al. Application of array comparative genomic hybridization in newborns with multiple congenital anomalies. *Adv Exp Med Biol*. 2016;912:1-9.

Wang Y, Cao L, Liang D, et al. Prenatal chromosomal microarray analysis in fetuses with congenital heart disease: a prospective cohort study. *Am J Obstet Gynecol*. 2018 Feb;218(2):244.e1-244.e17.

Weinstein V, Tanpaiboon P, Chapman KA, et al. Do the data really support ordering fragile X testing as a first-tier test without clinical features?. *Genet Med*. 2017;19(12):1317-1322.

Zou Z, Huang L, Lin S, et al. Prenatal diagnosis of posterior fossa anomalies: Additional value of chromosomal microarray analysis in fetuses with cerebellar hypoplasia. *Prenat Diagn*. 2018 Jan;38(2):91-98.

Policy History/Revision Information

Date	Summary of Changes
01/01/2022	<p>Applicable Codes</p> <ul style="list-style-type: none"> ● Updated list of applicable CPT codes to reflect annual edits: <ul style="list-style-type: none"> ○ Added 81349 ○ Revised description for 81228 and 81229 <p>Supporting Information</p> <ul style="list-style-type: none"> ● Archived previous policy version CS017NJ.R

Instructions for Use

This Medical Policy provides assistance in interpreting UnitedHealthcare standard benefit plans. When deciding coverage, the federal, state or contractual requirements for benefit plan coverage must be referenced as the terms of the federal, state or contractual requirements for benefit plan coverage may differ from the standard benefit plan. In the event of a conflict, the federal, state or contractual requirements for benefit plan coverage govern. Before using this policy, please check the federal, state or contractual requirements for benefit plan coverage. UnitedHealthcare reserves the right to modify its Policies and Guidelines as necessary. This Medical Policy is provided for informational purposes. It does not constitute medical advice.

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