



**Role of catheter-directed therapies in the treatment of acute pulmonary embolism.
Expert opinion of the Polish PERT Initiative, Working Group on Pulmonary
Circulation, Association of Cardiovascular Interventions, and Association of Intensive
Cardiac Care of the Polish Cardiac Society**

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Role of catheter-directed therapies in the treatment of acute pulmonary embolism. Expert opinion of the Polish PERT Initiative, Working Group on Pulmonary Circulation, Association of Cardiovascular Interventions, and Association of Intensive Cardiac Care of the Polish Cardiac Society

Short title: CDT in acute PE

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ABSTRACT

Thanks to advances in interventional cardiology technologies the catheter-directed treatment has become recently a viable therapeutic option in the treatment of patients with acute pulmonary embolism at high risk of early mortality. Current transcatheter techniques allow local fibrinolysis or embolectomy with minimal risk of complications. Therefore they can be considered in high risk patients as an alternative to surgical pulmonary embolectomy when systemic thrombolysis is contraindicated or ineffective. They are also considered in patients with intermediate — high risk with a lack of improvement or clinical deterioration despite anticoagulation. The purpose of this article is to present the role of transcatheter techniques in the treatment of patients with acute pulmonary embolism. We describe current knowledge and experts' opinion in this field. Interventional treatment is described in the broader context of patient care organization and therapeutic modalities. We present the organization and responsibilities of pulmonary embolism response teams, the role of pre-procedural imaging, peri-procedural anticoagulation, patients selection, timing of intervention and intensive care support. Currently available catheter directed therapies are discussed in detail including standardized protocols, definitions of procedure success and failure. This expert opinion has been developed in collaboration with experts from various Polish scientific societies signifying the role of teamwork in the care for patients with acute pulmonary embolism.

Key words: interventional treatment, transcatheter techniques, percutaneous techniques, pulmonary embolectomy, local fibrinolysis, ineffective systemic thrombolysis, ineffective anticoagulation, acute pulmonary embolism, intensive care, pulmonary embolism response

team

INTRODUCTION

This expert opinion has been initiated by the Polish PERT Initiative [1] and developed in collaboration with experts of the Polish Cardiac Society representing the Working Group on Pulmonary Circulation, the Association of Intensive Cardiac Care and the Association of Cardiovascular Interventions. The interdisciplinary approach signifies the role of teamwork in the care for patients with acute pulmonary embolism (PE).

As per the European Society of Cardiology (ESC) guidelines, the first-line treatment in patients with acute high-risk PE is primary reperfusion, preferentially systemic thrombolysis (ST). However, approximately 50% of this population do not receive this treatment due to contraindications or increased risk of bleeding [2]. Moreover, ST is associated with a nearly 2% risk of intracranial hemorrhage [3] and is ineffective in some patients [4]. Catheter-directed treatment (CDT) became a viable therapeutic option thanks to advances in interventional cardiology technologies.

The purpose of this article is to present the role of the developing interventional cardiology technologies in the treatment of acute PE. We refer to 2 recently published European documents: the ESC guidelines for the diagnosis and management of acute PE [5] and a consensus statement on the interventional treatment of PE by 2 ESC groups, that is, the Working Group on Pulmonary Circulation and Right Ventricular Function and the European Association of Percutaneous Cardiovascular Interventions [2].

The Delphi method was used for the selection of issues presented in the article [6]. Firstly, 3 experts (GK, AA, and MK) suggested 62 questions that were sent to all the authors of this document, who in turn had to assess the relevance of each topic for this article. The topics were rated on a scale from 1 (irrelevant) to 10 (especially relevant). Issues with an average score greater than 7.0 were arbitrarily accepted. Issues with an average score of 3.0 or less were rejected. The remaining issues were reassessed by the authors as 0 (irrelevant) or 1 (relevant). Ultimately, 55 topics from the initial list were accepted. An additional 4 issues were proposed in the first round of the Delphi survey and accepted in the second round.

TASKS OF A PULMONARY EMBOLISM RESPONSE TEAM

A pulmonary embolism response team (PERT) is composed of specialists from various medical disciplines who cooperate in real time and provide optimal and coordinated care for patients with acute PE. PERT members stratify patients according to risk and assess their

eligibility for anticoagulation, reperfusion including ST, CDT, or surgical pulmonary embolectomy (SPE) as well as supportive treatment, including extracorporeal membrane oxygenation (ECMO), Impella RP, and inferior vena cava (IVC) filter [7]. Each specialist contributes their knowledge, skills, experience, and a unique approach to the treatment of acute PE.

Globally, the role of PERT in making individualized therapeutic decisions in acute PE has been increasing considerably over the past decade [8]. This applies especially to hemodynamically unstable patients with absolute contraindications to ST or those with severe comorbidities (including cancer) as well as patients with acute intermediate-high-risk PE with no improvement on anticoagulation. The current ESC guidelines recommend formation of PERTs in individual hospitals depending on the local resources and access to specialists (ESC class IIa recommendation; C level of evidence) [5]. Establishing a PERT has been shown to significantly improve accessibility to invasive therapy of acute PE and facilitate rapid patient qualification for such treatment, which subsequently leads to improved efficacy owing to increased experience of intervention teams [9, 10]. At Massachusetts General Hospital (Boston, United States), where the first PERT was created, a considerable increase in the use of CDT among patients with acute PE (mainly in patients with acute intermediate-high-risk PE) was observed over several years [10]. Moreover, accurate risk stratification, patient selection, and improved treatment availability were factors that led to significant mortality reduction when periods before and after PERT creation were compared [11, 12]. Typical clinical scenarios that warrant a PERT consult are shown in [Table 1](#).

Details on PERT organization and procedures are presented in a previous publication by the Polish PERT Initiative [1].

In brief, the organization and operating of PERT are based on the coordinator and specialist team members. The PERT coordinator should be available at all times (in the so-called 24/7 mode) at a dedicated phone number and upon receiving the notification, should be able to arrange quick consultations (<30 minutes) with relevant specialists. These consultations may take the form of a teleconference during which all participants have access to the patient's medical and imaging data. Treatment recommendations should be the result of joint decision making by the PERT members. The PERT coordinator (or a designated person) simultaneously acts as a secretary who collects the necessary clinical and imaging data and provides PERT recommendations to the physician currently caring for the patient. Information communication technology tools (dedicated applications, instant messaging) can be a significant facilitator in sharing and collecting patient information; however, care must

be taken to protect patients' personal data.

The PERT should include specialists with practical experience in various treatment strategies for acute PE as well as experts who could assist the team in case of complications or comorbidities that require modification of standard treatment protocols for acute PE. We believe that the PERT's "core" should include a physician experienced in cardiovascular interventions, a cardiac surgeon or thoracic surgeon, and a physician experienced in intensive care, who, if necessary, should be supported by specialists in anesthesiology, angiology, vascular surgery, radiology, emergency medicine, neurology, neurosurgery, oncology, hematology, and pulmonology [1]. The coordinator activates PERT after obtaining the necessary information on the patient's condition, including the results of additional examinations. The activation is usually phased over a period necessary to obtain results and insights about the dynamics of the disease. In straightforward situations, the PERT coordinator can make decisions and recommendations independently without activating other team members. A detailed diagram of the proposed PERT organization is shown in [Figure 1](#).

The 3-step PERT activation process (the coordinator, core PERT, regular PERT depending on the complexity of the clinical situation), usually used in currently existing teams, performs well in Poland, and moreover, it is easier to implement. However, the final composition of the PERT as well as its operation may vary from facility to facility, depending on the operation and experience of a given hospital. This is confirmed by data on PERTs from the United States as well as recently published experiences from Polish centers [9, 13–16].

Choosing the optimal therapy (including e.g. ST, CDT, SPE, and ECMO) is one of the most important tasks of the PERT in the setting of acute PE; therefore, the ideal organizational solution is to create PERTs in hospitals with all treatment options available in one location. If the PERT is established in a hospital without a cardiac surgery department, a formal cooperation with a cardiac surgery center should be ensured to enable immediate transfer of patients for further treatment. According to experts, a consultation with a cardiac surgeon is not a prerequisite to qualify a patient for CDT, especially in emergencies. Nevertheless, every PERT should also have access to treatment with extracorporeal mechanical circulatory support (eg, ECMO), which in Poland is usually associated with cardiac surgery units. In addition to the acute-phase treatment of acute PE, PERTs can play a role in optimizing patient management in the following months, including determination of the mode and duration of long-term anticoagulant treatment, potential implantation of an IVC filter, and patient follow-up for chronic thromboembolic pulmonary hypertension [17–22].

IMAGING STUDIES TO DETERMINE ELIGIBILITY FOR INTERVENTIONAL TREATMENT OF ACUTE PULMONARY EMBOLISM

Computed tomography

Computed tomography (CT) pulmonary angiography is the gold standard in the diagnostic workup to confirm or exclude acute PE. It is commonly believed that the test should be performed on an at least 16-slice CT scanner. The ESC recommends emergency ST in cases of strongly suspected acute PE not confirmed on CT angiography when the clinical presentation is convincing, echocardiography shows signs of right ventricle (RV) pressure overload, and the patient's critical condition only allows bedside diagnostic tests [5].

CT angiography facilitates precise visualization of the pulmonary arterial tree at least to the segmental level as well as assessment of signs of pulmonary hypertension, and RV pressure overload. It allows to accurately determine the location, morphology, and size of thrombi, which is essential for assessing patient's eligibility for interventional treatment. Diagnostic efficacy depends on the technical quality of the test; nonetheless, the accuracy of eligibility assessment for interventional treatment of lesions located in the proximal pulmonary arteries (up to and including the level of the lobar arteries) is remarkably high [5].

An accurate study report should include information presented in **Table 2**.

The physician drafting the report should firstly assess the quality. There were attempts to make the assessment of the degree of pulmonary circulation obstruction more objective by implementing time-consuming 3- or 5-point scales but this has not been widely accepted in clinical practice.

The pulmonary trunk diameter is measured at the level of the bifurcation. Pulmonary hypertension is indicated by a pulmonary trunk width greater than 29 mm or the ratio of the transverse diameter of the pulmonary trunk to the ascending aorta greater than 1.0.

The transverse dimensions of the RV and the left ventricle (LV) are measured in the axial plane as the distance between the ventricular endocardium and the interventricular septum, perpendicular to the long axis of the heart. The maximum ventricular dimensions may be found at different levels. RV dilatation is confirmed if a RV/LV diameter ratio is greater than 1. The RV/LV ratio is the most essential measurement required in the assessment of eligibility for interventional treatment.

In addition, endovascular treatment preparation should include assessment of obstructions or anatomical variations of vessels that constitute the access path for catheters, as seen on imaging studies (**Figure 2**).

Echocardiography

Transthoracic echocardiography (TTE) is used in the diagnostic workup and risk stratification of patients with acute PE and also in the evaluation of treatment efficacy. Signs of RV pressure overload or dysfunction, presence of thrombi in the heart chambers, and other potential causes of hemodynamic instability are of particular importance while deciding on interventional treatment in patients with acute PE.

Indicators of RV dysfunction whose prognostic significance for acute PE was confirmed in numerous studies and that are simple to measure on TTE are as follows: increased RV/LV ratio greater than 1 (measurement in the apical 4-chamber view) and decreased tricuspid annular plane systolic excursion (TAPSE) of 16 mm or less [5, 23, 24]. The prognostic role of other echocardiographic parameters has currently been investigated [25, 26].

TTE is of great importance in monitoring response to treatment in patients with acute high-risk PE who do not show hemodynamic improvement on thrombolytic treatment and after 2 to 4 hours of observation. TTE should be performed in intermediate-high-risk patients who deteriorate hemodynamically despite anticoagulation or whose condition do not improve despite anticoagulation treatment. In such situations, worsening/no improvement in echocardiographic parameters is an indication to consider invasive treatment, including CDT.

Angiography of the pulmonary vascular bed during catheter-directed treatment

Images obtained during CT angiography should be reviewed before the procedure. However, of note, CT angiography of the pulmonary arteries may not reflect the current situation — particularly in patients after ST or after prolonged anticoagulation. Prior to CDT, selective pulmonary angiography can be performed using an automated injector (usually with 25–30 ml of contrast agent) or manually. The most common projections are AP or RAO 30° (the right lung) and LAO 30° (the left lung). Pulmonary angiography may be omitted in catheter-directed infusion procedures (catheter-directed thrombolysis, CDL).

RISK STRATIFICATION IN PATIENTS WITH ACUTE PULMONARY EMBOLISM

Eligibility for interventional treatment of acute PE requires the assessment of patient's risk of death [5, 27]. Risk stratification includes assessment of clinical presentation and abnormalities in imaging and laboratory findings that correlate with the severity of acute PE and the risk of early death (ie, within 30 days). Based on this, 3 risk groups are distinguished: high, intermediate (further divided into intermediate-high and intermediate-low), and low (Table 3). Patients are classified as high risk if any of the following acute PE manifestations is present:

cardiac arrest, obstructive shock, persistent hypotension.

In other patients, risk is determined based on clinical severity (PESI/sPESI classification) and evidence of RV overload in imaging and laboratory findings, as shown in [Table 3](#).

At the same time, it is important to remember that risk defined in such a way is dynamic and may change during treatment and follow-up.

[Table 4](#) summarizes the most important risk factors for hemodynamic collapse in patients without an initial diagnosis of acute high-risk PE. They are useful for monitoring treatment effects in patients with acute PE. Worsening or no improvement in the above-mentioned abnormalities suggest ineffectiveness of pharmacological treatment of acute PE.

Currently, early warning scores that could identify patients at high risk of hemodynamic deterioration are being explored [28]. The National Early Warning Score 2 (NEWS2) is an example. It includes 6 physiological parameters: respiratory rate, arterial blood oxygen saturation, body temperature, systolic blood pressure, heart rate, and level of consciousness. The higher the score, the higher the risk of death. A score of 5 or more indicates that the patient's condition needs to be urgently reassessed and treatment escalation should be considered; a score of 7 or greater calls for immediate treatment optimization.

CATHETER-DIRECTED TREATMENT IN THE MANAGEMENT ALGORITHM FOR PATIENTS WITH ACUTE PULMONARY EMBOLISM

The clinical practice guidelines [5] include CDT among reperfusion treatment modalities, along with ST and SPE. The role of these therapies in the management algorithm for patients with acute PE is shown in Figure 3 (Central Figure). The aim of reperfusion therapy is to restore patency of the pulmonary arteries more effectively than anticoagulation. Its goal is to locally dissolve (CDL) or remove (catheter-directed mechanical thrombectomy [CDMT]) embolic material from the pulmonary bed, reduce the RV afterload, and improve the efficiency of pulmonary gas exchange [29]. Clinical effects of reperfusion include an increase in systemic pressure, a decrease in tachycardia, an improvement in organ perfusion, and an increase in blood oxygen saturation or a decrease in oxygen demand. Of note, the main goal of CDT is to improve the patient's general condition, not to completely clear thrombi out of the pulmonary arterial bed. Usually, CDT is first performed in the lung with more thrombi detected. Thrombi located in the main pulmonary arteries, lobar branches, and the initial sections of the large segmental arteries are anatomically accessible for CDT treatment. Acute PE at the segmental or subsegmental level is rarely an indication for CDT.

According to the ESC guidelines, [5] CDT's role varies depending on the severity of acute PE. In acute high-risk PE, the role of CDT is to restore the patency of the pulmonary artery as quickly as possible so that the patient with hypotension or shock can be stabilized. CDT is not the first-line treatment in this patient population and should be considered in patients with contraindications to ST or patients ineligible for SPE. CDT should also be considered in patients in whom ST has not been effective. A recent meta-analysis showed that CDT can reduce the risk of in-hospital death [30] compared with ST.

In acute intermediate-high-risk PE, CDT is a rescue treatment option in patients who become hemodynamically unstable while on anticoagulant therapy. Also, patients who do not improve on anticoagulation may be considered candidates for CDT to prevent RV decompensation. Table 5 summarizes indications for CDT in acute PE, and Table 6 summarizes contraindications to ST.

DEFINITION OF FAILURE OF ANTITHROMBOTIC THERAPY IN ACUTE PULMONARY EMBOLISM

Failure of anticoagulation

We propose the following definition of failure of anticoagulation: (1) hemodynamic deterioration in an initially hemodynamically stable patients, even if they do not meet the criteria for overt shock; or (2) no improvement after anticoagulation [2].

Hemodynamic deterioration and lack of improvement can be assessed based on the increase or no change, respectively, in the parameters shown in [Table 4](#).

One way to make the diagnosis of clinical deterioration objective is to use the NEWS scale described above.

There are no data on the optimal duration of anticoagulation after which failure of treatment can be identified; thus, such duration should be tailored individually for each patient and decided upon with the PERT team. The ESC guidelines indicate a period of 24 to 48 hours of therapeutic anticoagulation. We believe that this period may be subject to change as the experience of the teams performing the procedures and the safety of the technologies increases.

Unsuccessful systemic thrombolysis

The goal of ST in patients with acute PE is to rapidly achieve hemodynamic stability and failure to do so should be considered as an unsuccessful ST [2]. Although, hemodynamic instability persisting 36 hours after the end of intravenous thrombolysis has been described in

8% of patients [4], there is no accepted definition of ST failure in the treatment of patients with acute PE. In our opinion, the occurrence of a complete hemodynamic collapse during or after infusion (after excluding massive bleeding) should be considered as the primary criterion for ST failure. In addition, no hemodynamic improvement several hours after full-dose ST also warrants the diagnosis of treatment failure. Although there are no data to specify this time frame, we believe that lack of improvement within 2 to 4 hours after the end of intravenous thrombolysis warrants the diagnosis of treatment failure and, in justified cases, the initiation of CDT.

Making the decision to perform urgent interventional treatment in case of a complete hemodynamic destabilization or sudden cardiac arrest during thrombolysis poses a major challenge. In such situations, the decision to escalate therapy and immediately perform an intervention should be made on a case-by-case basis taking into account the capabilities and experience of the local PERT. It is worth noting that tissue plasminogen activator is rapidly metabolized, and its plasma half-life is about 4 to 5 minutes. Thus, after 20 minutes, less than 10% of the initial concentration remains in plasma. [Table 7](#) summarizes the currently accepted definitions of anticoagulation failure and ST failure in acute PE.

TIME TO CATHETER-DIRECTED TREATMENT

The time from the PERT's decision to the start of CDT depends on the patient's condition. However, reliable data on the optimal time to treatment are lacking. We believe that once the decision is made, interventional treatment should be implemented as soon as possible. Of note, a major reason for prolongation of time to CDT can be the need to transport a patient from a center that does not have CDT capabilities.

VASCULAR ACCESS DURING CATHETER-DIRECTED TREATMENT

Femoral access is the preferred vascular access for CDT. Before establishing vascular access, ultrasound evaluation of the external femoral and iliac veins is recommended to rule out the presence of thrombi. In some cases, angiography of the iliac veins and IVC is also performed. Ultrasound-guided puncture is recommended, especially for procedures with anticipated thrombolysis or in patients recently treated with thrombolysis. If there are anatomical obstacles in the IVC or bilateral anatomical obstacles in the external iliac vein or the superficial femoral vein such as thrombi, abdominal tumors, vascular anomalies, or filter thrombosis, the procedure should be performed with access through one of the jugular veins.

If the thrombosis is present in the femoral or iliac vein unilaterally, the procedure should be performed using access established on the other limb.

After the procedure is completed, the vascular access sheath is removed. The access site can be secured with a hemostatic “Z”-stitch (for >8 F devices) or a compression dressing usually for 4 to 6 hours.

PERIOPERATIVE ANTICOAGULATION

The ESC recommends that patients with acute high-risk PE be treated with unfractionated heparin (UFH), including a weight-adjusted bolus. UFH should also be the preferred option in patients at risk of hemodynamic instability who will require primary reperfusion treatment. If there are no absolute contraindications, for example, active bleeding, then parenteral anticoagulation with UFH should be used during CDT. Given that there are no conclusive data in the literature, anticoagulation intensity and monitoring remain to be considered on a case-by-case basis. With CDMT, we suggest using a standard UFH dose in accordance with the guidelines for the treatment of acute PE. In CDL-treated patients who receive UFH as the initial treatment, we suggest continuing UFH during the procedure and up to a maximum of 4 hours after its completion at a flow rate of 300 to 600 U/h (subtherapeutic dose: activated partial thromboplastin time [APTT] < 60 seconds, or activated clotting time [ACT] <200 seconds), and then continue at full dose. In patients treated with low-molecular-weight heparins (LMWHs) at a therapeutic weight-adjusted dose, we suggest continuous infusion of UFH for the duration of the procedure and up to 4 hours afterwards at a flow rate of 300 to 600 U/h (subtherapeutic dose: APTT <60 seconds, or ACT up to 200 seconds) without prebolus administration. In patients treated with oral anticoagulants, caution is advised during the procedure and lower doses of UFH should be used with ACT control not exceeding 200 s. In most patients, after the intervention is completed and clinical stability is reached, the vascular access sheaths are removed and it is possible to switch UFH to subcutaneous LMWH and then to NOACs/vitamin K antagonists or UFH directly to NOACs.

CATHETER-DIRECTED THROMBOLYSIS

CDL is one of the strategies of reperfusion therapy. It involves infusing a fibrinolytic agent directly into the affected pulmonary artery (local thrombolysis) using percutaneous endovascular catheter. The principles of the procedure are shown in [Figure 4](#) [31, 32].

A distinctive feature of currently available infusion catheters such as EkoSonic (Boston Scientific), UniFuse (Angiodynamics), Cragg-McNamara (Medtronic), Fountain infusion

system (Merit Medical), or pigtail catheter, is the so-called treatment zone at the distal end of the catheter with small holes in the catheter wall used for the administration of a thrombolytic drug. Catheter length and treatment zones are selected individually for each patient. The catheters of the EkoSonic system are additionally equipped with an ultrasound core mounted within the catheter, which allows the delivery of acoustic waves into the thrombi to separate fibrin strands and enhance the fibrinolysis process [33, 34].-

The insertion of infusion catheters into the pulmonary arteries is done under fluoroscopic guidance and should be preceded by: (1) a detailed analysis of CT angiography with regard to thrombus distribution in the pulmonary arteries to assess indications for unilateral or bilateral local thrombolysis and to determine target catheter placement in the pulmonary bed; and (2) ultrasound evaluation of the vascular access. The treatment zone of infusion catheters is typically placed within the main and lobar arteries. The diameter of the vascular sheath should account for the planned number and total diameter of infusion catheters to be inserted. Two-channel cannulas are a practical solution.

A J-tip 0.035-inch guidewire is the optimal choice for the insertion of an infusion catheter. A Swan-Ganz, pigtail, or multipurpose catheter can be used to place the guidewire in the distal branches of the target artery. It also enables assessment of the hemodynamic parameters of the pulmonary bed.

Catheters should be secured for the duration of the fibrinolytic drug infusion to prevent accidental dislodgement or ejection. Catheter removal does not require fluoroscopy.

In practice, alteplase (recombinant tissue plasminogen activator [r-tPA]) is most commonly used in CDL. The most commonly used dose regimen is an infusion of 1 mg/h/catheter (0.5–2 mg/h/catheter). Treatment time and total dose vary from center to center and range from 5 to 24 hours and 12 to 24 mg of tPA, respectively. Recent studies indicate that the optimal treatment time is 5 to 10 hours, with a total dose of 10 to 20 mg [35, 36]. In our opinion, it may be good practice to conduct a 5-hour infusion of tPA at a dose of 1 mg/h/catheter with a subsequent decision to terminate or extend treatment depending on the effects and safety of the therapy. A 1- to 2-mg tPA catheter-directed bolus is used at some centers to initiate the infusion. Available data show that local thrombolysis in patients at increased hemorrhagic risk and with relative contraindications to thrombolysis is safe. There are some case reports showing a successful and safe use of low-dose CDL in patients after recent (<3 weeks major trauma) surgery or stroke [37]. In our opinion, relative contraindications to ST usually do not constitute a contraindication to local thrombolysis. In addition, in patients with acute non-high-risk PE, CDL should be preferred to ST in those at an increased risk of bleeding, which

includes the following factors: age older than 75 years, history of bleeding, renal disease, liver damage, malignancy, anemia, thrombocytopenia, diabetes, antiplatelet therapy, recent trauma, or a minor surgery. In patients with absolute contraindications to thrombolysis not eligible for surgical treatment, CDMT is preferred.

Continuous infusion of UFH is the standard anticoagulation used during local thrombolysis and in the early postoperative period.

Safety monitoring during thrombolytic therapy necessitates regular clinical evaluation as well as evaluation of red blood cell parameters and coagulation parameters. Although scientific data are limited, some centers monitor the above-mentioned parameters at 3- to 6-hour intervals, and the decision to discontinue therapy or reduce the dose is made depending on the dynamics of their changes. The occurrence of life-threatening bleeding is an absolute indication to discontinue fibrinolytic therapy.

The results of the ongoing Hi-Peitho study (Ultrasound-facilitated, Catheter-directed, Thrombolysis in Intermediate-high Risk Pulmonary Embolism; NCT04790370) will be important for the further development of catheter-directed thrombolysis techniques. This is a phase 4, multicenter, randomized trial comparing ultrasound-facilitated catheter-directed thrombolysis with heparin in a population of patients with PE of intermediate- high risk.

CATHETER-DIRECTED MECHANICAL THROMBECTOMY

The main goal of CDMT is to remove embolic material quickly and directly from the pulmonary arteries, restore patency, and improve blood flow [38]. Usually, removal of about 50% of the volume of thrombus is sufficient to achieve a significant improvement in hemodynamic and clinical parameters in a patient with acute intermediate-high- or high-risk PE [39]. [Figure 5](#) shows the idea of CDMT.

There is a growing body of evidence from observational studies indicating that CDMT in patients with acute high- and intermediate-high-risk PE is safe and effective and is associated with a low rate of serious complications, especially hemorrhagic complications, significant and rapid improvement in hemodynamic and clinical parameters, and shortened hospitalization [40]. However, to date, there are no randomized clinical trials showing improved prognosis compared with pharmacological treatment or SPE.

In some patients without absolute contraindications to thrombolysis, a combination (hybrid), pharmacomechanical treatment is possible, namely, thrombectomy supplemented with low-dose thrombolysis administered before, during, or after the catheter-directed procedure, especially when thrombectomy is not effective enough [40, 41].

Complications of catheter-directed mechanical thrombectomy

CDMT can be technically difficult and requires operators to have the experience and knowledge of passing and manipulating large-diameter catheters within the RV and pulmonary arteries. Potential complications of CDMT, besides complications at the vascular access site (hematomas, aneurysms, retroperitoneal bleeding), include cardiac tamponade, guidewire- or catheter-related pulmonary artery injury, distal embolization, alveolar hemorrhage, excessive blood loss due to aspiration, and bradycardia/atrioventricular block/asystole (resulting from a transient increase in bradykinin, adenosine, or potassium levels secondary to hemolysis or the catheter compressing the atrioventricular node or right bundle branch), hemolysis, and hemoglobinuria (rheolytic thrombectomy). In addition, acute kidney injury after administration of a contrast agent (contrast-induced nephropathy) may occur.

Contraindications to catheter-directed mechanical thrombectomy

Contraindications to CDMT, in addition to lack of patient consent, include: disseminated pulmonary metastases (risk of perforation and bleeding), foci of tuberculosis, hemorrhagic diathesis, severe anemia, an IVC filter (in the case of femoral access), thrombus in the RV and right atrium, especially crossing the patent foramen ovale (PFO) (relative contraindication).

Procedure

Typically, the procedure begins by inserting a pigtail catheter into the pulmonary artery and performing pulmonary artery angiography to localize thrombi and determine the anatomy of the pulmonary arteries. In some centers, the pigtail catheter is left in place for the duration of the procedure for monitoring purposes, while the therapeutic catheter is inserted from another access site. Angiography is not necessary if a current CT pulmonary angiogram of good quality is available. The next stage of the procedure is the insertion of a guidewire into the pulmonary artery (through the vena cava, right atrium, and RV), followed by the appropriate therapeutic catheter, depending on the device. During the procedure, the patient should be continuously monitored (ECG, systemic blood pressure, oxygen saturation). It may be necessary to administer oxygen. The procedure should be terminated if: no more thrombus can be removed (distal thrombus, organized thrombus, thrombus diameter larger than the diameter of the catheter), hemodynamic improvement is noted (improvement or stabilization of systemic pressure, reduction of pulmonary artery pressure, improvement of arterial oxygen

saturation, reduction of heart rate), or clinical improvement is reached (reduction of dyspnea, cough). If blood loss is excessive (eg, exceeds 300–400 ml), the benefit-risk balance should be evaluated before the procedure is continued.

Catheter-directed mechanical thrombectomy devices

A rapid progress in the field of CDMT devices has been noted in recent years. Two types of such devices can be distinguished—for thrombus fragmentation (maceration) and various types of thrombus aspiration. The most used techniques are discussed below.

Thrombus fragmentation

A technique that had been available for many years was thrombus fragmentation using a rotational movement of a pigtail catheter in the pulmonary arteries. The technique had a relatively low success rate, although some small-sample observational studies showed its clinical utility [42]. However, simplicity, widespread availability in hemodynamic laboratories, and low cost were the definite advantages of this technique. CLEANER XT (Rex Medical, Conshohocken, Pennsylvania, United States) is another system available for thrombus fragmentation. It is inserted through a catheter into the thrombus, then a drive system that rotates an atraumatic sinuous wire is activated to break up the clot. A few case reports have shown the effectiveness of the device in patients with acute PE [43–45]. At present, however, due to the availability of more modern and effective mechanical thrombectomy devices, thrombus fragmentation techniques are becoming obsolete.

AspirexS (Straub Medical, Wangs, Switzerland)

The device is inserted through an 8-F catheter and uses a rotating Archimedes screw which provides fragmentation and aspiration of the thrombus, followed by thrombus transportation throughout the catheter. The drive system allows for the rotation rate of 40 000 revolutions per minute. Some observational studies have been published on the use of this method in patients with acute PE [46].

Rheolytic thrombectomy

The AngioJet PE device (Boston Scientific, Minneapolis, MN, US) provides fragmentation and aspiration of intravascular thrombi using a saline jet based on the Bernoulli phenomenon. The device's Power Pulse mode also allows preinjection of a low-dose thrombolytic into the thrombus. Case series, including some from Poland, show the relatively high effectiveness of

the AngioJet system in patients with acute PE [14, 47, 48]. However, significant hemolysis can occur during the procedure, which can result in serious adverse events, for example: hypotension, dyspnea, bradycardia, (release of bradykinin and adenosine from erythrocytes and platelets), or worsening renal failure (hemoglobinuria) [49]. This led the United States Food and Drug Administration (FDA) to issue a warning for the use of the AngioJet system in the treatment of patients with acute PE. For this reason, the device should be used with caution, observing a limit of about 20 seconds per application; moreover, the total use time in one session should not exceed 120 seconds. However, when used by experienced teams, AngioJet appears to be effective and relatively safe. In a recent observational study, rheolytic thrombectomy was administered to 56 patients with acute intermediate-high- to high-risk PE with relative or absolute contraindications to thrombolysis. The treatment resulted in significant hemodynamic and clinical improvement. During hospitalization, major bleeding occurred in 7.1% of patients, and death occurred in 8.9%. Perioperative deterioration of renal function occurred in as many as 39.3% of patients, but only 1 patient (1.8%) required dialysis. The role of the AngioJet system in the treatment of patients with acute PE requires further investigation [50].

Indigo 8 F/ Lightning 12 (Penumbra Inc, Alameda, CA, US)

The Indigo 8 F system enables direct thrombus aspiration from the pulmonary bed using an 8 F catheter (CAT8TRQ) connected to an aspiration pump. The advantage of this system is the almost immediate hemodynamic and clinical improvement, but at the expense of perioperative blood loss and sometimes the need for blood transfusion after surgery (average blood loss per operation is about 200–400 ml) [49, 51, 52]. It should also be noted that the diameter of the catheter (8 F) precludes complete aspiration of large thrombi. In some cases, thrombus fragmentation is necessary. The EXTRACT PE study included 119 patients older than 18 years of age with acute intermediate-high-risk PE of less than 14 days' duration without prior thrombolytic treatment. There was a significant reduction in the RV/LV ratio (from 1.47 before to 1.04 at 48 hours after the procedure, a reduction of 0.43 points or 27.3%) and a reduction in systolic pulmonary artery pressure (from 49 to 47 mm Hg, a mean reduction of 4.7 mm Hg). Severe perioperative complications occurred in 2 patients (1.7%): both patients experienced access site bleeding, one patient experienced hemoptysis due to pulmonary artery perforation and died. In addition, minor bleeding complications occurred in 3 patients. Two patients died during 30-day follow-up due to progression of pre-existing comorbidities [53]. Recently, the next generation of the device, Lightning 12, has been

released. It has a slightly distinctive design that reduces the risk of catheter deformation while maintaining flexibility, and a larger diameter of 12 F. The aspiration pump has a pressure valve that responds to overly rapid blood flow to reduce blood loss. The first experiences with the device, including from Polish centers, seem encouraging [54].

FlowTrieve (Inari Medical, Irvine, CA, US)

It is a catheter with 3 nitinol disks that open when slid out of a 20 F sheath, which enables complete clot aspiration when inserted into the thrombus. In the FLARE study [55] (104 patients undergoing percutaneous embolectomy with the FlowTrieve system), there was a significant reduction in the RV/LV ratio at 48 hours after the procedure (1.56 vs 1.15; $P < 0.0001$; a reduction of 0.38). The mean hospitalization time was 4.1 days (and in 41.3% of patients, the mean was 1.5 days), with a relatively low rate of serious adverse events in 4 patients (3.8%): one patient experienced massive hemoptysis probably due to reperfusion injury requiring lower lobectomy; 2 patients experienced respiratory deterioration requiring intubation; and the last patient experienced ST elevation myocardial infarction treated with coronary angioplasty. There is also some concern about the diameter of the vascular sheath (20–24 F) and the risk of hematoma at the vascular access site with the use of such a large device [55]. Currently, large prospective observational studies and randomized clinical trials are underway to confirm the efficacy of the FlowTrieve device in the treatment of acute PE (The PEERLESS Study; A prospective, multicenter, randomized controlled trial of the FlowTrieve System compared to Catheter-Directed Thrombolysis (CDT) for use in the treatment of acute pulmonary embolism, NCT05111613).

Angiovac (AngioDynamics, Inc)

A veno-venous extracorporeal bypass circuit created for the aspiration of large thrombi from the right heart, mainly the right atrium, possibly also the RV. The 26 F drainage (suction) cannula has a funneled tip and drains blood to a extracorporeal circulation pump with an attached reservoir with a filter in which embolic material (thrombi, vegetations, neoplasms, etc) is collected. The blood is then reinfused back into the vein (femoral or possibly jugular) through a 16- to 20-F inflow cannula. The device is used for the nonsurgical catheter-directed vegetation removal in the course of cardiac device-related infective endocarditis, catheter-related thrombi in cancer patients, as well as in-transit thrombi passing through the heart in patients with or at risk for acute PE [56].

INFERIOR VENA CAVA FILTERS IN THE TREATMENT OF ACUTE

PULMONARY EMBOLISM

Indications for implantation of an IVC filter are limited to 2 clinical scenarios: when a patient with acute PE has absolute contraindications to anticoagulant therapy and in case of recurrent PE despite adequate anticoagulant therapy [5]. The routine use of filters in patients with PE is not recommended. Most current filters are devices inserted percutaneously into the IVC from a femoral or jugular access that can be safely removed after a few weeks or months, or left in place long term (if necessary). The device should be implanted during catheter-directed intervention, using the same vascular access. The implantation procedure is preceded by angiography of the IVC to rule out thrombi, and the filter is most often placed in the infrarenal portion of the IVC. After the procedure (up to 24 hours), the correct position of the filter should be checked with an abdominal X-ray. IVC filters are effective in protecting against recurrence of acute PE; however, they may increase the risk of deep vein thrombosis [57]. In a review of the literature including 9002 procedures, the most commonly described complication was venous wall penetration in 19% of patients. Penetration with involvement of adjacent structures was observed in 3.6% of study population. Major intervention was required in 0.9% of cases (eg, surgical removal of the filter, placement of an endovascular stent-graft, nephrostomy). Other rare complications include filter fracture or displacement; deaths were found very rarely (2 cases) [58].

SURGICAL PULMONARY EMBOLICTOMY

Indications

In practice, SPE is usually used in a patient with acute PE in whom other treatment options are ineffective or contraindicated.

The advantage of surgical treatment of patients with acute PE is the ability to safely remove accompanying thrombus “in transit” in the right heart, especially thrombus trapped in the PFO [59]. ST or interventional treatment of PE carries the risk of thrombus traveling from the right heart into the pulmonary circulation, which, together with concomitant RV overload, can lead to cardiovascular decompensation. In case of a thrombus straddling PFO, ST and percutaneous treatment can result in the release of a fragment of the thrombus located in the left atrium, and subsequently, lead to an embolus in the arterial circulation [60]. In patients with acute PE and concomitant chronic lesions in the pulmonary circulation with indications for reperfusion therapy, successful lesion removal can only be achieved surgically [61, 62]. Due to the complexity of the procedure and the required extensive experience, it is advisable to perform such procedures in centers experienced in pulmonary endarterectomy.

Treatment results

Currently, there are no randomized clinical trials evaluating and comparing surgical treatment with other treatment options. This population is very heterogeneous and includes hemodynamically unstable patients, those in cardiogenic shock, often with multiple organ failure as well as extreme cases after cardiac arrest—surgical treatment is the treatment of last resort in such patients. Hence, surgical outcomes depend on the patient's initial condition, and the mortality rates in the literature vary considerably. In a registry-based study, in-hospital mortality was 15.9% (in patients without shock, 7.9%; those in shock, 23.7%; and those after cardiac arrest, 44.4%) [63]. In addition, the results depended on the experience of the center. In centers with extensive experience in performing surgical embolectomy, the total mortality rate was 4.2% to 6.6% (in patients without shock, 0%–3.6%; those in shock, 10.2%–12%; and those after cardiac arrest, 22%) [59, 64–66].

A limitation of SPE is the number and availability of cardiac surgery departments, which is often associated with the need to transport the patient to a distant facility, whereas percutaneous interventions can be implemented in most hospitals with access to a hemodynamic laboratory. Of note, percutaneous procedure does not preclude SPE.

MONITORING AND INTENSIVE CARE OF A PATIENT WITH ACUTE PULMONARY EMBOLISM

Pharmacological support of circulation

Some patients with acute PE require treatment with inotropes or vasopressors. Symptoms of low cardiac output and cardiogenic shock are the most common indications for these drugs. Their dosage and effects on selected hemodynamic parameters are shown in [Table 8](#) [68–70]. Of the inotropic drugs, dobutamine is the most commonly used in acute PE. Low doses (2–5 µg/kg/min) increase cardiac output and reduce pulmonary resistance, while higher doses can cause tachycardia and increase oxygen consumption [71, 72]. In patients with low blood pressure, the most commonly recommended drug is norepinephrine [69–71].

Mechanical circulatory support

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) can be used in severely hemodynamically compromised patients

[73] with refractory cardiac arrest [74] as a bridge to recovery and bridge to CDT, SPE, or ST [74–77] and, according to the recommendations from the United States, also during those

therapies [78]. VA-ECMO can be used as a bridge to CDT or SPE in patients after unsuccessful ST [79]. The ECMO-first strategy supplemented with percutaneous mechanical thrombectomy can be used for acute, life-threatening PE [80]. The duration of VA-ECMO in patients with acute PE should depend on their hemodynamic status, symptoms of cardiogenic shock, and risk of multiple organ failure. Based on the ESC guidelines, ECMO is only to be considered in patients with refractory shock or cardiac arrest only in combination with SPE or CDT (class IIb recommendation) [5]. We believe that the decision to start ECMO in an individual patient should be made by the PERT team and should be based on the patient's characteristics, previous treatment, and the center's experience. There are emerging reports on the use of new devices for RV support in acute PE such as the Impella RP microaxial flow pump [77].

Monitoring

ECG, blood pressure, and blood loss should be monitored during CDT. Hemodynamic monitoring during CDT should be kept to a minimum. Measurements of right atrial pressure, pulmonary artery pressure, and mixed venous oxygen saturation seem to be a minimal and sufficient set of parameters assessed before and after the procedure.

The patient should be monitored for at least 24 hours after the intervention due to the risk of potential complications associated with the procedure. Continuous monitoring of ECG, arterial blood oxygen saturation, and respiratory rate is recommended. Monitoring of central venous pressure and mixed venous oxygen saturation may be considered for high-risk patients. Systematic evaluation of pulse oximetry parameters is advisable on the first day, during and after the procedure. On the next day, a repeat arterial blood gas test should be performed and the concentrations of BNP/NT-proBNP, troponin, eGFR levels measured. Additionally, echocardiography should be performed immediately after the procedure and at 24 and 48 hours [5, 78, 81–83].

Mechanical ventilation

Mechanical ventilation — either noninvasive or invasive — is unnecessary in most cases of acute PE, and hypoxemia can usually be easily managed with conventional oxygen therapy. Arterial blood oxygen saturation of less than 90% requires initiation of oxygen therapy; however, greater values do not rule out respiratory failure [84]. If conventional oxygen therapy is insufficient, high-flow nasal oxygen therapy (HFNOT) can be considered as it provides flow rates of up to 60 l/min and is more comfortable for the patient than oxygen

masks [85, 86].

When using invasive ventilatory support, it is important to keep in mind that positive chest pressure can reduce venous return and exacerbate RV failure and hypotension [87]. Hence, positive end-expiratory pressure (PEEP) should be used with caution [88]. Acute PE reduces the cross-sectional pulmonary vascular area, which results in increased pulmonary vascular resistance. Mechanically ventilated patients with poor cardiopulmonary reserve who have increasing pulmonary vascular resistance may experience deterioration of RV function and consequent severe hemodynamic impairment [89]. Therefore, small tidal volumes (6 ml/kg) should be used to maintain end-inspiratory pressure of less than 30 cm H₂O. A lung-protective ventilation strategy (ARDSnet strategy), that is, reducing plateau pressures, is the treatment of choice [5, 90].

Noninvasive ventilation is associated with reduced hospitalization time, less complications, and lower mortality compared with invasive ventilation [91]. If a patient on noninvasive ventilation requires increasingly higher tidal volumes, it can be assumed that intubation will be needed in the near future.

OPERATOR QUALIFICATIONS AND CHARACTERISTICS OF REFERENCE CENTERS FOR INTERVENTIONAL TREATMENT OF ACUTE PULMONARY EMBOLISM

Interventional treatment of acute PE should be performed by experienced operators at reference centers. In emergency and immediate life-threatening situations and in situations in which patient transport is not possible, the procedure can also be performed by an experienced interventional cardiologist outside the referral center after consultation with the PERT team.

The referral center should: have a PERT that consults patients 24/7, provide access to interventional treatment of acute PE 24/7, collaborate with a cardiac surgery center that can ensure pulmonary embolectomy 24/7, and optionally, offer post-discharge outpatient care. The referral center should have its own registry/database of acute PE interventions. Participation in clinical trials, observational studies, or multicenter registries is also advisable for such centers.

The center's experience measured as the number of performed procedures influences the results of interventional treatment of acute PE. A recent study reported lower in-hospital mortality in centers performing >12 procedures per year compared with centers performing 1 to 3 procedures per year [92]. Another study found that in-hospital mortality was lower in hospitals performing at least 8 procedures per year compared with low-volume facilities (6%

vs. 11.3%) [93]. We agree that acute PE interventions should be performed on a regular basis at a referral center; however, it is not possible to make a clear recommendation on the number of interventions that should be performed due to the lack of data from well-designed clinical trials.

Interventional treatment should be tailored to the individual patient's profile. The equipment of the referral center should allow to perform at least one method based on thrombectomy and at least one based on catheter-directed fibrinolysis, both with proven efficacy.

Interventional treatment of acute PE requires the ability to perform diagnostic and therapeutic procedures in the pulmonary circulation and experience in the universal techniques used in interventional cardiology. It is also necessary to acquire skills in the use of specific devices designed for catheter-directed thrombectomy, thrombus fragmentation, and local fibrinolysis.

The requirements to be met by an independent invasive cardiology operator and a right heart catheterization specialist have been defined, respectively, by the Association of Cardiovascular Interventions and the Pulmonary Circulation Section of the Polish Cardiac Society.

There are insufficient scientific data to formulate clear eligibility criteria for interventional treatment of acute PE; however, we suggest that it should be a specialist who holds at least one of the above-mentioned certifications (or other corresponding certifications from medical societies) and who systematically performs interventional procedures in the pulmonary bed. An independent operator in the field of acute PE is expected to participate in conferences including in their scope interventional treatment of acute PE and publish their results.

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REFERENCES

1. Araszkiwicz A, Kurzyna M, Kopeć G, et al. Expert opinion on the creating and operating of the regional Pulmonary Embolism Response Teams (PERT). Polish PERT Initiative. *Cardiol J.* 2019; 26(6): 623–632, doi: [10.5603/CJ.2019.0127](https://doi.org/10.5603/CJ.2019.0127), indexed in Pubmed: [31970735](https://pubmed.ncbi.nlm.nih.gov/31970735/).
2. Pruszczyk P, Klok FA, Kucher N, et al. Percutaneous treatment options for acute pulmonary embolism: a clinical consensus statement by the ESC Working Group on Pulmonary Circulation and Right Ventricular Function and the European Association of Percutaneous Cardiovascular Interventions. *EuroIntervention.* 2022; 18(8): e623–e638, doi: [10.4244/EIJ-D-22-00246](https://doi.org/10.4244/EIJ-D-22-00246), indexed in Pubmed: [36112184](https://pubmed.ncbi.nlm.nih.gov/36112184/).
3. Meyer G, Vicaut E, Danays T, et al. Fibrinolysis for patients with intermediate-risk pulmonary embolism. *N Engl J Med.* 2014; 370(15): 1402–1411, doi: [10.1056/NEJMoa1302097](https://doi.org/10.1056/NEJMoa1302097), indexed in Pubmed: [24716681](https://pubmed.ncbi.nlm.nih.gov/24716681/).
4. Meneveau N, Séronde MF, Blonde MC, et al. Management of unsuccessful thrombolysis in acute massive pulmonary embolism. *Chest.* 2006; 129(4): 1043–1050, doi: [10.1378/chest.129.4.1043](https://doi.org/10.1378/chest.129.4.1043), indexed in Pubmed: [16608956](https://pubmed.ncbi.nlm.nih.gov/16608956/).
5. Konstantinides SV, Meyer G, Becattini C, et al. 2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European Respiratory Society (ERS). *Eur Heart J.* 2020; 41(4): 543–603, doi: [10.1093/eurheartj/ehz405](https://doi.org/10.1093/eurheartj/ehz405), indexed in Pubmed: [31504429](https://pubmed.ncbi.nlm.nih.gov/31504429/).
6. Eubank BH, Mohtadi NG, Lafave MR, et al. Using the modified Delphi method to establish clinical consensus for the diagnosis and treatment of patients with rotator cuff pathology. *BMC Med Res Methodol.* 2016; 16: 56, doi: [10.1186/s12874-016-0165-8](https://doi.org/10.1186/s12874-016-0165-8), indexed in Pubmed: [27206853](https://pubmed.ncbi.nlm.nih.gov/27206853/).
7. Kabrhel C, Jaff MR, Channick RN, et al. A multidisciplinary pulmonary embolism response team. *Chest.* 2013; 144(5): 1738–1739, doi: [10.1378/chest.13-1562](https://doi.org/10.1378/chest.13-1562), indexed in Pubmed: [24189880](https://pubmed.ncbi.nlm.nih.gov/24189880/).
8. Heresi GA, Porres-Aguilar M. Pulmonary embolism response teams: A concept in progress and beyond borders. *Kardiol Pol.* 2021; 79(12): 1301–1302, doi: [10.33963/KP.a2021.0174](https://doi.org/10.33963/KP.a2021.0174), indexed in Pubmed: [34874056](https://pubmed.ncbi.nlm.nih.gov/34874056/).
9. Schultz J, Giordano N, Zheng H, et al. EXPRESS: A Multidisciplinary Pulmonary Embolism Response Team (PERT) - Experience from a national multicenter

- consortium. *Pulm Circ.* 2019 [Epub ahead of print]; 9(3): 2045894018824563, doi: [10.1177/2045894018824563](https://doi.org/10.1177/2045894018824563), indexed in Pubmed: [30632901](https://pubmed.ncbi.nlm.nih.gov/30632901/).
10. Rosovsky R, Chang Y, Rosenfield K, et al. Changes in treatment and outcomes after creation of a pulmonary embolism response team (PERT), a 10-year analysis. *J Thromb Thrombolysis.* 2019; 47(1): 31–40, doi: [10.1007/s11239-018-1737-8](https://doi.org/10.1007/s11239-018-1737-8), indexed in Pubmed: [30242551](https://pubmed.ncbi.nlm.nih.gov/30242551/).
 11. Chaudhury P, Gadre SK, Schneider E, et al. Impact of Multidisciplinary Pulmonary Embolism Response Team Availability on Management and Outcomes. *Am J Cardiol.* 2019; 124(9): 1465–1469, doi: [10.1016/j.amjcard.2019.07.043](https://doi.org/10.1016/j.amjcard.2019.07.043), indexed in Pubmed: [31495443](https://pubmed.ncbi.nlm.nih.gov/31495443/).
 12. Myc LA, Solanki JN, Barros AJ, et al. Adoption of a dedicated multidisciplinary team is associated with improved survival in acute pulmonary embolism. *Respir Res.* 2020; 21(1): 159, doi: [10.1186/s12931-020-01422-z](https://doi.org/10.1186/s12931-020-01422-z), indexed in Pubmed: [32571318](https://pubmed.ncbi.nlm.nih.gov/32571318/).
 13. Araszkievicz A, Kurzyna M, Kopeć G, et al. Pulmonary embolism response team: A multidisciplinary approach to pulmonary embolism treatment. Polish PERT Initiative Report. *Kardiol Pol.* 2021; 79(12): 1311–1319, doi: [10.33963/KP.a2021.0130](https://doi.org/10.33963/KP.a2021.0130), indexed in Pubmed: [34643260](https://pubmed.ncbi.nlm.nih.gov/34643260/).
 14. Roik M, Wretowski D, Łabyk A, et al. Initial experience of pulmonary embolism response team with percutaneous embolectomy in intermediate-high- and high-risk acute pulmonary embolism. *Kardiol Pol.* 2019; 77(2): 228–231, doi: [10.5603/KP.a2018.0239](https://doi.org/10.5603/KP.a2018.0239), indexed in Pubmed: [30566224](https://pubmed.ncbi.nlm.nih.gov/30566224/).
 15. Sławek-Szmyt S, Jankiewicz S, Smukowska-Gorynia A, et al. Implementation of a regional multidisciplinary pulmonary embolism response team: PERT-POZ initial 1-year experience. *Kardiol Pol.* 2020; 78(4): 300–310, doi: [10.33963/KP.15230](https://doi.org/10.33963/KP.15230), indexed in Pubmed: [32165606](https://pubmed.ncbi.nlm.nih.gov/32165606/).
 16. Pietrasik A, Gąsecka A, Kurzyna P, et al. Characteristics and Outcomes of Patients Consulted by a Multidisciplinary Pulmonary Embolism Response Team: 5-Year Experience. *J Clin Med.* 2022; 11(13), doi: [10.3390/jcm11133812](https://doi.org/10.3390/jcm11133812), indexed in Pubmed: [35807097](https://pubmed.ncbi.nlm.nih.gov/35807097/).
 17. Provias T, Dudzinski DM, Jaff MR, et al. The Massachusetts General Hospital Pulmonary Embolism Response Team (MGH PERT): creation of a multidisciplinary program to improve care of patients with massive and submassive pulmonary embolism. *Hosp Pract (1995).* 2014; 42(1): 31–37, doi: [10.3810/hp.2014.02.1089](https://doi.org/10.3810/hp.2014.02.1089), indexed in Pubmed: [24566594](https://pubmed.ncbi.nlm.nih.gov/24566594/).

18. Kabrhel C, Rosovsky R, Channick R, et al. A Multidisciplinary Pulmonary Embolism Response Team: Initial 30-Month Experience With a Novel Approach to Delivery of Care to Patients With Submassive and Massive Pulmonary Embolism. *Chest*. 2016; 150(2): 384–393, doi: [10.1016/j.chest.2016.03.011](https://doi.org/10.1016/j.chest.2016.03.011), indexed in Pubmed: [27006156](https://pubmed.ncbi.nlm.nih.gov/27006156/).
19. Ciurzyński M, Kurzyna M, Kopec G, et al. An expert opinion of the Polish Cardiac Society Working Group on Pulmonary Circulation on screening for chronic thromboembolic pulmonary hypertension patients after acute pulmonary embolism: Update. *Kardiol Pol*. 2022; 80(6): 723–732, doi: [10.33963/KP.a2022.0141](https://doi.org/10.33963/KP.a2022.0141), indexed in Pubmed: [35665906](https://pubmed.ncbi.nlm.nih.gov/35665906/).
20. Darocha S, Roik M, Kopec G, et al. Balloon pulmonary angioplasty in chronic thromboembolic pulmonary hypertension: a multicentre registry. *EuroIntervention*. 2022; 17(13): 1104–1111, doi: [10.4244/EIJ-D-21-00230](https://doi.org/10.4244/EIJ-D-21-00230), indexed in Pubmed: [34219663](https://pubmed.ncbi.nlm.nih.gov/34219663/).
21. Kopec G, Dzikowska-Diduch O, Mroczek E, et al. Characteristics and outcomes of patients with chronic thromboembolic pulmonary hypertension in the era of modern therapeutic approaches: data from the Polish multicenter registry (BNP-PL). *Ther Adv Chronic Dis*. 2021; 12: 204062232110029, doi: [10.1177/20406223211002961](https://doi.org/10.1177/20406223211002961), indexed in Pubmed: [33854746](https://pubmed.ncbi.nlm.nih.gov/33854746/).
22. Kopec G, Kurzyna M, Mroczek E, et al. Database of Pulmonary Hypertension in the Polish Population (BNP-PL): design of the registry. *Kardiol Pol*. 2019; 77(10): 972–974, doi: [10.33963/KP.14988](https://doi.org/10.33963/KP.14988), indexed in Pubmed: [31553328](https://pubmed.ncbi.nlm.nih.gov/31553328/).
23. Pruszczyk P, Goliszek S, Lichodziejewska B, et al. Prognostic value of echocardiography in normotensive patients with acute pulmonary embolism. *JACC Cardiovasc Imaging*. 2014; 7(6): 553–560, doi: [10.1016/j.jcmg.2013.11.004](https://doi.org/10.1016/j.jcmg.2013.11.004), indexed in Pubmed: [24412192](https://pubmed.ncbi.nlm.nih.gov/24412192/).
24. Pruszczyk P, Kurnicka K, Ciurzyński M, et al. Defining right ventricular dysfunction by echocardiography in normotensive patients with pulmonary embolism. *Pol Arch Intern Med*. 2020; 130(9): 741–747, doi: [10.20452/pamw.15459](https://doi.org/10.20452/pamw.15459), indexed in Pubmed: [32579314](https://pubmed.ncbi.nlm.nih.gov/32579314/).
25. Wiliński J, Skwarek A, Borek R, et al. Subcostal echocardiographic assessment of tricuspid annular kick (SEATAK): A novel independent predictor of 30-day mortality in patients with acute pulmonary embolism. *Kardiol Pol*. 2022; 80(11): 1127–1135, doi: [10.33963/KP.a2022.0213](https://doi.org/10.33963/KP.a2022.0213), indexed in Pubmed: [36088580](https://pubmed.ncbi.nlm.nih.gov/36088580/).

26. Wiliński J, Skwarek A, Borek R, et al. Right ventricular wall thickness indexed to body surface area as an echocardiographic predictor of acute pulmonary embolism in high-risk patients. *Kardiol Pol.* 2022; 80(2): 205–207, doi: [10.33963/KP.a2021.0180](https://doi.org/10.33963/KP.a2021.0180), indexed in Pubmed: [34904219](https://pubmed.ncbi.nlm.nih.gov/34904219/).
27. Pruszczyk P, Skowrońska M, Ciużyński M, et al. Assessment of pulmonary embolism severity and the risk of early death. *Pol Arch Intern Med.* 2021; 131(12), doi: [10.20452/pamw.16134](https://doi.org/10.20452/pamw.16134), indexed in Pubmed: [34775739](https://pubmed.ncbi.nlm.nih.gov/34775739/).
28. Gerry S, Bonnici T, Birks J, et al. Early warning scores for detecting deterioration in adult hospital patients: systematic review and critical appraisal of methodology. *BMJ.* 2020; 369: m1501, doi: [10.1136/bmj.m1501](https://doi.org/10.1136/bmj.m1501), indexed in Pubmed: [32434791](https://pubmed.ncbi.nlm.nih.gov/32434791/).
29. Kosiorek A, Kosowski M, Reczuch K, et al. Recurrent pulmonary embolism in a patient after COVID-19 treated with percutaneous and surgical approach. *Kardiol Pol.* 2021; 79(9): 1042–1043, doi: [10.33963/KP.a2021.0056](https://doi.org/10.33963/KP.a2021.0056), indexed in Pubmed: [34231871](https://pubmed.ncbi.nlm.nih.gov/34231871/).
30. Pietrasik A, Gasecka A, Kotulecki A, et al. Catheter-directed therapy to treat intermediate- and high-risk pulmonary embolism: Personal experience and review of the literature. *Cardiol J.* 2022 [Epub ahead of print], doi: [10.5603/CJ.a2022.0075](https://doi.org/10.5603/CJ.a2022.0075), indexed in Pubmed: [35975795](https://pubmed.ncbi.nlm.nih.gov/35975795/).
31. Pasha AK, Siddiqui MU, Siddiqui MD, et al. Catheter directed compared to systemically delivered thrombolysis for pulmonary embolism: a systematic review and meta-analysis. *J Thromb Thrombolysis.* 2022; 53(2): 454–466, doi: [10.1007/s11239-021-02556-7](https://doi.org/10.1007/s11239-021-02556-7), indexed in Pubmed: [34463919](https://pubmed.ncbi.nlm.nih.gov/34463919/).
32. Stępniewski J, Magoń W, Jonas K, et al. Catheter-directed thrombolysis for the treatment of acute pulmonary embolism refractory to systemic fibrinolysis. *Pol Arch Intern Med.* 2021; 131(6): 568–570, doi: [10.20452/pamw.15924](https://doi.org/10.20452/pamw.15924), indexed in Pubmed: [33825418](https://pubmed.ncbi.nlm.nih.gov/33825418/).
33. Kucher N, Boekstegers P, Müller OJ, et al. Randomized, controlled trial of ultrasound-assisted catheter-directed thrombolysis for acute intermediate-risk pulmonary embolism. *Circulation.* 2014; 129(4): 479–486, doi: [10.1161/CIRCULATIONAHA.113.005544](https://doi.org/10.1161/CIRCULATIONAHA.113.005544), indexed in Pubmed: [24226805](https://pubmed.ncbi.nlm.nih.gov/24226805/).
34. Piazza G, Hohlfelder B, Jaff MR, et al. SEATTLE II Investigators. A Prospective, Single-Arm, Multicenter Trial of Ultrasound-Facilitated, Catheter-Directed, Low-Dose Fibrinolysis for Acute Massive and Submassive Pulmonary Embolism: The SEATTLE II Study. *JACC Cardiovasc Interv.* 2015; 8(10): 1382–1392, doi: [10.1016/j.jcin.2015.04.020](https://doi.org/10.1016/j.jcin.2015.04.020), indexed in Pubmed: [26315743](https://pubmed.ncbi.nlm.nih.gov/26315743/).

35. Tapson VF, Sterling K, Jones N, et al. A Randomized Trial of the Optimum Duration of Acoustic Pulse Thrombolysis Procedure in Acute Intermediate-Risk Pulmonary Embolism: The OPTALYSE PE Trial. *JACC Cardiovasc Interv.* 2018; 11(14): 1401–1410, doi: [10.1016/j.jcin.2018.04.008](https://doi.org/10.1016/j.jcin.2018.04.008), indexed in Pubmed: [30025734](https://pubmed.ncbi.nlm.nih.gov/30025734/).
36. Stępniewski J, Kopeć G, Musiałek P, et al. Hemodynamic Effects of Ultrasound-Assisted, Catheter-Directed, Very Low-Dose, Short-Time Duration Thrombolysis in Acute Intermediate-High Risk Pulmonary Embolism (from the EKOS-PL Study). *Am J Cardiol.* 2021; 141: 133–139, doi: [10.1016/j.amjcard.2020.11.004](https://doi.org/10.1016/j.amjcard.2020.11.004), indexed in Pubmed: [33220318](https://pubmed.ncbi.nlm.nih.gov/33220318/).
37. Stępniewski J, Kopeć G, Magoń W, et al. Ultrasound-assisted, catheter-directed, low-dose thrombolysis for the treatment of acute intermediate-high risk pulmonary embolism. *Pol Arch Intern Med.* 2018; 128(6): 394–395, doi: [10.20452/pamw.4272](https://doi.org/10.20452/pamw.4272), indexed in Pubmed: [29806658](https://pubmed.ncbi.nlm.nih.gov/29806658/).
38. Konstantinides SV, Meyer G, Becattini C, et al. 2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European Respiratory Society (ERS): The Task Force for the diagnosis and management of acute pulmonary embolism of the European Society of Cardiology (ESC). *Eur Respir J.* 2019; 54(3), doi: [10.1183/13993003.01647-2019](https://doi.org/10.1183/13993003.01647-2019), indexed in Pubmed: [31473594](https://pubmed.ncbi.nlm.nih.gov/31473594/).
39. Azarian R, Wartski M, Collignon MA, et al. Lung perfusion scans and hemodynamics in acute and chronic pulmonary embolism. *J Nucl Med.* 1997; 38(6): 980–983, indexed in Pubmed: [9189155](https://pubmed.ncbi.nlm.nih.gov/9189155/).
40. Schultz J, Andersen A, Kabrhel C, et al. Catheter-based therapies in acute pulmonary embolism. *EuroIntervention.* 2018; 13(14): 1721–1727, doi: [10.4244/EIJ-D-17-00437](https://doi.org/10.4244/EIJ-D-17-00437), indexed in Pubmed: [29175770](https://pubmed.ncbi.nlm.nih.gov/29175770/).
41. Sławek-Szmyt SL, Jankiewicz S, Grygier M, et al. A novel hybrid catheter-directed technique to treat intermediate-high risk pulmonary embolism. *Cardiol J.* 2022; 29(2): 342–345, doi: [10.5603/CJ.a2022.0007](https://doi.org/10.5603/CJ.a2022.0007), indexed in Pubmed: [35244199](https://pubmed.ncbi.nlm.nih.gov/35244199/).
42. Schmitz-Rode T, Janssens U, Duda SH, et al. Massive pulmonary embolism: percutaneous emergency treatment by pigtail rotation catheter. *J Am Coll Cardiol.* 2000; 36(2): 375–380, doi: [10.1016/s0735-1097\(00\)00734-8](https://doi.org/10.1016/s0735-1097(00)00734-8), indexed in Pubmed: [10933345](https://pubmed.ncbi.nlm.nih.gov/10933345/).
43. Barjaktarevic I, Friedman O, Ishak C, et al. Catheter-directed clot fragmentation using the Cleaner™ device in a patient presenting with massive pulmonary embolism. *J*

- Radiol Case Rep. 2014; 8(2): 30–36, doi: [10.3941/jrcr.v8i2.1455](https://doi.org/10.3941/jrcr.v8i2.1455), indexed in Pubmed: [24967017](https://pubmed.ncbi.nlm.nih.gov/24967017/).
44. Kurzyna M, Pietrasik A, Opolski G, et al. Contemporary methods for the treatment of pulmonary embolism - is it prime-time for percutaneous interventions? *Kardiol Pol.* 2017; 75(11): 1161–1170, doi: [10.5603/KP.a2017.0125](https://doi.org/10.5603/KP.a2017.0125), indexed in Pubmed: [28715074](https://pubmed.ncbi.nlm.nih.gov/28715074/).
 45. Pietrasik A, Gąsecka A, Smyk JM, et al. Acute-on-chronic pulmonary embolism and concomitant paradoxical embolism: two diseases, one intervention. *Pol Arch Intern Med.* 2022; 132(1), doi: [10.20452/pamw.16155](https://doi.org/10.20452/pamw.16155), indexed in Pubmed: [34851065](https://pubmed.ncbi.nlm.nih.gov/34851065/).
 46. Bayiz H, Dumantepe M, Teymen B, et al. Percutaneous aspiration thrombectomy in treatment of massive pulmonary embolism. *Heart Lung Circ.* 2015; 24(1): 46–54, doi: [10.1016/j.hlc.2014.06.014](https://doi.org/10.1016/j.hlc.2014.06.014), indexed in Pubmed: [25060976](https://pubmed.ncbi.nlm.nih.gov/25060976/).
 47. Latacz P, Simka M, Brzegowy P, et al. Treatment of high- and intermediate-risk pulmonary embolism using the AngioJet percutaneous mechanical thrombectomy system in patients with contraindications for thrombolytic treatment - a pilot study. *Wideochir Inne Tech Maloinwazyjne.* 2018; 13(2): 233–242, doi: [10.5114/wiitm.2018.75848](https://doi.org/10.5114/wiitm.2018.75848), indexed in Pubmed: [30002757](https://pubmed.ncbi.nlm.nih.gov/30002757/).
 48. Bonvini RF, Righini M, Roffi M. Angiojet rheolytic thrombectomy in massive pulmonary embolism: locally efficacious but systemically deleterious? *J Vasc Interv Radiol.* 2010; 21(11): 1774–6; author reply 1776, doi: [10.1016/j.jvir.2010.01.051](https://doi.org/10.1016/j.jvir.2010.01.051), indexed in Pubmed: [21029953](https://pubmed.ncbi.nlm.nih.gov/21029953/).
 49. Ciampi-Dopazo JJ, Romeu-Prieto JM, Sánchez-Casado M, et al. Aspiration Thrombectomy for Treatment of Acute Massive and Submassive Pulmonary Embolism: Initial Single-Center Prospective Experience. *J Vasc Interv Radiol.* 2018; 29(1): 101–106, doi: [10.1016/j.jvir.2017.08.010](https://doi.org/10.1016/j.jvir.2017.08.010), indexed in Pubmed: [29102272](https://pubmed.ncbi.nlm.nih.gov/29102272/).
 50. Akbal ÖY, Keskin B, Tokgöz HC, et al. A seven-year single-center experience on AngioJet rheolytic thrombectomy in patients with pulmonary embolism at high risk and intermediate-high risk. *Anatol J Cardiol.* 2021; 25(12): 902–911, doi: [10.5152/AnatolJCardiol.2021.28303](https://doi.org/10.5152/AnatolJCardiol.2021.28303), indexed in Pubmed: [34866585](https://pubmed.ncbi.nlm.nih.gov/34866585/).
 51. Pieraccini M, Guerrini S, Laiolo E, et al. Acute Massive and Submassive Pulmonary Embolism: Preliminary Validation of Aspiration Mechanical Thrombectomy in Patients with Contraindications to Thrombolysis. *Cardiovasc Intervent Radiol.* 2018; 41(12): 1840–1848, doi: [10.1007/s00270-018-2011-3](https://doi.org/10.1007/s00270-018-2011-3), indexed in Pubmed: [29980817](https://pubmed.ncbi.nlm.nih.gov/29980817/).
 52. Araszkiwicz A, Sławek-Szmyt S, Jankiewicz S, et al. Continuous Aspiration Thrombectomy in High- and Intermediate-High-Risk Pulmonary Embolism in Real-

- World Clinical Practice. *J Interv Cardiol.* 2020; 2020: 4191079, doi: [10.1155/2020/4191079](https://doi.org/10.1155/2020/4191079), indexed in Pubmed: [32904502](https://pubmed.ncbi.nlm.nih.gov/32904502/).
53. Sista AK, Horowitz JM, Tapson VF, et al. Indigo Aspiration System for Treatment of Pulmonary Embolism: Results of the EXTRACT-PE Trial. *JACC Cardiovasc Interv.* 2021; 14(3): 319–329, doi: [10.1016/j.jcin.2020.09.053](https://doi.org/10.1016/j.jcin.2020.09.053), indexed in Pubmed: [33454291](https://pubmed.ncbi.nlm.nih.gov/33454291/).
 54. Stępniewski J, Magoń W, Podolec P, et al. The PENUMBRA Lightning 12 system for treatment of acute intermediate-high pulmonary embolism. Initial experience in Pulmonary Circulation Center Krakow, Poland. *Postepy Kardiol Interwencyjnej.* 2022; 18(3): 314–316, doi: [10.5114/aic.2022.120974](https://doi.org/10.5114/aic.2022.120974), indexed in Pubmed: [36751285](https://pubmed.ncbi.nlm.nih.gov/36751285/).
 55. Tu T, Toma C, Tapson VF, et al. A Prospective, Single-Arm, Multicenter Trial of Catheter-Directed Mechanical Thrombectomy for Intermediate-Risk Acute Pulmonary Embolism: The FLARE Study. *JACC Cardiovasc Interv.* 2019; 12(9): 859–869, doi: [10.1016/j.jcin.2018.12.022](https://doi.org/10.1016/j.jcin.2018.12.022), indexed in Pubmed: [31072507](https://pubmed.ncbi.nlm.nih.gov/31072507/).
 56. Puślecki M, Stefaniak S, Katarzyński S, et al. AngioVac: The first in Poland percutaneous solid thrombus aspiration from the right atrium. *Kardiol Pol.* 2022; 80(1): 103–104, doi: [10.33963/KP.a2021.0128](https://doi.org/10.33963/KP.a2021.0128), indexed in Pubmed: [34643258](https://pubmed.ncbi.nlm.nih.gov/34643258/).
 57. Bikdeli B, Chatterjee S, Desai NR, et al. Inferior Vena Cava Filters to Prevent Pulmonary Embolism: Systematic Review and Meta-Analysis. *J Am Coll Cardiol.* 2017; 70(13): 1587–1597, doi: [10.1016/j.jacc.2017.07.775](https://doi.org/10.1016/j.jacc.2017.07.775), indexed in Pubmed: [28935036](https://pubmed.ncbi.nlm.nih.gov/28935036/).
 58. Jia Z, Wu A, Tam M, et al. Caval Penetration by Inferior Vena Cava Filters: A Systematic Literature Review of Clinical Significance and Management. *Circulation.* 2015; 132(10): 944–952, doi: [10.1161/CIRCULATIONAHA.115.016468](https://doi.org/10.1161/CIRCULATIONAHA.115.016468), indexed in Pubmed: [26169756](https://pubmed.ncbi.nlm.nih.gov/26169756/).
 59. Zieliński D, Zygier M, Dyk W, et al. Acute pulmonary embolism with coexisting right heart thrombi in transit-surgical treatment of 20 consecutive patients. *Eur J Cardiothorac Surg.* 2023 [Epub ahead of print], doi: [10.1093/ejcts/ezad022](https://doi.org/10.1093/ejcts/ezad022), indexed in Pubmed: [36661312](https://pubmed.ncbi.nlm.nih.gov/36661312/).
 60. Seo WW, Kim SE, Park MS, et al. Systematic Review of Treatment for Trapped Thrombus in Patent Foramen Ovale. *Korean Circ J.* 2017; 47(5): 776–785, doi: [10.4070/kcj.2016.0295](https://doi.org/10.4070/kcj.2016.0295), indexed in Pubmed: [28955396](https://pubmed.ncbi.nlm.nih.gov/28955396/).
 61. Ius F, Hoepfer MM, Fegbeutel C, et al. Extracorporeal membrane oxygenation and surgical embolectomy for high-risk pulmonary embolism. *Eur Respir J.* 2019; 53(4), doi: [10.1183/13993003.01773-2018](https://doi.org/10.1183/13993003.01773-2018), indexed in Pubmed: [30728206](https://pubmed.ncbi.nlm.nih.gov/30728206/).

62. Pietrasik A, Gąsecka A, Leśniewski M, et al. Hybrid treatment of massive pulmonary embolism by catheter-directed and surgical embolectomy. *Postepy Kardiol Interwencyjnej*. 2021; 17(2): 236–238, doi: [10.5114/aic.2021.107512](https://doi.org/10.5114/aic.2021.107512), indexed in Pubmed: [34400933](https://pubmed.ncbi.nlm.nih.gov/34400933/).
63. Kon ZN, Pasrija C, Bittle GJ, et al. The Incidence and Outcomes of Surgical Pulmonary Embolectomy in North America. *Ann Thorac Surg*. 2019; 107(5): 1401–1408, doi: [10.1016/j.athoracsur.2018.10.035](https://doi.org/10.1016/j.athoracsur.2018.10.035), indexed in Pubmed: [30476479](https://pubmed.ncbi.nlm.nih.gov/30476479/).
64. Pasrija C, Kronfli A, Rouse M, et al. Outcomes after surgical pulmonary embolectomy for acute submassive and massive pulmonary embolism: A single-center experience. *J Thorac Cardiovasc Surg*. 2018; 155(3): 1095–1106.e2, doi: [10.1016/j.jtcvs.2017.10.139](https://doi.org/10.1016/j.jtcvs.2017.10.139), indexed in Pubmed: [29452460](https://pubmed.ncbi.nlm.nih.gov/29452460/).
65. Neely RC, Byrne JG, Gosev I, et al. Surgical Embolectomy for Acute Massive and Submassive Pulmonary Embolism in a Series of 115 Patients. *Ann Thorac Surg*. 2015; 100(4): 1245–51; discussion 1251, doi: [10.1016/j.athoracsur.2015.03.111](https://doi.org/10.1016/j.athoracsur.2015.03.111), indexed in Pubmed: [26165484](https://pubmed.ncbi.nlm.nih.gov/26165484/).
66. Hayes SN, Tweet MS, Adlam D, et al. Spontaneous Coronary Artery Dissection: JACC State-of-the-Art Review. *J Am Coll Cardiol*. 2020; 76(8): 961–984, doi: [10.1016/j.jacc.2020.05.084](https://doi.org/10.1016/j.jacc.2020.05.084), indexed in Pubmed: [32819471](https://pubmed.ncbi.nlm.nih.gov/32819471/).
67. Hartman AR, Manetta F, Lessen R, et al. Acute surgical pulmonary embolectomy: a 9-year retrospective analysis. *Tex Heart Inst J*. 2015; 42(1): 25–29, doi: [10.14503/THIJ-13-3877](https://doi.org/10.14503/THIJ-13-3877), indexed in Pubmed: [25873794](https://pubmed.ncbi.nlm.nih.gov/25873794/).
68. Green EM, Givertz MM. Management of acute right ventricular failure in the intensive care unit. *Curr Heart Fail Rep*. 2012; 9(3): 228–235, doi: [10.1007/s11897-012-0104-x](https://doi.org/10.1007/s11897-012-0104-x), indexed in Pubmed: [22805893](https://pubmed.ncbi.nlm.nih.gov/22805893/).
69. Tycińska A, Grygier M, Biegus J, et al. Mechanical circulatory support. An expert opinion of the Association of Intensive Cardiac Care and the Association of Cardiovascular Interventions of the Polish Cardiac Society. *Kardiol Pol*. 2021; 79(12): 1399–1410, doi: [10.33963/KP.a2021.0169](https://doi.org/10.33963/KP.a2021.0169), indexed in Pubmed: [34861044](https://pubmed.ncbi.nlm.nih.gov/34861044/).
70. McDonagh TA, Metra M, Adamo M, et al. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J*. 2021; 42(36): 3599–3726, doi: [10.1093/eurheartj/ehab368](https://doi.org/10.1093/eurheartj/ehab368), indexed in Pubmed: [34447992](https://pubmed.ncbi.nlm.nih.gov/34447992/).
71. Lahm T, McCaslin CA, Wozniak TC, et al. Medical and surgical treatment of acute right ventricular failure. *J Am Coll Cardiol*. 2010; 56(18): 1435–1446, doi: [10.1016/j.jacc.2010.05.046](https://doi.org/10.1016/j.jacc.2010.05.046), indexed in Pubmed: [20951319](https://pubmed.ncbi.nlm.nih.gov/20951319/).

72. Zamanian RT, Haddad F, Doyle RL, et al. Management strategies for patients with pulmonary hypertension in the intensive care unit. *Crit Care Med*. 2007; 35(9): 2037–2050, doi: [10.1097/01.ccm.0000280433.74246.9e](https://doi.org/10.1097/01.ccm.0000280433.74246.9e), indexed in Pubmed: [17855818](https://pubmed.ncbi.nlm.nih.gov/17855818/).
73. Kmiec L, Philipp A, Floerchinger B, et al. Extracorporeal Membrane Oxygenation for Massive Pulmonary Embolism as Bridge to Therapy. *ASAIO J*. 2020; 66(2): 146–152, doi: [10.1097/MAT.0000000000000953](https://doi.org/10.1097/MAT.0000000000000953), indexed in Pubmed: [30720492](https://pubmed.ncbi.nlm.nih.gov/30720492/).
74. Karami M, Mandigers L, Miranda DD, et al. Survival of patients with acute pulmonary embolism treated with venoarterial extracorporeal membrane oxygenation: A systematic review and meta-analysis. *J Crit Care*. 2021; 64: 245–254, doi: [10.1016/j.jcrc.2021.03.006](https://doi.org/10.1016/j.jcrc.2021.03.006), indexed in Pubmed: [34049258](https://pubmed.ncbi.nlm.nih.gov/34049258/).
75. Kaso ER, Pan JA, Salerno M, et al. Venoarterial Extracorporeal Membrane Oxygenation for Acute Massive Pulmonary Embolism: a Meta-Analysis and Call to Action. *J Cardiovasc Transl Res*. 2022; 15(2): 258–267, doi: [10.1007/s12265-021-10158-0](https://doi.org/10.1007/s12265-021-10158-0), indexed in Pubmed: [34282541](https://pubmed.ncbi.nlm.nih.gov/34282541/).
76. Elbadawi A, Mentias A, Elgendy IY, et al. National trends and outcomes for extracorporeal membrane oxygenation use in high-risk pulmonary embolism. *Vasc Med*. 2019; 24(3): 230–233, doi: [10.1177/1358863X18824650](https://doi.org/10.1177/1358863X18824650), indexed in Pubmed: [30834824](https://pubmed.ncbi.nlm.nih.gov/30834824/).
77. Goldberg JB, Giri J, Kobayashi T, et al. Surgical Management and Mechanical Circulatory Support in High-Risk Pulmonary Embolisms: Historical Context, Current Status, and Future Directions: A Scientific Statement From the American Heart Association. *Circulation*. 2023; 147(9): e628–e647, doi: [10.1161/CIR.0000000000001117](https://doi.org/10.1161/CIR.0000000000001117), indexed in Pubmed: [36688837](https://pubmed.ncbi.nlm.nih.gov/36688837/).
78. Giri J, Sista AK, Weinberg I, et al. Interventional Therapies for Acute Pulmonary Embolism: Current Status and Principles for the Development of Novel Evidence: A Scientific Statement From the American Heart Association. *Circulation*. 2019; 140(20): e774–e801, doi: [10.1161/CIR.0000000000000707](https://doi.org/10.1161/CIR.0000000000000707), indexed in Pubmed: [31585051](https://pubmed.ncbi.nlm.nih.gov/31585051/).
79. Weinberg A, Tapson VF, Ramzy D. Massive Pulmonary Embolism: Extracorporeal Membrane Oxygenation and Surgical Pulmonary Embolectomy. *Semin Respir Crit Care Med*. 2017; 38(1): 66–72, doi: [10.1055/s-0036-1597559](https://doi.org/10.1055/s-0036-1597559), indexed in Pubmed: [28208200](https://pubmed.ncbi.nlm.nih.gov/28208200/).
80. Liu Z, Chen J, Xu X, et al. Extracorporeal Membrane Oxygenation-First Strategy for Acute Life-Threatening Pulmonary Embolism. *Front Cardiovasc Med*. 2022; 9: 875021, doi: [10.3389/fcvm.2022.875021](https://doi.org/10.3389/fcvm.2022.875021), indexed in Pubmed: [35722115](https://pubmed.ncbi.nlm.nih.gov/35722115/).

81. Mostafa A, Briasoulis A, Telila T, et al. Treatment of Massive or Submassive Acute Pulmonary Embolism With Catheter-Directed Thrombolysis. *Am J Cardiol.* 2016; 117(6): 1014–1020, doi: [10.1016/j.amjcard.2015.12.041](https://doi.org/10.1016/j.amjcard.2015.12.041), indexed in Pubmed: [26833207](https://pubmed.ncbi.nlm.nih.gov/26833207/).
82. VanDyck TJ, Pinsky MR. Hemodynamic monitoring in cardiogenic shock. *Curr Opin Crit Care.* 2021; 27(4): 454–459, doi: [10.1097/MCC.0000000000000838](https://doi.org/10.1097/MCC.0000000000000838), indexed in Pubmed: [33967209](https://pubmed.ncbi.nlm.nih.gov/33967209/).
83. Ventetuolo CE, Klinger JR. Management of acute right ventricular failure in the intensive care unit. *Ann Am Thorac Soc.* 2014; 11(5): 811–822, doi: [10.1513/AnnalsATS.201312-446FR](https://doi.org/10.1513/AnnalsATS.201312-446FR), indexed in Pubmed: [24828526](https://pubmed.ncbi.nlm.nih.gov/24828526/).
84. Erol S, Gürün Kaya A, Arslan Ciftçi F, et al. Is oxygen saturation variable of simplified pulmonary embolism severity index reliable for identification of patients, suitable for outpatient treatment. *Clin Respir J.* 2018; 12(2): 762–766, doi: [10.1111/crj.12591](https://doi.org/10.1111/crj.12591), indexed in Pubmed: [27997739](https://pubmed.ncbi.nlm.nih.gov/27997739/).
85. Messika J, Goutorbe P, Hajage D, et al. Severe pulmonary embolism managed with high-flow nasal cannula oxygen therapy. *Eur J Emerg Med.* 2017; 24(3): 230–232, doi: [10.1097/MEJ.0000000000000420](https://doi.org/10.1097/MEJ.0000000000000420), indexed in Pubmed: [28452810](https://pubmed.ncbi.nlm.nih.gov/28452810/).
86. Song HZ, Gu JX, Xiu HQ, et al. The value of high-flow nasal cannula oxygen therapy after extubation in patients with acute respiratory failure. *Clinics (Sao Paulo).* 2017; 72(9): 562–567, doi: [10.6061/clinics/2017\(09\)07](https://doi.org/10.6061/clinics/2017(09)07), indexed in Pubmed: [29069260](https://pubmed.ncbi.nlm.nih.gov/29069260/).
87. Jardin F, Vieillard-Baron A. Right ventricular function and positive pressure ventilation in clinical practice: from hemodynamic subsets to respirator settings. *Intensive Care Med.* 2003; 29(9): 1426–1434, doi: [10.1007/s00134-003-1873-1](https://doi.org/10.1007/s00134-003-1873-1), indexed in Pubmed: [12910335](https://pubmed.ncbi.nlm.nih.gov/12910335/).
88. Vassilakopoulos T, Zakynthinos S, Roussos Ch. Respiratory muscles and weaning failure. *Eur Respir J.* 1996; 9(11): 2383–2400, doi: [10.1183/09031936.96.09112383](https://doi.org/10.1183/09031936.96.09112383), indexed in Pubmed: [8947090](https://pubmed.ncbi.nlm.nih.gov/8947090/).
89. Zochios V, Keeshan A. Pulmonary Embolism in the Mechanically-Ventilated Critically Ill Patient: Is it Different? *J Intensive Care Soc.* 2013; 14(1): 36–44, doi: [10.1177/175114371301400109](https://doi.org/10.1177/175114371301400109).
90. Torbicki A, Perrier A, Konstantinides S, et al. Guidelines on the diagnosis and management of acute pulmonary embolism: the Task Force for the Diagnosis and Management of Acute Pulmonary Embolism of the European Society of Cardiology

- (ESC). *Eur Heart J*. 2008; 29(18): 2276–2315, doi: [10.1093/eurheartj/ehn310](https://doi.org/10.1093/eurheartj/ehn310), indexed in Pubmed: [18757870](https://pubmed.ncbi.nlm.nih.gov/18757870/).
91. Carreaux G, Millán-Guilarte T, De Prost N, et al. Failure of Noninvasive Ventilation for De Novo Acute Hypoxemic Respiratory Failure: Role of Tidal Volume. *Crit Care Med*. 2016; 44(2): 282–290, doi: [10.1097/CCM.0000000000001379](https://doi.org/10.1097/CCM.0000000000001379), indexed in Pubmed: [26584191](https://pubmed.ncbi.nlm.nih.gov/26584191/).
92. Sedhom R, Elbadawi A, Megaly M, et al. Hospital procedural volume and outcomes with catheter-directed intervention for pulmonary embolism: a nationwide analysis. *Eur Heart J Acute Cardiovasc Care*. 2022; 11(9): 684–692, doi: [10.1093/ehjacc/zuac082](https://doi.org/10.1093/ehjacc/zuac082), indexed in Pubmed: [35830539](https://pubmed.ncbi.nlm.nih.gov/35830539/).
93. Jung RG, Simard T, Hibbert B, et al. Association of annual volume and in-hospital outcomes of catheter-directed thrombolysis for pulmonary embolism. *Catheter Cardiovasc Interv*. 2022; 99(2): 440–446, doi: [10.1002/ccd.30080](https://doi.org/10.1002/ccd.30080), indexed in Pubmed: [35083846](https://pubmed.ncbi.nlm.nih.gov/35083846/).

Table 1. Typical clinical scenarios warranting PERT consultation
Acute high-risk PE with contraindications to ST or after ineffective ST
Acute intermediate-high-risk PE with clinical and hemodynamic deterioration during anticoagulant treatment—clinical, imaging, and/or laboratory data indicating worsening of PE (Table 4)
Acute intermediate-high-risk PE without clinical and hemodynamic improvement despite anticoagulant therapy—clinical, imaging and/or laboratory data indicating persistence of PE (Table 4)
Acute intermediate-high-risk PE with absolute contraindications to ST
Acute PE with a thrombus in the RV, the so-called thrombus in transit, including the presence of a thrombus passing through the PFO/ASD.
Acute PE with coexisting symptoms of paradoxical embolism such as acute myocardial infarction, ischemic stroke
Acute high-risk or intermediate-high-risk PE in a pregnant patient
Acute nonthrombotic PE (eg, fat embolism, amniotic fluid, iatrogenic embolism)
Acute PE superimposed on chronic thromboembolic pulmonary hypertension
Acute PE with existing contraindications/complications of anticoagulant treatment
Abbreviations: ASD, atrial septal defect; PE, pulmonary embolism, PFO, patent foramen

ovale; RV, right ventricle; ST, systemic thrombolysis

Table 2. Key features to be assessed on chest computed tomography angiography in patients with acute pulmonary embolism considered for catheter-directed therapy

<p>Determination of direct symptoms of acute PE</p> <p>Location of individual thrombi, central (main and lobar arteries)/peripheral (segmental and subsegmental arteries) embolism</p> <p>Differentiation of acute/chronic embolism</p> <p>Assessment of pulmonary artery trunk diameter</p> <p>Features of right ventricular overload (the right ventricle/left ventricle diameter ratio, flattening or leftward shift of the interventricular septum, contrast agent pooling in the inferior vena cava and hepatic veins)</p> <p>Presence of significant thoracic abnormalities, with particular emphasis on pulmonary parenchymal abnormalities</p>
<p>Abbreviations: see Table 1</p>

Table 3. Classification of pulmonary embolism based on severity and risk of early (in-hospital or 30-day) death

Risk of early death	Risk factor			
	Hemodynamic instability	Clinical indices of the severity of acute PE and/or comorbidities: PESI class III-IV or sPESI ≥ 1	RV dysfunction on TTE or CTPA (PK/LK >1 or TAPSE ≤ 16 mm)	Elevated cardiac troponin levels

High		+	(+) ^a	+	(+) ^a
Intermediate	High	–	+	+	+
	Low	–	+	One or none present	
Low		–	–	–	Optional testing; if negative

a Troponin levels or PESI or sPESI scores are not required for the diagnosis of acute high-risk PE

Abbreviations: CTPA, computed tomography pulmonary angiogram; PESI, Pulmonary Embolism Severity Index; sPESI, simplified Pulmonary Embolism Severity Index; TAPSE, tricuspid annular plane systolic excursion; TTE, transthoracic echocardiography; other — see [Table 1](#)

Table 4. Clinical, imaging, and laboratory indicators of pulmonary embolism severity in patients without hemodynamic instability^a [2]

Clinical	Imaging	Laboratory
HR >100/min SBP 90–100 mm Hg Respiratory rate > 20 breaths/min SaO ₂ < 90% (without oxygen therapy) Comorbidities: heart failure, active neoplasm	Echocardiography (at least 1 parameter) RV/LV >1.0 TAPSE ≤16 mm No inspiratory collapsibility of the IVC CTPA: RV/LV >1.0	elevated troponin levels or NT-proBNP >600 pg/ml or Lactate level ≥2 mmol/l

Abbreviations: SBP, systolic blood pressure; HR, heart rate; IVC, inferior vena cava; LV, left ventricle; NT-proBNP, N-terminal fragment of B-type natriuretic propeptide; SaO₂, arterial blood oxygen saturation; other — see [Tables 1 and 3](#)

*Adapted from „Pruszczyk P, Klok FA, Kucher N, et al. Percutaneous treatment options for acute pulmonary embolism: a clinical consensus statement by the ESC Working Group on Pulmonary Circulation and Right Ventricular Function and the European Association of Percutaneous Cardiovascular Interventions. *EuroIntervention*. 2022; 18(8): e623–e638”

Table 5. Indications for catheter-directed therapies in acute pulmonary embolism

Risk of death	Indications ^a	Comment
High	<ul style="list-style-type: none"> – Contraindications to ST (Table 6) – Ineffective ST (Table 7) 	Systemic thrombolysis is the first-line treatment in patients with acute high-risk PE and no contraindications ^b
Intermediate-high	<ul style="list-style-type: none"> – Failure of anticoagulation defined as hemodynamic deterioration or lack of improvement (Table 7) 	CDT appears to have a more favorable safety profile compared with ST

^a Catheter-directed treatment is an alternative to surgical embolectomy. The decision on the use of one of these methods should be consulted by PERT and should be based on individual characteristics of pulmonary embolism episode, the patient’s condition, and availability of experienced interventional or surgical teams

^bIn our opinion, in patients with acute high-risk PE in whom percutaneous or cardiac surgery cannot be performed, relative contraindications to thrombolysis should not preclude the use of ST as a life-saving treatment.

Abbreviations: see [Table 1](#) and [Figure 1](#)

Table 6. Absolute and relative contraindications to fibrinolytic treatment based on Konstantinides et al. [5]

Absolute contraindications	Relative contraindications
– History of hemorrhagic stroke or stroke of unknown origin	– Transient ischemic attack in previous 6 months

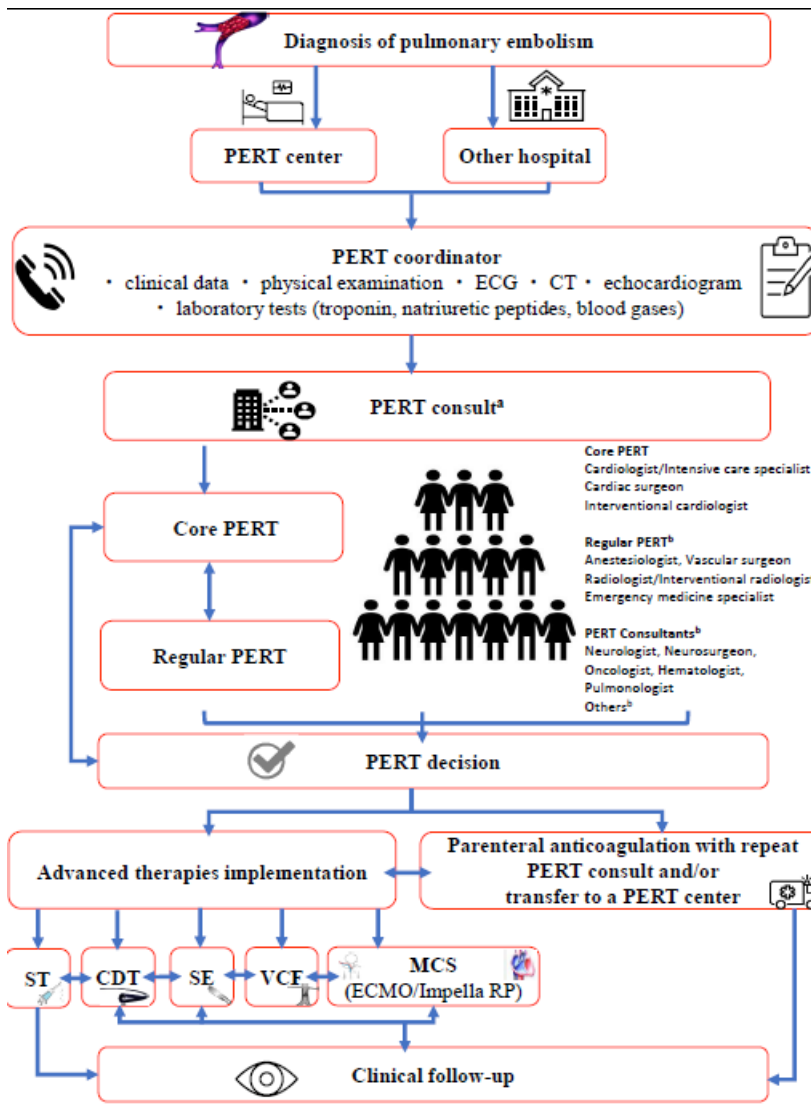
<ul style="list-style-type: none"> – Ischemic stroke in previous 6 months – Major trauma, surgery, or head injury in previous 3 weeks – Central nervous system neoplasm – Hemorrhagic diathesis – Active bleeding 	<ul style="list-style-type: none"> – Oral anticoagulation – Pregnancy or first postpartum week – Noncompressible puncture sites – Traumatic resuscitation – Refractory hypertension (systolic blood pressure >180 mm Hg) – Advanced liver disease – Infective endocarditis – Active peptic ulcer disease – Use of extracorporeal membrane oxygenation
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Table 7. Definition of pharmacological treatment failure in acute pulmonary embolism		
Clinical setting	No improvement^a	Hemodynamic deterioration^b
Ineffective ST in patients with acute high-risk PE	No hemodynamic improvement 2–4 hours after completing full-dose ST	Overt cardiorespiratory instability necessitating cardiopulmonary resuscitation, mechanical ventilation, catecholamines, or ECMO
Ineffective anticoagulation in intermediate-high-risk patients	No improvement in parameters shown in Table 4 despite therapeutic anticoagulation	or escalation of the parameters shown in Table 4
<p>a Despite full-dose anticoagulation/fibrinolysis</p> <p>b After starting anticoagulation/fibrinolysis</p> <p>Abbreviations: see Table 1</p>		

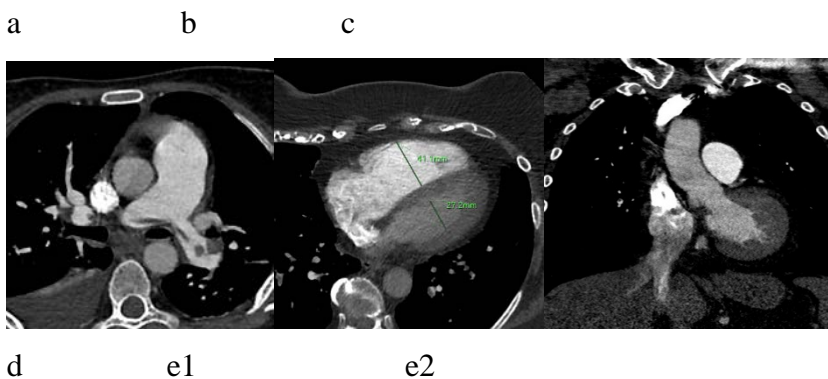
Table 8. Effects of vasopressors and inotropes on selected hemodynamic parameters			
Drug/dose	Hemodynamic effects	Drug/dose	Hemodynamic effects
Dopamine 0.5–20 µg/kg/min	↑CO ↑PVR ↑SVR	Dobutamine 2.5–20 µg/kg/min	↑↑CO ↓PVR ↓SVR
Adrenaline 0.01–0.5 µg/kg/min	↑↑CO ↑PVR ↑↑SVR	Milrinone 0.125–0.75 µg/kg/min	↑CO ↓PVR ↓SVR
Norepinephrine 0.05–0.4 µg/kg/min	↑CO ↑PVR ↑↑SVR	Enoximone 2–10 µg/kg/min	↑CO ↓PVR ↓SVR
Vasopressin 0.02–0.04 U/min	↔ PVR ↑↑SVR	Levosimendan 0.05–0.2 µg/kg/min	↑CO ↓PVR ↓SVR
Abbreviations: ↑, increase; ↓ decrease; CO, cardiac output; PVR, pulmonary vascular resistance; SVR, systemic vascular resistance			

Figure 1. A detailed chart of PERT organization.

Abbreviations: ECG, electrocardiogram; CDT, catheter-directed treatment; MCS, mechanical circulatory support; SPE, surgical pulmonary embolectomy; CT, computed tomography; IVCF, inferior vena cava filter; other — see [Table 1](#)



^aConsultations are usually held with the use of telecommunications tools, including those enabling the transmission of imaging test results, ^badditionally, as needed



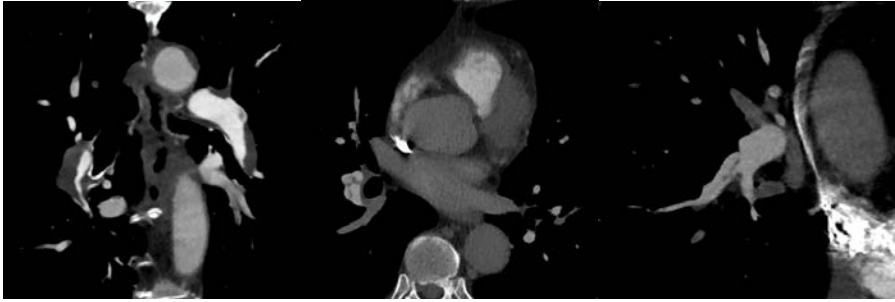


Figure 2. Features of pulmonary embolism (PE) on computed tomographic pulmonary angiogram. Acute PE: saddle PE, that is, a thrombus at the bifurcation of the dilated pulmonary trunk (**A**); dilatation of the right ventricle with flattening of the interventricular septum (**B**); right ventricular to left ventricular diameter ratio, 1.5; contrast agent pooling into the inferior vena cava and hepatic veins (**C**). Chronic PE: wall-adherent thrombi within the pulmonary arteries (**D**); **E1** and **E2** – stenosis and septations in the lumen of the arteries of the right lower lobe

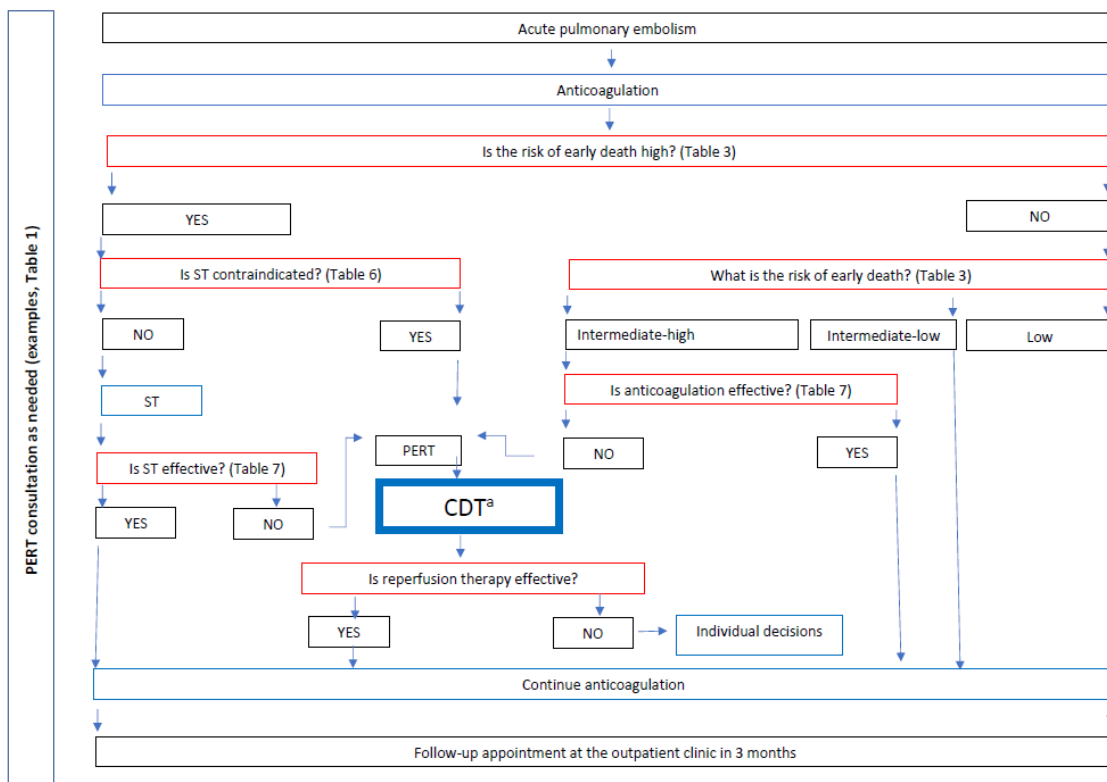


Figure 3. The role of catheter-directed therapies in acute pulmonary embolism (PE).

Red boxes include essential questions to be answered when determining the best therapeutic strategy for a patient with acute PE. Blue boxes indicate treatment methods used in a specific clinical situations.

^aIn patients with acute high-risk PE and contraindications to systemic thrombolysis (ST), surgical pulmonary embolectomy (ESC class I recommendation) or percutaneous treatment (ESC class IIa recommendation) is recommended. In patients with acute high-risk PE in whom percutaneous or cardiac surgery cannot be performed, relative contraindications to thrombolysis should not preclude the use of ST as a life-saving treatment.

^bIn intermediate-high-risk patients who deteriorate hemodynamically on anticoagulant therapy, rescue thrombolytic therapy (ESC class IB recommendation) is advised; alternatively, surgical embolectomy (ESC class IIa recommendation) or transcatheter therapy (ESC class IIa recommendation) should be considered. In our opinion, in patients who do not improve with anticoagulation as well as in patients with an increased risk of bleeding who deteriorate clinically/hemodynamically, catheter-directed therapies should be considered as a safer and no less effective modality compared with ST or surgical pulmonary embolectomy

Abbreviations: PERT, pulmonary embolism response team; other — see [Table 1](#) and [Figure 1](#)

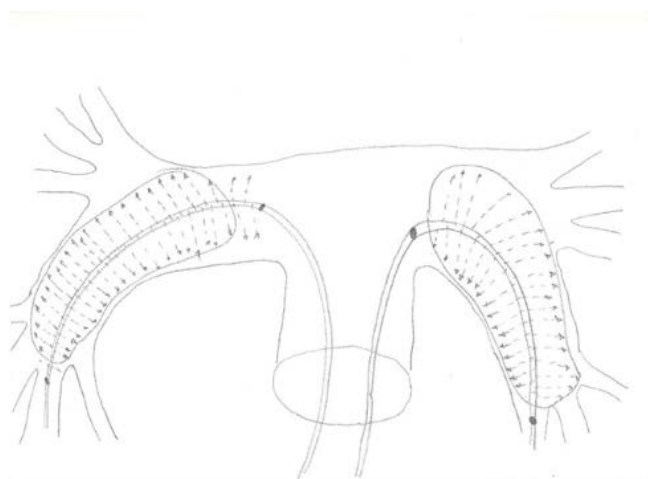


Figure 4. Catheter-directed thrombolysis. The treatment zones on the catheters used for the fibrinolytic drug delivery (marker bands/black markers) are placed in the thrombus filling the right and left pulmonary arteries. The thrombolytic drug penetrates the thrombus through numerous small holes in the catheter walls in the treatment zones. This mode of administration allows for significantly smaller doses while maintaining high efficacy and a better safety profile compared with systemic thrombolysis [22]

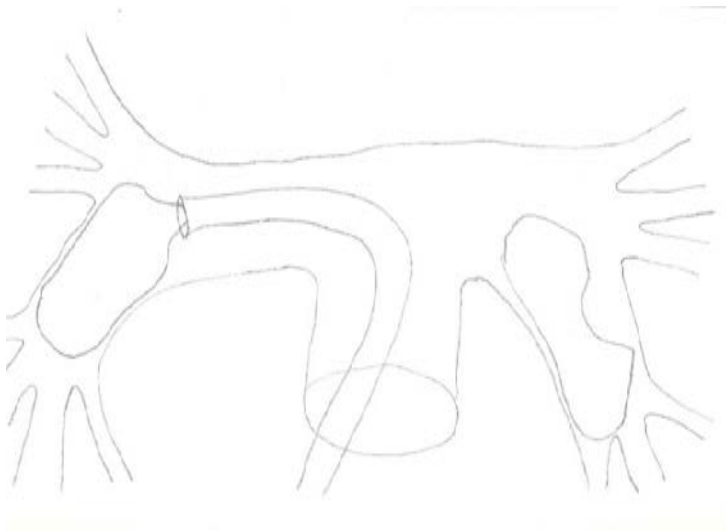


Figure 5. Catheter-directed mechanical thrombectomy. The catheter used to remove the thrombus is placed in the right pulmonary artery