

New Alström Syndrome Phenotypes Based on the Evaluation of 182 Cases

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Background: Alström syndrome is a recessively inherited genetic disorder characterized by congenital retinal dystrophy that leads to blindness, hearing impairment, childhood obesity, insulin resistance, and type 2 diabetes mellitus. We provide new details on cardiologic, hepatic, gastrointestinal, urologic, pulmonary, and neurobehavioral phenotypes in Alström syndrome and describe the histopathologic findings in 5 individuals.

Methods: We obtained data on 182 patients from clinical examinations, medical record reviews, standardized questionnaires, and personal interviews with physicians and parents.

Results: Dilated cardiomyopathy occurred in 60% of patients. Age at onset was either during infancy, often before vision disturbances were noted, or in adolescence or adulthood. There is a risk of recurrence of infantile cardiomyopathy. Hyperinsulinemia (92%) developed in early child-

hood and progressed to type 2 diabetes mellitus in 82% of those older than 16 years. Hypertriglyceridemia (54%) precipitated pancreatitis in 8 patients. Urologic dysfunction and gastrointestinal disturbances occurred in 48% and 35% of patients, respectively. Fifty-three percent of patients had persistent pulmonary symptoms. Neurologic symptoms in 20% of patients included clonic tic and absence seizures. Developmental motor or language delays were observed in 46% of patients. Fibrotic infiltrations of multiple organs, that is, kidney, heart, liver, lung, urinary bladder, gonads, and pancreas, were observed.

Conclusions: The wide-ranging and complex spectrum of phenotypes reported herein broadens those previously described for Alström syndrome. These findings will aid physicians in making an early and accurate diagnosis and will help effect appropriate monitoring and treatment.

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ALSTRÖM SYNDROME (Online Mendelian Inheritance in Man [OMIM] 203800) is a rare (approximately 300 cases known) autosomal recessively inherited disorder that affects multiple organ systems.¹⁻³ Patients develop early retinal pigmentary degeneration that leads to blindness and sensorineural hearing deficits. Metabolic disturbances begin in childhood and include severe insulin resistance; hyperinsulinemia; type 2 diabetes mellitus, truncal obesity; hypogonadism in males; hypertriglyceridemia; hypothyroidism; accelerated skeletal maturity that results in short stature, scoliosis, or kyphosis; and low growth hormone levels. Multiple organ failure, including dilated cardiomyopathy (DCM) and congestive heart failure (CHF), and hepatic or renal failure may occur. Clinical expression, onset, rate of progression, and severity of most of the features are variable, even within sibships.⁴ Delayed diagnosis and misdiagnosis are common, making esti-

mates of the incidence of Alström syndrome difficult.⁵

We present new clinical and pathologic findings in a cohort of 182 patients with Alström syndrome representing 117 unrelated kindreds. We describe the clinical course of DCM and expand the phenotypic spectrum to include pulmonary, urologic, gastrointestinal (GI), neurologic, and developmental features.

METHODS

PATIENTS

Patients were identified through physician referrals and through Alström Syndrome International (<http://www.jax.org/alstrom>). Family members completed extensive questionnaires and personal interviews. To be included in the study, patients had to have congenital retinal dystrophy and 3 or more of the following: childhood obesity, hearing impairment, DCM, insulin resistance, type 2 diabetes mellitus, hypogonadism, normal extremities, normal mentation, and a family history of Alström syndrome. Our database currently lists

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304 patients with Alström syndrome worldwide. We collected sufficient clinical information to include 182 of these patients in this study. Although some patients have been followed up for up to 12 years, the amount of information available for each varies. If a condition was not reported by parents or medically documented, we inferred that it was not present. Because some evaluations are not routinely performed, the true prevalence of some phenotypes may be higher than reflected herein.

Samples of DNA were available for mutational analysis from 139 of 182 patients. Thus far, mutations in at least 1 allele of *ALMS1*^{6,7} have been identified in 63 patients; 36 additional patients had 2p13-specific haplotypes consistent with linkage. We examined the cardinal features and new phenotypes in patients whose diagnosis was confirmed genetically and in 86 patients whose conditions were clinically diagnosed by phenotypic evaluation. All features were present in both groups. We obtained written informed consent from all participants or parents of minors. The institutional review board of The Jackson Laboratory and the ethical review committee of Alström Syndrome International independently approved the study protocols. No financial remuneration was given to patients or families for participation in this study.

CLINICAL EXAMINATIONS

Patient assessment included ophthalmologic, audiologic, and general physical examinations. We obtained blood samples using standard venipuncture techniques after an overnight fast. Serum chemistries and routine urinalysis were performed using traditional methods in licensed clinical laboratories.

A fasting glucose level of 110 to 126 mg/dL (6.1-7.0 mmol/L) or a 2-hour level of 140 to 200 mg/dL (7.8-11.1 mmol/L) in response to an oral glucose challenge or basal hyperinsulinemia (insulin level >15 μ U/mL [>104 pmol/L]) was evidence of impaired glucose tolerance. Glucose levels greater than 126 mg/dL (>7.0 mmol/L) or glycosylated hemoglobin levels greater than 7% of total hemoglobin indicated diabetes mellitus. We interpreted elevated thyrotropin levels in the presence of normal triiodothyronine and thyroxine levels as "subclinical hypothyroidism," and elevated creatinine (>2.0 mg/dL [>152 μ mol/L]) or blood urea nitrogen (>20 mg/dL [>7.1 mmol/L of urea]) levels or proteinuria was evidence of renal insufficiency. Bone age was assessed using the scales of Gruelich and Pyle.⁸ Pubertal onset was defined as a testicular size greater than 4 mL in boys and as a Tanner 2 breast stage in girls. We considered male hypogonadism as a stretched penis of less than 4 cm in prepubertal boys and of less than 9 cm in adults. Amenorrhea was defined as the absence of menarche in girls older than 15 years or cessation of menstruation for at least 6 months. Patients with hypertension had arterial pressure greater than 140/90 mm Hg (adults) and 130/80 mm Hg (patients aged <18 years).

PSYCHOMOTOR DEVELOPMENT, BEHAVIOR, AND INTELLIGENCE TESTING

We estimated mentation and neurobehavioral traits based on the level of school and social performance and interviews with parents. Intelligence tests included the Wechsler Adult Intelligence Scale-Revised, the Bayley Scales of Infant Development II, Birth to Three Test of Language and Learning Development, Behavior Assessment System for Children, and the Haptic Intelligence Scale for the Adult Blind. The ages at which children first sat, walked, and organized phrases of at least 2 words were used as psychomotor developmental milestones during childhood.

PATHOLOGY SAMPLES

We obtained postmortem tissue samples and pathology reports from 3 women and 2 men aged 27 to 42 years. Autopsies

were performed in local hospitals 5 to 15 hours after death. Tissues were preserved in 10% formalin/90% ethanol and were processed according to standard protocols.

STATISTICAL ANALYSIS

χ^2 and paired *t* tests were used for comparisons between groups. We used 2 statistical analysis programs: SPSS for Windows, version 10.0.5 (SPSS Inc, Chicago, Ill) and JMP version 5.0.1 (SAS Institute Inc, Cary, NC).

RESULTS

PATIENT POPULATION

Alström syndrome has multinational geographic distribution among diverse racial and ethnic groups. Twenty-one infants with limited clinical records died between ages 5 days and 16 months: 19 had CHF or other cardiac complications, and in 2 the cause of death was undetermined. The reported symptoms and at least 1 other affected sibling suggest Alström syndrome as the most likely diagnosis for these patients.

The remaining 161 patients (78 females and 83 males; age range, 18 months to 48 years) includes 88 new patients and 47 kindreds previously described.^{3-6,9-24} The consanguinity rate was 30%. Thirty-one of the 161 patients died during study observation: 12 of CHF (age range, 10-27 years), 7 of renal failure (age range, 22-48 years), 4 of pulmonary failure (age range, 29-42 years), 3 of liver failure (age range, 21-32 years), and 5 of undetermined causes (age range, 9-48 years).

ALSTRÖM SYNDROME PHENOTYPES

Frequency, mean age at onset, and age range of clinical features that were observed in our patient population are shown in **Figure 1**.

Neurosensory

Nearly all patients (98%) developed pendular or searching nystagmus and photodysphoria during the first year of life (age range, birth to 40 weeks) and reduced visual acuity in childhood. All patients older than 15 years were legally blind. Electroretinograms initially showed an absence of cone function and progressive deterioration of rod function. Degeneration of the retinal pigment epithelium, poorly defined macula consistent with cone-rod dystrophy, attenuated vessels, and optic disc pallor were reported. Subcapsular cataracts were present in 52 patients (32%; age range, 10-44 years).

Mild-to-profound bilateral sensorineural, predominantly high-frequency, hearing impairment evolved throughout childhood (89%; age range, 2-21 years; mean age at onset, 5 years). Chronic otitis media and glue ear, particularly frequent in patients younger than 12 years, resulted in additional conductive hearing loss in 68 (42%) of 161 patients.

Anthropomorphic Measurements

Most children had rapid growth, with height above the 50th percentile before puberty but final adult height below the

5th percentile (**Figure 2A** and **B**). The mean \pm SD height of patients older than 16 years was 158.7 ± 0.9 cm in males ($n=40$) and 150.4 ± 1.5 cm in females ($n=46$). Childhood obesity occurred in 158 (98%) of 161 patients. Although mean \pm SD birth weight was within the reference range (2998 ± 518 g; $n=53$), rapid weight gain was observed within 2 to 36 months, with a mean age at onset of 18 months (**Figure 2C** and **D**). Body mass index (calculated as weight in kilograms divided by the square of height in meters) ranged from 21 to 53 in males ($n=69$) and from 24 to 51 in females ($n=63$) (**Figure 2E** and **F**). Obesity in some patients moderated with the onset of other clinical complications. The presence of hyperphagia was inconclusive from food intake records ($n=26$; age range, 4-35 years).

Physical Features

Skeletal age was 1 to 3 years in advance of chronologic age in children younger than 16 years ($n=28$). Thoracic and lumbar scoliosis, kyphosis, or lordosis was present in 110 (68%) of 161 patients (age range, 4-42 years). Fingers tended to be short and tapered. The children had characteristic short, thick, wide, and flat feet (**Figure 3**). Polydactyly was absent in 158 (98%) of 161 patients. Three patients fulfilled the diagnostic criteria but had digital abnormalities. One child was born with 2 clubfeet, and another had postaxial polydactyly. Both of these patients had affected siblings with normal digits. The third patient with polydactyly had a confirmed mutation in *ALMS1* (G.B.C., written communication, 2004). Craniofacial features included deep-set eyes and slightly hyperplastic ears. Dental abnormalities in 33% of patients consisted of a pronounced gap between the upper front teeth, crowding, late eruption, and selective brown enamel discoloration. Twenty-six males (age range, 14-32 years) and 20 females (age range, 7-48 years) (29%) had alopecia.

Endocrine

Hyperinsulinemia usually developed between ages 18 months and 4 years (92%). Most patients were insulin resistant or glucose intolerant ($n=117$; age range, 2-48 years); 110 patients (68%) developed acanthosis nigricans (age range, 5-48 years). Type 2 diabetes mellitus was diagnosed as early as age 5 years, with a median age at onset of 16 years. Eighty-two percent of patients older than 16 years were diabetic. Most patients had moderate to severe hypertriglyceridemia (triglyceride level, 200-1000 mg/dL [$2.26-11.29$ mmol/L]), with normal total cholesterol levels ($n=80$; age range, 2-42 years). Eight patients developed acute pancreatitis (age range, 18-26 years), with triglyceride levels greater than 10000 mg/dL (>112.90 mmol/L). Hypothyroidism was observed in 28 (36%) of 78 patients measured (age range, 8-42 years), and 20 additional patients (age range, 4-37 years) had subclinical hypothyroidism.

Gonadal

Hypergonadotropic and hypogonadotropic hypogonadism were common in males (64/83; 77%). Puberty was often delayed, but masculinization and secondary sexual characteristics in adult males were normal ($n=35$). The most

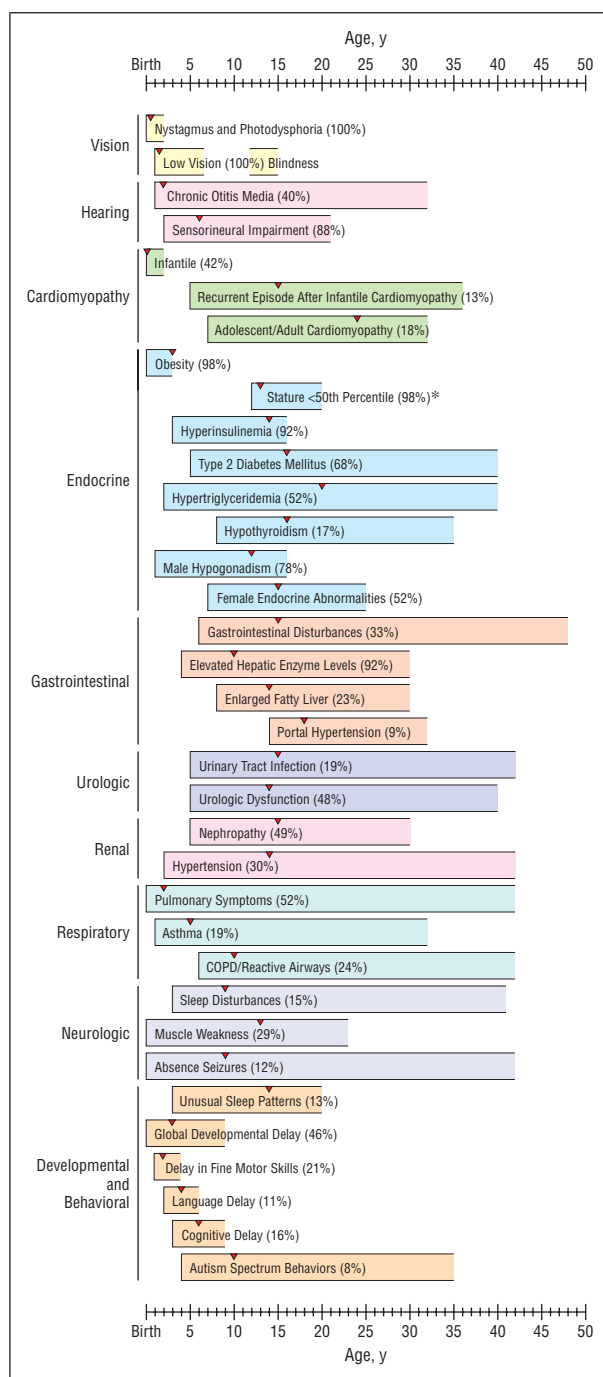


Figure 1. The mean age (arrowheads) and age range (solid bars) at the onset of each clinical feature of Alström syndrome in our cohort. The percentage of patients in whom the phenotype was observed is given in parentheses. Asterisk indicates final height below the 50th percentile in patients older than 16 years; COPD, chronic obstructive pulmonary disease.

frequent observation was diminished basal testosterone levels for age and increased baseline luteinizing hormone/follicle-stimulating hormone levels typical of primary gonadal failure (age range, 16-32 years). Gynecomastia was present in 31 males, and cryptorchidism was present in 2. Mean menarchal age was 12.6 years ($n=36$). Endocrine disturbances in 42 (54%) of 78 females included hirsutism, abnormal breast development, cystic ovaries, precocious puberty (pubertal onset at age <8 years), endometriosis,

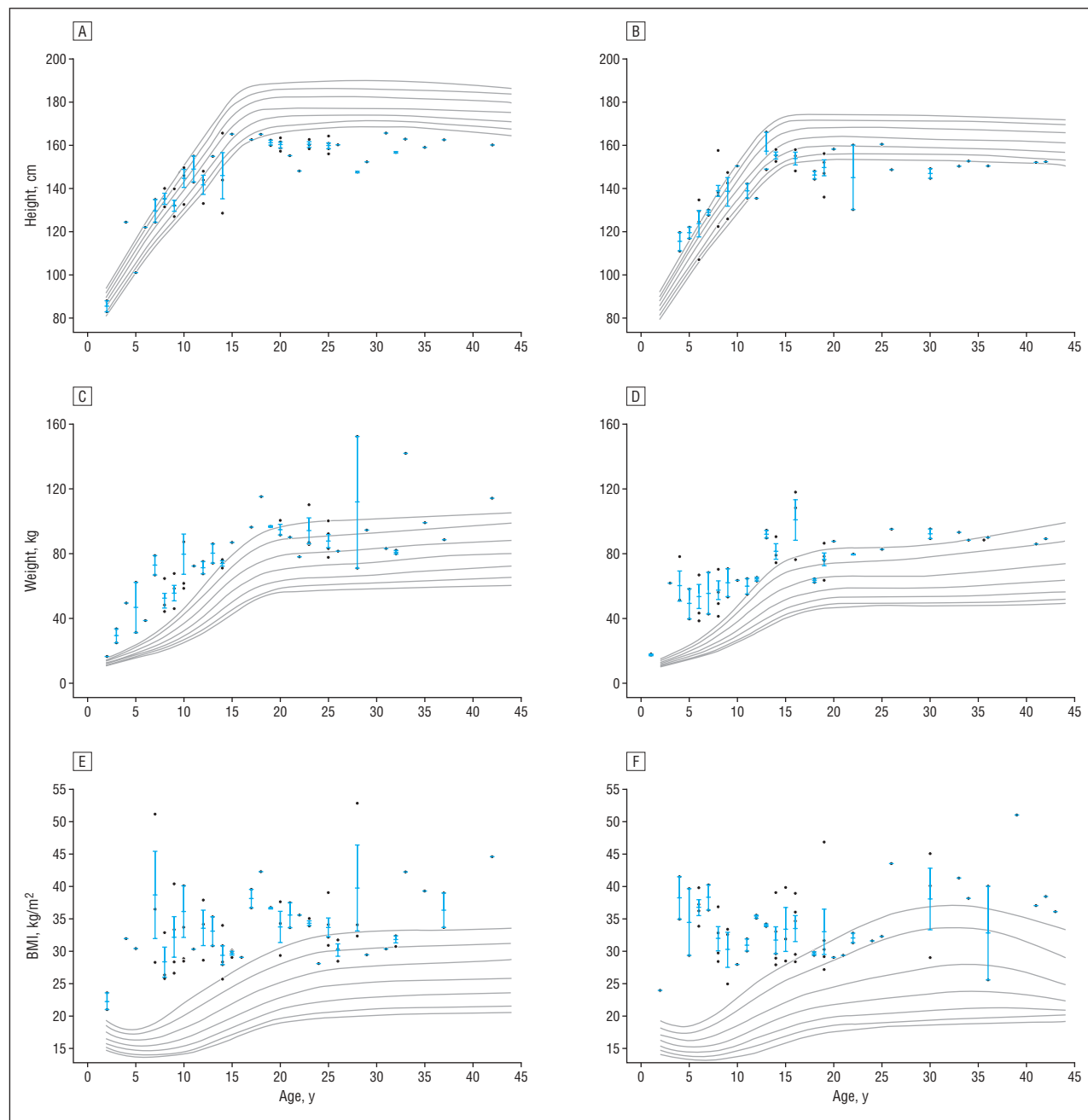


Figure 2. Anthropometric measurements in patients with Alström syndrome. Mean \pm SEM height in males (A) and females (B); weight in males (C) and females (D); and body mass index (BMI) in males (E) and females (F) compared with controls. Control values for the 5th, 10th, 25th, 50th, 75th, and 95th percentiles (gray lines) were taken from stature-for-age, weight-for-age, and BMI-for-age percentile charts (<http://www.cdc.gov>) and from Najjar and Rowland.²⁵

irregular menses, or amenorrhea. External genitalia were normal in those females examined ($n=42$). No patients in this study have reproduced.

Cardiac

Seventy (38%) of 182 patients have had no signs of cardiac failure to date (age range, 2–33 years), although the risk remains for developing DCM in the future. Dilated cardiomyopathy occurred in 112 patients (62%) (Figure 4). These patients can be divided into 2 groups: infant onset and adult onset. Seventy-nine patients (43%) had DCM and CHF in infancy (age range, 1 week to 16

months). Most of these infants (57 of 77) survived, with apparent atypical recovery of cardiac function within 3 years. Although previous studies¹¹ suggest that infants who survived DCM had progressive improvement in cardiac function with no evidence of long-term negative effects, we found that after a variable interval of normal cardiac function, 24 of these patients experienced an abrupt recurrence of DCM between ages 5 and 36 years, and 10 have died. The reappearance of CHF in a growing number of these patients suggests that cardiac function should be regularly monitored. A second group of 33 (18%) of the 182 patients had no cardiac history in infancy but developed DCM as adolescents or adults (age



Figure 3. Physical features in a 13-year-old girl with Alström syndrome: truncal obesity and scoliosis (A); short distal phalanges and tapered fingers (B); and flat, wide, and thick feet (C).

range, 7-32 years). These patients have a poor clinical prognosis; 11 of 33 have died (age range, 14-48 years).

Hepatic and GI

There was mild to severe elevation in liver transaminase levels as early as age 4 years in 89 (92%) of 97 patients tested. Hepatomegaly and splenomegaly were observed in patients as young as 8 years. Biopsies revealed hepatic steatosis, inflammation, bridging fibrosis, and cirrhosis (n=16). Portal hypertension resulted in hemorrhaging esophageal and gastric varices (n=14; age range, 14-37 years). Two patients required a surgical transjugular intrahepatic portosystemic shunt at ages 18 and 32 years, respectively. General GI disturbances in 57 patients (35%) included frequent upper GI pain, chronic diarrhea, and constipation; gastroesophageal reflux was diagnosed, based on findings from either upper GI series or endoscopies, in 35 patients.

Urologic and Renal

General urologic disturbances and abnormal voiding patterns were reported in 57 females and 20 males (48%). Recurrent urinary tract infections were common (age range, 2-40 years) in males and females. Premicturition discomfort, difficulty initiating voiding, poor flow, long voiding intervals, retention, urgency, and urge incontinence suggested a variable decrease in bladder sensation and activity or, conversely, overactivity. Six females aged 17 to 19 years had initial urinary retention followed, 6 to 12 months later, by detrusor overactivity, incontinence, and substantial lower abdominal and perineal pain that required anticholinergic medication use, self-catheterization, or surgical urinary diversion. The change from a voiding pattern of hyporeflexia to bladder overactivity, urgency to void, and incontinence

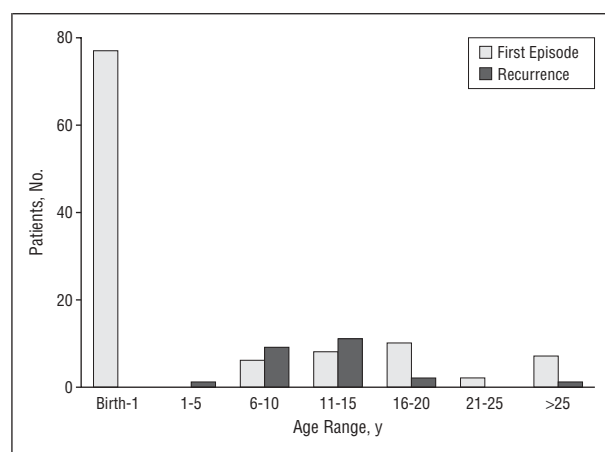


Figure 4. Age at onset and age at recurrence of dilated cardiomyopathy (DCM) in patients with Alström syndrome. A recurrence consisted of congestive heart failure after an apparent recovery from DCM as infants.

is unusual, and the reasons for it are not understood. There was no association between urinary tract infection ($P=.83$) or bladder activity issues ($P=.52$) with kidney function or any indication that vesicoureteral reflux causes the renal damage in patients with Alström syndrome. Renal insufficiency was observed in 80 (50%); of 161 patients (age range, 5-42 years). Renal function declined as patients aged, and end-stage renal disease was the cause of death in 7 patients. Forty-eight patients (30%) were hypertensive, some as young as 2 years (age range, 2-42 years). Three patients have undergone successful kidney transplantation.

Pulmonary

Chronic asthma; sinusitis; bronchitis; a dry, barking cough; and alveolar hypoventilation with reduced forced expiratory volume in 1 second were reported in 85 (53%)

Table. Synopsis of Medical History and Clinical Status of Patients for Whom Pathologic Studies Were Available

Patient No./ Sex/Age, y	Clinical Presentation*						Cause of Death
	Endocrine	Cardiac (Age)	Hepatic GI	Pulmonary	Renal	Gonadal	
7/F/25	Diabetes mellitus	Normal	Clinically normal	Chronic bronchitis	Renal failure	Amenorrhea, hirsutism	Renal failure
20/M/29	Diabetes mellitus (uncontrolled)	DCM (16 y)	Hepatosplenomegaly, cirrhosis, GER	ARDS	Renal failure	Hypogonadism, normal secondary characteristics	ARDS
30/F/42	Diabetes mellitus	DCM (3 wk), CHF (36 y)	Steatosis, splenomegaly, cirrhosis, GER	COPD, chronic bronchitis, gram-negative pneumonia	Normal	Irregular menstruation, ovarian cysts	ARDS
34/M/32	Diabetes mellitus (uncontrolled)	DCM (mild)	Hepatosplenomegaly, cirrhosis, esophageal varices, TIPS, GER	BP	Renal failure	Hypogonadism, normal secondary characteristics	Hepatic and renal failure
137/F/33	Diabetes mellitus	DCM	Hepatomegaly, cirrhosis	BP	Renal failure	Amenorrhea, hirsutism	Septicemia

Abbreviations: ARDS, acute (adult) respiratory distress syndrome; BP, bronchiopneumonia; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; DCM, dilated cardiomyopathy; GER, gastroesophageal reflux; GI, gastrointestinal; TIPS, transjugular intrahepatic portosystemic shunt.

*All of these patients were totally blind, hearing impaired, and obese as children and had a diagnosis of Alström syndrome. Features are described that were present before the time of death. No urinary dysfunction was reported in these patients.

of 161 patients (age range, 2-42 years). Multiple bouts of bronchopneumonia were a frequent finding. More severely compromised lung function in 39 patients (24%; age range, 10-48 years) included lower airway obstruction with consolidation and with acute inflammation, chronic obstructive pulmonary disease, acute (adult) respiratory distress syndrome, and emphysema. Diffusing capacity of the lung for carbon monoxide, ground glass opacification, or lung biopsies revealed structural fibrotic changes (n=6; age range, 10-40 years). None of the patients in this study smoked.

Neurobehavioral

Developmental milestones were delayed in 39 males and 35 females (46%). Fine and gross motor skill and mixed receptive-expressive language delays were reported. Autistic-spectrum behavioral abnormalities, excessive startle, partial unilateral paralysis, unexplained joint or muscle pain, muscle dystonia, and hyporeflexia were observed in 33 patients (20%; age range, 9 months to 41 years). Twenty of these patients had frequent absence seizures. Birth complications included neonatal hypoxia and hypotonia (n=26). Twenty-five patients (16%) had generalized sleep disturbances (age range, 3-41 years); 4 had obstructive sleep apnea.

Pathologic Findings

The **Table** describes the clinical condition of 5 patients from whom pathologic specimens were available. Glomerular and interstitial renal fibrosis was observed in all 5 patients. Affected glomeruli appeared as densely packed balls of collagen with no recognizable structure. Such glomeruli were often found adjacent to normal glomeruli (**Figure 5A**) but were also clustered in areas of dense interstitial fibrosis. The percentage of affected glomeruli varied from 20% to 90%. The severity of intersti-

tial fibrosis also varied from patient to patient (**Figure 5B**). There was interstitial fibrosis in the pancreas of 4 of 5 patients (**Figure 5C**). Three patients had micronodular cirrhosis of the liver with severe portal fibrosis, fatty changes, and nodules of regenerative liver parenchyma (**Figure 5D**). Two patients had only mild portal fibrosis. Of the 4 patients with a medical history of DCM, heart sections were available from 3. We found myocardial fibrosis ranging from severe to moderate (**Figure 5E**). A patient who did not have a history of DCM had mild myocardial fibrosis (data not shown).

We observed testicular atrophy with obliterating fibrosis of seminiferous tubules (**Figure 5F**). Ovaries were densely fibrotic with cystic changes (**Figure 5G**). Primary or secondary follicles were absent or minimal. There was no corpora lutea. There were many hemosiderin-laden macrophages in alveoli in lungs from patients with severe myocardial and interstitial fibrosis (**Figure 5H**). One had a focal area of suppurative bronchitis and bronchiectasis. One lung had severe changes consistent with bronchiolitis obliterans obstructive pneumonia, including large fascicles and nodules of fibroblasts and collagen and nearly no normal tissue. Relatively intact alveoli had very thickened walls and contained large macrophages, sometimes hemosiderin-laden (**Figure 5I**). Urinary bladders from 1 male and 2 female patients had thick fascicles of collagen between bundles of smooth muscle and in the submucosa (**Figure 5J**). There was severe reduction of cell layers in the posterior retina and nearly absent peripheral retinal cells. Deposits of melanin pigment were scattered in outer and inner nuclear layers (**Figure 5K**). In the few sections of brain available, no lesions were observed.

COMMENT

Alström syndrome is recognized as a complex disease that affects multiple organ systems. Diagnosis is difficult because

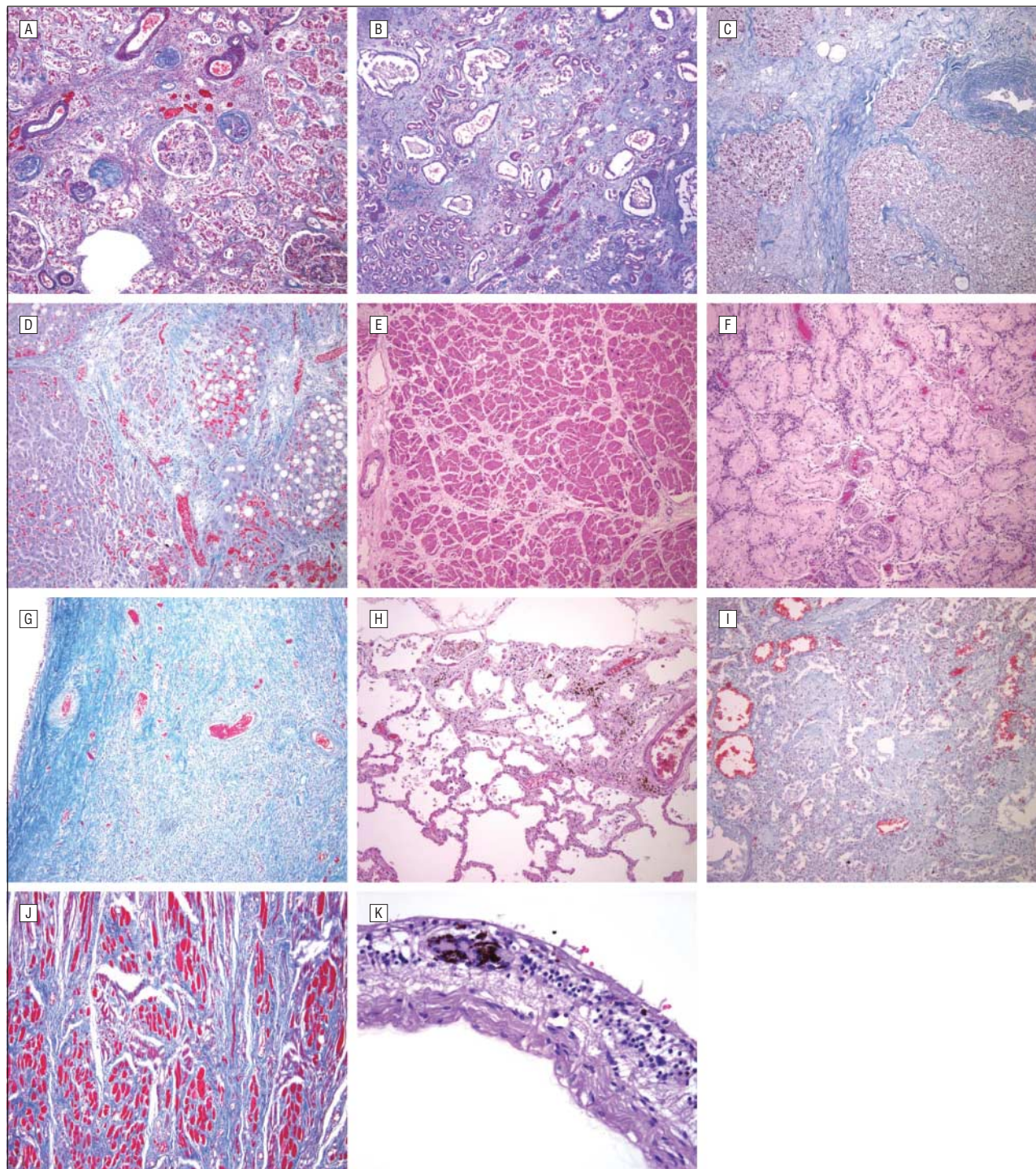


Figure 5. Histopathologic findings in patients with Alström syndrome. A, Renal cortex showing small sclerotic glomeruli admixed with normal glomeruli (Masson trichrome, original magnification x50). B, Renal medulla with severe interstitial fibrosis (Masson trichrome, original magnification x25). C, Autolyzed pancreas with extensive fibrosis between lobules and around blood vessels (Masson trichrome, original magnification x50). D, Cirrhotic liver with extensive portal fibrosis and rounded regenerative nodules, 2 of which show fatty change (Masson trichrome, original magnification x50). E, Fibrotic heart with light pink-staining collagen between the cardiac muscle fibers, some of which are enlarged. Interstitial fibrosis is so mild in normal hearts that it would not show at this magnification (hematoxylin-eosin, original magnification x50). F, Testis with severely atrophic seminiferous tubules (hematoxylin-eosin, original magnification x50). G, Ovary with extensive fibrosis and devoid of oocytes, follicles, and corpora lutea. In the upper left is a portion of a cyst lined by a cuboidal epithelium (Masson trichrome, original magnification x50). H, Lung that is generally well aerated showing hemosiderin-laden macrophages (heart failure cells) in alveoli (hematoxylin-eosin, original magnification x50). I, Lung almost completely obliterated by interwoven bundles of collagen (Masson trichrome, original magnification x100). J, Urinary bladder with severe interstitial fibrosis. Normal bladders have very little collagen between smooth muscle bundles (Masson trichrome, original magnification x50). K, Severely atrophic retina showing that all layers are severely reduced in thickness from nerve fiber layer at bottom, ganglionic cell layer, inner plexiform layer, inner nuclear layer, and outer plexiform layer. The outer nuclear layer and photoreceptors are entirely lacking. A characteristic clump of melanin, presumably from the pigment epithelium, is present in the inner nuclear layer (hematoxylin-eosin, original magnification x100). All findings are from patient 30 except F (from patient 20) and I and K (from patient 137).

of the gradual unfolding of the phenotypes and the similarity to other disorders. This study reveals increasingly complex ways in which the various organ systems are involved and a more problematic clinical picture that includes features not generally thought to be associated with Alström syndrome. Pulmonary, urologic, and GI features not previously described occur in many patients. Moreover, the presence of digital anomalies and neurobehavioral involvement blurs the distinction between Bardet-Biedl and Alström syndromes.²⁴

Until now, only 1 study has suggested renal fibrotic infiltration.²⁶ This study demonstrates that patients with Alström syndrome have severe fibrosis in multiple organs. This fibrosis may underlie the clinical phenotypes and suggests a common pathologic mechanism. Whether the fibrotic changes are a direct result of the mutated gene or, alternatively, an acute or late-stage chronic inflammatory response to cellular insult due to the loss of function of *ALMS1* is unknown.

No clinical features were found in our patients that distinguish those with and without confirmed mutations. Research is ongoing to detect genotype-phenotype correlations and to elucidate the protein product, expression patterns, and mechanistic links to the phenotype. Intrafamilial differences in disease presentation observed in patients who carry the same mutation⁶ suggest that unknown genetic or environmental modifiers probably interact with *ALMS1*. Insights into the pathogenesis of Alström syndrome will depend on functional analysis of the gene. Until this information is available, a clear understanding of the broad spectrum of the phenotype, including its variability, will help resolve ambiguities concerning current diagnostic, management, and treatment strategies and minimize adverse outcomes, improve the quality of life, and lengthen the survival of patients with Alström syndrome.

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REFERENCES

1. Alström CH, Hallgren B, Nilsson LB, Åsander A. Retinal degeneration combined with obesity, diabetes mellitus and neurogenous deafness: a specific syndrome (not hitherto described) distinct from Laurence-Moon-Biedl syndrome. a clinical endocrinological and genetic examination based on a large pedigree. *Acta Psychiatr Neurol Scand*. 1959;34(suppl 129):1-35.
2. Hopkinson I, Marshall JD, Paisey RB, Carey C, MacDermott S. Alström syndrome. Available at: <http://www.genetests.org>. Accessed January 26, 2005.
3. Maffei P, Munno V, Marshall JD, Scandellari C, Siculo N. The Alström syndrome: is it a rare or unknown disease? *Ann Ital Med Int*. 2002;17:221-228.
4. Paisey RB, Carey CM, Parkinson MJ, Parkinson C, Cole MD. Alström syndrome: the case for secondary prevention [abstract]. *Diabetes Res Clin Pract*. 2000;50(suppl 1):S202.
5. Dyer DS, Wilson ME, Small KW, Pai GS. Alström syndrome: a case misdiagnosed as Bardet-Biedl syndrome. *J Pediatr Ophthalmol Strabismus*. 1994;31:272-274.
6. Collin GB, Marshall JD, Ikeda A, et al. Mutations in *ALMS1* cause obesity, type 2 diabetes and neurosensory degeneration in Alström syndrome. *Nat Genet*. 2002;31:74-78.
7. Hearn T, Renforth GL, Spalluto C, et al. Mutation of *ALMS1*, a large gene with a tandem repeat encoding 47 amino acids, causes Alström syndrome. *Nat Genet*. 2002;31:79-83.
8. Gruelich WW, Pyle SI. *Radiographic Atlas of Skeletal Development of the Hand and Wrist*. 2nd ed. Stanford, Calif: Stanford University Press; 1959.
9. Marshall JD, Ludman MD, Shea SE, et al. Genealogy, natural history, and phenotype of Alström syndrome in a large Acadian kindred and three additional families. *Am J Med Genet*. 1997;73:150-161.
10. Collin GB, Marshall JD, Boerkoel CF, et al. Alström syndrome: further evidence for linkage to human chromosome 2p13. *Hum Genet*. 1999;105:474-479.
11. Michaud JL, Héon E, Guilbert F, et al. Natural history of Alström syndrome in early childhood: onset with dilated cardiomyopathy. *J Pediatr*. 1996;128:225-229.

12. Russell-Eggitt IM, Clayton PT, Coffey R, Kriss A, Taylor DSI, Taylor JFN. Alström syndrome: report of 22 cases and literature review. *Ophthalmology*. 1998; 105:1274-1280.
13. Paisley RB, Carey CM, Bower L, et al. Hypertriglyceridaemia in Alstrom's syndrome: causes and associations in 37 cases. *Clin Endocrinol (Oxf)*. 2004;60: 228-231.
14. Charles SJ, Moore AT, Yates JRW, Green T, Clark P. Alstrom's syndrome: further evidence of autosomal recessive inheritance and endocrinological dysfunction. *J Med Genet*. 1990;27:590-592.
15. Alter CA, Moshang T. Growth hormone deficiency in two siblings with Alström syndrome. *AJDC*. 1993;147:97-99.
16. Maffei P, Munno V, Marshall JD, et al. GH and IGF-I axis in Alström syndrome [abstract]. *J Endocrinol Invest*. 2000;23(suppl 6):29.
17. Makaryus AN, Popkowski B, Kort S, Paris Y, Mangion JA. A rare case of Alström syndrome presenting with rapidly progressive severe dilated cardiomyopathy diagnosed by echocardiography. *J Am Soc Echocardiogr*. 2002;16:194-196.
18. Sebag J, Albert DM, Craft JL. The Alström syndrome: ophthalmic histopathology and renal ultrastructure. *Br J Ophthalmol*. 1984;68:494-501.
19. Chen BH, Chiou SS, Tsai RK, Lin YF, Wu JR. Acute lymphoblastic leukemia in one of two siblings with Alström syndrome. *J Formos Med Assoc*. 2000;99: 792-795.
20. Chou PI, Chen CH, Chen JT, Wen LY, Wu DA, Feldon SE. Alström syndrome with subclinical insulin-resistant diabetes and hepatic dysfunction: a family report. *J Pediatr Ophthalmol Strabismus*. 2000;37:179-182.
21. Puech B, Guilbert F, Dupuis C, Brevière G-M. Congenital achromatopsia and congestive cardiomyopathy [in French]. *Bull Soc Ophthalmol Fr*. 1982;82:265-267.
22. Fiscuci C, Stroia V, Catrinioiu D, Bucur A. Sindromul Alstrom-prezentarea a 2 cazuri clinice. *Rev Rom Pediatr*. 2002;LI:276-280.
23. Evans PM, Ansari BM, Page MD. Alström's syndrome with Klinefelter's karyotype. *J Intern Med*. 2000;248:89-92.
24. Beales PL, Warner AM, Hitman GA, Thakker R, Flintner FA. Bardet-Biedl syndrome: a molecular and phenotypic study of 18 families. *J Med Genet*. 1997; 34:92-98.
25. Najjar MF, Rowland M. Anthropometric reference data and prevalence of overweight, United States, 1976-80. *Vital Health Stat 11*. 1987;238:1-73.
26. Goldstein J, Fialkow P. The Alström syndrome: report of three cases with further delineation of the clinical, pathophysiological, and genetic aspects of the disorder. *Medicine (Baltimore)*. 1973;52:53-71.

Correction

Error in Figure. In the Original Investigation by Mozaffarian and colleagues titled "Fish Consumption and Stroke Risk in Elderly Individuals: The Cardiovascular Health Study," published in the January 24, 2005, issue of the ARCHIVES (2005;165:200-206), an error occurred in the **Figure** on page 203, in which all except the black survival line were deleted during printing. The correct Figure appears below.

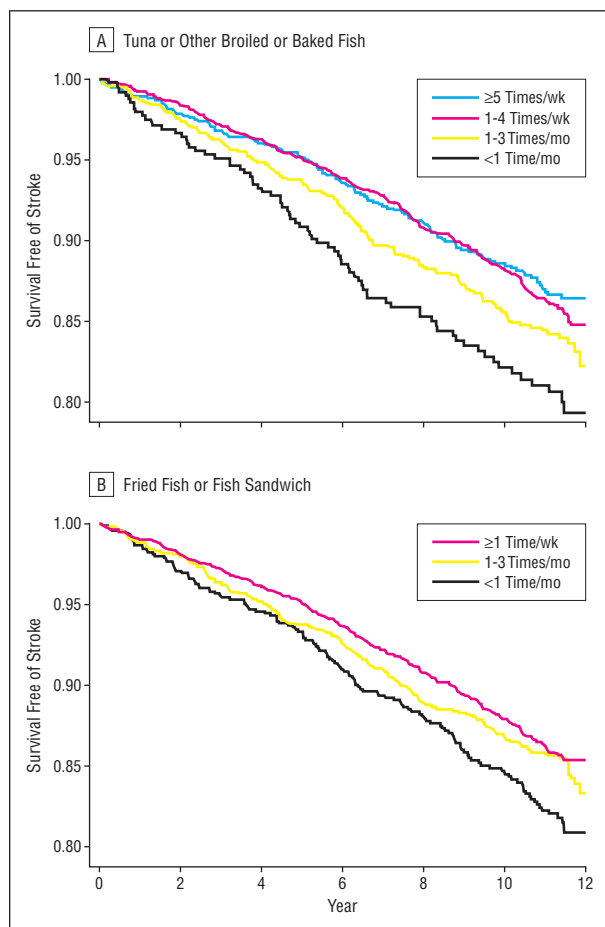


Figure. Survival free of stroke, according to tuna/other fish and fried fish/fish sandwich consumption. $P = .002$ and $P = .02$ for survival differences according to tuna/other fish (A) and fried fish/fish sandwich (B) intake, respectively (log-rank tests for equality of survivor functions).