Mid-term outcomes and AI-enhanced risk prediction in balloon pulmonary angioplasty for chronic thromboembolic pulmonary hypertension: A comprehensive analysis

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Backgrounds

CTEPH presents as a life-threatening condition characterized by obstruction or obliteration of the pulmonary vascular bed due to organized thrombi. This obstruction leads to increased pulmonary vascular resistance (PVR), progressive pulmonary hypertension, and eventual right heart failure. While pulmonary endoarterectomy is recommended as the sole curative treatment for eligible CTEPH patients, not all patients meet the criteria for surgical intervention.

Recently, Balloon Pulmonary Angioplasty (BPA) has emerged as a less invasive alternative for treating Chronic Thromboembolic Pulmonary Hypertension (CTEPH). Advanced computed tomography techniques have enabled precise identification of peripheral lesions in CTEPH. At our Center, a BPA strategy guided by cone-beam computed tomography (CBCT) and/or multi-detector CT (MDCT) findings aims to simplify procedures and reduce complications. However, the long-term efficacy of BPA and predictors for retreatment remain unclear.

This retrospective study seeks to elucidate BPA's efficacy, complications, and the potential for AI-driven risk prediction of retreatment.

Methods

Methods: 201 patients treated with BPA from April 2010 to May 2022 were included int this study. Patient histories included acute venous thromboembolism (VTE) in 49 patients, cancer history in 23 patients, coronary artery disease (CAD) in 2 patients, surgery history in 58 patients, hemodialysis (HD) in 2 patients, hypertension (HT) in 56 patients, and dyslipidemia (DLP) in 44 patients. The retrospective assessments comprised:

1. Technical success rate of BPA
2. Number of BPA procedures for each patient and average procedure count
3. Procedure-related complications
4. Rate of re-BPA procedures
5. AI analysis of risk factors for reBPA

Fundamental way of BPA

We inserted a 9F indwelling sheath (Arrow-Flex; Teleflex, Durham, NC) into a vein and advanced a 6F long sheath (Bright Tip Sheath Introducer; Cordis/Johnson & Johnson, New Brunswick, NJ) to the main pulmonary artery through the 9F sheath, using a 0.035-inch wire (Radifocus Guide Wire M; Terumo, Tokyo, Japan) (refer to Fig. 1).

Figure 1. 9F indwelling sheath, 6F long sheath, and 6F guiding catheter

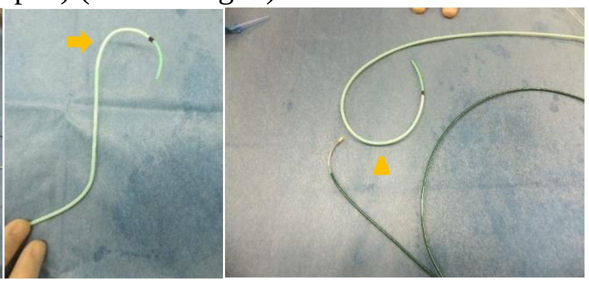


Figure 2. 6F long sheath were manually reshaped for left pulmonary artery (arrow), or right pulmonary artery (arrowhead)

Figure 3.(Left): Selective angiography of Rt. A9 showed irregular web in the proximal RtA9 as well as slit like lesion in the distal segmental artery. Angiography showed poor flow of subsegmental artery.
(Center): after passing through web with the guidewire, balloon inflation using 2mm balloon to the proximal web was performed.
(Right): angiography showed the marked improve of the blood flow and subsegmental artery was clearly visualized.

Figure 3. Final angiography showed the improvement of blood flow of pulmonary artery (Left), as well as improved venous return of the pulmonary vein (Right).

Heparin (5000 U) was administered upon sheath insertion, with an additional 1000 U of heparin added every hour during the procedure. The 6F sheath could be manually reshaped for easier engagement of the right or left pulmonary artery (see Fig. 2).

We employed a 6F guiding catheter (Mach 1 peripheral MP; Boston Scientific, Natick, MA) to select a branch of the pulmonary artery (refer to Fig. 1) and performed either wedged or selective angiography. Subsequently, we navigated a 0.014-inch wire (Cruise; Asahi Intec, Tokyo, Japan) to the targeted lesion. After determining the vessel diameter using CBCT or MDCT, we typically utilized a 2-mm balloon for the initial dilatation to mitigate the risk of pulmonary artery rupture or dissection.

Vessel dilation was carried out using balloon catheters of appropriate sizes: 2 to 4 mm (IKAZUCHI PAD, Kaneka, Osaka, Japan) or 5 to 7 mm (Aviator Plus, Cordis/Johnson & Johnson), depending on the vessel diameter measured by CBCT. The maximum size was capped at not exceeding 90% of the original vessel diameter to account for tapering and shrinkage of pulmonary arteries due to reduced flow before BPA. Balloon inflation was manually performed until the indentation disappeared or until the balloon reached full expansion (see Fig. 3).

Results

- Technical success rate of BPA
  The technical success rate was 99.5% (200/201).
- Number of BPA procedures for each patient and average procedure count
- BPA frequency varied: once in 3 patients, twice in 16 patients, thrice in 15 patients, four times in 48 patients, five times in 36 patients, six times in 37 patients, and more than 10 procedures in 10 patients. The average procedure count was 5.27 times for all patients.
- Complications were noted in 36 patients, including 24 with hemorrhagic complications, and embolization procedures were performed in 25 patients (Figure 4). Only one patient experienced a serious complication.
- During the follow up period (1.2-162 months), 30 patients underwent re-BPA procedures. Preliminary findings indicate favorable mid-term outcomes with improvements in hemodynamic parameters and functional status.

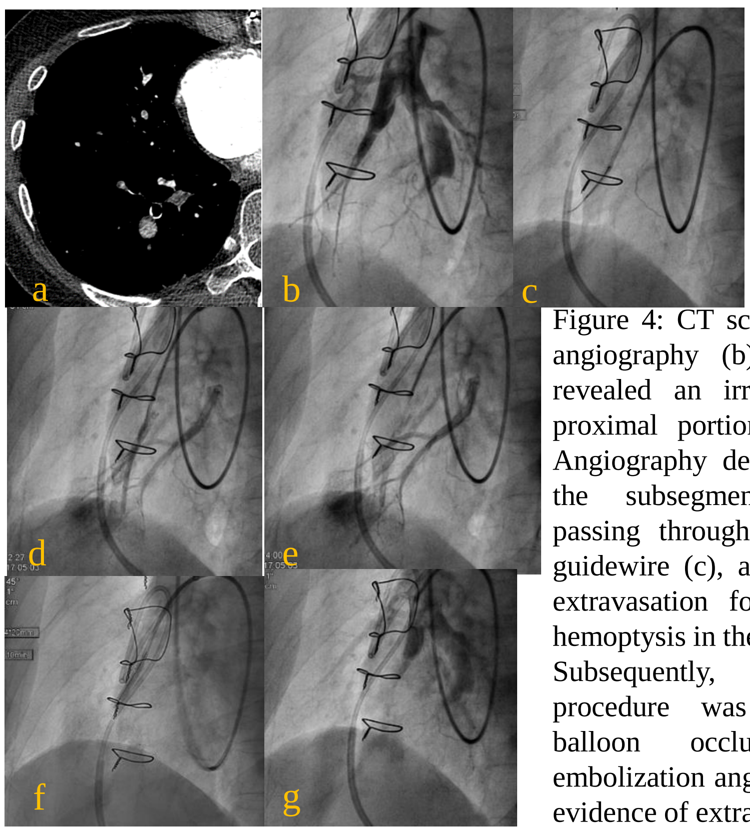
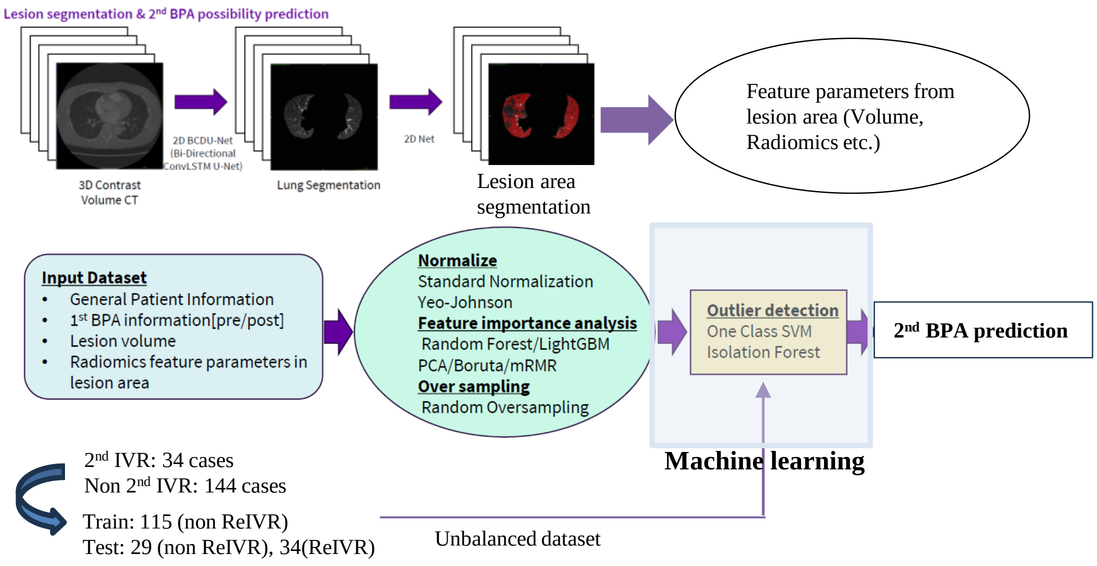


Figure 4: CT scan (a) and Selective angiography (b) of the right A8 revealed an irregular web in the proximal portion of the right A9. Angiography depicted poor flow in the subsegmental artery. Upon passing through the web with the guidewire (c), angiography revealed extravasation followed by massive hemoptysis in the patient (d, e). Subsequently, an embolization procedure was performed under balloon occlusion (f). Post-embolization angiography showed no evidence of extravasation (g).

- AI risk analysis



Use General Patient Information, 1st BPA information[pre/post], Lesion volume

1) StandardNormalize + yeo-johnson + Feature importance analysis with Boruta Analysis

Accuracy = 0.634, Precision = 0.669, Recall = 0.641, F1 = 0.655, AUC = 0.644

Accuracy = (TP+TN)/(TP+TN+FP+FN), Precision = TP/(TP+FP), Recall = TP/(TP+FN), F1 = 2 x Precision x Recall/(Precision+Recall)

2) Cluster analysis for training data of 1)

K-means clustering for 5 clusters: 144 non ReIVR data -> [9. 84. 4. 31. 16.]

=> Take 84 + 31 = 115 data for analysis Train

training: 92, test 23(+34 ReIVR)

Accuracy = 0.752, Precision = 0.825, Recall = 0.806, F1 = 0.815, AUC = 0.722

Discussion

The findings of this study shed light on the efficacy and safety of Balloon Pulmonary Angioplasty (BPA) as a treatment option for Chronic Thromboembolic Pulmonary Hypertension (CTEPH) in the mid-term. Notably, the study reveals a low incidence of serious complications associated with BPA, reaffirming its safety profile.

Moreover, the study introduces an innovative approach by integrating artificial intelligence (AI) for predicting the risk of retreatment in CTEPH patients. By leveraging various patient parameters and procedural data, the AI-driven risk prediction model might offer a valuable tool for clinicians in decision-making processes.

However, it is essential to acknowledge the limitations inherent in retrospective studies, including potential biases and incomplete data capture. Additionally, while the AI model shows promise, further validation through prospective studies with larger and more diverse patient cohorts is necessary to ensure its reliability and generalizability.

Conclusion

In conclusion, this comprehensive analysis contributes to the growing body of evidence supporting the efficacy of BPA in treating CTEPH. Furthermore, the integration of AI-driven risk prediction represents a significant advancement in optimizing patient management strategies. Continued research efforts are warranted to refine predictive models and validate findings, ultimately enhancing the personalized care of CTEPH patients undergoing

Reference

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