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Outcomes of lung transplantation for end stage lung disease with connective tissue disease: a systematic review and meta-analysis

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Abstract

Background Lung transplantation is the most important treatment for end-stage lung disease. However, the clinical outcomes of lung transplantation in patients with connective tissue disease(CTD) complicated with end-stage pulmonary complications are unclear. Consequently, we performed a systematic review and meta-analysis to compare the survival rates and incidences of adverse events between patients with and without CTD who underwent lung transplantation for end-stage lung disease.

Methods We searched the PubMed, Embase, Web of Science, Cochrane, Wanfang, VIP, CNKI, and CBM databases from their inception until October 18, 2023, for eligible studies. A meta-analysis of each study was performed using State14.0 with a 95% confidence interval (CI). A randomized or fixed-effect model was applied according to the heterogeneity test. The systematic review was registered in PROSPERO (CRD42023483687).

Results Our final analysis included 12 publications on 369 patients with CTD and 2,165 without, all of whom underwent lung transplantation. The survival at 1 month (OR = 2.20, 95% CI: 0.75–6.47, *P* = 0.485), 6 months (OR = 0.61, 95% CI: 0.33–1.14, *P* = 0.099), 1 year (OR = 1.05, 95% CI: 0.66–1.66, *P* = 0.982), 2 years (OR = 0.50, 95% CI: 0.23–1.06, *P* = 0.096), 3 years(OR = 1.11, 95% CI: 0.70–1.78, *P* = 0.703) and 5 years (OR = 2.08, 95% CI: 1.11–3.91, *P* = 0.027), grade 3 primary graft dysfunction (PGD) incidence (OR = 1.33, 95% CI: 0.68–2.60, *P* = 0.184), rejection events incidence (OR = 1.19, 95% CI: 0.61–2.32, *P* = 0.607) and intensive care unit (ICU) LOS (SMD = 0.54, 95% CI:-0.26-1.34, *P* = 0.187) were similar between the two groups. Patients with CTD had a greater risk of PGD incidence (OR = 2.91, 95% CI: 1.43–5.95, *P* = 0.003), a longer post-transplant hospital length of stay (LOS) (SMD = 0.52, 95% CI: 0.09–0.96, *P* = 0.009) and post-transplant time to extubation (SMD = 0.68, 95% CI: 0.12–1.25, *P* = 0.023).

Conclusions The survival rate and the incidence of grade 3 PGD in CTD patients after lung transplantation are comparable to those of other patients undergoing lung transplantation for end-stage lung disease. Thus, Lung transplantation should be a strongly considered therapeutic option for patients with CTD who are suffering from end-stage lung disease. Nevertheless, when selecting patients with CTD for lung transplantation, it is crucial to focus on enhancing perioperative management to reduce the burden of hospitalization post-transplantation.

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Keywords Connective tissue disease, Lung transplantation, Primary graft dysfunction, Meta-analysis

Introduction

Connective tissue disease (CTD) is a heterogeneous group of disorders characterized by abnormal connective tissue morphology and function that can involve multiple systems.

It mainly includes systemic sclerosis (SSc), rheumatoid arthritis (RA), dermatomyositis and polymyositis (DM/PM), Sjögren's syndrome, antisynthetase syndrome, systemic lupus erythematosus, and mixed connective tissue disease [1]. CTD most commonly affects the lungs. Studies have shown that more than 50% of patients with CTD develop interstitial lung disease or pulmonary hypertension, and some patients will eventually develop end-stage lung disease, which significantly increases their risk of mortality [2–4].

Lung transplantation is the most important treatment for end-stage lung disease, and is becoming increasingly utilized in clinical practice. Research has shown that lung transplantation significantly improves the survival rate and prognosis for patients with end-stage lung disease [5–7]. Among them, patients with idiopathic pulmonary fibrosis (IPF) are the main recipients of lung transplantation, accounting for 30% of lung transplantation. The American Thoracic Society/European Respiratory Society/Japanese Respiratory Society/Latin American Thoracic society (ATS/ERS/JRS/ALAT) guideline suggest that lung transplantation can reduce the risk of death by 75% in patients with IPF compared to treatment alone [8]. However, despite the increasing number of lung transplants, primary graft dysfunction (PGD) remains the leading cause of death in perioperative lung transplant patients, with an incidence of approximately 10–30% and a mortality rate of up to 40%. PGD3, in particular, has a 5-year mortality rate of up to 60% [9, 10]. For patients with CTD and end-stage lung disease, lung transplantation is an effective treatment option [1]. However, it remains unclear whether there are differences in survival and prognosis between CTD patients and other patients after lung transplantation, as the underlying disease in CTD patients has not been corrected.

Several studies have demonstrated that survival after lung transplantation for CTD was comparable with that of other patients, but the study populations are mainly from public databases on organ transplantation [11–14]. It remains unclear whether the survival outcomes of CTD patients after lung transplantation are consistent with those of other patients when compared based on other clinical data. Furthermore, multiple investigations have documented varying incidences of PGD post-lung transplantation in patients with CTD compared to those without CTD, yet the outcomes remain inconsistent [15–17]. Therefore, in order to compare the survival rates and incidences of adverse events between patients with and without CTD who underwent lung transplantation for end-stage lung disease, we conducted a systematic review and meta-analysis of the existing literature.

Materials and methods

Search strategy

We searched for studies published in Chinese or English in the PubMed, Embase, Web of Science, Cochrane, Wanfang, VIP, CNKI, and CBM databases from their respective inceptions until October 18, 2023. The search strategy included the following two main criteria: lung transplantation and connective tissue disease. A more detailed search strategy, which was modified accordingly for the different databases, is shown in Appendix 1. The protocol for this review was registered and published in the International Prospective Register of Systematic Reviews (PROSPERO) under reference number CRD42023483687.

Study selection

PGD is an early form of acute lung injury that occurs within 72 h of post-transplant. The grading criteria were determined by assessing the extent of diffuse pulmonary infiltrates evident on chest imaging and the severity of hypoxemia, as indicated by the ratio of partial arterial oxygen pressure (PaO_2) over the fraction of inspired oxygen (FiO_2). Grade 3 PGD is determined by post-transplant arterial blood gas analysis: $PaO_2/FiO_2 < 200$ and diffuse alveolar lesions on chest radiography [18, 19].

A study was included in this meta-analysis if it met the following criteria: (1) the study comparing post-transplant outcomes in patients who had lung transplantation for CTD with those who had lung transplantation for other indications; (2) the study focused on the post-transplant survival, rejection, the occurrence of PGD, hospital length of stay(LOS), intensive care unit (ICU) LOS, post-transplant time to extubation; (3) the patients' aged were at least 18 years; (4) it was an observational study; and (5) the study was published before October 18, 2023. Studies were excluded if: (1) they were based on analysis of United Network for Organ Sharing (UNOS) or Scientific Registry of Transplant Recipients (SRTR) national databases; (2) they used different outcome measures; (3) the study design was incomplete; (4) reviews, case reports, editorials, letters, meta-analyses, correspondences, or studies involving animal research; (5) duplicated studies; (6) full text was not available; or (7) the study was published in a language other than English and Chinese.

Data extraction and quality assessment

Two researchers extracted all data independently, and the following information was included: name of the first author, year of publication, size of the sample, study design, population type, smoking history and post-transplant outcomes. The quality of the included studies was assessed using a modified Newcastle-Ottawa Scale for cohort studies. This method evaluates the quality of the included studies from three aspects: selection, comparability and outcome. It is divided into 9 points, and the quality of the study is evaluated separately for every point [20].

Statistical analysis

State version 14.0 was used to analyse lung transplantation outcomes for CTD. Dichotomous outcomes are expressed as odds ratio (OR) and 95% confidence interval (CI). Continuous outcomes are expressed as standardized mean difference (SMD) and 95% CI. We assessed the heterogeneity across studies using the I^2 statistics, and I^2 > 50% indicated significant heterogeneity. The random-effect model was used. Otherwise, the fixed-effect model was used. When we confirmed heterogeneity, a sensitivity analysis was conducted by omitting each study to assess individual studies' influence. Finally, publication bias was analysed using funnel plots.

Result

Results of studies screening

We initially identified 7,218 studies using our search criteria, of which 6,184 remained after removing duplicates. After eliminating duplicate literature, reading titles, abstracts, and full texts and strictly following the inclusion and exclusion criteria for literature screening. The remaining 12 studies were included in our meta-analysis, as is shown in Fig. 1 [15–17, 21–29].

Basic characteristics and quality assessment of the included studies

All 12 studies were published in English. A total of 7 literature case groups were SSc, 4 literature case groups were CTD, and 1 literature was PM/DM and non-myositis connective tissue disease (NM-CTD) patients. Most of the studies (7/12) had IPF in the control population. One study compared patients who were matched to those with CTD by basic characteristics. Patients with CTD were significantly younger (6/11) and more likely female (8/11) than patients without CTD. Some studies (2/7) showed that patients with CTD lung transplantation had a higher body mass index (BMI). The basic characteristics of the selected studies are listed in Table 1. Most of the included studies had satisfactory quality with reasonable selection criteria, comparable patient characteristics, and adequate follow-up, as shown in Table 2.

Results of Meta-analysis

Survival

Three studies reported 1-month patient survival, three studies reported 6-month patient survival, 6 studies reported patient survival at 1 year, 2 studies at 2 years, 4 studies at 3 years, and 3 studies at 5 years. The I^2 =23.0%, so a fixed-effect model was used for statistical analysis [15, 17, 21, 22, 25–29]. Pooled results of 1 month (OR = 2.20, 95% CI: 0.75–6.47, P = 0.485), 6 months (OR = 0.61, 95% CI: 0.33–1.14, P = 0.099), 1 year (OR = 1.05, 95% CI: 0.66–1.66, P = 0.982), 2 years (OR = 0.50, 95% CI: 0.23–1.06, P = 0.096), 3 years (OR = 1.11, 95% CI: 0.70–1.78, P = 0.703) and 5 years (OR = 2.08, 95% CI: 1.11–3.91, P = 0.027) patient survival

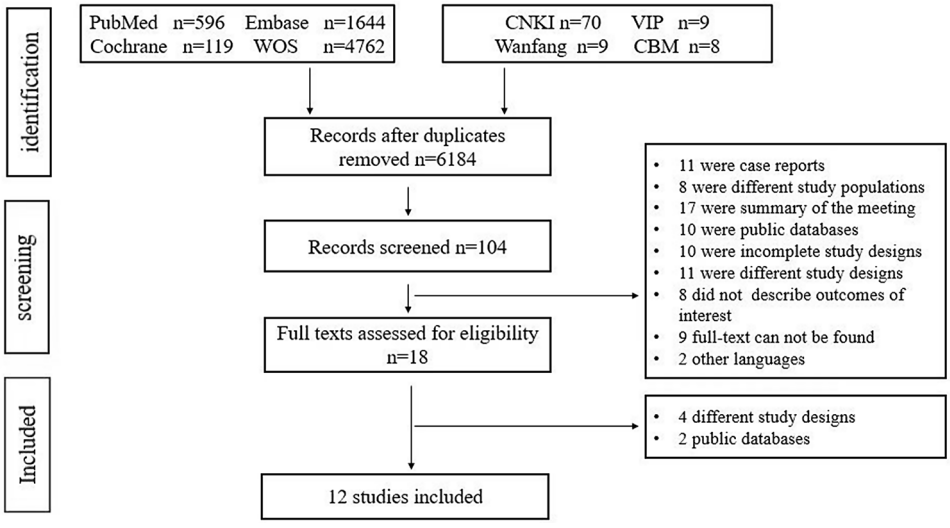

Fig. 1 Flow diagram of study selection

Table 1 Basic information about the included studies

Studie(s)	Arms	Sample size	Recipients age (y, mean ± SD)	Recipients' female (%)	Recipients BMI (kg/m^2)	Recipients smoking history(%	trans-plant type[#]
fernandez2017	SSc	15	52.17 ± 2.59	10 (67%)	NR	9 (60%)	4/11/0
	Non-SSc	500	53.91 ± 2.48	194 (39%)*	NR	NR	178/322/0
ju2021	CTD	31	53.2 ± 13.7	19 (61.3%)	21.62 ± 3.40	2 (6.5%)	12/18/1
	IPF	98	62.3 ± 7.2	7 (7.1) **	20.83 ± 2.72	7 (7.1%)	41/57/0
miele2016	SSc	35	50.7 ± 9.5	17 (49%)	24.3 ± 4.3	NR	3/32/0
	Non-SSc	109	53.9 ± 8.6	43 (39%)	26 ± 4.8	NR	12/97/0
csucska2021	CTD	33	61.47 ± 8.91	NR	25.31 ± 7.21	NR	NR
	Non-CTD	461	NR	NR	NR	NR	NR
schachna2006	SSc	29	46.6 ± 9.6	16 (55%)	25.2 ± 2.9	14 (48%)	18/9/2
	IPF	70	55.7 ± 8.6*	28 (40%)	27.5 ± 3.8*	40 (57%)	66/4/0
	PAH	38	41.5 ± 9.3*	32 (84%)*	23.2 ± 6.5	9 (24%)*	29/5/4
sottile2013	SSc	23	49.3 ± 8.8	12 (52.2%)	22.9 ± 3.2	20 (43.5%)	NR
	Non-SSc	46	51.5 ± 7.9	21 (45.6%)	26.9 ± 4.9*	28 (53.8%)	NR
shruti2017	SSc	9	52.6 ± 8.1	7 (77.8%)	NR	NR	2/7/0
	Non-SSc	42	40.3 ± 12.7*	25 (59.5%)	NR	NR	3/26/13
nakayama2023	SSc	15	50.4 ± 11.1	10 (67%)	20.9 ± 5.2	9 (60%)	8/7/0
	IPF	20	55.1 ± 7.9	4 (20%)*	20.7 ± 4.2	15 (75%)	11/9
park2018	CTD	15	48.9 ± 14.7	10 (66.7%)	21.5 ± 3.2	NR	NR
	IPF	47	59.6 ± 6.9*	11 (23.4%)*	21.9 ± 3.3	NR	NR
yazdani2014	RA	10	59.4 ± 5.6	5 (50%)	24.1 ± 3.3	7 (70%)	3/6/1
	IPF	53	61.0 ± 4.04	15 (28%)	26.9 ± 4.0	39 (74%)	13/40/0
	SSc	17	45.4 ± 12.7[a, b]	10 (59%)[b]	27.6 ± 7.4	5 (33%)[b]	3/13/1
Yang xc2021	NM	28	55.0 ± 11.8	16 (57.1%)	21.6 ± 3.7	NR	22/6/0
	PM/DM	8	54.6 ± 9.9	3 (37.5%)	23.1 ± 2.0	NR	4/4/0
	IPF	180	59.2 ± 9.3*	15 (8.3%)*	21.3 ± 2.7	NR	130/50/0
natalini2021	CTD	101	55.6 ± 12.8	58 (58%)	26.1 ± 4.1	NR	16/80/NR
	IPF	501	64.3 ± 7.4 *	115 (23.7%)*	26.8 ± 3.5	NR	187/300/NR*

SSc, systemic sclerosis; IPF, idiopathic pulmonary fibrosis; CTD: connective tissue disease; PAH, pulmonary arterial hypertension; RA, rheumatoid arthritis; NM, non-myositis; PM/DM, dermatomyositis and polymyositis; NR: not reported; BMI: body mass index; SD, standard deviation

[#]Values are the number of patients undergoing single-lung/bilateral-lung/combined heart-lung transplantation

[*]There was a significant difference compared with the patients with CTD, $P<0.05$

[a]There was a significant difference was compared with the patients with RA, $P<0.05$

[b]There was a significant difference compared with the patients with IPF, $P<0.05$

was shown be similar between patients with CTD and without CTD after lung transplantation, as is shown in Fig. 2. Among them, analysis of 4 studies with patients with SSc in the case group, heterogeneity $I^2 = 26.4\%$, and a fixed-effect model was used for statistical analysis. Pooled results of the survival of post-transplant were shown to be equivalent between SSc patients and without CTD (OR = 1.13, 95% CI: 0.77–1.67, $P = 0.973$), as is shown in Appendix2 [22, 25, 27, 28]. Analysis of 6 studies with patients with IPF in the control group, heterogeneity $I^2 = 35.1\%$, and a fixed-effect model was used for statistical analysis. Pooled results of the survival of post-transplant was equivalent between patients with CTD and IPF (OR = 1.06, 95% CI: 0.78–1.44, $P = 0.710$), as shown in Appendix 3 [15, 17, 25–27, 29].

PGD

Three studies reported that the incidence of post-transplant PGD. The I^2 =35%; thus, the fixed-effect model was used for statistical analysis. The results showed the incidence of post-transplant PGD was considerably higher (OR = 2.91, 95% CI: 1.43 – 5 = – 0.95, $P = 0.003$) among patients with CTD compared with patients without CTD, as shown in Fig. 3 [15, 17, 26]. Five studies reported that the incidence of grade 3 PGD, the I^2 =53%, so a random-effect model was used for statistical analysis. Pooled results of post-transplant grade 3 PGD incidence were shown to be equivalent between patients with CTD and without CTD (OR = 1.33, 95% CI: 0.68–2.60, $P = 0.184$), as shown in Fig. 4 [15–17, 24, 26].

Table 2 NOS results for the included studies

Studie(s)	Selection				Comparability	Outcome		
	Representativeness Of the exposed cohort	Selection of the Non exposed cohort	Ascertainment of exposure	Incident disease	Comparability	Assessment of outcome	Length of follow-up	Adequacy of follow-up
fernandez2017	B	B	A	A	B	B	A	A
ju2021	A	A	A	A	B	B	A	B
miele2016	B	A	A	A	A	B	A	A
csucska2021	A	A	A	A	C	B	A	C
schachna2006	B	A	A	A	B	A	A	B
sottile2013	B	A	A	A	B	B	A	B
shruti2017	B	A	A	A	B	B	A	B
park2018	A	A	A	A	B	B	A	A
yazdani2014	B	A	A	A	A	B	A	A
nakayama2023	B	B	A	A	B	A	A	A
Yang xc2021	A	A	A	A	B	B	B	B

Selection: (1) Representativeness of the exposed cohort: A, truly representative of the average patient who underwent lung transplantation for CTD; B, somewhat representative of the average patient who underwent lung transplantation for CTD; C, selected group; and D, no description of the derivation of the cohort. **(2) Selection of the nonexposed cohort**: A, drawn from the same community as the exposed cohort; B, drawn from a different source; and C, no description of the derivation of the nonexposed cohort. **(3) Ascertainment of exposure**: A, secure record (e.g., surgical records); B, structured interview; C, written self-report; and D, no description. **(4) Demonstration that outcome of interest was not present at the start of the study**: A, yes; B, no; C, no description. **Comparability: (5) Comparability of cohorts based on the design or analysis**: A, study controls for comorbidities; B, study controls for additional risk factors (such as recipient or donor age, or severity of illness, and so forth); and C, not done. **Outcome: (6) Assessment of outcome**: A, independent blind assessment; B, record linkage; C, self-report; and D, no description. **(7) Was follow-up long enough for outcomes to occur**: A, yes; B, no. **(8) Adequacy of follow-up of cohorts**: A, complete follow-up—all subjects accounted for; B, subjects lost to follow-up unlikely to introduce bias (small number lost), follow-up rate higher than 90%, or description provided of those lost; C, follow-up rate 90% or lower (select an adequate percentage) and no description of those lost; and D, no statement

Rejection

Two studies reported the incidence of post-transplant rejection. The I^2 =0%, so a fixed-effect model was used for statistical analysis. Pooled results of post-transplant rejection were shown to be equivalent between patients with CTD and without CTD (OR = 1.19, 95% CI: 0.61–2.32, P = 0.607), as shown in Appendix 4 [23, 28].

ICU LOS, hospital LOS and extubation time

Five studies reported the incidence of ICU LOS, Hospital LOS and extubation time. The I^2 =80.6%, so a random-effect model was used for statistical analysis. The results showed that the incidence of hospital LOS (SMD = 0.52, 95% CI: 0.09–0.96, P = 0.009) and extubation time (SMD = 0.68, 95% CI: 0.12–1.25, P = 0.023) were considerably longer among patients with CTD compared with patients without CTD, as is shown in Fig. 5 [15–17, 23, 26].

Sensitivity analysis

The ICU LOS, hospital LOS, and extubation time were I^2>50%. Therefore, a sensitivity analysis was performed. The results did not change after each study was excluded individually, indicating that the results were relatively reliable, as is shown in Appendix 5.

Publication bias

Funnel plots were used to analyse publication bias in the ≥7 included studies. As can be seen in Appendix 6, the results showed that the plots were not completely symmetrical, suggesting a possible publication bias, this may be related to the small sample size of the included studies and the heterogeneity of the study populations.

Discussion

This is the first meta-analysis based on a comparison of clinical experience that will compare lung transplant outcomes in patients with CTD with other patients. The analysis revealed that there were no significant differences observed in postoperative survival rates, the incidence of grade 3 PGD, or the ICU LOS between the two groups. However, patients with CTD exhibited significantly higher overall incidence of PGD, hospital LOS, and extended postoperative extubation time compared to other lung transplant recipients.

Our results provide strong evidence for lung transplantation as a viable treatment for patients with CTD exhibiting end-stage lung disease. Notably, both short-term and long-term survival outcomes post-transplantation were comparable between CTD and non-CTD patients [1, 16, 30]. To our knowledge, this meta-analysis is the first to employ a statistical approach that corroborates the recommendations from the current organ transplant database, thereby underscoring the efficacy of lung transplantation for CTD-related end-stage lung disease based on clinical research. Notably, we performed subgroup analyses of patients with SSc, the most studied in the literature, to understand their postoperative survival outcomes. Our results indicate that there is no significant difference in the 1-year and 2-year survival rate of SSc

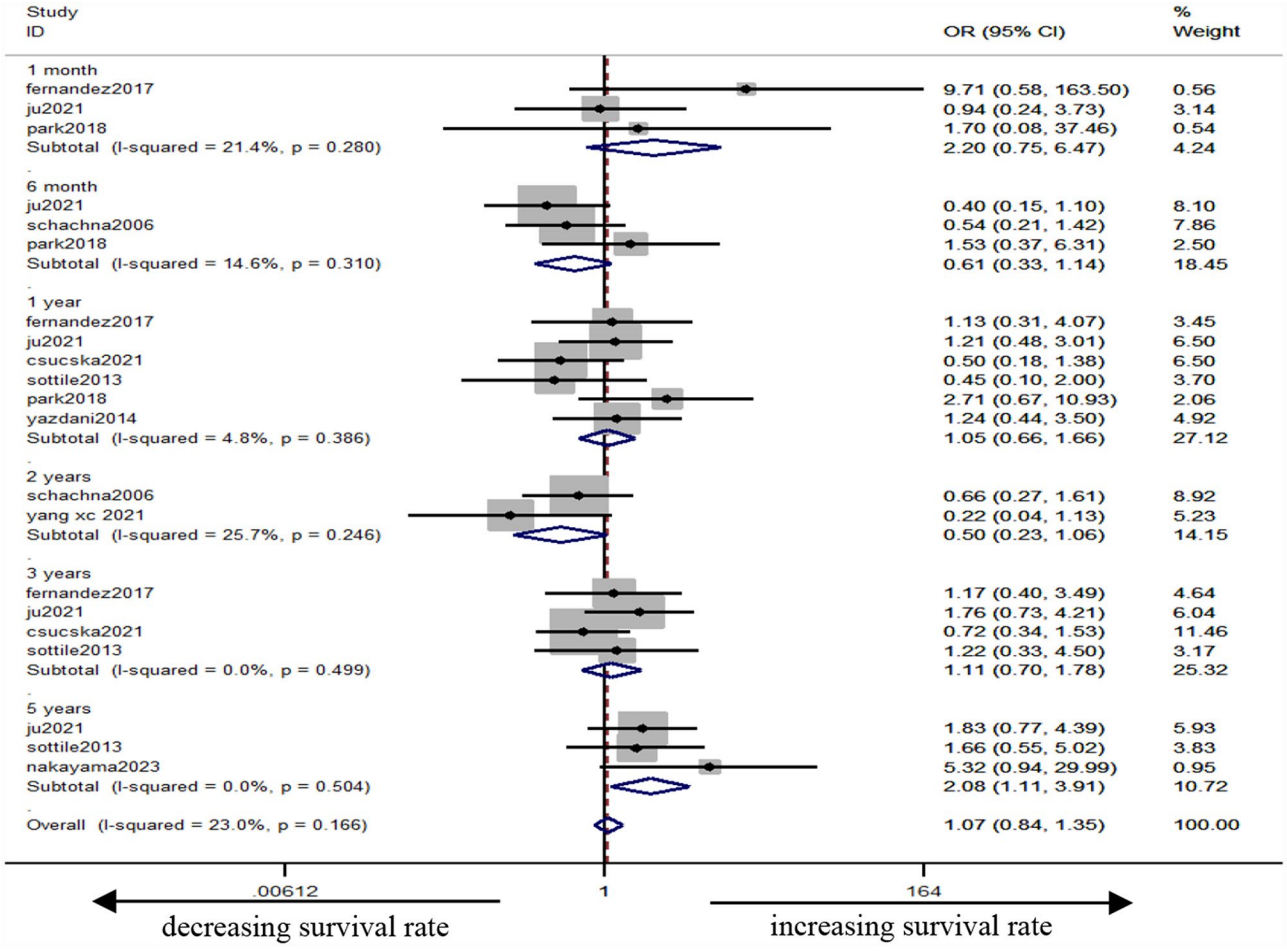

Fig. 2 Meta-analysis of the pooled effect of patient survival in patients who were transplanted for CTD vs. non-CTD

patients after lung transplantation compared with other lung transplant patients. However, the 5-year survival rate for SSc patients is significantly reduced compared to non-SSc patients. Several previous studies based on the public database on organ transplantation have shown no significant difference in the survival rate of patients with SSc who underwent lung transplantation compared with other lung transplant patients [30, 31]. Another study by Bernstein et al. based on the UNOS database, SSc patients who underwent lung transplantation at 1 year ($n = 229$) had a 48% increase in 1-year mortality compared with other patients [12]. This may suggest that the long-term survival rate of patients with SSc after lung transplantation is lower than that of other lung transplant patients. However, due to the lack of research momentum, the lack of subgroup analysis of other lung transplant patients according to disease type, and the limited clinical data provided by the current study, we are unable to further determine the exact reason for the difference in the five-year survival rate between SSc and other patients after lung transplantation.

PGD affects approximately 30% of lung transplant recipients, resulting in lower survival rates in lung transplant recipients compared with other solid organ transplant recipients [18, 19]. The prognosis for grade 3 PGD is significantly worse than that for grade 1 or grade 2 PGD. Specifically, grade 3 PGD is associated with a 5-year mortality rate of up to 60%, which is considerably higher than for lower grades. Moreover, grade 3 PGD is also linked to higher rates of postoperative bronchiolitis obliterans (BOS), in addition to increased short- and long-term mortality [10]. Our study showed that the incidence of grade 3 PGD is comparable between CTD and non-CTD patients. To a certain extent, this proves that the survival rate of CTD patients after lung transplantation is no different from that of other patients, suggesting that lung transplantation is an effective treatment for CTD-related end-stage lung disease.

Our study also showed that patients with CTD had a higher incidence of PGD after lung transplantation, this suggests that CTD patients have a higher risk of PGD grade 1–2 after transplantation compared with other lung transplant patients, which may be related to the race,

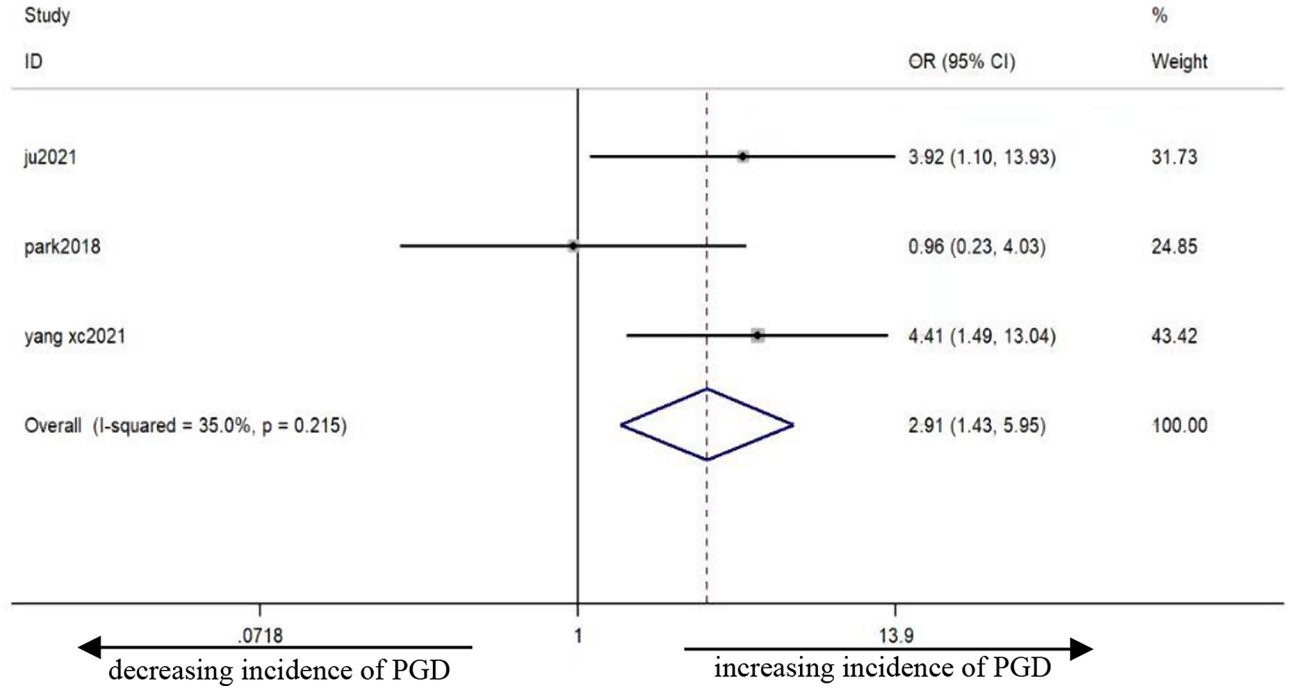

Fig. 3 Meta-analysis of the incidence of PGD in patients who post-transplant for CTD vs. non-CTD

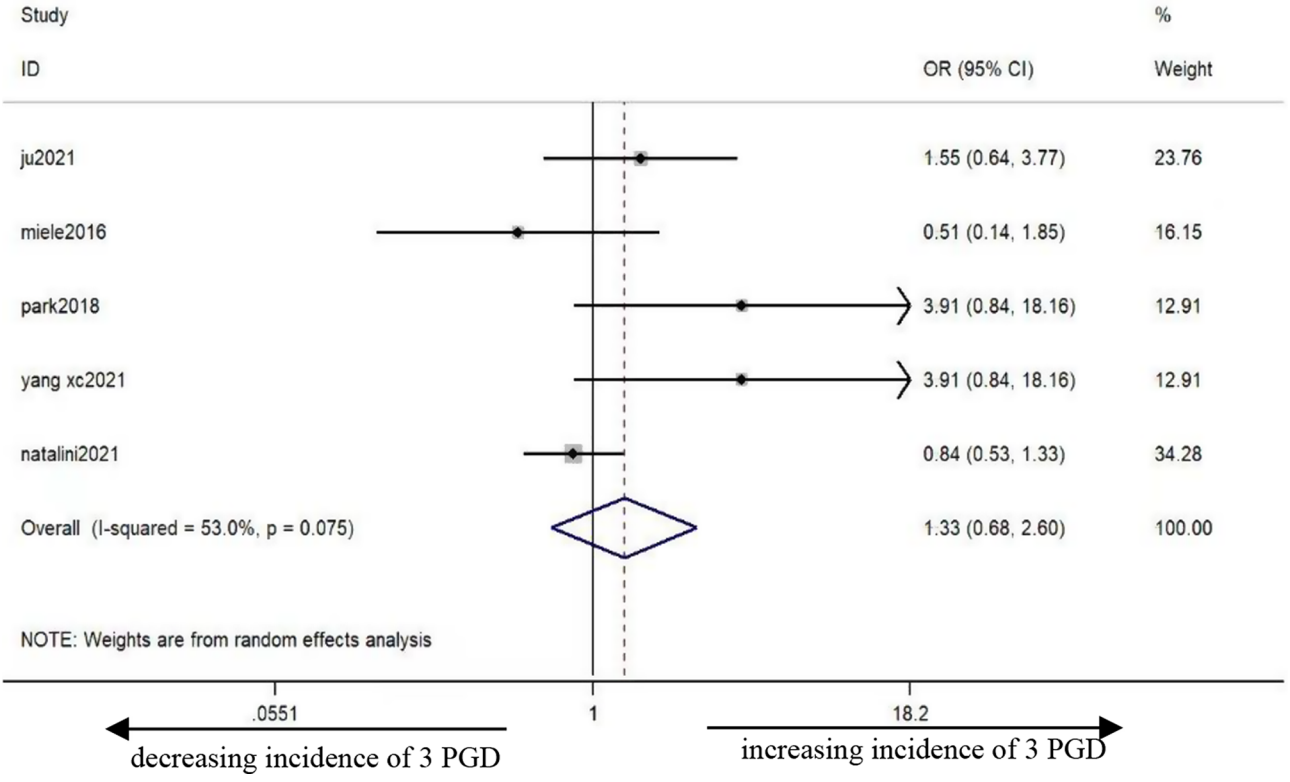

Fig. 4 Meta-analysis of grade 3 PGD incidence in patients who post-transplant for CTD vs. non-CTD

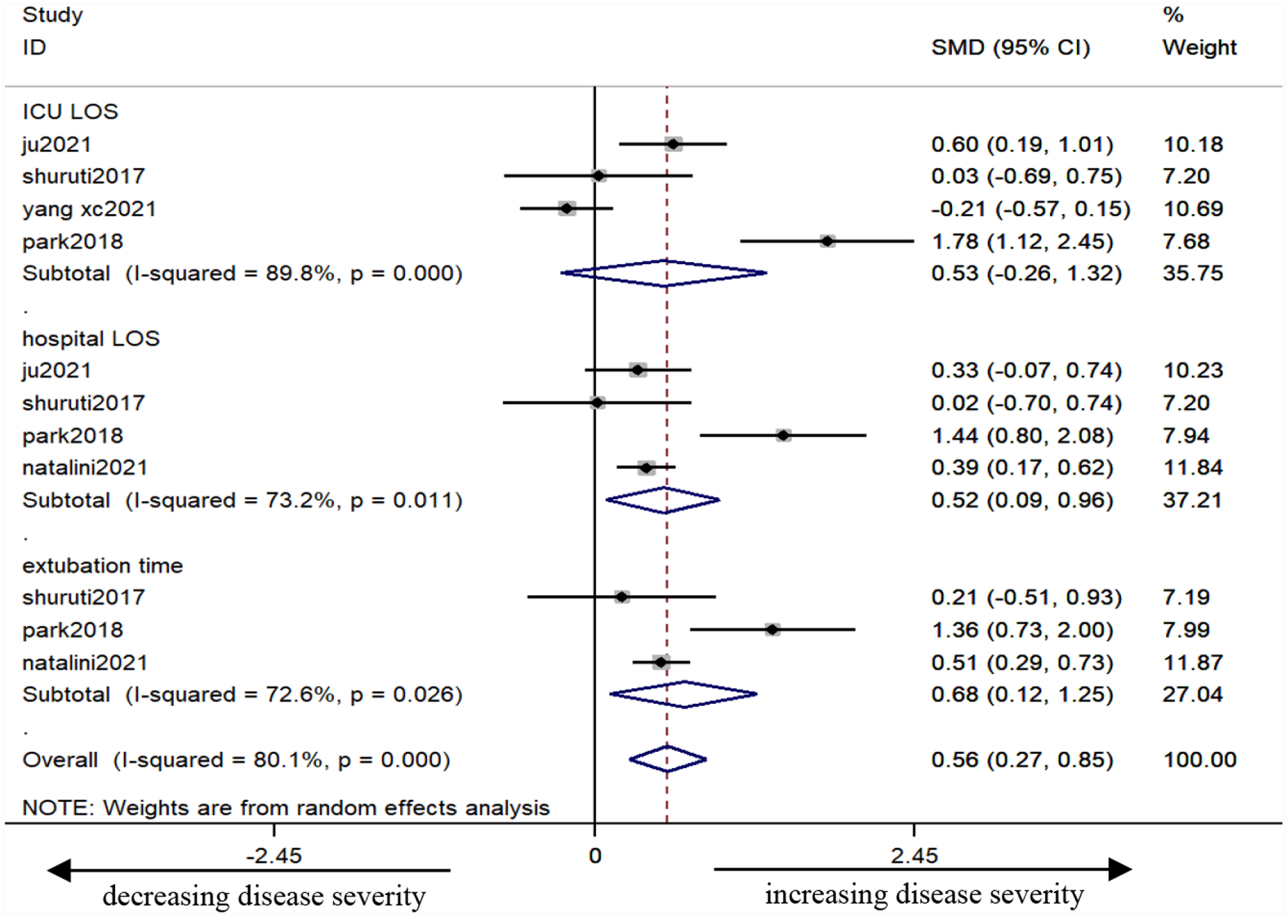

Fig. 5 Meta-analysis of the ICU LOS, hospital LOS, and extubation time in patients who post-transplant for CTD vs. non-CTD

gender, and pre-existing conditions of the CTD patients. In addition, the occurrence of PGD is also related to the basic condition of the lung transplant donor, the preservation of the donor lung, the surgical method, and the intraoperative management [32–34]. However, due to the lack of data on lung transplant donors and intraoperative conditions in the included literature, the exact cause of the higher incidence of postoperative PGD in patients with CTD has not been determined. We can improve the function of the donor lung by improving the preservation strategy of the donor lung, providing extracorporeal life support during surgery, and strengthening perioperative lung-protective ventilation and fluid management to reduce the occurrence of PGD after lung transplantation in patients with CTD [35–38].

In addition, our study described the length of stay in the ICU, length of hospital stay, and duration of extubation to understand the severity of disease in patients after lung transplantation. Notably, the hospitalization duration and the interval to extubation post-surgery were significantly prolonged in the CTD cohort, whereas the duration of postoperative ICU residence remained comparable between groups. This may be related to the higher incidence of postoperative PGD in patients with CTD mentioned in our study. Specifically, due to the higher incidence of PGD grade 1 and 2, the length of hospital stay and mechanical ventilation time of patients increases, which in turn amplifies the clinical burden associated with hospital care.

There were, however, some key limitations to this study. Firstly, depending on the type of CTD, the clinical outcomes after lung transplantation also vary. However, due to the lack of studies on lung transplantation in patients with other types of CTD, most of the CTD patients included in this study are SSc patients, so it is not enough to represent patients with comprehensive CTD. Secondly, the majority of pulmonary complications observed in CTD patients following lung transplantation were interstitial lung disease and pulmonary hypertension, but due to the limited basic data included in the literature, there is no complete data for specific causes of lung transplantation. Thirdly, the severity of PGD was evaluated at four distinct time points after the reperfusion: T0 (within 6 h of reperfusion), T24 (24 h post-reperfusion), T48 (48 h post-reperfusion), and T72 (72 h post-reperfusion) [35–38]. However, there is a lack of detailed differentiation of

time points for PGD diagnosis in the included studies. Last but not least, there is potential heterogeneity due to differences in the baseline characteristics of the included patients.

In conclusion, this study found that lung transplantation is an effective treatment for patients with CTD and end-stage lung disease. The survival rate of CTD patients after lung transplantation and the incidence of grade 3 PGD were comparable to those of other patients undergoing lung transplantation for end-stage lung disease. However, when selecting patients with CTD for lung transplantation, it is necessary to pay attention to and actively prevent and deal with grade 1 and grade 2 PGD after lung transplantation, so as to reduce the burden of hospitalization and promote early recovery.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12890-025-03640-x.

Supplementary Material 1

Supplementary Material 2

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Author contributions
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Data availability
All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Consent for publication
All authors have read and agreed to the published version of the manuscript.

Competing interests
The authors declare no competing interests.
Compliance with ethical approval.

Ethical approval
and informed consent were not required for this study as it was a systematic review of previously published studies. This review was registered and published in the International Prospective Register of Systematic Reviews. (PROSPERO) under reference number CRD42023483687.

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