

Successful Management of Plastic Bronchitis in a Child Post Fontan: Case Report and Literature Review

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Abstract

Purpose Plastic bronchitis is the occlusion of the major bronchial airways by a firm, gelatinous mucoid cast. It is a rare condition, which while classically described in asthma and sickle cell disease has greater mortality in patients with congenital heart disease. The management of this disease is obscure given the lack of clinical data regarding treatment therapies.

Methods We describe a case of an 11-year-old female status after Fontan surgery who presented with respiratory distress secondary to atelectasis of the right lung.

Results A bronchoscopy was performed demonstrating an obstructing bronchial cast with successful extraction. The plastic bronchitis continued to recur and she was placed on multiple inhaled mucolytics as well as inhaled tissue plasminogen activator with temporary resolution. Further evaluation of the etiology of her casts revealed that she had elevated pulmonary arterial pressures. Repeated bronchoscopic removal of the casts was utilized as well as continuation of the aggressive airway clearance. Ultimately fenestration of her Fontan was performed along with treatment of pulmonary vasodilators sildenafil and bosentan. Although there was improvement of the cast formation, her airway clearance could only be weaned to four times a day therapy with which she was discharged home after a 3-month hospitalization. She continues to remain on

this therapy and has not required hospitalization since the initial incident over 1 year ago.

Conclusions Plastic bronchitis in a patient with Fontan physiology presents a treatment dilemma that may require comprehensive therapy in severe cases such as described.

Keywords Tissue plasminogen activator · Bronchoscopy · Dornase · Plastic bronchitis

Introduction

Plastic bronchitis is a rare, potentially fatal, condition noted in patients after Fontan surgery. The mucoid impaction with cast formation occludes the major bronchi with firm, gelatinous material [1]. Seen in asthma and sickle cell disease, the morbidity and mortality is greater in congenital heart disease [2]. Clinical management for both acute and chronic plastic bronchitis remains difficult and poorly defined.

Case Report

An 11-year-old female with an unbalanced atrial-ventricular canal status post lateral tunnel Fontan procedure at age 5 years though nonsyndromic presented with a 5-day history of cough and respiratory distress. Chest roentgenogram (Fig. 1) demonstrated right lung atelectasis and pleural effusion for which she received fiberoptic bronchoscopy. A bronchial cast with mucoid impaction extended from the carina to both main stem bronchi with histology revealing an acellular mucinous fibrin collection (Fig. 2). She received sildenafil to mitigate elevated pulmonary arterial (PA) pressure of 17 mmHg, which was

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discovered 10 months previously on a cardiac catheterization. At that time, she was started on sildenafil, but therapy was discontinued due to dizziness. A right chest tube was eventually placed for her pleural effusion. Her echocardiogram demonstrated a mildly hypoplastic left ventricle as well as mild hypertrophy of the right ventricle, although biventricular function was normal. There was retrograde flow through the right Fontan during expiration. There otherwise was no evidence of anasarca, hypoproteinemia, or liver disease. Despite these measures, her respiratory status worsened and she was intubated, mechanical ventilation was started, and nebulized tissue plasminogen activator (tPA) and alfa dornase were utilized with partial clearing of atelectasis. However, complete contralateral atelectasis prompted repeat selective bronchoscopy to restore lung volume with the removal of a large occluding bronchial cast from the left-mainstem bronchus. She improved clinically with extubation as inhaled tPA was slowly tapered off. Her postextubation ventilation therapy consisted of high-flow nasal cannula and bilevel positive airway pressure (BiPAP).

She remained on airway clearance with vest therapy, intrapulmonary percussive ventilation (IPV), inhaled dornase, N-acetyl cysteine, and 3 % hypertonic saline. A fourth bronchoscopy was required to clear recurrent right lung atelectasis and restore lung volume as decreased ventilation/perfusion ratio resulted in hypoxemia. Additional therapeutic modalities deployed included azithromycin and bosentan. Despite maximal medical therapy,

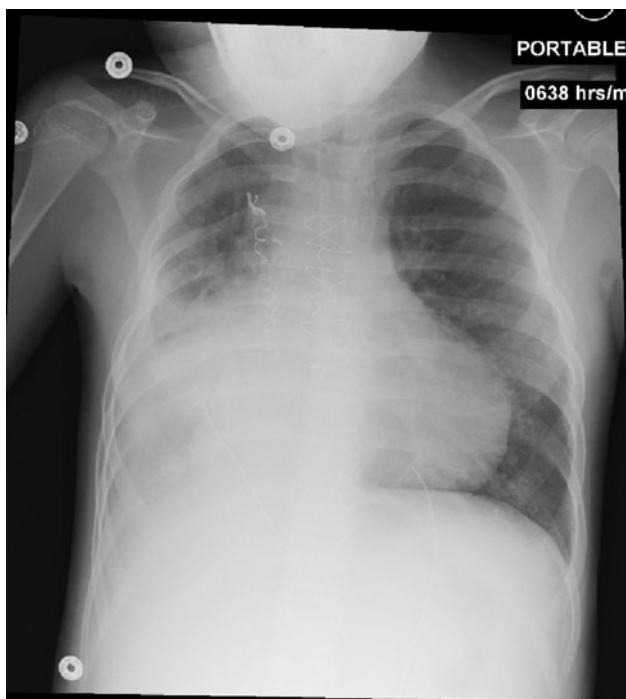


Fig. 1 Presenting roentgenogram demonstrating right lung atelectasis

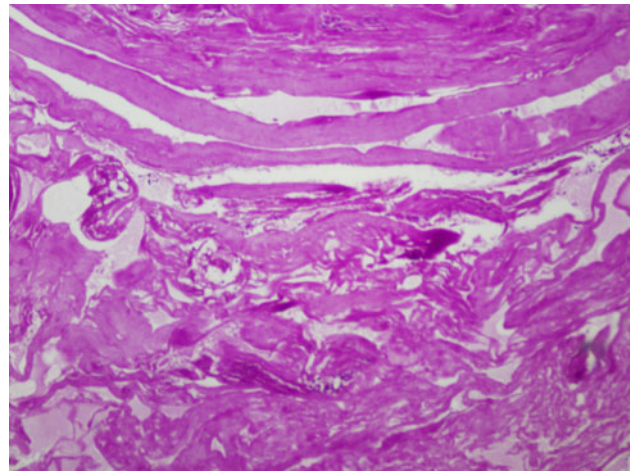


Fig. 2 Period acid schiff stain of the patient's bronchial cast showing acellular mucin structure

including repeat inhaled tPA, atelectasis persisted. A repeat cardiac catheterization was performed, demonstrating a PA pressure of 20 mmHg. Ultimately surgical fenestration of the Fontan with drainage into the left atrium was required. Her mean oxygen saturations were now decreased to the high eighties at baseline and her clinical status improved, although she was unable to be weaned completely off her airway clearance therapy without recurrence of atelectasis. She was discharged after 3 months of hospitalization on daytime oxygen and nocturnal BiPAP. Home airway clearance included IPV treatments, albuterol, N-acetyl cysteine, dornase, hypertonic saline, azithromycin, bosentan, and sildenafil. She remained clinically stable without hospital admission. Chest film remains clear with no atelectasis 6 months later.

Discussion

Plastic bronchitis is a potentially fatal albeit rare condition. The pathophysiology and overall clinical management are poorly defined. Documented as early as Galen in 131–200 A.D. [3, 4], plastic bronchitis is uncommon in children, with only 40 cases reported before 1985 and 72 cases before 1989 [5]. Initial disease mechanisms focused on tuberculosis infection, atopy, and asthma [3, 4, 6–8]. Gross examination of expectorated or mechanically removed casts demonstrated homogenous, cylindrical entities involving multiple branching airway generations [4]. Histologic examination of the bronchial casts first showed highly structured fibrin with incorporated mucin. Other characteristics included hypercellularity with eosinophils, Charcot-Leyden crystals, and Curschmann's spirals [4, 9, 10].

Sear et al. in 1997 [11] delineated a novel scheme for subtype classification. Type 1 casts were considered

inflammatory and consistent with a fibrin structure and eosinophilia. Type 2 were generally acellular and mucin containing often seen in congenital heart disease. Brogan et al. reclassified casts depending on the disease states of asthma, cardiac, and idiopathic. Madsen et al. expanded this classification to cardiac, lymphatic, asthmatic, and sickle cell-related disease states [1, 2]. Madsen et al. [2] formulated this classification based on details of previous case studies. Cardiac patients described by them include eight Fontan patients, three Blalock–Taussig shunt patients, and one Glenn shunt patient. Bronchial casts are noted in other disease states, such as sickle cell disease [12–14], metastatic lung tumors [4, 15, 16], viral infections [17, 18], smoke inhalation [19–21], bronchopulmonary aspergillosis [22–27], thalassemia alpha [28], sulfur mustard inhalation [29], solvent aspiration [30], and the use of pegylated interferon [31].

Pathophysiology

The Fontan physiology has evolved since its first description by Fontan et al. in 1971 [32], but its current iteration resolves around the concept of passive flow of venous blood into the pulmonary circulation from the inferior vena cava and superior vena cava, drainage into the atria, and propulsion to the system from a single ventricular system. Although the operation is life-saving, its physiology is unnatural and may lead to multiple complications. Previously described complications include ventricular dysfunction, elevated pulmonary vascular resistance, valve dysfunction, lymphatic derangements, pulmonary arteriovenous malformations, thrombotic circuit occlusion, and intractable arrhythmias [32].

Plastic bronchitis in congenital heart disease patients varies given specifics of the cardiac disease and the associated complex hemodynamics. Previously reported successful therapeutic interventions focused on optimizing post Fontan cardiac hemodynamics and lowering central venous pressure. Bowen et al. demonstrated resolution of bronchial casts in a patient with pericardial effusion utilizing surgical pericardectomy [9]. Three additional cases of pericardial effusions and plastic bronchitis as a complication of Fontan operation have been detailed [2, 13, 33]. Bronchial casts in Fontan patients also have been eliminated by methods of fenestration [32–35], stent placement [36], atrial pacing [2, 37], anticoagulation therapy [38], and pulmonary vasodilation [39–41].

The role of lymphatic dysfunction was explored by Languépin et al. [42] as chylous bronchial casts were noted after cardiac surgery. Three such cardiopathy cases associated with plastic bronchitis demonstrated severe lymphatic dysfunction. Two cases were relieved by thoracic duct ligation or low-fat diet and chest physiotherapy.

A third case showed only mild improvement with the aforementioned therapy [42]. Lung biopsy in this case revealed large subpleural and peribronchial lymphatic dilations. Histology in all cases showed PAS-positive fibrin and mucin with interspersed lymphocytes, while lacking eosinophils and Charcot-Leydin crystals. Conceptually, increased central venous pressure may lead to lymphatic obstruction, retrograde flow, and chylous leakage within the airways. Animal experiments in the past have shown that increased systemic venous pressure increased formation of thoracic duct lymph, impedes return of lymph into the great veins, and decreases pulmonary lymph flow [43, 44]. Hug et al. presented a case of a 4-year-old with Fontan circulation associated plastic bronchitis in the setting of left innominate vein thrombosis [45]. Histopathology revealed dilated pulmonary lymph vessels with rupture and leakage into the alveoli.

Systemic lymphatic disease states also are associated with plastic bronchitis. Turner's and Noonan's syndrome have been associated with lymphatic dysplasia. Along with lymphangiomatosis [46], chylothorax [47], or other lymphatic dysplasias [48, 49], the pathophysiology of plastic bronchitis may involve both lymphatic and vascular dynamics.

Acute Management

No clinical prospective studies have examined plastic bronchitis therapy. Evidence is based on success or failure within individual case studies. Acute management involves the stabilization of the cardiopulmonary system, potentially requiring intubation for respiratory failure [28, 35, 37, 50, 51]. General airway clearance measures with bronchodilators and chest physiotherapy should be initiated. In emergent cases, immediate bronchoscopy, whether rigid or flexible, should be considered. Shah et al. [52] argue that although rigid bronchoscopy is generally the mainstay for foreign body removal, lavage is not always possible. Bronchial casts are unique foreign bodies that may be friable or dissolvable, making lavage a necessary component of its removal. While bronchoscopy can be effective for acute therapy, it does not prevent recurrence nor should it be utilized on a chronic basis.

Case studies have described the use of inhaled therapies [2, 12, 53–56], anti-inflammatories [57, 58], diuretics [38], and surgical palliation [34, 35, 59, 60]. Brogan et al. [2] incubated a cast from a Fontan patient in vitro with acetylcysteine, DNase, urokinase, and tPA, demonstrating that acetylcysteine had the greatest effect in dissolving the casts. The use of inhaled DNase has yielded success [12, 53, 54]. Quasney et al. [56] utilized in vitro incubation and clinical therapy with inhaled urokinase with patient improvement. Few conflicting reports show no clinical

benefit for use of tPA in plastic bronchitis [36, 61]. However, there has been reported effective use of inhaled tPA [55, 62], and Wakeham et al. [63] showed long-term and efficacious therapy over the course of 18 months without any adverse complications. A murine model studied the safety of prolonged, repeated administration of inhaled pulmonary formulation tPA [64]. Nearly month-long therapy of high doses (>1 mg/kg/day) resulted in fatal pulmonary hemorrhage, whereas low-dose therapy was well tolerated.

Anti-inflammatory therapy use of corticosteroids and macrolides has been documented [2, 57, 58]. Macrolides have shown benefit in airway inflammation in other chronic lung disease [57]. However, specific benefit of clarithromycin in plastic bronchitis demonstrates conflicting results [36, 57]. Low-dose azithromycin at a dose of 250 mg three times per week in conjunction with an oral corticosteroid 5-day course was shown to be effective in one case with eosinophilic and Charcot-Leydin cast [58]. Corticosteroid use also was successful for the treatment of an 8-year-old Fontan circulation patient with 1 % eosinophilia and casts showing mild eosinophilic infiltration [65]. Based on limited data, it seems that the use of anti-inflammatory therapy may primarily benefit eosinophilic-type casts. However, this does not preclude use on a trial basis for alternative forms of bronchial casts.

Chronic Therapy

In patients who undergo or have completed Fontan physiology, prevention of recurrence becomes difficult due to the complexity of the disease state. For Fontan procedures, a thorough analysis of circuit patency for obstruction due to stenosis and thrombosis is essential. Other hemodynamic alterations, such as pericardial effusions and atrial-ventricular dyssynchrony, should be investigated. Central venous pressure should be evaluated and elevated pressures corrected with pulmonary vasodilators or stent fenestration.

Correction of hemodynamics should relieve elevated central venous pressures and secondary lymphatic flow. In the setting of normal hemodynamics or lack of response to corrective measures, hemodynamic-independent lymphatic dysfunction should be considered. The cast histology should include oil red O stain to evaluate for triglyceride presence [42]. Lymphangiography may be helpful to analyze lymphatic flow abnormalities, particularly with previous chylothorax history or current chylous casts. If lymphatic dysfunction is present, use of low-fat and medium-chain triglyceride diet or, alternatively, thoracic duct ligation may need to be utilized [42, 59].

If therapeutic approaches to hemodynamic instabilities and lymphatic dysfunction do not improve clinical status, then long-term combination therapy with inhalants, anti-

inflammatories, and pulmonary vasodilators may be required, which was in our case study. Whereas long-term, inhaled mucolytic therapy has been relatively safe to use as demonstrated in cystic fibrosis, prolonged inhaled tPA has only been demonstrated without complications in one human case study [63] and therefore should be used with caution. Incubation of removed bronchial casts in solution in vitro with various therapeutic agents and analyzing their efficacy may allow the clinician to individually tailor therapy. If all medical and surgical options have been exhausted, then cardiac and/or cardiac-lung transplant may need to be considered [60].

Conclusions

Plastic bronchitis in patients with Fontan circulation maintains a higher mortality compared with cases associated with asthma, atopy, and infection. Acute therapy requires aggressive bronchoscopy regimen, inhaled mucolytics, and aggressive airway clearance. For patients with complete or partial passive drainage of venous blood into the pulmonary vasculature, it is important to stabilize any hemodynamic or lymphatic compromise and intervene appropriately. Long-term airway clearance, inhalation, and anti-inflammatory treatment may be necessary and has been shown to be effective in the presented case study.

Conflict of interest None.

References

- Madsen P, Shah SA, Rubin BK (2005) Plastic bronchitis: new insights and a classification scheme. *Paediatr Respir Rev* 6(4): 292–300
- Brogan TV, Finn LS, Pyskaty DJ Jr, Redding GJ, Ricker D, Inglis A, Gibson RL (2002) Plastic bronchitis in children: a case series and review of the medical literature. *Pediatr Pulmonol* 34(6): 482–487. doi:10.1002/ppul.10179
- Leggat PO (1954) Plastic bronchitis. *Dis Chest* 26(4):464–473
- Johnson RS, Sita-Lumsden EG (1960) Plastic bronchitis. *Thorax* 15:325–332
- Hoskison E, Judd O, Dickinson E, Dux A (2010) Plastic bronchitis requiring bronchoscopy. *J Laryngol Otol* 124(12):1321–1324
- Morgan AD, Bogomoletz W (1968) Mucoïd impaction of the bronchi in relation to asthma and plastic bronchitis. *Thorax* 23(4): 356–369
- Oliver T (1899) Remarks on plastic or croupous bronchitis. *Br Med J* 2(2010):69–72
- Kokkola K, Vaara J (1975) Broncholithic casts. A case report. *Ann Chir Gynaecol Fenn* 64(4):233–235
- Bowen A, Oudjhane K, Odagiri K, Liston SL, Cumming WA, Oh KS (1985) Plastic bronchitis: large, branching, mucoïd bronchial casts in children. *AJR Am J Roentgenol* 144:371–375
- Cairns-Bazarian AM, Conway EE Jr, Yankelowitz S (1992) Plastic bronchitis: an unusual cause of respiratory distress in children. *Pediatr Emerg Care* 8(6):335–337

11. Seear M, Hui H, Magee F, Bohn D, Cutz E (1997) Bronchial casts in children: a proposed classification based on nine cases and a review of the literature. *Am J Respir Crit Care Med* 155(1): 364–370
12. Manna SS, Shaw J, Tibby SM, Durward A (2003) Treatment of plastic bronchitis in acute chest syndrome of sickle cell disease with intratracheal rhDNase. *Arch Dis Child* 88(7):626–627
13. Moser C, Nussbaum E, Cooper DM (2001) Plastic bronchitis and the role of bronchoscopy in the acute chest syndrome of sickle cell disease. *Chest* 120(2):608–613
14. Raghuram N, Pettignano R, Gal AA, Harsch A, Adamkiewicz TV (1997) Plastic bronchitis: an unusual complication associated with sickle cell disease and the acute chest syndrome. *Pediatrics* 100(1):139–142
15. Jariwalla AG, Seaton A, McCormack RJ, Gibbs A, Campbell IA, Davies BH (1981) Intrabronchial metastases from renal carcinoma with recurrent tumour expectoration. *Thorax* 36(3):179–182
16. Kuperman T, Wexler ID, Shoseyov D, Weintraub M, Revel-Vilk S, Kerem E (2006) Plastic bronchitis caused by neoplastic infiltrates in a child. *Pediatr Pulmonol* 41(9):893–896. doi: [10.1002/ppul.20370](https://doi.org/10.1002/ppul.20370)
17. Hasegawa M, Inamo Y, Fuchigami T, Hashimoto K, Morozumi M, Ubukata K, Watanabe H, Takahashi T (2010) Bronchial casts and pandemic (H1N1) 2009 virus infection. *Emerg Infect Dis* 16(2):344–346
18. Oikawa J, Ogita J, Ishiwada N, Okada T, Endo R, Ishiguro N, Ubukata K, Kohno Y (2009) Human bocavirus DNA detected in a boy with plastic bronchitis. *Pediatr Infect Dis J* 28(11):1035–1036. doi: [10.1097/INF.0b013e3181ac4d](https://doi.org/10.1097/INF.0b013e3181ac4d)
19. Pietak SP, Delahaye DJ (1976) Airway obstruction following smoke inhalation. *Can Med Assoc J* 115(4):329–331
20. Cox RA, Burke AS, Soejima K, Murakami K, Katahira J, Traber LD, Herndon DN, Schmalstieg FC, Traber DL, Hawkins HK (2003) Airway obstruction in sheep with burn and smoke inhalation injuries. *Am J Respir Cell Mol Biol* 29(3 Pt 1):295–302. doi: [10.1165/rmb.4860](https://doi.org/10.1165/rmb.4860)
21. Prater ME, Deskin RW (1998) Bronchoscopy and laryngoscopy findings as indications for tracheotomy in the burned child. *Arch Otolaryngol Head Neck Surg* 124(10):1115–1117
22. Werkhaven J, Holinger LD (1987) Bronchial casts in children. *Ann Otol Rhinol Laryngol* 96(1 Pt 1):86–92
23. Sulavik SB (1988) Bronchocentric granulomatosis and allergic bronchopulmonary aspergillosis. *Clin Chest Med* 9(4):609–621
24. Denning DW, Follansbee SE, Scolaro M, Norris S, Edelstein H, Stevens DA (1991) Pulmonary aspergillosis in the acquired immunodeficiency syndrome. *N Engl J Med* 324(10):654–662. doi: [10.1056/NEJM199103073241003](https://doi.org/10.1056/NEJM199103073241003)
25. Miller WT Jr, Sais GJ, Frank I, Geftter WB, Aronchick JM, Miller WT (1994) Pulmonary aspergillosis in patients with AIDS. Clinical and radiographic correlations. *Chest* 105(1):37–44
26. Sledziewska J, Zaleska J, Wiatr E, Plodziszewska M, Zaleska M, Pirozynski M, Bestry I, Rowinska-Zakrzewska E (2001) Plastic bronchitis and mucoid impaction: uncommon disease syndromes with expectoration mucus plugs. *Pneumonol Alergol Pol* 69(1–2): 50–61
27. Kim DH, Lee JH, Kim BH, Choi EK, Park JS, Kim KY, Choi YH, Myong NH, Lee KY (2002) Chronic necrotizing bronchopulmonary aspergillosis with elements of bronchocentric granulomatosis. *Korean J Intern Med* 17(2):138–142
28. Veras TN, Lannes GM, Piva JP, Stein RT, Jones MH, Silva VD, Garcia PC, Pitrez PM (2005) Plastic bronchitis in a child with thalassemia alpha. *J Pediatr (Rio J)* 81(6):499–502. doi: [10.2223/JPED.1425](https://doi.org/10.2223/JPED.1425)
29. Veress LA, O'Neill HC, Hendry-Hofer TB, Loader JE, Rancourt RC, White CW (2010) Airway obstruction due to bronchial vascular injury after sulfur mustard analog inhalation. *Am J Respir Crit Care Med* 182(11):1352–1361. doi: [10.1164/rccm.200910-1618OC](https://doi.org/10.1164/rccm.200910-1618OC)
30. Koga T, Kawazu T, Iwashita K, Yahata R (2004) Pulmonary hyperinflation and respiratory distress following solvent aspiration in a patient with asthma: expectoration of bronchial casts and clinical improvement with high-frequency chest wall oscillation. *Respir Care* 49(11):1335–1338
31. Garcia E, da Silva Junior AF, Schorr F, Hota M, Brizzi RG, da Silva AB (2009) Bronchial casts attributed to the use of pegylated interferon and ribavirin. *J Bras Pneumol* 35(7): 713–716
32. Davies RR, Chen JM, Mosca RS (2011) The Fontan procedure: evolution in technique; attendant imperfections and transplantation for “failure.”. *Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu* 14(1):55–66
33. Muller W, von der Hardt H, Rieger CH (1987) Idiopathic and symptomatic plastic bronchitis in childhood. A report of three cases and review of the literature. *Respiration* 52(3):214–220
34. Chaudhari M, Stumper O (2004) Plastic bronchitis after Fontan operation: treatment with stent fenestration of the Fontan circuit. *Heart* 90(7):801. doi: [10.1136/hrt.2003.029041](https://doi.org/10.1136/hrt.2003.029041)
35. Wilson J, Russell J, Williams W, Benson L (2005) Fenestration of the Fontan circuit as treatment for plastic bronchitis. *Pediatr Cardiol* 26(5):717–719. doi: [10.1007/s00246-005-0913-8](https://doi.org/10.1007/s00246-005-0913-8)
36. McMahon CJ, Nihill MR, Reber A (2001) The bronchial cast syndrome after the Fontan procedure: further evidence of its etiology. *Cardiol Young* 11(3):345–351
37. Barber BJ, Burch GH, Tripple D, Balaji S (2004) Resolution of plastic bronchitis with atrial pacing in a patient with fontan physiology. *Pediatr Cardiol* 25(1):73–76. doi: [10.1007/s00246-003-0529-9](https://doi.org/10.1007/s00246-003-0529-9)
38. Stiller B, Riedel F, Paul K, van Landeghem FK (2002) Plastic bronchitis in children with Fontan palliation: analogue to protein losing enteropathy? *Pediatr Cardiol* 23(1):90–94
39. Apostolopoulou SC, Papagiannis J, Rammos S (2005) Bosentan induces clinical, exercise and hemodynamic improvement in a pre-transplant patient with plastic bronchitis after Fontan operation. *J Heart Lung Transplant* 24(8):1174–1176. doi: [10.1016/j.healun.2004.11.018](https://doi.org/10.1016/j.healun.2004.11.018)
40. Haseyama K, Satomi G, Yasukochi S, Matsui H, Harada Y, Uchita S (2006) Pulmonary vasodilation therapy with sildenafil citrate in a patient with plastic bronchitis after the Fontan procedure for hypoplastic left heart syndrome. *J Thorac Cardiovasc Surg* 132(5):1232–1233. doi: [10.1016/j.jtcvs.2006.05.067](https://doi.org/10.1016/j.jtcvs.2006.05.067)
41. Reinhardt Z, Uzun O, Bhole V, Ofoc V, Wilson D, Onuzo O, Wright JG, Stumper O (2010) Sildenafil in the management of the failing Fontan circulation. *Cardiol Young* 20(5):522–525. doi: [10.1017/S1047951110000648](https://doi.org/10.1017/S1047951110000648)
42. Languelin J, Scheinmann P, Mahut B, Le Bourgeois M, Jaubert F, Brunelle F, Sidi D, de Blic J (1999) Bronchial casts in children with cardiopathies: the role of pulmonary lymphatic abnormalities. *Pediatr Pulmonol* 28(5):329–336
43. Laine GA, Allen SJ, Katz J, Gabel JC, Drake RE (1986) Effect of systemic venous pressure elevation on lymph flow and lung edema formation. *J Appl Physiol* 61(5):1634–1638
44. Witte MH, Dumont AE, Clauss RH, Rader B, Levine N, Breed ES (1969) Lymph circulation in congestive heart failure: effect of external thoracic duct drainage. *Circulation* 39(6):723–733
45. Hug MI, Ersch J, Moenkhoff M, Burger R, Fanconi S, Bauersfeld U (2001) Chylous bronchial casts after Fontan operation. *Circulation* 103(7):1031–1033
46. Nair LG, Kurtz CP (1996) Lymphangiomas presenting with bronchial cast formation. *Thorax* 51(7):765–766
47. Schmitz J, Schatz J, Kirsten D (2004) Plastic bronchitis. *Pneumologie* 58(6):443–448. doi: [10.1055/s-2004-818457](https://doi.org/10.1055/s-2004-818457)

48. Castet D, Lavandier M, Asquier E, Beaulieu F, de Lajarte AY (1998) Bronchial casts associated with pulmonary lymphatic anomalies. *Rev Mal Respir* 15(1):89–91
49. Cuvelier A, Molano LC, Poignie P, Marie I, Picquenot JM (2006) Noneosinophilic inflammatory bronchial casts. *Am J Med* 119(4):e1–e2. doi:10.1016/j.amjmed.2005.10.050
50. DiCindio S, Theroux M, Costarino AT Jr, Cook S, O'Reilly R (2004) Plastic bronchitis: a case report. *Paediatr Anaesth* 14(6):520–523. doi:10.1111/j.1460-9592.2004.01265.x
51. Noizet O, Leclerc F, Leteurtre S, Bricchet A, Pouessel G, Dorkenoo A, Fourier C, Cremer R (2003) Plastic bronchitis mimicking foreign body aspiration that needs a specific diagnostic procedure. *Intensive Care Med* 29(2):329–331. doi:10.1007/s00134-002-1610-1
52. Shah MB, Bent JP, Vicencio AG, Veler H, Arens R, Parikh SR (2008) Flexible bronchoscopy and interdisciplinary collaboration in pediatric large airway disease. *Int J Pediatr Otorhinolaryngol* 72(12):1771–1776. doi:10.1016/j.ijporl.2008.08.011
53. Tzifa A, Robards M, Simpson JM (2005) Plastic bronchitis; a serious complication of the Fontan operation. *Int J Cardiol* 101(3):513–514. doi:10.1016/j.ijcard.2004.03.085
54. Kamin W, Klar-Hlawatsch B, Truebel H (2006) Easy removal of a large mucus plug with a flexible paediatric bronchoscope after administration of rhDNase (pulmozyme). *Klin Padiatr* 218(2):88–91. doi:10.1055/s-2005-836608
55. Costello JM, Steinhorn D, McColley S, Gerber ME, Kumar SP (2002) Treatment of plastic bronchitis in a Fontan patient with tissue plasminogen activator: a case report and review of the literature. *Pediatrics* 109(4):e67
56. Quasney MW, Orman K, Thompson J, Ring JC, Salim M, Schoumacher RA, Watson D, Novick W, Deitcher SR, Joyner R (2000) Plastic bronchitis occurring late after the Fontan procedure: treatment with aerosolized urokinase. *Crit Care Med* 28(6):2107–2111
57. Shinkai M, Rubin BK (2005) Macrolides and airway inflammation in children. *Paediatr Respir Rev* 6(3):227–235. doi:10.1016/j.prrv.2005.06.005
58. Schultz KD, Oermann CM (2003) Treatment of cast bronchitis with low-dose oral azithromycin. *Pediatr Pulmonol* 35(2):139–143. doi:10.1002/ppul.10196
59. Shah SS, Drinkwater DC, Christian KG (2006) Plastic bronchitis: is thoracic duct ligation a real surgical option? *Ann Thorac Surg* 81(6):2281–2283. doi:10.1016/j.athoracsur.2005.07.004
60. Lamour JM, Hsu DT, Quaegebeur JM, Pinney SP, Mital SR, Mosca RS, Chen JM, Addonizio LJ (2004) Heart transplantation to a physiologic single lung in patients with congenital heart disease. *J Heart Lung Transplant* 23(8):948–953. doi:10.1016/j.healun.2004.06.012
61. Peleg U, Schwartz S, Sirota G, Hochman I, Cohen D, Picard E (2005) Persistent plastic bronchitis in a child after cardiac surgery. *Isr Med Assoc J* 7(2):122–124
62. Do TB, Chu JM, Berdjis F, Anas NG (2009) Fontan patient with plastic bronchitis treated successfully using aerosolized tissue plasminogen activator: a case report and review of the literature. *Pediatr Cardiol* 30(3):352–355. doi:10.1007/s00246-008-9312-2
63. Wakeham MK, Van Bergen AH, Torero LE, Akhter J (2005) Long-term treatment of plastic bronchitis with aerosolized tissue plasminogen activator in a Fontan patient. *Pediatr Crit Care Med* 6(1):76–78. doi:10.1097/01.PCC.0000149320.06424.1D
64. Lackowski NP, Pitzer JE, Tobias M, Van Rheen Z, Nayar R, Mosharaff M, Stringer KA (2010) Safety of prolonged, repeated administration of a pulmonary formulation of tissue plasminogen activator in mice. *Pulm Pharmacol Ther* 23(2):107–114. doi:10.1016/j.pupt.2009.10.009
65. Onoue Y, Adachi Y, Ichida F, Miyawaki T (2003) Effective use of corticosteroid in a child with life-threatening plastic bronchitis after Fontan operation. *Pediatr Int* 45(1):107–109