Title: **Hereditary interstitial lung diseases manifesting in early childhood in Japan**

Running title: **Genetic variations in lung disease**

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Disclosure

None of the authors have any conflicts of interest.

Abstract

Background: Genetic variations associated with interstitial lung diseases (ILD) have not been extensively studied in Japanese infants.

Methods: Forty-three infants with unexplained lung dysfunction were studied. All 43, 22, and 17 infants underwent analyses of surfactant protein (SP)-C gene (*SFTPC*) and ATP-binding cassette A3 gene (*ABCA3*), SP-B gene (*SFTPB*), and SP-B western blotting, respectively. Two and four underwent assessment of GM-CSF stimulating phosphorylation of signal transducer and activator of transcription-5 (pSTAT-5) and analyses of FOXF1 gene (*FOXF1*), respectively.

Results: ILD was diagnosed clinically in nine infants: four, three, and two had interstitial pneumonitis (IP), hereditary pulmonary alveolar proteinosis (hPAP), and alveolar capillary dysplasia with misalignment of pulmonary veins (ACD/MPV), respectively. Genetic variations considered responsible were detected in six (67%) of the nine infants with ILD: in three with hPAP (*SFTPC* p.Leu45Arg and p.Gln145fs, and *ABCA3* p.Arg1583Trp/p.Val1495CysfsX21), two with IP (*SFTPC* p.Lys63Glu and p.Ser72Asn/p.Gly100Ala), and one with ACD/MPV (*FOXF1* p.Leu300ArgfsX79).

None showed *SFTPB* mutations or defects in pSTAT-5. The 17 bronchoalveolar lavage or tracheal aspirates contained enough SP-B protein.

Conclusion: The SP-C abnormality was most prevalent and SP-B deficiency was rare in Japanese infants with hereditary ILD.

Introduction

Pulmonary diseases that require transient assisted ventilation, such as respiratory distress syndrome due to lung immaturity, are often encountered by neonatologists working in neonatal intensive care units (NICU). However, although rare, there are genetic disorders of lung dysfunction manifesting in early childhood that cannot be explained by prematurity. These pulmonary diseases may be classified into two groups: disorder of alveolar type II epithelial cells (AEC2) and disorder of alveolar macrophages. Disorder of AEC2 includes surfactant protein (SP)-B deficiency (1), SP-C abnormality (2), and ATP-binding cassette A3 (ABCA3) deficiency (3). Disorder of alveolar macrophages includes abnormality in granulocyte macrophage colony-stimulating factor (GM-CSF) receptor (4, 5) and dysfunction of macrophages associated with hypogammaglobulinemia (6). Although considerable overlapping exists, genetic disorders of SP-B and alveolar macrophages are likely to manifest hereditary pulmonary alveolar porteinosis (hPAP), while those of SP-C and ABCA3 are likely to manifest hPAP and/or interstitial pneumonitis (IP) (7). In addition, genetic disorders of thyroid transcription factor-1 (TTF-1) -associated thyroid dysfunction (8) and alveolar capillary

dysplasia with misalignment of pulmonary veins (ACD/MPV) (9) often manifest interstitial lung disease (ILD) in early childhood. Thus, genetic abnormalities leading to hereditary ILD (HILD), including hPAP, IP, and ACD/MPV, vary.

As ILD is rare and as helpful measures such as high-resolution computed tomography, bronchoalveolar lavage (BAL), and/or lung biopsy are often difficult to perform in small infants, especially in neonates, it may often be difficult for neonatologists to determine the cause of these lung diseases. However, abnormalities in the SP-B gene (*SFTPB*), SP-C gene (*SFTPC*), ABCA3 gene (*ABCA3*), and FOXF1 gene (*FOXF1*) are known to be responsible for SP-B deficiency, SP-C abnormality, ABCA3 deficiency, and some of ACD/MPV (7,10), respectively. Therefore, analyses of these genes in addition to qualitative analyses of SP-B by western blotting in BAL or tracheal aspirates (11) are helpful to understand the associations between genetic abnormalities and disease phenotypes in these disorders. Assessment of GM-CSF stimulating phosphorylation of signal transducer and activator of transcription-5 (pSTAT-5) also helps in the diagnosis of alveolar macrophage dysfunction (5).

Accordingly, we developed a new system to aid Japanese neonatologists working in the NICU to search for genetic causes of unexplained lung dysfunction in infants. Here, we report this system and preliminary results of an investigation on the causative genetic abnormalities involved in HILD.

Results

During the 2.5-year study period between February 2011 and July 2013, we had a total of 43 consultations from 34 institutions regarding the causes of lung dysfunction in 43 infants. Lung dysfunction manifested within four weeks after birth in 34 infants (early onset) and one month or later after birth in the remaining nine infants (Table 1). Clinically, nine patients were diagnosed as having ILD (Table 2): four with IP were based on findings in biopsied lung specimens except in one patient (Case 4 in Table 3) in whom the diagnosis was based on a 2-year history of lung dysfunction, computed tomography, and serum KL-6 (12, 13); three with hPAP were based on the results of microscopic BAL examination, and two with ACD/MPV were based on findings in

biopsied or autopsied lung specimen. Others included four diagnoses responsible for or possibly associated with lung dysfunction for each one case: gastroesophageal reflux disease, severe combined immunodeficiency, Kabuki make-up syndrome, and congenital adrenal hypoplasia (14 – 16). One case with congenital adrenal hypoplasia showed delayed maturation of lung surfactant system due to deficiency of endogenous steroids.

The hPAP was suspected in five cases including three with early onset (Cases 1, 2, and 3 in Table 3) and two with late onset (case 6 in Table 3 and another case without proven genetic variations) based on computed tomography before the analyses shown in Figure 1. Genetic abnormalities likely to be responsible for lung dysfunction were detected in six of the nine patients with ILD (Tables 2, 3 and Figure 1). These abnormalities were found during the first round examination for *SFTPC* and *ABCA3* in five patients (Cases 1 – 5 in Table 3): *SFTPC* mutations (five different mutations) in four cases and compound heterozygous *ABCA3* mutations in one case (Table 3). Two other compound heterozygous *ABCA3* mutations, i.e., *ABCA3*

p.Pro73Leu/p.Gly1205Arg and *ABCA3* p.Thr761Met/p.Ala1362Val, were detected in two (Cases 7, 8 in Table 3) of the 34 infants without ILD: one full-term infant with p.Pro73Leu/p.Gly1205Arg manifested lung dysfunction immediately after birth, but recovered with transient assisted ventilation only, and another with p.Thr761Met/p.Ala1362Val born at gestational week 27 weighing 778 g manifested lung dysfunction at 8 months after birth, and was being treated currently with vasodilators and home oxygen.

Twenty-two patients underwent second round examination (Figure 1). None of the 22 showed *SFTPB* mutations (Figure 1). The BAL or tracheal aspirates were available for western blotting analysis in 17 of the 22 infants and contained enough SP-B protein. Milky appearance of the BAL with eosinophilic materials on the microscopic examination supported the diagnosis of hPAP in three cases (Cases 1, 2, and 3 in Table 3), but not in two late-onset cases with suspected hPAP (Case 6 in Table 3 and another). The pSTAT-5 was assessed in two infants: one with *ABCA3* mutations (Case 3 in Table 3) and another with suspected hPAP by computed tomography, but not with BAL (Case

6, in Table 3). Results indicated normally functioning macrophages in both cases.

Five infants had severe persistent pulmonary hypertension unresponsive to treatment. Four of them underwent analysis of *FOXF1*. Only Case 6 with a diagnosis of ACD/MPV showed an abnormality in *FOXF1*, i.e., a novel frameshift mutation (Table 3). A female infant with ACD/MPV and birth-weight of 3024g who died at 4 days after birth from lung dysfunction due to pulmonary hypertension, exhibited no abnormalities in *SFTPC*, *ABCA3,* and *SFTPB,* but did not undergo examination for *FOXF1* because her family did not give informed consent to the analysis of *FOXF1*. Thus, this system was helpful to determine causative genetic variations in six (67%) of the nine patients with ILD and 14.0% of all 43 referrals.

Family members of five cases underwent genetic testing. Two *SFTPC* variations (Case 1 and 6) were derived from *de novo*, and one *SFTPC* variation (Case 4) inherited from maternal family line (Table 3). Four *ABCA3* variations (Case 3 8) were inherited from both parents.

Clinical factors were compared between six and 37 infants with and without gene

mutations, respectively (Table 4). Neither a low birth weight < 2500 g, Apgar score < 7 at 5-min, nor timing of onset of lung dysfunction differentiated these cases. However, the frequencies of infants with a positive BAL test result, assisted ventilation > 30 days, and histologically proven ILD were significantly higher in the former six patients than the latter 37 patients.

Discussion

The system presented here was useful for determination of genetic variations that were possibly causative for ILD in six (67%) of the nine patients and 14% of all 43 referrals with severe and unexplained lung dysfunction. These six HILD cases included four cases of SP-C abnormality, one of ABCA3 deficiency, and one of FOXF1 abnormality. None of these cases was affected by SP-B deficiency. As no infants had hypothyroidism, examination of TTF-1 abnormality was not performed in this study. However, □as infants with thyroid transcription factor-1 abnormality (*NKX2-1* mutation) do not necessarily have hypothyroidism□(17), it is possible that some infants had thyroid transcription factor-1 abnormality in this study population.

Among the 12 genetic variations detected in the eight cases (Cases 1 – 8 in Table 3), two in Cases 1 and 6 were reported previously (18, 19). To our knowledge, 10 other mutations in six cases (Cases 2 – 5, 7, 8) have not been reported to date, i.e., four *SFTPC* mutations of heterozygous p.Gln145fs, heterozygous p.Lys63Glu, p.Ser72Asn, and p.Gly100Ala, and six *ABCA3* mutations of p.Arg1583Trp, p.Val1495CysfsX21, p.Pro73Leu, p.Gly1205Arg, p.Thr761Met, and p.Ala1362Val. The pro SP-C amino acids of codons 63, 72, and 100 are well preserved in many mammals and two *SFTPC* mutations, i.e., p.Lys63Glu (Case 4), and p.Ser72Asn (Case 5), were judged as "damaging" with both SIFT and Polyphen-2. Although p.Gly100Ala was "damaging" with Polyphen-2 only, but not with SIFT, mutations of p.Gly100Val and p.Gly100Ser are associated with lung dysfunction (20, 21). Frameshift mutations were detected in Case 2 (*SFTPC* p.Gln145fs) and Case 3 (*ABCA3* p.Val1495CysfsX21), and such mutations can be associated with abnormal protein function. *SFTPC* p.His142fs was reported in a neonate with SP-C abnormality (22). The p.Arg1583Trp in Case 3 was judged as "damaging" with both SIFT and Polyphen-2. Therefore, we speculated that these six mutations were responsible for ILD in the four infants. Whether the three

variations in cases 7 and 8 except *ABCA3* p.Thr761Met were causative for lung dysfunction is undetermined. The *ABCA3* p.Thr761Met in case 8 was judged as "damaging" with both SIFT and polyphen-2 occurring in one in 6,500 European and Americans according to the exome sequencing project. Thus, the p.Thr761Met may be responsible for lung dysfunction in case 8. More than 30 different mutations of *SFTPC* (2, 7, 18, 20 – 27) and more than 70 different mutations of *ABCA3* (3, 7, 21, 28 – 31) have been reported in association with lung dysfunction. Thus, the first round examination for *SFTPC* and *ABCA3* efficiently detected genetic abnormalities in five of the nine patients with ILD in this study.

The SP-B deficiency is one of the major causes of surfactant protein dysfunction disorders in Western countries: of 25 cases of hereditary surfactant protein dysfunction disorder in the UK, six (24%), seven (28%) and 12 (48%) were SP-B deficiency, SP-C abnormality, and ABCA3 deficiency, respectively (21). In those with SP-B deficiency, more than 30 *SFTPB* mutations were reported (1, 3, 7, 11, 21, 31 – 33). However, none of the 22 cases tested had *SFTPB* mutations in this study (Table 2, Figure 1). There

have been no reports of patients with diagnosis of SP-B deficiency in Japanese patients to date (34). The 121ins2 mutation responsible for SP-B deficiency, estimated to occur in ~1 in 1,000 Americans, is not found in Korean or South African populations (31). The ABCA3 deficiency accounts for 48% (12/25) of surfactant protein dysfunction disorders in the UK, while its deficiency was seen in only one of the six cases of HILD in this study. Thus, it was suggested that there are ethnic differences in the prevalence rates of SP-B deficiency and ABCA3 deficiency.

There were two patient with ACD/MPV in this study, and one of them had a *FOXF1* mutation (heterozygous p.Leu300ArgfsX79) which is listed in a recent report (19). Approximately 80% of ACD/MPV cases have anomalies of other organs, particularly of the cardiovascular, gastrointestinal, and genitourinary systems (35). The previous study (19) substantiates the suggestion that mutations in *FOXF1* lead to manifestation of ACD/MPV and that this transcription factor is involved in development of the pulmonary, cardiovascular, gastrointestinal, and genitourinary systems. Although rare, late presentation has been reported (36, 37), with affected patients typically developing

lung dysfunction and pulmonary hypertension a few hours after birth. Our Case 6 with late onset at 3 months after birth who has survived until age two years had no anomalies in other organs and is currently being treated with vasodilators and home oxygen. Another case with ACD/MPV in whom the analysis of *FOXF1* was not given exhibited a typical course and died four days after birth.

As our E-mail Network of Neonatologists covers almost all neonatologists who treat severe cases in NICU in Japan, most infants with severe and unexplained lung dysfunction may have been referred to us. However, it was possible that some neonates who died very early were not referred to us. Four of the nine infants with ILD including one with ACD/MPV but not with *FOXF1* analysis were born after the announcement of this system in February 2011, and three of the four were identified to have genetic abnormalities (Cases 2, 3, and 6). As there were approximately 2,625,000 neonates during the 2.5-year study period in Japan, the prevalence of HILD was estimated to be at least one in 875,000 (3/2,625,000).

Neither clinical factors, such as a low Apgar score, timing of onset of lung dysfunction, nor use of inhaled nitric oxide differentiated HILD from patients with not-proven gene mutations in this study. However, in patients in UK, respiratory distress at birth was the presenting symptom in all six infants with *SFTPB* mutations and in 10 of 12 infants with confirmed *ABCA3* mutations, while patients with *SFTPC* mutations were more likely to present later with chronic cough, failure to thrive, or oxygen dependency (24). Indeed, three of the four patients with *SFTPC* mutations manifested lung dysfunction later, i.e., 6 days, 2 weeks, and 5 months after birth, while one infant with *ABCA3* mutations showed lung dysfunction immediately after birth in this study. In addition, gene mutations were efficiently detected in infants with assisted ventilation for more than 30 days, positive findings for pulmonary alveolar proteinosis in the BAL, and/or histologically confirmed ILD (Table 4). This information may be useful for clinicians in searching for specific mutations responsible for lung dysfunction.

In conclusion, 43 infants with severe and unexplained lung dysfunction were referred to us over a 2.5-year study period. Nine (21%) of these patients were diagnosed clinically

as having ILD. Mutations of *SFTPC* in four cases, *ABCA3* in one case, and *FOXF1* in one case were considered to be responsible for ILD in six of the nine patients. None of 22 patients including 20 with early onset and no improvement of lung dysfunction and two with late onset and suspected hPAP had *SFTPB* mutations. These observations suggested that the prevalence of HILD is at least 1 per 875,000 Japanese infants, the SP-C abnormality is the most prevalent aberration, and SP-B deficiency is rare among Japanese infants with ILD.

Methods

The present system was announced to Japanese neonatologists via an E-mail Network of Neonatologists in February 2011 after receiving approval from the Institutional Review Board of the Hokkaido University Graduate School of Medicine. Collaboration with the Japan Society for Premature and Newborn Medicine (JSPNM) was begun in February 2012 to facilitate collection of cases with severe and unexplained lung dysfunction: the JSPNM announced 3300 neonatologists four times annually since February 2012 to register prospectively patients with unexplained

sustained respiratory distress due to genetic disorder or unknown origin, and not patients with respiratory failure due to known reasons including infection, congenital heart disease, systemic bone disease, neuromuscular disease, malformations, pulmonary hypertension after birth asphyxia, and bronchopulmonary dysplasia caused by prematurity. Most Japanese neonatologists were members of the JSPNM and the members were working at approximately 90% of all facilities with NICU in Japan.

1. Patients

All of the 43 families provided detailed clinical information and blood samples were obtained for genetic analysis with written informed consent.

Our system offered a stepwise laboratory examination for patients with unexplained lung dysfunction (Figure 1). All 43 cases underwent first round examination including analysis of *SFTPC* and *ABCA3*. Then, 22 cases including 20 with early onset requiring assisted ventilation and no improvement of respiratory status and two cases with late onset and suspected hPAP underwent second round examination. Analysis of *SFTPB* was performed in these 22 cases. In 17 of them, the BAL or tracheal aspirates was

available for SP-B western blotting analysis and microscopic examination. Among the 22 cases, two proceeded to third round examination of pSTAT-5. Finally, four of five patients with severe persistent pulmonary hypertension unresponsive to treatment underwent analysis of *FOXF1*.

2. Analyses of the *SFTPC*, *ABCA3*, *SFTPB*, and *FOXF1* genes

Genomic DNA was extracted from peripheral blood using a QIAamp DNA Blood Mini Kit (Qiagen, Hilden, Germany). PCR primers reported previously were used for *SFTPC* (23). PCR primers for *SFTPB*, *ABCA3*, and *FOXF1* were designed using Primer3 (38) to amplify all of the coding exons and their exon-intron boundaries. PCR was performed using a GeneAmp PCR System 2700 (Applied Biosystems, Foster, CA) with AmpliTaq Gold 360 PCR Master Mix (Life Technologies, Carlsbad, CA) in a 20-μL reaction mixture containing 40 ng of DNA template, and 0.5 μ mol/l of each primer. PCR conditions were variable for each amplicon: incubation at 95°C for 10 min followed by 40 cycles of three or two steps (depending on primer): 1) denaturation at 95°C for 30 s, annealing at 58°C – 60°C for 30 s, and extension at 72°C for 1 min, or 2)

denaturation at 95°C for 30 s and extension at 63°C for 1 min: with a final extension at 72°C for 10 min. PCR products were analyzed by electrophoresis using 2.0% agarose gels and purified with a QIAquick Gel Extraction Kit (Qiagen). Purified products were subjected to nucleotide sequence analysis by a commercial sequencing service (FASMAC, Kanagawa, Japan). Nucleotide sequences were compared with the reported reference sequences: NM_003018.3 (*SFTPC*), NM_001089.2 (*ABCA3*), NM_198843.2 (*SFTPB*), or NM_001451.2 (*FOXF1*).

3. SP-B western blotting analyses of BAL or tracheal aspirates

BAL and tracheal aspirates were used without centrifugation and lipid extraction. Samples corrected for protein concentration were suspended in Laemmli sample buffer. Tricine/sodium dodecyl sulfate polyacrylamide gel electrophoresis was performed as reported previously (39) and aliquots of 20 μg of protein per lane were separated on 16% polyacrylamide gels. The proteins were transferred onto polyvinylidene fluoride membranes and examined by western blotting. Polyclonal antibody to Human SP-B (Hycult, Uden, The Netherlands) was used as the primary antibody at a concentration of

1:50, and horseradish peroxidase-conjugated anti-rabbit IgG (GE Healthcare, Little Chalfont, UK) was used as the secondary antibody at a concentration of 1:1000. The blots were then visualized using Immobilon western chemiluminescent HRP substrate (Millipore, Billerica, MA).

4. Analyses of GM-CSF-induced phosphorylation of signal transducer and activator of transcription (pSTAT-5)

Peripheral blood mononuclear cells were suspended in Roswell Park Memorial Institute medium with 10% fetal bovine serum at a concentration of 1×10^6 cells per mL, and were incubated in the presence or absence of 20 ng/mL GM-CSF for 15 min. Whole cell lysates were prepared by homogenization in 1×SDS sample buffer, separated by Glycine/SDS-PAGE according to the standard procedure, and transferred onto PVDF membranes. Anti-STAT-5 (pY694) antibody (BD, San Diego, CA) was used at a final concentration of 0.5 μg/mL, and anti-actin antibody (Sigma, St. Louis, MO) was used at a final concentration of 1 μg/mL as a loading control.

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Figure legend

Figure 1: Flow diagram showing patient selection criteria for various examinations and test results

All 43 patients underwent analyses of *SFTPC* and *ABCA3* in the first step. Among 30 patients with early onset requiring assisted ventilation, 20 did not exhibit improvement in the respiratory status. These 20 and two with late onset and suspected hPAP (Case 6 and another) underwent second round examination for *SFTPB*. In 17 of the 22 patients, BAL or tracheal aspirates was available for SP-B western blotting analysis (Table 1). Milky appearance of the BAL with eosinophilic materials on the microscopic examination supported the diagnosis of hPAP in three cases (Cases 1, 2, and 3), but not in two late-onset cases with suspected hPAP (Case 6 and another). Two cases (Cases 3 and 6) underwent assessment of pSTAT-5 because Case 3 was not identified to have *ABCA3* mutation at that time and because Case 6 was strongly suggested to be hPAP on computed tomography. Four of five patients with severe pulmonary hypertension unresponsive to treatment underwent analysis of *FOXF1*. One who died from pulmonary hypertension and ACD/MPV at four days old did not undergo analysis of

FOXF1.

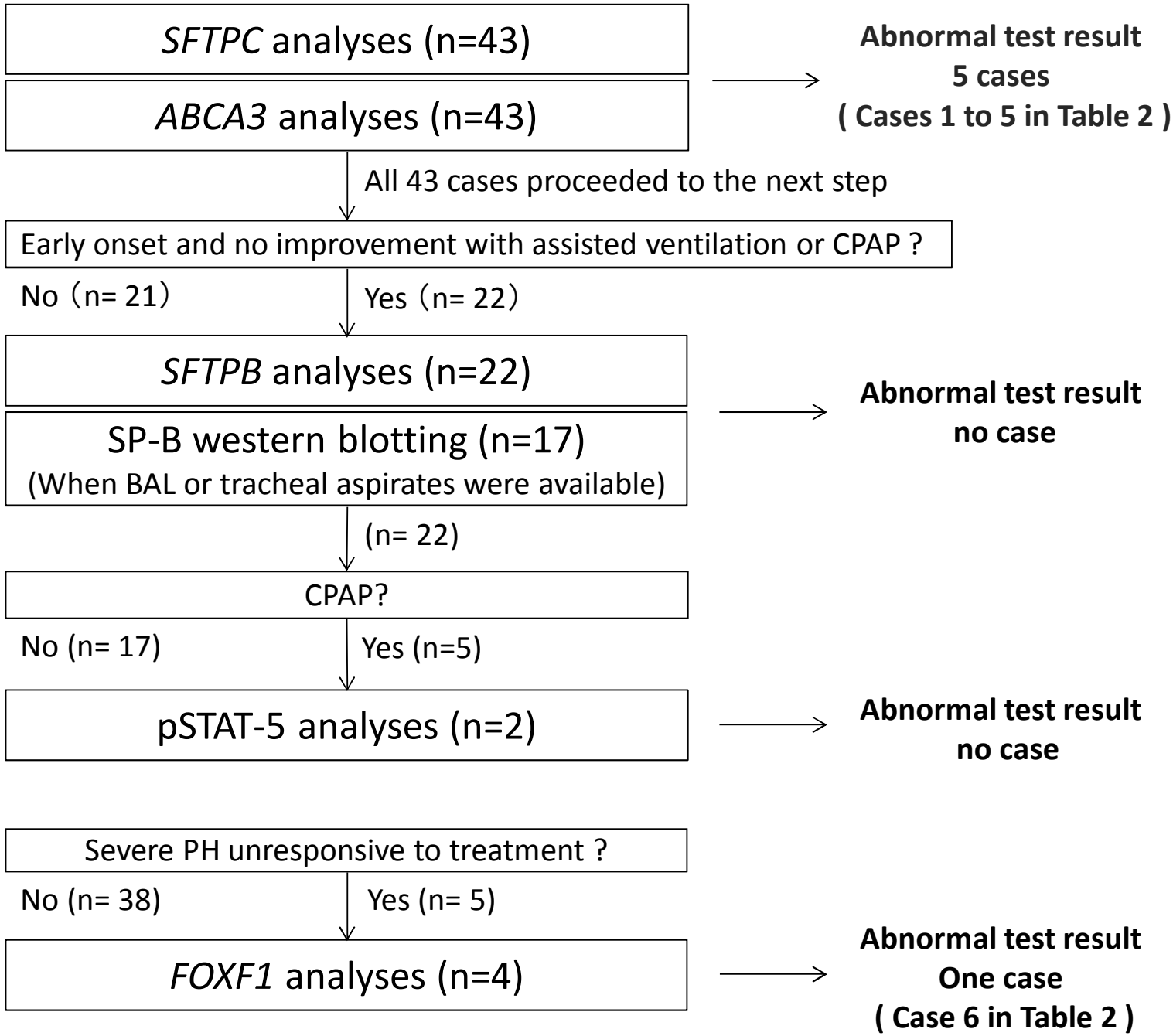
SFTPC analyses (n=43)
ABCA3 analyses (n=43)
Abnormal test result
5 cases
(Cases 1 to 5 in Table 2)
All 43 cases proceeded to the next step
Early onset and no improvement with assisted ventilation or CPAP ?
No（n= 21）
Yes（n= 22）
SFTPB analyses (n=22)
Abnormal test result
no case
SP-B western blotting (n=17)
(When BAL or tracheal aspirates were available)
(n= 22)
CPAP?
No (n= 17)
Yes (n=5)
pSTAT-5 analyses (n=2)
Abnormal test result
no case
Severe PH unresponsive to treatment ?
No (n= 38)
Yes (n= 5)
FOXF1 analyses (n=4)
Abnormal test result
One case
(Case 6 in Table 2)

Table 1. Demographic characteristics of 43 patients

	Early onset	Late onset
No. of patients	34[a]	9[b]
Male sex	22 (65%)	5 (56%)
Onset of lung dysfunction	0 (0 – 14) days	6 (3 – 60) months
Gestation length (weeks)	38 (28 – 41)	40 (27 – 41)
Apgar Score < 7 (5 min)	6 (18%)	0 (0%)
Assisted ventilation	30 (88%)	5 (56%)
iNO	16 (47%)	2 (22%)
BAL/Tracheal aspirates	15 (44%)	2 (22%)
CT/HRCT	22 (65%)	9 (100%)
Lung biopsy/autopsy	6 (18%)	3 (33%)
Poor outcome (death)	8 (24%)	2 (22%)

Early onset was defined as manifestation of lung dysfunction within 4 weeks after birth. Median (range) or number (percentage) is indicated.
CT/HRCT, availability of computed tomography or high-resolution computed tomography; iNO, use of inhaled nitric oxide

aClinically, asphyxia and/or meconium aspiration syndrome were suspected in nine infants.

[b]Presumptive clinical diagnosis was interstitial pneumonitis in four cases, respiratory failure associated with immune disorder in two cases, and pulmonary alveolar proteinosis in one case.

Table 2. Relationship between clinical diagnosis and genetic variations responsible for lung dysfunction

Clinical diagnosis		No. of infants with abnormality/No. of infants tested				
		SFTPC	*ABCA3*	*SFTPB*	pSTAT-5	*FOXF1*
Interstitial pneumonitis	(n=4)	2/4	0/4	0/0	0/0	0/0
hPAP	(n=3)	2/3	1/3	0/3	0/1	0/0
ACD/MPV	(n=2)	0/2	0/2	0/2	0/1	1/2
Others[a]	(n=34)	0/34	0/34	0/17	0/0	0/2
Overall	(n=43)	4/43	1/43	0/22	0/2	1/4

ABCA3 variations seen in two cases (Case 7, 8 in Table 3) were not included in this table.

Others[a] included four diagnoses responsible for or possibly associated with lung dysfunction for each one case: gastroesophageal reflux disease, severe combined immunodeficiency, Kabuki make-up syndrome, and congenital adrenal hypoplasia.

Table 3. Eight patients in whom genetic variations were found

Case	BW/GW	Onset	Diagnosis	AV	iNO	Genotype	SIFT/Polyphen-2	Origin of variations	Treatment	Outcomes
1	3204/40	0 day	hPAP	Yes	No	*SFTPC* c.134T>G: p.Leu45Arg (het)	Damaging/Damaging	*de novo*	Surfactant, steroids, Hch	Undergoing treatment, 43 months
2	2600/40	6 days	hPAP	Yes	No	*SFTPC* c.433delC: p.Gln145fs (het)	Not done	Unknown[c]	Surfactant, steroids, Hch	Died, 77 days
3	3230/40	0 day	hPAP	Yes	Yes	*ABCA3* c.4747C>T: p.Arg1583Trp, *ABCA3* c.4483_4507del25: p.Val1495CysfsX21	Damaging/Damaging Not done	Mother (asymptomatic) Father (asymptomatic)	Surfactant, steroids, Hch	Died, 7 months
4	3060/41	5 months	IP[a]	No	No	*SFTPC* c.187A>G: p.Lys63Glu (het)	Damaging/Damaging	Mother (asymptomatic) and mother's father (pulmonary fibrosis)	Steroids, Hch	Undergoing treatment, 54 months
5	3520/38	2 weeks	IP	Yes	No	*SFTPC* c.215G>A: p.Ser72Asn, *SFTPC* c.299G>C: p.Gly100Ala	Damaging/Damaging Damaging/Benign	Unknown[c]	Steroids, CsA, CPM, AZP	Undergoing treatment, 13 years
6	3344/41	3 months	ACD/MPV	Yes	Yes	*FOXF1* c.899delT: p.Leu300ArgfsX79 (het)	Not done	*de novo*	Steroids, vasodilator	Undergoing treatment, 24 months
7	3194/40	0 day	URD	Yes	No	*ABCA3* c.218C>T: p.Pro73Leu, *ABCA3* c.3613G>A: p.Gly1205Arg	Tolerated/Benign[b] Tolerated/Benign[b]	Unknown[c]	None	Recovered
8	778/27	8 months	CLD, PH	Yes	No	*ABCA3* c.2282C>T: p.Thr761Met, *ABCA3* c.4085C>T: p.Ala1362Val	Damaging/Damaging Tolerated/Benign[b]	Mother (asymptomatic) Father (asymptomatic)	Vasodilator	Undergoing treatment, 17 months

AV, use of assisted ventilation; AZP, azathioprine; BW/GW, birth weight/gestational week at delivery; CLD, chronic lung disease; CPM, cyclophosphamide; CsA, cyclosporine A; Hch, hydroxychloroquine; iNO, use of inhaled nitric oxide; PH, pumonary hypertention; URD, unexplained respiratory distress

[a]Diagnosed based on medical history, computed tomography, and serum KL-6.

[b]Three of the four variations in Cases 7 and 8 were considered not to be causative for lung dysfunction. The variations at codon 73 and 1205 in Case 7 are not listed in dbSNP or the 1000 Genome Project database. The variation at codon 1362 in Case 8 was identified in more than 1.0% of Japanese according to the 1000 Genome Project.

[c]Genetic testing of family members was not performed.

Table 4. Comparison of demographic characteristics between 6 and 37 patients

	6 patients[a]	37 patients	*P*-value
Preterm birth (<37 weeks)	0 (0.0%)	6 (16%)	0.3813
Birth weight < 2500g	0 (0.0%)	8 (22%)	0.2662
Male sex	3 (50%)	24 (65%)	0.3941
Apgar score < 7 at 5 min	0 (0.0%)	7 (19%)	0.3195
Timing of onset			
Immediately after birth	2 (33%)	27 (73%)	0.0767
Within 4 weeks after birth	4 (67%)	30 (81%)	0.3686
iNO	2 (33%)	16 (43%)	0.5034
Assisted ventilation	5 (83%)	30 (81%)	0.6922
More than 30 days	5 (83%)	10 (27%)	0.0146
Positive for PAP on BAL	3 (50%)	0 (0.0%)	0.0016
Histologically proven ILD	3 (50%)	3 (8.1%)	0.0272

iNO, use of inhaled nitric oxide; PAP, pulmonary alveolar proteinosis

[a]Six infants in whom causative genetic abnormalities were detected, not including two cases (Case 7 and 8 in Table 3) because it was uncertain whether detected variations were causative for their lung dysfunction.