**Name of journal: *World Journal of Cardiology***

**ESPS Manuscript NO: 11668**

**Columns: TOPIC HIGHLIGHT**

WJC 6th Anniversary Special Issues (3): Cardiomyopathy

**Infant with cardiomyopathy: When to suspect inborn errors of metabolism?**

Ficicioglu C *et al.* Cardiomyopathy

Can Ficicioglu, Stephanie Byers

**Can Ficicioglu, Stephanie Byers,** The Children’s Hospital of Philadelphia, Section of Metabolism, Perelman School of Medicine at the University of Pennsylvania, Philadelphia, PA 19104, United States

**Author contributions:** Byers S contributed to the literature review, writing paper; Ficicioglu C contributed to the literature review, designing the major elements of the paper, writing and editing the paper

**Correspondence to:** **Can Ficicioglu, MD, PhD,** The Children’s Hospital of Philadelphia, Perelman School of Medicine at the University of Pennsylvania, 3501 Civic Center blvd #9054, Philadelphia, PA 19106, United States. [ficicioglu@email.chop.edu](mailto:Ficicioglu@email.chop.edu)

**Telephone:** +1-215-5903376 **Fax:** +1-215-5904297

**Received:** May 29, 2014 **Revised:** July 21, 2014

**Accepted:** September 04, 2014

**Published online:**

**Abstract**

Inborn errors of metabolism are identified in 5%-26% of infants and children with cardiomyopathy. Although fatty acid oxidation disorders, lysosomal and glycogen storage disorders and organic acidurias are well-known to be associated with cardiomyopathies, emerging reports suggest that mitochondrial dysfunction and congenital disorders of glycosylation may also account for a proportion of cardiomyopathies. This review article clarifies when primary care physicians and cardiologists should suspect inborn errors of metabolism in a patient with cardiomyopathy, and refer the patient to a metabolic specialist for a further metabolic work up, with specific discussions of “red flags” which should prompt additional evaluation.

© 2014 Baishideng Publishing Group Inc. All rights reserved.

**Key words:** Cardiomyopathy; Inherited metabolic disorders; Inborn errors of metabolism

**Core tip:** We highlight some very helpful red flags that, when present, should point physicians in the direction of doing a metabolic workup in patients with cardiomyopathy. Short case presentations will help readers to transfer efficiently metabolic diagnostic tools in their own practice. This article will be an essential reference for physicians as they evaluate patients with cardiomyopathy.

Ficicioglu C, Byers S. Infant with cardiomyopathy: When to suspect inborn errors of metabolism? *World J Cardiol* 2014; In press

**INTRODUCTION**

Cardiomyopathy is rare in children (1.13 cases annually per 100000) but it often has catastrophic consequences including heart failure and death[1]. While the etiology of cardiomyopathy in infancy and childhood is varied, inborn errors of metabolism cause a substantial percentage of pediatric cardiomyopathies. Determining the etiology of cardiomyopathy presenting in the first year of life is critical to ensure optimal treatment and management, provide appropriate genetic counseling, and anticipate additional medical complications which may arise.

Previously, it was reported that approximately 5% of pediatric cardiomyopathies are due to an inborn error of metabolism[2], however a more recent study found a substantially higher percentage, with 26% of hypertrophic and 16% of dilated cardiomyopathies having a metabolic etiology[3]. A separate study found five out of 35 infants (13.5%) diagnosed in the first year of life had a metabolic etiology to their cardiomyopathy[4]. Over 40 different metabolic disorders are known to cause cardiomyopathy[2]. Most commonly, disturbances of fatty acid oxidation, organic acidurias and storage disorders are implicated; however congenital disorders of glycosylation and mitochondrial disorders have more recently been identified in infants with cardiomyopathy[2,3,5,6].

This review article clarifies when primary care physicians and cardiologists should suspect inborn errors of metabolism in a patient with cardiomyopathy, and refer the patient to a metabolic specialist for a further metabolic work up. Short case presentations are designed to help readers transfer efficiently metabolic diagnostic tools into their clinical practice.

**WHEN TO SUSPECT A METABOLIC DIAGNOSIS IN A CHILD PRESENTING WITH CARDIOMYOPATHY**

Table 1 includes a summary of some of the more common metabolic disorders associated with cardiomyopathy along with pathognomonic biochemical abnormalities. Several “red flags” may be evident in the medical history and on initial physical examination. Identification of the following “red flags” should warrant a consultation with a metabolic specialist.

***Medical history***

A thorough medical history, including prenatal history, may give evidence of metabolic disease. Maternal history of acute fatty liver or HELLP syndrome (hemolysis, elevated liver enzymes, and low platelets) during pregnancy may indicate that the fetus was affected with a fatty acid oxidation disorder. Newborn metabolic screening result should be obtained. A normal newborn screening is reassuring; however, many IEMs such as storage disorders, mitochondrial disorders and congenital disorders of glycosylation are not included in the newborn screening panels; they could present with cardiomyopathy. Episodes of vomiting, lethargy, hypoglycemia, and metabolic decompensation in the context of poor feeding or illness are important clues of the potential presence of IEMs. A history of multisystem involvement, delayed developmental milestones, low muscle tone, developmental regression, coarse facial features, enlarged tongue, feeding difficulties and failure to thrive, recurrent ear and/or upper respiratory infections, rhabdomyolysis, muscle pain or spasms warrant consultation with a metabolic specialist.

**Cardiomyopathy with hypoglycemia:** Episodes of hypoglycemia, particularly nonketotic hypoglycemia, can be a red flag that there is a disturbance of energy production. In conjunction with cardiomyopathy, disorders of fatty acid oxidation are high on the list of differential diagnoses. Although some glycogen storage disorders may also be associated with episodic hypoglycemia, the hepatic glycogenoses are not generally associated with cardiomyopathy.

***Family history***

Family history of other closely related individuals with cardiomyopathy of unexplained etiology warrants further genetics evaluation. As most inborn errors of metabolism are inherited in an autosomal recessive manner, affected siblings and siblings who died at a young age from uncertain etiology should raise the suspicion for a metabolic etiology. X-linked disorders and many mitochondrial disorders are often inherited from the mother, thus family history should include second and third degree relatives, particularly on the maternal side. Mitochondrial disorders may show considerable inter-individual variation, thus focus on maternal family history for other features of mitochondrial disorders, such as migraines, seizures, stroke-like episodes, developmental disabilities/regression, movement disorders, and exercise intolerance, may provide additional indication of mitochondrial dysfunction. Information regarding parental consanguinity and ethnic origins may also increase the suspicion of a metabolic etiology.

**Cardiomyopathy with Hypotonia:** Hypotonia can be a key indicator of systemic muscle disease not limitedto the heart. In an infant, hypotonia often results in the failure to meet developmentalmilestones on time. Hypotonia can also manifest as difficulty feeding and respiratorydistress in an infant. For an infant with severe hypotonia and cardiomyopathy,Pompe disease should be excluded from the differentials. Congenital disorders ofglycosylation and mitochondrial disorders may also present with cardiomyopathy andhypotonia due to an inability to produce and utilize energy in muscle. Lastly, due to thebuild-up of toxic waste products, organic acidurias may present in this manner.

***Physical examination***

Thorough examination of the patient should be performed and focused on the following: (1) Detection of hepatosplenomegaly, hypertrophic tonsils, joint contractures (indicative of lysosomal storage disorders); (2) Assessment of a neurologic function (may be abnormal in mitochondrial disorders, storage disorders, malonic aciduria); and (3) Identification of dysmorphic features such as coarsened facial features (pathognomonic for mucopolysaccharidosis).

Hearing and vision should always be included in the exam. Involvement of multiple organ systems in a child with cardiomyopathy should increase the suspicion for an IEM.

**Cardiomyopathy with hepatomegaly:** Hepatomegaly is a characteristic feature of storage disorders due toaccumulation of waste materials in the liver. Liver biopsy may showcharacteristic storage materials. These waste materials may accumulatein other areas of the body, including soft tissues, joints and bones,which may be identified on physical examination. Coarse facial featuresin an infant with hepatomegaly should highly increase the suspicion of a storage disorder.

***Laboratory studies***

Confirmation of IEMs often relies on measuring the enzyme activity and/or identifying the genetic mutations responsible, but gene sequencing and copy number analysis may take weeks to months prior to having results. In an experienced laboratory, biochemical analysis can expeditiously determine whether a metabolic etiology warrants further investigation for some IEMs. In the absence of an obvious syndromic etiology, we recommend a biochemical evaluation as a standard of care for all infants with cardiomyopathy. Specifically, we recommend an acylcarnitine profile, plasma lactate/pyruvate, creatine kinanse and urine organic acids that could help in the diagnosis of fatty acid oxidation defects or malonic acidemia, which can be treated. Additional laboratory studies such as urine glycosaminoglycan quantification (for lysosomal storage disorders), N and O-glycans with carbohydrate deficient transferrin analysis (for congenital disorders of glycosylation) and specific enzyme analysis (for glycogen storage disorders and lysosomal storage disorders) may need to be performed to rule out some IEMs (Table 2).

**MAJOR ETIOLOGICAL CATEGORIES**

The major categories of inborn errors of metabolism associated with cardiomyopathy in infants are fatty acid oxidation disorders, lysosomal storage disorders, glycogen storage disorders, mitochondrial disorders and organic acidurias.

Fatty acids are used by the body as an alternative energy source when glucose is not available. Disorders of almost every step of the beta oxidation pathway, as well as disorders of fatty acid uptake and transport, have been identified and associated with cardiomyopathy. Carnitine-acylcarnitine translocase (CACT) deficiency, carnitine palmitoyltransferase II (CPT II) deficiency, very long-chain acyl-CoA dehydrogenase (VLCAD) deficiency, long-chain 3-hydroxyacyl-CoA dehydrogenase (LCHAD) deficiency, trifunctional protein (TFP) deficiency and glutaric acidemia type 2are well known to be associated with cardiomyopathy[7]; however others such as MCAD have also rarely been identified in infants with cardiomyopathy[8].

Lysosomal storage disorders (LSD) are an individually rare, but collectively common group of disorders in which waste materials accumulate in the lysosome. The accumulation of these materials in various organs and tissues throughout the body is the main mode of pathogenesis for these disorders; however the exact mechanisms are unknown. Of the lysosomal storage disorders, Hurler syndrome (mucopolysaccharidosis type I) and Hunter syndrome (mucopolysaccharidosis type II) are the most well-known to be associated with cardiomyopathy in infancy and childhood. Maroteaux-Lamy (mucopolysaccharidosis type VI) has also been reported as a presenting with cardiomyopathy in the infant period[9]. Inheritance is autosomal recessive, with the notable exception of Hunter syndrome and Fabry syndrome, which are both X-linked. LSDs are also notable in that enzyme replacement therapies (ERTs) are available for many of these disorders. ERTs halt the further accumulation of additional waste materials in the heart, but may not fully reverse the damage already done, further stressing the importance of early diagnosis.

Caused by many enzymes involved in the synthesis and breakdown of glycogen, glycogen storage disorders have primarily either hepatic or muscle involvement. Generally, muscle glycogenoses do not have symptoms of hypoglycemia. Pompe disease, a disorder which falls into both categories of lysosomal storage disorders and glycogen storage disorders, is one of the most common metabolic disorders associated with cardiomyopathy in infants. Infantile onset is associated with extreme hypotonia, failure to thrive, respiratory distress and cardiomyopathy. Although there are juvenile and adult-onset forms of Pompe disease, cardiomyopathy is not a feature of the later onset disorder. A similar disorder, Danon disease, is X-linked and affected males exhibit cardiomyopathy, intellectual disability and myopathy. ERT is available for Pompe disease, but not Danon disease at this time. Other glycogen storage disorders, which rarely present with cardiomyopathy in the infant period, include type III (debranching enzyme deficiency)[10] and type IV (Andersen disease)[11].

Mitochondrial disorders typically have multisystem involvement, which can include hypertrophic or dilated cardiomyopathy, as well as left ventricular non-compaction[6]. Although mitochondrial disorders are estimated to have an incidence of 1 in 5000 births, these disorders are likely under diagnosed. Many of the well characterized mitochondrial disorders, including Leigh syndrome, MELAS and MERRF, are known to include cardiomyopathy[6].

Congenital disorders of glycosylation (CDGs) are a heterogeneous group of disorders caused by enzymatic disturbances in the synthesis of glycoproteins. The spectrum of CDGs is ever expanding. Several case reports in the literature suggest that CDGs should be considered in infants with cardiomyopathy and multisystem disorders. Infants with CDG Ia (phosphomannomutase 2 deficiency) are have been most often been reported to have hypertrophic cardiomyopathy[12-16] and infants with dolichol kinase deficiency have been reported to have dilated cardiomyopathy[17,18]. Case reports exist for cardiomyopathy associated with other CDGs[12,19].

Organic acidurias are the result of enzyme deficiencies characterized by the excretion of specific organic acids in the urine. Although this group is large, only a few have been associated with cardiomyopathy. Barth syndrome, characterized by urinary excretion of 3-methylglutaconic acid due to defects in the mitochondrial protein tafazzin, causes dilated cardiomyopathy in infant males, which is often severe[20]. Propionic acidemia is the most well-known; however, individuals with propionic acidemia generally do not develop cardiomyopathy in the newborn period. Cardiomyopathy has rarely been reported in infants with methylmalonic acidemia[21].

**NEWBORN SCREENING**

With the advent and standardization of neonatal screening in the United States, many metabolic disorders associated with cardiomyopathy are identified within the first days of life. Fatty acid oxidation disorders, including VLCAD deficiency, LCHAD deficiency and carnitine uptake deficiency, as well as propionic acidemia are included in the disorders recommended by the American College of Medical Genetics as part of the core panel of disorders included on the newborn screen[22]. Despite the inclusion of several inborn errors of metabolism, this should not lead to a false sense of comprehensiveness. False negatives have been reported[23] and individuals with fatty acid oxidation disorders may have normal acylcarnitine profiles when they are not in a state of metabolic decompensation. Lysosomal storage disorders, congenital glycosylation defects, glycogen storage disorders or mitochondrial disorders are not screened. Although many states are moving towards screening for lysosomal storage disorders, it is uncertain whether there will be universal acceptance of neonatal screening for these disorders.

**CASE PRESENTATIONS**

The following cases represent several infants who presented in the newborn period with cardiomyopathy and a metabolic etiology was determined.

***Patient 1***

He is a male infant of Puerto Rican ethnicity. He presented to an emergency department in the setting of respiratory distress. Upon evaluation, the patient was found to have pneumonia. An echocardiogram was performed, which revealed dilated cardiomyopathy with severe dysfunction. The ejection fraction was estimated at 20%. The patient was transferred to our medical center for further evaluation and management of his cardiac dysfunction.

Physical examination of the patient showed an interactive male, with frontal bossing and dysmorphic features, including depressed nasal bridge, and low set, posteriorly rotated ears. He was developmentally delayed and had a history of failing his newborn hearing screen. Family history was significant for consanguinity, as the patient’s parents are first cousins. Family history was also remarkable for a sister who died at age 3 years 5 mo from unspecified cardiac dysfunction.

***Red flags for IEM and final diagnosis: Patient 1***

**Red flags: (1)** Family history of sibling death due to unspecified cardiac dysfunction. Further investigation revealed that she had coarse facial features and developmental delay as well; (2) Consanguinity; and (3)Coarse facial features, dysmorphic features, hearing loss, and developmental delay.

The deceased sibling had the same signs and symptoms as this patient and the parents are consanguineous. This suggests the likelihood that they have an autosomal recessive genetic disorder. The patient had many other clinical findings besides dilated cardiomyopathy so this is not simply an isolated cardiomyopathy. Based on coarse facial features, hearing loss, developmental delay, hearing loss and cardiomyopathy, lysosomal storage disorders such as mucopolysaccharidosis were suspected first in the differential diagnosis. Leukocyte enzyme analysis showed alpha-iduronidase activity of 0 nmol substrate/hr/mg/protein (normal 6-71.4). This is consistent with a diagnosis of Mucopolysaccharidosis type 1, or Hurler syndrome. Genetic testing confirmed this diagnosis with homozygous c.208C > T (p.Q70X) mutations in the *IDUA* gene. Urinary glycosaminoglycan (GAGs) quantitation showed elevation at 163.51mg/nmol creatinine.

Following the diagnosis of MPS1, this patient started enzyme replacement therapy (Aldurazyme). The patient’s cardiac function has stabilized at one year of age and he will continue to be followed for signs of cardiac dysfunction.

***Patient 2***

He is an 8-mo-old ex-full term male born to a 32-year-old G1P0 Haitian mother and Dominican father. Pregnancy was unremarkable except for hypertrophic cardiomyopathy noted on second trimester ultrasounds that was confirmed by fetal echocardiogram. He was initially asymptomatic, but echocardiogram at birth confirmed the presence of biventricular hypertrophy with increased trabeculation and decreased left ventricular function. Cardiac catheterization and endomyocardial muscle biopsy at three weeks of life revealed non-specific findings of cardiomyopathy with muscle disarray, and there was no evidence of glycogen accumulation. Additional metabolic workup included normal acylcarnitine profile and urine amino acids, grossly normal plasma amino acids, normal ammonia and cholesterol levels, essentially normal urine carnitine levels, plasma carnitine levels, and creatinine kinase level. Lactate was normal, pyruvate level was slightly low, and elevated lactate/pyruvate ratio at 53 (normal 10-20). Pompe disease was ruled out based on normal enzyme activity.

***Red flags for IEM and final diagnosis: Patient 2***

**Red flags:** There was no clear explanation for this patient’s hypertrophic cardiomyopathy. It appeared to be an isolated cardiomyopathy without significant neurologic or other organ involvement. Elevated lactate/pyruvate ratio was a red flag for mitochondrial disorders. This warranted further mitochondrial work up.

The patient had genetic testing for mutations in genes associated with mitochondrial disorders. The patient was found to have two predicted pathogenic variants in the *SLC25A3* gene, c.599T > G (pL200W) and c.886-898delins7 (p.G296-S300delinsQIP). Parental testing indicated that the *SLC25A3* variants were in trans.

Mutations in *SLC25A3* are associated with mitochondrial phosphate carrier deficiency. There are only two papers in the literature describing five children from two families with mutations in this gene. Of the five children reported, three died in early infancy[24]. Two of the other children had difficult neonatal courses, but were living at age 9 and 17 as of 2011[25]. Mitochondrial phosphate carrier deficiency is characterized by hypertrophic cardiomyopathy, skeletal myopathy and lactic acidosis.

Patient 2 was listed for a cardiac transplant and received a heart at 8 mo of age. Following the surgery, this patient was observed to have new-onset seizures. Patient 2 continues to be followed by Cardiology, Metabolism, and Neurology at 10 mo of age.

***Patient 3***

He was previously reported[26] and is included with permission of the original author. A full term male of African American ethnicity presented at 5 mo of age in the setting of decreased oral intake, fatigue with feeds, cough and fever. His prenatal history was unremarkable. His first months were significant for poor head control and gross motor delays. Echocardiogram demonstrated left ventricular dilation, spongiform appearance of the left ventricular free wall and poor ventricular functioning. The ejection fraction was shortened at 21%.

***Red flags for IEM and final diagnosis: Patient 3***

**Red flags:** Hypotonia, developmental delay in addition to cardiomyopathy. These symptoms warranted further testing to rule out IEM. The metabolic tests such as plasma acylcarnitine profile, blood and urine carnitine levels, Creatine kinase (CK) and urine organic acid analysis should be ordered as the first step tests.

Biochemical evaluation included urine organic acids [increased excretion of malonic acid (1060 mg/g creatinine) and methylmalonate (59 mg/g creatinine)], plasma acylcarnitine profile (elevated malonyl carnitine of 0.13 nmol/mL), lactate/pyruvate (normal), and creatine kinase (normal). The patient was neither acidotic nor hypoglycemic.

Malonyl-CoA decarboxylase enzyme assay showed 12% of normal activity. Retrospective analysis of the patient’s newborn screening showed an elevated malonyl carnitine of 0.39 nmol/mL, which was not reported due to lack of routine screening for this compound and lack of established standards.

This patient was treated with carnitine supplementation, medium-chain triglyceride supplementation and a high-carbohydrate diet. After one year of treatment, the patient did not have any further episodes of metabolic decompensation, but developmental delays persisted. Follow-up cardiac surveillance continued to show left ventricle dilation with a shortening fraction of 41%.

**CONCLUSION**

In conclusion, determining the etiology of cardiomyopathy in the infant is a critical for determining a treatment plan, accurate genetic counseling and discussion of prognosis. A significant proportion of infants with cardiomyopathy may have a metabolic etiology and some of these benefits greatly from diagnosis and follow up treatment. The efficacy of such treatments makes it important to exclude metabolic causes for all infants presenting with cardiomyopathy.

**REFERENCES**

1 **Wilkinson JD**, Landy DC, Colan SD, Towbin JA, Sleeper LA, Orav EJ, Cox GF, Canter CE, Hsu DT, Webber SA, Lipshultz SE. The pediatric cardiomyopathy registry and heart failure: key results from the first 15 years. *Heart Fail Clin* 2010; **6**: 401-13, vii [PMID: 20869642 DOI: 10.1016/j.hfc.2010.05.002]

2 **Cox GF.** Diagnostic Approaches to Pediatric Cardiomyopathy of Metabolic Genetic Etiologies and Their Relation to Therapy. *Prog Pediatr Cardiol* 2007; **24**: 15-25 [PMID: 19030119 DOI: 10.1016/j.ppedcard.2007.08.013]

3 **Kindel SJ**, Miller EM, Gupta R, Cripe LH, Hinton RB, Spicer RL, Towbin JA, Ware SM. Pediatric cardiomyopathy: importance of genetic and metabolic evaluation. *J Card Fail* 2012; **18**: 396-403 [PMID: 22555271 DOI: 10.1016/j.cardfail.2012.01.017]

4 **Badertscher A**, Bauersfeld U, Arbenz U, Baumgartner MR, Schinzel A, Balmer C. Cardiomyopathy in newborns and infants: a broad spectrum of aetiologies and poor prognosis. *Acta Paediatr* 2008; **97**: 1523-1528 [PMID: 18652581 DOI: 10.1111/j.1651-2227.2008.00957.x]

5 **Wicks EC**, Elliott PM. Genetics and metabolic cardiomyopathies. *Herz* 2012; **37**: 598-610 [PMID: 22936369 DOI: 10.1007/s00059-012-3659-0]

6 **Meyers DE**, Basha HI, Koenig MK. Mitochondrial cardiomyopathy: pathophysiology, diagnosis, and management. *Tex Heart Inst J* 2013; **40**: 385-394 [PMID: 24082366]

7 **Kompare M**, Rizzo WB. Mitochondrial fatty-acid oxidation disorders. *Semin Pediatr Neurol* 2008; **15**: 140-149 [PMID: 18708005 DOI: 10.1016/j.spen.2008.05.008]

8 **Marcì M**, Ajovalasit P. Medium-Chain Acyl-CoA Dehydrogenase Deficiency in an Infant with Dilated Cardiomyopathy. *Cardiol Res Pract* 2009; **2009**: 281389 [PMID: 20049317]

9 **Hayflick S**, Rowe S, Kavanaugh-McHugh A, Olson JL, Valle D. Acute infantile cardiomyopathy as a presenting feature of mucopolysaccharidosis VI. *J Pediatr* 1992; **120**: 269-272 [PMID: 1735826 DOI: 10.1016/S0022-3476(05)80441-X]

10 **Valayannopoulos V**, Bajolle F, Arnoux JB, Dubois S, Sannier N, Baussan C, Petit F, Labrune P, Rabier D, Ottolenghi C, Vassault A, Broissand C, Bonnet D, de Lonlay P. Successful treatment of severe cardiomyopathy in glycogen storage disease type III With D,L-3-hydroxybutyrate, ketogenic and high-protein diet. *Pediatr Res* 2011; **70**: 638-641 [PMID: 21857385 DOI: 10.1203/PDR.0b013e318232154f]

11 **Taratuto AL**, Akman HO, Saccoliti M, Riudavets M, Arakaki N, Mesa L, Sevlever G, Goebel H, DiMauro S. Branching enzyme deficiency/glycogenosis storage disease type IV presenting as a severe congenital hypotonia: muscle biopsy and autopsy findings, biochemical and molecular genetic studies. *Neuromuscul Disord* 2010; **20**: 783-790 [PMID: 20833045 DOI: 10.1016/j.nmd.2010.07.275]

12 **Funke S**, Gardeitchik T, Kouwenberg D, Mohamed M, Wortmann SB, Korsch E, Adamowicz M, Al-Gazali L, Wevers RA, Horvath A, Lefeber DJ, Morava E. Perinatal and early infantile symptoms in congenital disorders of glycosylation. *Am J Med Genet A* 2013; **161A**: 578-584 [PMID: 23401092 DOI: 10.1002/ajmg.a.35702]

13 **Rudaks LI**, Andersen C, Khong TY, Kelly A, Fietz M, Barnett CP. Hypertrophic cardiomyopathy with cardiac rupture and tamponade caused by congenital disorder of glycosylation type Ia. *Pediatr Cardiol* 2012; **33**: 827-830 [PMID: 22374380 DOI: 10.1007/s00246-012-0214-y]

14 **Marquardt T**, Hülskamp G, Gehrmann J, Debus V, Harms E, Kehl HG. Severe transient myocardial ischaemia caused by hypertrophic cardiomyopathy in a patient with congenital disorder of glycosylation type Ia. *Eur J Pediatr* 2002; **161**: 524-527 [PMID: 12297897 DOI: 10.1007/s00431-002-1029-2]

15 **Noelle V**, Knuepfer M, Pulzer F, Schuster V, Siekmeyer W, Matthijs G, Vogtmann C. Unusual presentation of congenital disorder of glycosylation type 1a: congenital persistent thrombocytopenia, hypertrophic cardiomyopathy and hydrops-like aspect due to marked peripheral oedema. *Eur J Pediatr* 2005; **164**: 223-226 [PMID: 15645285 DOI: 10.1007/s00431-004-1611-x]

16 **Aronica E**, van Kempen AA, van der Heide M, Poll-The BT, van Slooten HJ, Troost D, Rozemuller-Kwakkel JM. Congenital disorder of glycosylation type Ia: a clinicopathological report of a newborn infant with cerebellar pathology. *Acta Neuropathol* 2005; **109**: 433-442 [PMID: 15714316 DOI: 10.1007/s00401-004-0975-3]

17 **Kapusta L**, Zucker N, Frenckel G, Medalion B, Ben Gal T, Birk E, Mandel H, Nasser N, Morgenstern S, Zuckermann A, Lefeber DJ, de Brouwer A, Wevers RA, Lorber A, Morava E. From discrete dilated cardiomyopathy to successful cardiac transplantation in congenital disorders of glycosylation due to dolichol kinase deficiency (DK1-CDG). *Heart Fail Rev* 2013; **18**: 187-196 [PMID: 22327749 DOI: 10.1007/s10741-012-9302-6]

18 **Lieu MT**, Ng BG, Rush JS, Wood T, Basehore MJ, Hegde M, Chang RC, Abdenur JE, Freeze HH, Wang RY. Severe, fatal multisystem manifestations in a patient with dolichol kinase-congenital disorder of glycosylation. *Mol Genet Metab* 2013; **110**: 484-489 [PMID: 24144945 DOI: 10.1016/j.ymgme.2013.09.016]

19 **Kranz C**, Basinger AA, Güçsavaş-Calikoğlu M, Sun L, Powell CM, Henderson FW, Aylsworth AS, Freeze HH. Expanding spectrum of congenital disorder of glycosylation Ig (CDG-Ig): sibs with a unique skeletal dysplasia, hypogammaglobulinemia, cardiomyopathy, genital malformations, and early lethality. *Am J Med Genet A* 2007; **143A**: 1371-1378 [PMID: 17506107 DOI: 10.1002/ajmg.a.31791]

20 **Rigaud C**, Lebre AS, Touraine R, Beaupain B, Ottolenghi C, Chabli A, Ansquer H, Ozsahin H, Di Filippo S, De Lonlay P, Borm B, Rivier F, Vaillant MC, Mathieu-Dramard M, Goldenberg A, Viot G, Charron P, Rio M, Bonnet D, Donadieu J. Natural history of Barth syndrome: a national cohort study of 22 patients. *Orphanet J Rare Dis* 2013; **8**: 70 [PMID: 23656970 DOI: 10.1186/1750-1172-8-70]

21 **Prada CE**, Al Jasmi F, Kirk EP, Hopp M, Jones O, Leslie ND, Burrow TA. Cardiac disease in methylmalonic acidemia. *J Pediatr* 2011; **159**: 862-864 [PMID: 21784454 DOI: 10.1016/j.jpeds.2011.06.005]

22 Newborn screening: toward a uniform screening panel and system. *Genet Med* 2006; **8 Suppl 1**: 1S-252S [PMID: 16783161]

23 **Ficicioglu C**, Coughlin CR, Bennett MJ, Yudkoff M. Very long-chain acyl-CoA dehydrogenase deficiency in a patient with normal newborn screening by tandem mass spectrometry. *J Pediatr* 2010; **156**: 492-494 [PMID: 20056241 DOI: 10.1016/j.jpeds.2009.10.031]

24 **Mayr JA**, Merkel O, Kohlwein SD, Gebhardt BR, Böhles H, Fötschl U, Koch J, Jaksch M, Lochmüller H, Horváth R, Freisinger P, Sperl W. Mitochondrial phosphate-carrier deficiency: a novel disorder of oxidative phosphorylation. *Am J Hum Genet* 2007; **80**: 478-484 [PMID: 17273968 DOI: 10.1086/511788]

25 **Mayr JA**, Zimmermann FA, Horváth R, Schneider HC, Schoser B, Holinski-Feder E, Czermin B, Freisinger P, Sperl W. Deficiency of the mitochondrial phosphate carrier presenting as myopathy and cardiomyopathy in a family with three affected children. *Neuromuscul Disord* 2011; **21**: 803-808 [PMID: 21763135 DOI: 10.1016/j.nmd.2011.06.005]

26 **Ficicioglu C**, Chrisant MR, Payan I, Chace DH. Cardiomyopathy and hypotonia in a 5-month-old infant with malonyl-coa decarboxylase deficiency: potential for preclinical diagnosis with expanded newborn screening. *Pediatr Cardiol* ; **26**: 881-883 [PMID: 16078122 DOI: 10.1007/s00246-005-1045-x]

**P-Reviewer:** Maleki AR, Peteiro J **S-Editor:** Ji FF **L-Editor: E-Editor:**

|  |  |  |
| --- | --- | --- |
| **Table 1 Red flags for inborn errors of metabolism associated with cardiomyopathy** | | |
| **Disorder** | **Pathognomonic biochemical abnormalities** | **Red flags** |
| Mitochondrial Disease | Elevated Plasma Lactate, elevated plasma alanine, proline | Hypotonia, developmental delays/regression, other organ involvement |
| Barth syndrome | Urinary excretion of 3-Methylglutaconic acid |
| VLCAD Deficiency | Elevation of C14:1 acylcarnitine species | Hypoglycemia, elevated creatine kinase, liver dysfunction, metabolic decompensation with illness |
| LCAHD | Elevation of hydroxy compounds C14-OH, C16-OH, C18-OH |
| Systemic primary carnitine deficiency | Very low plasma carnitine and elevated urinary carnitine extraction |
| Carnitine-palmitoyl transferase deficiency (CPT2) | Elevation of C12 to C18 acylcarnitines, notably of C16 and C18:1 |
| GSD II (Pompe) | Decreased acid alpha-glucosidase enzyme activity | Hypotonia, enlarged tongue |
| MPS1 (Hurler, Hurler-Scheie, Scheie) | Elevated urine GAGs, decreased alpha-L-iduronidase enzyme activity | Dysmorphic features (coarse features), hepatomegaly, hernia, hearing loss, corneal clouding( MPS1) Developmental delays/regression |
| MPS2 (Hunter) | Elevated urine GAGs, decreased iduronate-2-sulphatase *e*nzyme activity |
| Propionic Aciduria | Urine organic acids: Elevated 3-hydroxypropionate  Methylcitrate ,Tyglylglycine Propionylglycine.  Plasma acylcarnitines : Elevated C3 (propionylcarnitine) | Hypotonia, high anion gap acidosis, hyperammonemia, metabolic decompensation with illness |
| Malonic Aciduria |  | Developmental delay/regression, hypotonia, hypoglycemia |
| Congenital Disorders of Glycosylation | Abnormal carbohydrate deficient transferrin, abnormal N- and O-glycosylation profiles (qualitative and/or quantitative) | Hypotonia, developmental delays/regression hypoglycemia, liver dysfunction |

VLCAD: Very long-chain acyl-CoA dehydrogenase; GAGs: Glycosaminoglycan.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Table 2 Biochemical testing recommendations for metabolic evaluation** | | |  |  |  |
| Tier 1 |  |  |  |  |  |
|  | Creatine Kinase |  |  |  |  |
|  | Plasma Acylcarnitine Profile |  |  |  |  |
|  | Urine Organic Acids |  |  |  |  |
|  | Plasma Lactate/Pyruvate |  |  |  |  |
|  | Plasma amino acids  Enzyme analysis1 |  |  |  |  |
| Tier 2 |  |  |  |  |  |
|  | Carbohydrate deficient transferrin analysis |  |  |  |  |
|  | Urine Glycosaminoglycans |  |  |  |  |
|  | Lysosomal storage disease enzyme panel (large panels are available through many laboratories) | | | | |
| Tier 3 |  |  |  |  |  |
|  | Specific gene sequencing |  |  |  |  |

1If there is a high suspicion for a single metabolic disease for example Pompe disease.