REGULAR ARTICLE

Balloon Pulmonary Angioplasty for Chronic Thromboembolic Pulmonary Hypertension

J.D. Serfas, MD
Duke University Medical Center

Richard A. Krasuski, MD
Duke University Medical Center

Balloon pulmonary angioplasty (BPA) is a rapidly emerging and developing therapy for inoperable chronic thromboembolic pulmonary hypertension (CTEPH). BPA is associated with improvements in functional and hemodynamic status, imaging indices of right ventricular performance, and survival. However, BPA should only be undertaken at a CTEPH referral center with pulmonary thromboendarterectomy capability, and only after multidisciplinary discussion determines the patient is a poor candidate for pulmonary endarterectomy. Meticulous attention to procedural technique is critical to ensure procedural success and to limit the risk of complications. Randomized controlled trials are also needed to further refine BPA's role in comprehensive CTEPH care. Nonetheless, BPA is an increasingly effective and safe therapy for CTEPH that is associated with clinical improvements and is rapidly becoming a cornerstone of referral center CTEPH care.

INTRODUCTION

Chronic thromboembolic pulmonary hypertension (CTEPH) is unique in that it is potentially reversible with pulmonary thromboendarterectomy (PTE), which should be considered first-line therapy in eligible patients.[1] For patients who are poor candidates for PTE or have residual or recurrent pulmonary hypertension after PTE, balloon pulmonary angioplasty (BPA) has developed into a useful therapy that is associated with hemodynamic, imaging, and clinical improvements and is occupying an ever-enlarging niche in the care of CTEPH patients. In this review we will summarize the history, technical details, and recent data on BPA.

HISTORY OF BALLOON PULMONARY ANGIOPLASTY

BPA was first reported for CTEPH in 1988,[2] after having been used for applications in congenital heart disease for several years,[3] but it wasn't until 2001 that a larger series of 18 CTEPH patients who underwent BPA was reported.[4] The procedure was associated with improvements in World Health Organization (WHO) functional class, 6-minute walk distance (6MWD), and mean pulmonary artery pressure (mPAP), but the majority of patients developed pulmonary edema with 3 requiring mechanical ventilation and 1 dying within a week of the procedure. Because of the high rate of serious complications, physicians in the United States and Europe abandoned the procedure for many years. However, Japanese physicians continued to perform the procedure, which underwent iterative refinements and improvement in their hands, ultimately reducing complication rates and improving efficacy.[5-10] Owing to this success, it has been readopted by European and American centers[11-18] and is becoming a cornerstone of referral center CTEPH care throughout the world.

PATIENT SELECTION

BPA should be considered for patients who are deemed inoperable candidates for PTE, whether due to surgically inaccessible distal disease or other patient factors.[19] It may also be used for patients with residual post-PTE obstructive disease and pulmonary hypertension and occasionally as a stabilizing procedure in critically ill patients, ideally as a bridge to PTE.[20] BPA is best suited to treatment of segmental or subsegmental vessels, and should not be attempted on large, central clots or occlusions. The ultimate treatment strategy should be determined at an expert center after multidisciplinary discussion and only after careful consideration of PTE.

OUTCOMES

The evidence base for BPA began with several small and single-center studies[11-13,15,16,21-31] that demonstrated improved hemodynamics, WHO functional class, 6MWD (typically by 50 to 100 meters), brain natriuretic peptide levels, and imaging parameters.[21,22,24,26] These findings have since been largely confirmed in larger multicenter studies and meta-analyses,[14,32-38] including a 7-center registry that included 308 patients who underwent 1408 BPA procedures in Japan. In the latter study, mean pulmonary artery pressure was reduced from 43 mmHg to 23 mm Hg, pulmonary vascular resistance from 10.7 Wood units (WU) to 3.6 WU, brain natriuretic peptide level from 240 pg/mL to 39 pg/mL, and 6MWD increased by 111 meters.[39] In the absence of a well-powered randomized trial, little is known regarding the effect of BPA on survival, though multiple observational datasets have suggested a survival

Key Words——chronic thromboembolic pulmonary hypertension, balloon pulmonary angioplasty, pulmonary thromboendarterectomy, interventional cardiology
Correspondence: richard.krasuski@duke.edu

benefit.[29,40] The publication of the results of the Riociguat versus BPA in Nonoperable CTEPH (RACE) trial is eagerly awaited; preliminary data from its presentation at the European Respiratory Society meeting in 2019 are very encouraging.[41]

PREPROCEDURAL EVALUATION AND LESION SELECTION

Patients typically have undergone an extensive evaluation prior to determination of candidacy for both PTE and BPA, including echocardiography, computed tomography pulmonary angiography with or without dual-energy perfusion imaging, ventilation-perfusion scanning, and invasive nonselective pulmonary angiography. Once BPA is determined in multidisciplinary discussion to be the optimal treatment strategy, target lung zones for intervention should be identified. This is accomplished by assessing for perfusion defects, which can be seen on ventilation-perfusion scanning, dual-energy computed tomography perfusion imaging, or assessment of distal perfusion on invasive pulmonary angiography. Improvement of perfusion defects in the lower lung zones is likely to yield greater benefit than upper lung zones given their greater perfusion under physiologic conditions. Lower lung zones are also technically easier to approach, and as such should be prioritized.

Once a target lung zone has been identified, selective segmental or subsegmental injections are performed at the time of BPA to completely characterize specific vessels feeding the target zone. Lesions are categorized as ring-like stenoses, web lesions, subtotal occlusions, total occlusions, or tortuous lesions; success rates are highest and complications lowest with ring-like and web lesions, while total occlusions and tortuous lesions are riskier and less likely to be successfully treated,[31] although as experience has grown with BPA, more complex lesions have been successfully and safely treated, often with greater hemodynamic improvements.[42] Figure 1 reviews the approach to assessing and preparing a patient for BPA.

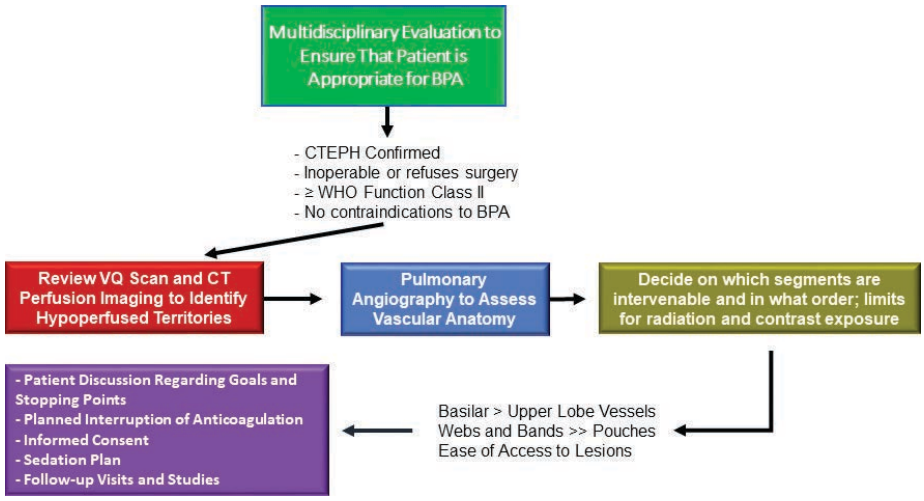

Figure 1: Clinical approach to potential candidates for balloon pulmonary angioplasty. There is significant evaluation and planning that is necessary before taking the patient for a BPA procedure. Imaging studies and clinical data must be thoroughly vetted to ensure that surgery is not the preferred treatment modality. Patients must have appropriate vascular access, adequate renal function, and ability to consent for the procedure. Lesions in territories that correspond to perfusion defects are preferred, as are regions normally with high perfusion (lower lobes) and those most easily accessed. In general webs, bands, and ring-lesions respond best to BPA. Anticoagulation must be appropriately interrupted to minimize the risk for recurrent thromboembolism. BPA indicates balloon pulmonary angioplasty; CTEPH, chronic thromboembolic pulmonary hypertension; V/Q, ventilation/perfusion; WHO, World Health Organization.

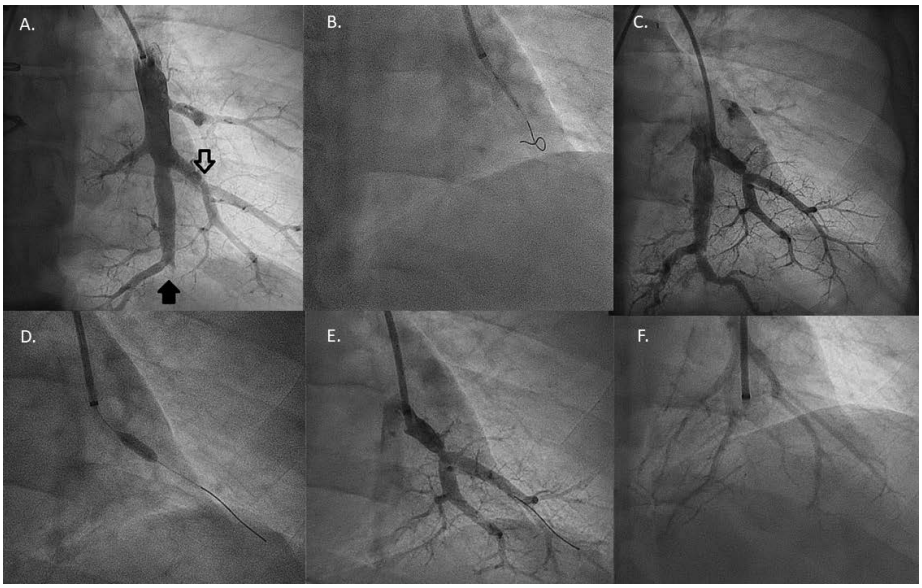

Figure 2: BPA of a web lesion in a 51-year-old male with prohibitive comorbidities and CTEPH complicated by severe pulmonary hypertension. His mean pulmonary artery pressure was 52 mm Hg and pulmonary vascular resistance was 9 Wood units before the first BPA. Panel **A** shows a selective angiogram of the left lower lobe. There are multiple lesions seen in several branches. The hollow arrow shows a complex web at the subsegment branch, the intervention for which is illustrated in this Figure. The lesion was first crossed with a *workhorse* wire and then ballooned several times with a 2 mm noncompliant balloon (**B**). Angiography afterwards (**C**) showed improved perfusion, but limited venous return (not shown). Two months later the lesion was dilated with a 4 mm noncompliant balloon (**D**) with some improvement in angiographic appearance (**E**), but dramatically improved venous return (**F**). CTEPH indicates chronic thromboembolic pulmonary hypertension.

TECHNICAL DETAILS

BPA is performed under conscious sedation over the course of several (typically 4 to 6) sessions to limit radiation and contrast exposure. Heparin is given to maintain an activated clotting time of 200 to 250 seconds. Femoral venous access is most commonly used, and a long (~90 cm) 6, 7, or 8 French sheath is advanced into the target pulmonary artery; a 6 or 7 French preshaped guide catheter is advanced through the sheath and positioned in the target segment. An atraumatic 0.014 in or 0.018 in guidewire is advanced across the target lesion, often under an inspiratory breath hold. The use of microcatheters, guide extensions, and balloon catheters can provide additional support. Polymer-jacketed guidewires have been associated with a higher risk for vascular injury and should ideally be avoided.[17] When the location of a web lesion is not readily apparent based on angiography alone, pressure wires can be used to identify areas of significant flow restriction, and have also been used to reduce the incidence of complications by titrating balloon dilation to keep pulmonary pressure distal to the lesion under 35 mm Hg.[36] Initial balloons are undersized to minimize the risk of vascular injury and reperfusion edema, although larger balloons can then be used, either in the same session or in later sessions if the risk of reperfusion edema is felt to be high. Sculpting or cutting balloons are not associated with improved performance compared with conventional balloons,[43] and should be used sparingly and only in experienced hands.[17] Intravascular ultrasound, optical coherence tomography, and cone beam computed tomography have also been used sparingly[44,45] but are often impractical.[46] Figures 2 and 3 present examples of an intervention to web lesion and a chronic total occlusion, respectively. This patient experienced significant improvements in 6-minute walk and function class; the effect of his procedure on his heart chambers is shown in Figure 4.

PREVENTING AND MANAGING COMPLICATIONS

Despite improvements in technique and improving safety over the years, BPA complications are still common.[27,28]

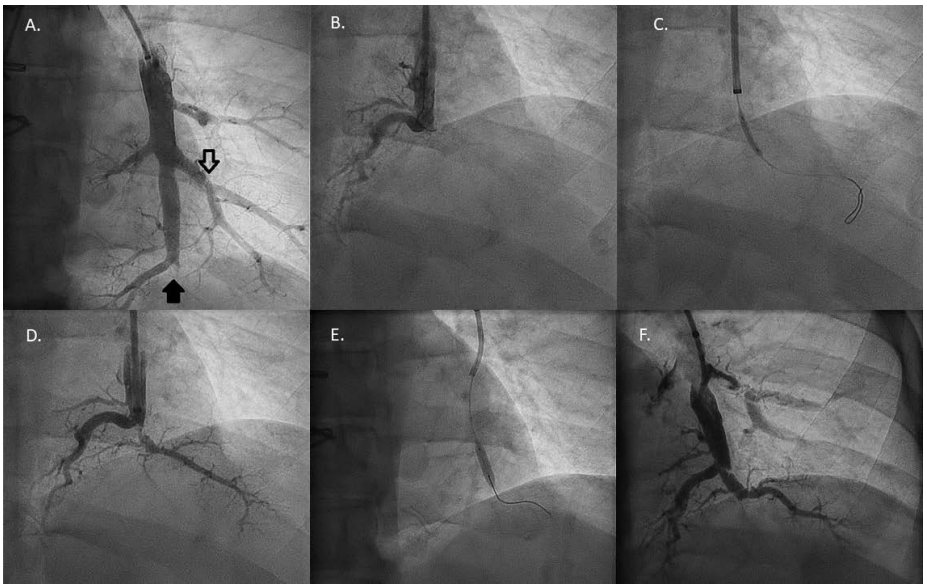

Figure 3: BPA of a distal occlusion in a 51-year-old male with prohibitive comorbidities and CTEPH complicated by severe pulmonary hypertension. His mean pulmonary artery pressure was 52 mm Hg and pulmonary vascular resistance was 9 Wood units before the first BPA. Panel **A** shows a selective angiogram of the left lower lobe. There are multiple lesions seen in several branches. The blackened arrow shows an occlusion at a distal branch, the intervention for which is illustrated in this Figure. Selective distal angiography (**B**) confirmed that the distal branch was occluded. This lesion was considerably more challenging to cross, but the *workhorse* wire was again successful (**C**), and the vessel was ballooned in several segments with a 2 mm noncompliant balloon. Angiography afterwards (**D**) showed dramatically improved perfusion and a sizable new vessel is evident. Two months later the lesion was redilated with a 4 mm balloon (**E**) with dramatic improvement in angiographic appearance (**F**) and pulmonary venous return (not shown). BPA indicates balloon pulmonary angioplasty; CTEPH, chronic thromboembolic pulmonary hypertension.

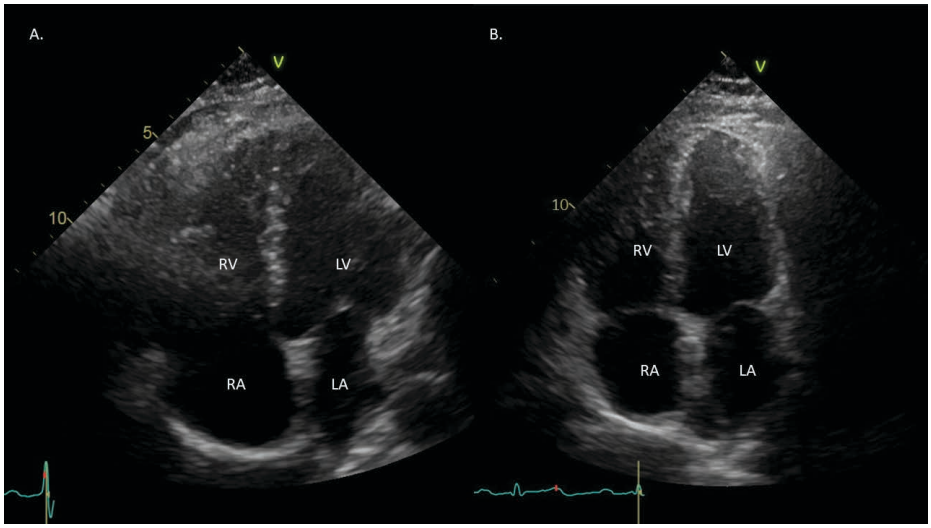

Figure 4: Cardiovascular remodeling after successful BPA. Apical 4-chamber views of transthoracic echocardiograms performed 2 weeks before BPA sessions began (**A**) and 1 year after sessions completed (**B**) for the male patient presented in Figures 2 and 3. This patient had 4 total sessions with 9 different lesions treated. Note the decrease in size of the RV and RA afterwards, with concomitant increase in size of the LA. There was also notable improvement in right ventricular systolic function seen. BPA indicates balloon pulmonary angioplasty; LA, left atrium; LV, left ventricle; RA, right atrium; LV, left ventricle.

Vascular injury due to wire or balloon trauma is the most common type of complication, and most often results in minor clinical manifestations such as asymptomatic infiltrate on chest X-ray or mild, self-limited hemoptysis,[39] which are not associated with worse long-term outcomes.[47] More serious complications can arise, however, and great care should be taken to prevent them.

This process should ideally begin well before the procedure; based on the observation that elevated pulmonary artery pressures are associated with higher risk for complications,[4,5] optimizing medical therapy for pulmonary hypertension prior to first BPA is likely wise,[48] and has been associated with reduced complication rates in the extension study of the RACE trial.[49]

Several intraprocedural techniques to reduce risk of complications have already been mentioned, such as prioritizing lower-risk web and ring-like lesions and the use of atraumatic wires and undersized balloons, which is especially important in the setting of severely elevated pulmonary pressures.

Complications must be swiftly recognized and treated, whether with heparin reversal, balloon sealing, covered stent placement, or vessel occlusion with coils or resorbable gel.[50] Traditional life support measures including intubation and mechanical ventilation, bronchoscopy, and surgical intervention are rarely necessary but should be readily available.

CONCLUSION

BPA is rapidly becoming a cornerstone therapy for referral center CTEPH care and continues to improve with rapid refinements in technique. Randomized trial data assessing the efficacy and safety of BPA is eagerly awaited.

References

1. Delcroix M, Torbicki A, Gopalan D, et al. ERS statement on chronic thromboembolic pulmonary hypertension. *Eur Respir J*. 2021;57(6):2002828. doi:10.1183/13993003.02828-2020.
2. Voorburg JA, Cats VM, Buis B, Bruschke AV. Balloon angioplasty in the treatment of pulmonary hypertension caused by pulmonary embolism. *Chest*. 1988;94(6):1249-1253. doi:10.1378/chest.94.6.1249.
3. Lock JE, Castaneda-Zuniga WR, Fuhrman BP, Bass JL. Balloon dilation angioplasty of hypoplastic and stenotic pulmonary arteries. *Circulation*. 1983;67(5):962-967. doi:10.1161/01.cir.67.5.962.
4. Feinstein JA, Goldhaber SZ, Lock JE, Ferndandes SM, Landzberg MJ. Balloon pulmonary angioplasty for treatment of chronic thromboembolic pulmonary hypertension. *Circulation*. 2001;103(1):10-13. doi:10.1161/01.cir.103.1.10.
5. Kataoka M, Inami T, Hayashida K, et al. Percutaneous transluminal pulmonary angioplasty for the treatment of chronic thromboembolic pulmonary hypertension. *Circ Cardiovasc Interv*. 2012;5(6):756-762. doi:10.1161/CIRCINTERVENTIONS.112.971390.
6. Sugimura K, Fukumoto Y, Satoh K, et al. Percutaneous transluminal pulmonary angioplasty markedly improves pulmonary hemodynamics and long-term prognosis in patients with chronic thromboembolic pulmonary hypertension. *Circ J*. 2012;76(2):485-488. doi:10.1253/circj.CJ-11-1217.
7. Taniguchi Y, Miyagawa K, Nakayama K, et al. Balloon pulmonary angioplasty: an additional treatment option to improve the prognosis of patients with chronic thromboembolic pulmonary hypertension. *EuroIntervention*. 2014;10(4):518-525. doi:10.4244/EIJV10I4A89.
8. Inami T, Kataoka M, Shimura N, et al. Pulmonary edema predictive scoring index (PEPSI), a new index to predict risk of reperfusion pulmonary edema and improvement of hemodynamics in percutaneous transluminal pulmonary angioplasty. *JACC Cardiovasc Interv*. 2013;6(7):725-736. doi:10.1016/j.jcin.2013.03.009.
9. Yanagisawa R, Kataoka M, Inami T, et al. Safety and efficacy of percutaneous transluminal pulmonary angioplasty in elderly patients. *Int J Cardiol*. 2014;175(2):285-289. doi:10.1016/j.ijcard.2014.05.011.
10. Sato H, Ota H, Sugimura K, et al. Balloon pulmonary angioplasty improves biventricular functions and pulmonary flow in chronic thromboembolic pulmonary hypertension. *Circ J*. 2016;80(6):1470-1477. doi:10.1253/circj.CJ-15-1187.
11. Kriechbaum SD, Wiedenroth CB, Wolter JS, et al. N-terminal pro-B-type natriuretic peptide for monitoring after balloon pulmonary angioplasty for chronic thromboembolic pulmonary hypertension. *J Heart Lung Transplant*. 2018;37(5):639-646. doi:10.1016/j.healun.2017.12.006.
12. Velázquez M, Albarrán A, Hernández I, et al. Balloon pulmonary angioplasty for inoperable patients with chronic thromboembolic pulmonary hypertension. observational study in a referral unit. *Rev Esp Cardiol (Engl Ed)*. 2019;72(3):224-232. doi:10.1016/j.rec.2018.02.020.
13. Brenot P, Jaïs X, Taniguchi Y, et al. French experience of balloon pulmonary angioplasty for chronic thromboembolic pulmonary hypertension. *Eur Respir J*. 2019;53(5):1802095. doi:10.1183/13993003.02095-2018.
14. Maschke SK, Hinrichs JB, Renne J, et al. C-Arm computed tomography (CACT)-guided balloon pulmonary angioplasty (BPA): Evaluation of patient safety and peri- and post-procedural complications. *Eur Radiol*. 2019;29(3):1276-1284. doi:10.1007/s00330-018-5694-6.
15. Godinas L, Bonne L, Budts W, et al. Balloon pulmonary angioplasty for the treatment of nonoperable chronic thromboembolic pulmonary hypertension: single-center experience with low initial complication rate. *J Vasc Interv Radiol*. 2019;30(8):1265-1272. doi:10.1016/j.jvir.2019.03.023.
16. Hoole SP, Coghlan JG, Cannon JE, et al. Balloon pulmonary angioplasty for inoperable chronic thromboembolic pulmonary hypertension: the UK experience. *Open Heart*. 2020;7(1):e001144. doi:10.1136/openhrt-2019-001144.
17. Mahmud E, Madani MM, Kim NH, et al. Chronic thromboembolic pulmonary hypertension: evolving therapeutic approaches for operable and inoperable disease. *J Am Coll Cardiol*. 2018;71(21):2468-2486. doi:10.1016/j.jacc.2018.04.009.
18. Karyofyllis P, Demerouti E, Giannakoulas G, et al. Balloon pulmonary angioplasty in patients with chronic thromboembolic pulmonary hypertension in Greece: data from the Hellenic Pulmonary Hypertension Registry. *J Clin Med*. 2022;11(8):2211. doi:10.3390/jcm11082211.
19. Lang I, Meyer BC, Ogo T, et al. Balloon pulmonary angioplasty in chronic thromboembolic pulmonary hypertension. *Eur Respir Rev*. 2017;26(143):160119. doi:10.1183/16000617.0119-2016.
20. Tsuji A, Ogo T, Demachi J, et al. Rescue balloon pulmonary angioplasty in a rapidly deteriorating chronic thromboembolic pulmonary hypertension patient with liver failure and refractory infection. *Pulm Circ*. 2014;4(1):142-147. doi:10.1086/675643.
21. Yamasaki Y, Nagao M, Abe K, et al. Balloon pulmonary angioplasty improves interventricular dyssynchrony in patients with inoperable chronic thromboembolic pulmonary hypertension: a cardiac MR imaging study. *Int J Cardiovasc Imaging*. 2017;33(2):229-239. doi:10.1007/s10554-016-0985-y.
22. Nagao M, Yamasaki Y, Abe K, et al. Energy efficiency and pulmonary artery flow after balloon pulmonary angioplasty for inoperable, chronic thromboembolic pulmonary hypertension: analysis by phase-contrast MRI. *Eur J Radiol*. 2017;87:99-104. doi:10.1016/j.ejrad.2016.12.015.
23. Yokokawa T, Sugimoto K, Nakazato K, et al. Electrocardiographic criteria of right ventricular hypertrophy in patients with chronic thromboembolic pulmonary hypertension after balloon pulmonary angioplasty. *Intern Med*. 2019;58(15):2139-2144. doi:10.2169/internalmedicine.2320-18.

24. Broch K, Murbraech K, Ragnarsson A, et al. Echocardiographic evidence of right ventricular functional improvement after balloon pulmonary angioplasty in chronic thromboembolic pulmonary hypertension. *J Heart Lung Transplant*. 2016;35(1):80-86. doi:10.1016/j.healun.2015.08.007.
25. Tatebe S, Sugimura K, Aoki T, et al. Multiple beneficial effects of balloon pulmonary angioplasty in patients with chronic thromboembolic pulmonary hypertension. *Circ J*. 2016;80(4):980-988. doi:10.1253/circj.CJ-15-1212.
26. Moriyama H, Murata M, Tsugu T, et al. The clinical value of assessing right ventricular diastolic function after balloon pulmonary angioplasty in patients with chronic thromboembolic pulmonary hypertension. *Int J Cardiovasc Imaging*. 2018;34(6):875-882. doi:10.1007/s10554-017-1296-7.
27. Kurzyna M, Darocha S, Pietura R, et al. Changing the strategy of balloon pulmonary angioplasty resulted in a reduced complication rate in patients with chronic thromboembolic pulmonary hypertension. A single-centre European experience. *Kardiol Pol*. 2017;75(7):645-654. doi:10.5603/KP.a2017.0091.
28. Mizoguchi H, Ogawa A, Munemasa M, Mikouchi H, Ito H, Matsubara H. Refined balloon pulmonary angioplasty for inoperable patients with chronic thromboembolic pulmonary hypertension. *Circ Cardiovasc Interv*. 2012;5(6):748-755. doi:10.1161/CIRCINTERVENTIONS.112.971077.
29. Siennicka A, Darocha S, Banaszkiewicz M, et al. Treatment of chronic thromboembolic pulmonary hypertension in a multidisciplinary team. *Ther Adv Respir Dis*. 2019;13:1753466619891529. doi:10.1177/1753466619891529.
30. Aoki T, Sugimura K, Tatebe S, et al. Comprehensive evaluation of the effectiveness and safety of balloon pulmonary angioplasty for inoperable chronic thrombo-embolic pulmonary hypertension: long-term effects and procedure-related complications. *Eur Heart J*. 2017;38(42):3152-3159. doi:10.1093/eurheartj/ehx530.
31. Kawakami T, Ogawa A, Miyaji K, et al. Novel angiographic classification of each vascular lesion in chronic thromboembolic pulmonary hypertension based on selective angiogram and results of balloon pulmonary angioplasty. *Circ Cardiovasc Interv*. 2016;9(10):e003318. doi:10.1161/CIRCINTERVENTIONS.115.003318.
32. Shimura N, Kataoka M, Inami T, et al. Additional percutaneous transluminal pulmonary angioplasty for residual or recurrent pulmonary hypertension after pulmonary endarterectomy. *Int J Cardiol*. 2015;183:138-142. doi:10.1016/j.ijcard.2015.01.034.
33. van Thor MCJ, Lely RJ, Braams NJ, et al. Safety and efficacy of balloon pulmonary angioplasty in chronic thromboembolic pulmonary hypertension in the Netherlands. *Neth Heart J*. 2020;28(2):81-88. doi:10.1007/s12471-019-01352-6.
34. Olsson KM, Wiedenroth CB, Kamp J-C, et al. Balloon pulmonary angioplasty for inoperable patients with chronic thromboembolic pulmonary hypertension: the initial German experience. *Eur Respir J*. 2017;49(6):1602409. doi:10.1183/13993003.02409-2016.
35. Inami T, Kataoka M, Ando M, Fukuda K, Yoshino H, Satoh T. A new era of therapeutic strategies for chronic thromboembolic pulmonary hypertension by two different interventional therapies; pulmonary endarterectomy and percutaneous transluminal pulmonary angioplasty. *PLoS One*. 2014;9(4):e94587. doi:10.1371/journal.pone.0094587.
36. Inami T, Kataoka M, Shimura N, et al. Pressure-wire-guided percutaneous transluminal pulmonary angioplasty: a breakthrough in catheter-interventional therapy for chronic thromboembolic pulmonary hypertension. *JACC Cardiovasc Interv*. 2014;7(11):1297-1306. doi:10.1016/j.jcin.2014.06.010.
37. Khan MS, Amin E, Memon MM, et al. Meta-analysis of use of balloon pulmonary angioplasty in patients with inoperable chronic thromboembolic pulmonary hypertension. *Int J Cardiol*. 2019;291:134-139. doi:10.1016/j.ijcard.2019.02.051.
38. Wang W, Wen L, Song Z, Shi W, Wang K, Huang W. Balloon pulmonary angioplasty vs riociguat in patients with inoperable chronic thromboembolic pulmonary hypertension: a systematic review and meta-analysis. *Clin Cardiol*. 2019;42(8):741-752. doi:10.1002/clc.23212.
39. Ogawa A, Satoh T, Fukuda T, et al. Balloon pulmonary angioplasty for chronic thromboembolic pulmonary hypertension: results of a multicenter registry. *Circ Cardiovasc Qual Outcomes*. 2017;10(11):e004029. doi:10.1161/CIRCOUTCOMES.117.004029.
40. Taniguchi Y, Jaïs X, Jevnikar M, et al. Predictors of survival in patients with not-operated chronic thromboembolic pulmonary hypertension. *J Heart Lung Transplant*. 2019;38(8):833-842. doi:10.1016/j.healun.2019.04.006.
41. Jais X, Brenot P, Bouvaist H, et al. Late breaking abstract - balloon pulmonary angioplasty versus riociguat for the treatment of inoperable chronic thromboembolic pulmonary hypertension: results from the randomised controlled RACE study. *Eur Respir J*. 2019;54(suppl 63):RCT1885. doi:10.1183/13993003.congress-2019.RCT1885.
42. Stępniewski J, Magoń W, Waligóra M, et al. Hemodynamic effects of balloon pulmonary angioplasty for the treatment of total and subtotal pulmonary artery occlusions in inoperable chronic thromboembolic pulmonary hypertension. *Int J Cardiol*. 2022;361:71-76. doi:10.1016/j.ijcard.2022.05.029.
43. Takigami M, Tsubata H, Nakanishi N, et al. The effectiveness of scoring balloon angioplasty in the treatment of chronic thromboembolic pulmonary hypertension. *PLoS One*. 2022;17(2):e0263244. doi:10.1371/journal.pone.0263244.
44. Nagayoshi S, Fujii S, Nakajima T, Muto M. Intravenous ultrasound-guided balloon pulmonary angioplasty in the treatment of totally occluded chronic thromboembolic pulmonary hypertension. *EuroIntervention*. 2018;14(2):234-235. doi:10.4244/EIJ-D-17-00770.
45. Inohara T, Kawakami T, Kataoka M, et al. Lesion morphological classification by OCT to predict therapeutic efficacy after balloon pulmonary angioplasty in CTEPH. *Int J Cardiol*. 2015;197:23-25. doi:10.1016/j.ijcard.2015.06.036.
46. Shimokawahara H, Ogawa A, Mizoguchi H, Yagi H, Ikemiyagi H, Matsubara H. Vessel stretching is a cause of lumen enlargement immediately after balloon pulmonary angioplasty: intravascular ultrasound analysis in patients with chronic thromboembolic pulmonary hypertension. *Circ Cardiovasc Interv*. 2018;11(4):e006010. doi:10.1161/CIRCINTERVENTIONS.117.006010.
47. Wiedenroth CB, Deissner H, Adameit MSD, et al. Complications of balloon pulmonary angioplasty for inoperable chronic thromboembolic pulmonary hypertension: impact on the outcome. *J Heart Lung Transplant*. 2022;41(8):1086-1094. doi:10.1016/j.healun.2022.05.002.
48. Wiedenroth CB, Ghofrani HA, Adameit MSD, et al. Sequential treatment with riociguat and balloon pulmonary angioplasty for patients with inoperable chronic thromboembolic pulmonary hypertension. *Pulm Circ*. 2018;8(3):2045894018783996. doi:10.1177/2045894018783996.
49. Jais X, Brenot P, Bouvaist H, et al. BPA and riociguat for the management of inoperable CTEPH: results of the extension study following the RACE randomized controlled trial (RCT). In: *D3. D003 COME TOGETHER - CLINICAL ADVANCES IN PULMONARY HYPERTENSION: LESSONS FROM BEST ABSTRACTS*. New York, NY: American Thoracic Society; 2021:A1182-A1182. doi:10.1164/ajrccm-conference.2021.203.1_MeetingAbstracts.A1182.
50. Hosokawa K, Abe K, Oi K, Mukai Y, Hirooka Y, Sunagawa K. Balloon pulmonary angioplasty-related complications and therapeutic strategy in patients with chronic thromboembolic pulmonary hypertension. *Int J Cardiol*. 2015;197:224-226. doi:10.1016/j.ijcard.2015.06.075.