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ORIGINAL ARTICLE

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Variation in incidence, prevention and treatment of persistent air leak after lung cancer surgery

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Key question

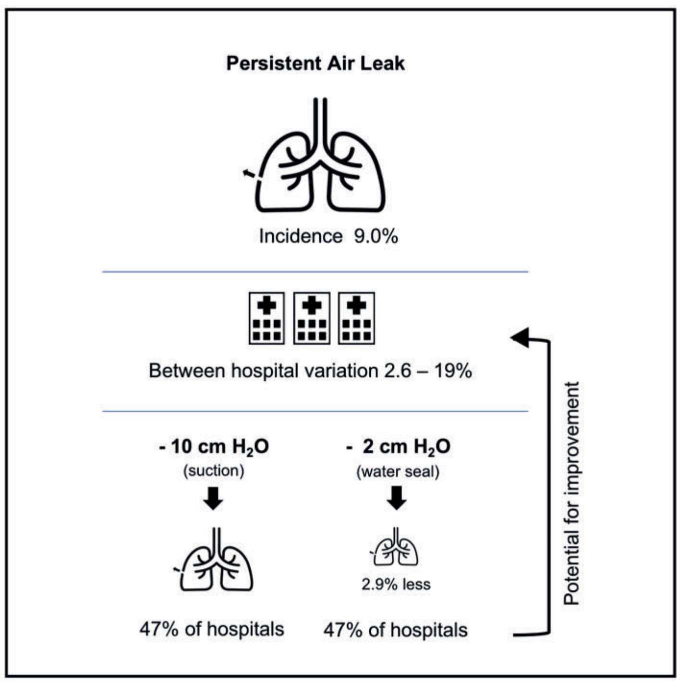
What is the variation in incidence and management of persistent air leak after lung resection among Dutch hospitals?

Key finding(s)

PAL incidence varied from 2.6% to 19%. Water seal drainage, used by 47% of hospitals, was associated with 2.9% less PAL.

Take-home message

Incidence and management of PAL vary among hospitals and should be reduced. They might be reduced by increasing awareness of complications and avoiding suction.



Abstract

OBJECTIVES: Persistent air leak (PAL; >5 days after surgery) is the most common complication after pulmonary resection and associated with prolonged hospital stay and increased morbidity. Literature is contradictory about the prevention and treatment of PAL. Variation is

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therefore hypothesized. The aim of this study is to understand the variation in the incidence, preventive management and treatment of PAL.

METHODS: Data from the Dutch Lung Cancer Audit for Surgery were combined with results of an online survey among Dutch thoracic surgeons. The national incidence of PAL and case-mix corrected between-hospital variation were calculated in patients who underwent an oncological (bi)lobectomy or segmentectomy between January 2012 and December 2018. By multivariable logistic regression, factors associated with PAL were assessed. A survey was designed to assess variation in (preventive) management and analysed using descriptive statistics. Hospital-level associations between management strategies and PAL were assessed by univariable linear regression.

RESULTS: Of 12 382 included patients, 9.0% had PAL, with a between-hospital range of 2.6–19.3%. Factors associated with PAL were male sex, poor lung function, low body mass index, high American Society of Anesthesiologists (ASA) score, pulmonary comorbidity, upper lobe resection, (bi)lobectomy (vs segmentectomy), right-sided tumour and robotic-assisted thoracic surgery. Perioperative (preventive) management of PAL differed widely between hospitals. When using water seal compared to suction drainage, the average incidence of PAL decreased 2.9%.

CONCLUSIONS: In the Netherlands, incidence and perioperative (preventive) management of PAL vary widely. Using water seal instead of suction drainage and increasing awareness are potential measures to reduce this variation.

Keywords: Lung cancer • Persistent air leak • Prolonged air leak • Treatment • Prevention

THORACIC

ABBREVIATIONS

ASA	American Society of Anesthesiologists
BMI	Body mass index
DLCA-S	Dutch Lung Cancer Audit for Surgery
PAL	Persistent or prolonged air Leak
RATS	Robotic-assisted thoracoscopic surgery
VATS	Video-assisted thoracoscopic surgery

INTRODUCTION

Persistent or prolonged air leak (PAL) is one of the most common complications after pulmonary resection, with incidence rates reported between 8% and 26% [1–8]. PAL is associated with prolonged length of hospital stay and increased morbidity, including pneumonia and intensive care unit admission [4, 9–11]. Studies regarding management of air leakage, and PAL in particular, are mostly inconclusive and some show even contradictive results [12–14]. This lack of convincing evidence can lead to management based on preferences of treating physicians or treatment teams, and large variation in clinical practice. This has been shown by Lang *et al.* [15] in the UK, in applying suction to chest drains. In the Netherlands, a national guideline on chest drain management is available; however, most recommendations are based on low levels of evidence [16]. A more recent guideline by the *Society for Translational Medicine* emphasizes the small sample sizes in randomized controlled trials and, therefore, argues that conclusions should be further tested in larger trials [17]. Besides a clinical review by Burt and Shrager [13], there are no guidelines regarding (preventive) management of PAL. Therefore, variation between hospitals in the incidence and management of PAL is suspected. The nationwide Dutch Lung Cancer Audit for Surgery (DLCA-S) was started in 2012 to monitor and improve the quality of care by registering processes and outcomes of lung surgery and can be used to test this hypothesis of between-hospital variation [18, 19]. Using DLCA-S data combined with results from an online survey among Dutch thoracic surgeons, this study aims to assess:

1. the incidence of PAL (%) in the Netherlands and risk factors associated with PAL;
2. between-hospital variation in the incidence of PAL;
3. between-hospital variation in the (preventive) management of PAL; and
4. associations between (preventive) management strategies and incidence of PAL on a hospital level.

MATERIALS AND METHODS

This study combines results from an online survey conducted among Dutch thoracic surgeons with data from the nationwide DLCA-S database. Approval of the Privacy Review Board of DLCA-S was obtained (8 August 2018; DLCAS201704), and consent of patients has been waived, in accordance with the Dutch Personal Data Protection Act. Surgeons gave their explicit approval for the use of their data by completing the survey. In the DLCA-S, PAL is defined as 'air leak >5 days after surgery', not originating from a bronchopleural fistula. This definition, which is in line with recent literature and international database definitions, was also used in the survey [20].

Analysis of national data of Netherlands

Data source. The DLCA-S was started in 2012 and participation was mandatory from the beginning for general lung surgeons trained and certified in non-cardiac thoracic surgery and from 2015 onwards also for cardiothoracic surgeons. It covers all lung surgical procedures in the Netherlands [18].

Patient selection. From 2012 to 2018, all patients with a (bi)lobectomy or segmentectomy for (suspected) lung cancer and a known age, gender, survival status 30 days after surgery and resection type were selected from the DLCA-S. In case of missing data on PAL or when it was unknown whether complications had occurred, patients were excluded. Hospitals with >5% missing data on PAL, calculated before excluding these patients, were excluded from hospital-level analyses.

Statistical analysis. The overall incidence of PAL was calculated. Baseline characteristics of patients with and without PAL were compared using χ^2 tests. Univariable and multivariable logistic regression analyses were performed to identify factors associated with PAL. Variables with a univariable *P*-value <0.10 were included in the multivariable logistic regression model. The variance inflation factor was calculated for all variables included in the multivariable model to test for multicollinearity.

Hospital incidence of PAL was adjusted for differences in case-mix between hospitals. Adjustment for case-mix was performed by calculating the probability of PAL for every patient with a logistic regression model. Factors included in this model, using backward selection, were sex, age, lung function [forced expiratory volume 1 s (%) and diffusing capacity for carbon monoxide (%) combined], body mass index (BMI), American Society of Anesthesiologists (ASA) score, Charlson comorbidity index, pulmonary comorbidity (mostly chronic obstructive pulmonary disease, but any other pulmonary comorbidity was included), lobe, side of the tumour, histological type and type of resection. To check the discrimination of the model, we calculated the *C*-statistic (area under the curve). For every hospital, the expected percentage of patients with PAL was calculated using the probabilities of the individual patients. Per hospital, the observed percentage of patients with PAL divided by the expected percentage was presented in a funnel plot with 95% and 99.8% confidence limits to visualize hospital outcome and to identify positive and negative outliers.

Online survey among Dutch thoracic surgeons

To gain insight in differences in routine perioperative care for patients undergoing lung resection, drain management and management in case of PAL, 3 semi-structured interviews were held with 2 lung surgeons (K.J.H. and W.H.S.) and 1 cardiothoracic surgeon (A.F.V.). Based on their feedback, an online survey was developed (Supplementary Material, Appendix S1) using Google Forms [21]. With the help of the professional associations involved in the DLCA-S, this survey was sent to all surgeons in the Netherlands performing oncological lung resections ($n = 138$). Descriptive statistics were used for the analysis of survey results. Results were analysed on a surgeon level and, if suitable, also on a hospital level. Emphasized was that water seal in digital drainage systems often consists of a slight negative pressure (e.g. -8 cm in Thopaz systems). We asked respondents to also consider this as a water seal.

Combining of survey results and Dutch Lung Cancer Audit for Surgery data

For each hospital, the true PAL rate calculated from the DLCA-S database was set against the PAL incidence rate estimated by thoracic surgeons in the online survey, to test how well aware surgeons are about their complication rates.

To assess hospital-level associations between (preventive) management strategies and the incidence of PAL, a hospital-level dataset with actual PAL incidence rates and case-mix adjusted PAL rates was created from the DLCA-S database. Local management strategies to reduce the PAL rate for each hospital were added manually based on survey results. Factors included were perioperative use of sealants; chest drain device; drain device setting directly postoperative and type of ward the patient is admitted to postoperatively. Data were considered missing in case surgeons from the same hospital entered conflicting answers. After checking whether the hospital PAL rate was normally distributed, univariable linear regression was used to test for associations, with hospital PAL rate as the dependent variable and management strategies as independent variables. This was done for case-mix unadjusted and adjusted data. Even though almost all hospitals in the Netherlands participated in the survey, the number of hospitals would be too limited to have enough power to perform a multivariable analysis.

RESULTS

Incidence of persistent air leak, risk factors and between-hospital variation

Of the 12 489 included patients, 107 (0.9%) had missing data on PAL and were excluded. Of the remaining 12 382 patients, 1111 had PAL resulting in a nationwide incidence rate of 9.0%. The baseline patient and tumour characteristics of patients with and without PAL are listed in Supplementary Material, Table S1.

In the multivariable logistic regression, male sex, poor lung function with a forced expiratory volume 1 s or diffusing capacity for carbon monoxide <80% (vs both >80%), BMI below 18.5 kg/m^2 (vs 18.5–25.0, being overweighed was protective), high ASA score, pulmonary comorbidity, upper lobe resection, (bi)lobectomy (vs segmentectomy), right-sided tumour and robotic-assisted thoracoscopic surgery [RATS; vs video-assisted thoracoscopic surgery (VATS)] were found to be significantly associated with PAL (Table 1). All these factors were included in the case-mix model supplemented with age, excluding surgical approach, which concerns a treatment choice. The case-mix adjusted hospital incidence of PAL ranged from 2.6% to 19.3%. Case-mix unadjusted and adjusted PAL rates are, respectively, shown in Fig. 1A and B, which shows significant differences between hospitals. The *C*-statistic (95% confidence interval) of the model was 0.67 (0.66–0.69).

Variation in management of persistent air leak

The online survey was completed by 68 surgeons (49.3% of those addressed) from 38 out of 43 hospitals performing lung surgery in the Netherlands. The results are summarized in Supplementary Material, Appendix S1. The majority of hospitals used protocols for postoperative drain management (97.4%), but only 60.5% of hospitals had described specific management in case of PAL in a protocol. Almost half of the surgeons (47.1%) estimated the occurrence of postoperative PAL in their hospital to be 5–10%, against 23.5% who estimated PAL <5% and 29.4% >10%.

The use of intraoperative preventive measures varied between hospitals. Of the surgeons, 17.6% ($n = 12$) used sealants routinely regardless of patients' conditions or type of resection, 13.2% ($n = 9$) never used them and 69.1% ($n = 47$) only used sealants when deemed indicated. Also, wide variation in postoperative management was seen. Of the hospitals, 60.5% ($n = 23$) used digital drainage systems and 13.2% ($n = 5$) used analogue systems only. The remaining 26.3% ($n = 10$) used both systems. Setting of the drain device directly postoperative was suction in 47.4% ($n = 18$) of the hospitals and water seal in 47.4% ($n = 18$) of the hospitals (5.2% conflicting answers, suggesting no uniform policy). In case of reintervention for PAL, 45.6% ($n = 31$) of the surgeons routinely performed computed tomography scan of the thoracic cavity before proceeding to reintervention,

Table 1: Probability for PAL,[a] results of univariable and multivariable analyses

Probability for PAL	Univariable logistic regression			Multivariable logistic regression		
Variables	*n*	OR (95% CI)	*P*-value	*n*	aOR (95% CI)	*P*-value
Total	12 382			12 382		
Age (years)[b]			0.187			
<60	2842	1				
60–69	4724	1.20 (1.01–1.42)				
70–79	4161	1.16 (0.98–1.38)				
>79	655	1.10 (0.81–1.49)				
Sex			<0.001			<0.001
Male	6620	1		6620	1	
Female	5762	0.62 (0.55–0.71)		5762	0.61 (0.53–0.69)	
Charlson comorbidity index			<0.001			0.812
0	4188	1		4188	1	
1	3374	1.48 (1.26–1.74)		3374	1.00 (0.84–1.21)	
2+	4820	1.36 (1.17–1.58)		4820	0.96 (0.81–1.14)	
Cardiac comorbidity			0.835			
No	9218	1				
Yes	3164	0.99 (0.86–1.14)				
Pulmonary comorbidity			<0.001			**<0.001**
No	8020	1		8020	1	
Yes	4362	1.81 (1.60–2.05)		4362	1.61 (1.39–1.86)	
ECOG score[b]			0.165			
0–I	9828	1				
II+	465	1.33 (0.99–1.78)				
Unknown/missing	2089	1.03 (0.88–1.22)				
ASA score[c]			<0.001			**0.010**
I–II	8097	1		8097	1	
III+	3591	1.41 (1.23–1.61)		3591	1.23 (1.07–1.42)	
Unknown/missing	694	1.01 (0.76–1.34)		694	1.24 (0.91–1.67)	
Lung function[d]			<0.001			**<0.001**
FEV1% and DLCO% >80%	4008	1		4008	1	
FEV1% or DLCO% <80%	7601	1.95 (1.68–2.27)		7601	1.63 (1.39–1.91)	
Both unknown/missing	773	1.16 (0.85–1.58)		773	1.23 (0.89–1.70)	
BMI (kg/m^2)			<0.001			<0.001
<18.5	109	2.25 (1.43–3.56)		109	2.24 (1.40–3.58)	
18.5–25	1724	1		1724	1	
25–30	1488	0.59 (0.47–0.75)		1488	0.60 (0.47–0.76)	
>30	690	0.35 (0.24–0.51)		690	0.36 (0.25–0.52)	
Unknown/missing	8371	0.64 (0.54–0.75)		8371	0.69 (0.58–0.82)	
Pathological stage[e]			0.206			
Stage 0	228	1.00 (0.63–1.60)				
Stage I	6115	1				
Stage II	3070	1.16 (1.00–1.34)				
Stage III	1633	1.00 (0.82–1.21)				
Stage IV	305	0.89 (0.58–1.36)				
Unknown/missing	1031	0.86 (0.67–1.10)				
Pathological T-stage[e]			0.207			
pT1a(mi)-b-c (and T0 Tis)	4869	1				
pT2a-b	4269	1.01 (0.87–1.16)				
pT3	1847	1.21 (1.01–1.45)				
pT4	527	1.12 (0.83–1.53)				
Unknown/missing	870	0.93 (0.72–1.21)				
Tumour side			<0.001			0.002
Left	4958	1		4958	1	
Right	7245	1.25 (1.10–1.42)		7245	1.22 (1.07–1.42)	
Unknown/missing	179	0.33 (0.14–0.81)		179	0.38 (0.14–1.00)	
Histological type			0.002			0.467
Benign	471	0.87 (0.62–1.24)		471	0.84 (0.59–1.20)	
Adenocarcinoma	6762	1		6762	1	
Squamous cell carcinoma	3345	1.26 (1.10–1.45)		3345	1.09 (0.94–1.26)	
Different NSCLC	1220	0.84 (0.67–1.06)		1220	0.92 (0.73–1.16)	
SCLC	146	0.86 (0.46–1.60)		146	0.83 (0.44–1.55)	
Other/unknown/missing	438	0.83 (0.58–1.21)		438	0.86 (0.69–1.25)	
Type of resection			<0.001			0.009
Bilobectomy	810	1.36 (1.09–1.70)		810	1.23 (0.97–1.56)	
Lobectomy	11 177	1		11 177	1	
Segmentectomy (anatomical)	395	0.52 (0.32–0.82)		395	0.54 (0.34–0.87)	

Continued

Table 1: Continued

Probability for PAL	Univariable logistic regression			Multivariable logistic regression		
Variables	*n*	OR (95% CI)	*P*-value	*n*	aOR (95% CI)	*P*-value
Lobe[f]			<0.001			
Lower lobe	3742	1				
Middle lobe	634	0.43 (0.28–0.69)				
Upper lobe	6987	1.54 (1.33–1.78)				
Upper and middle lobe	336	1.36 (0.92–2.01)				
Lower and middle lobe	452	2.13 (1.58–2.86)				
Unknown/missing	231	1.20 (0.74–1.95)				
Surgical approach			<0.001			<0.001
Thoracotomy	3170	0.99 (0.85–1.15)		3170	0.89 (0.76–1.04)	
VATS	6800	1		6800	1	
RATS	304	2.14 (1.56–2.92)		304	2.06 (1.48–2.88)	
UVATS	511	1.20 (0.89–1.62)		511	1.11 (0.81–1.53)	
Conversion to thoracotomy	1265	1.19 (0.98–1.46)		1265	1.03 (0.83–1.26)	
Unknown/missing	332	0.79 (0.51–1.22)		332	0.99 (0.61–1.60)	
Induction therapy			0.359			
No/unknown/missing	11 545	1				
Chemoradiotherapy	526	0.78 (0.56–1.10)				
Other	311	0.99 (0.67–1.47)				
Year of surgery			0.357			
2012	1155	1				
2013	1497	0.96 (0.72–1.27)				
2014	1427	1.05 (0.80–1.39)				
2015	1901	1.10 (0.85–1.43)				
2016	1970	1.07 (0.82–1.39)				
2017	2153	1.22 (0.95–1.57)				
2018	2279	1.19 (0.93–1.53)				

[a]PAL: air leak >5 days after surgery.

[b]ECOG score: Eastern Cooperative Oncology Group performance score.

[c]ASA score: American Society of Anesthesiologists physical status classification system.

[d]Lung function: combined measure of DLCO and FEV1.

[e]Pathological (T-)stage: TNM 7th edition till 2016, TNM 8th edition from 2017.

[f]Although 'Lobe' was a significantly associated with PAL in univariable analysis, there was too much overlap with the variable 'Type of resection', to put both variables in the multivariable model. Although not presented here, lobe continued to be significantly associated with PAL in multivariable analysis.

aOR: adjusted odds ratio; BMI: body mass index; CI: confidence interval; DLCO: diffusing capacity of the lungs for carbon monoxide; FEV1: forced expiratory volume in 1 s; NSCLC: non-small-cell lung cancer; OR: odds ratio; PAL: persistent air leak; RATS: robotic-assisted thoracoscopic surgery; SCLC: small-cell lung cancer; TNM: tumour, node and metastasis; UVATS: uniportal video-assisted thoracoscopic surgery; VATS: video-assisted thoracoscopic surgery.

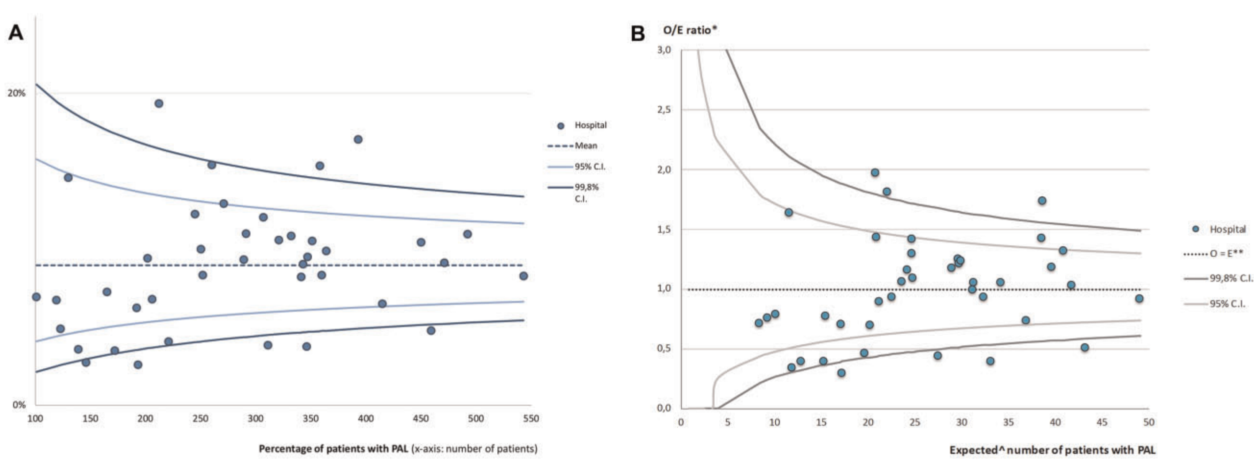

Figure 1: Funnel plot of between-hospital variation in PAL (2012–2018): (**A**) unadjusted and (**B**) adjusted for case-mix. *O/E ratio: observed number of PAL divided by expected^ number of PAL. **O = E: the observed number equals the expected^ number of patients with PAL. ^Expected based on population characteristics in the hospital. CI: confidence interval; PAL: persistent air leak.

47.1% (*n* = 32) did this only when they considered it to be contributing.

Estimation of own results and associations between (preventive) management strategies and the incidence of persistent air leak

The percentages of PAL per hospital as registered in the DLCA-S were compared with the estimated percentages from the online survey (Fig. 2). Eighteen hospitals (45%) had an estimated percentage of PAL concordant with their actual PAL rate. Surgeons from 12 hospitals (30%) underestimated the incidence of PAL in their hospitals. Most of these hospitals had a PAL incidence above the national average of 9.0%.

For 36 hospitals, both data on incidence of PAL, derived from the DLCA-S, and data on postoperative management were available. In univariable analyses on these data, the postoperative drain device setting immediately after surgery was the only factor significantly associated with PAL (Table 2). Hospitals applying water seal, compared to those applying suction immediately after closing the thoracic cavity, had 2.9% less PAL (case-mix adjusted).

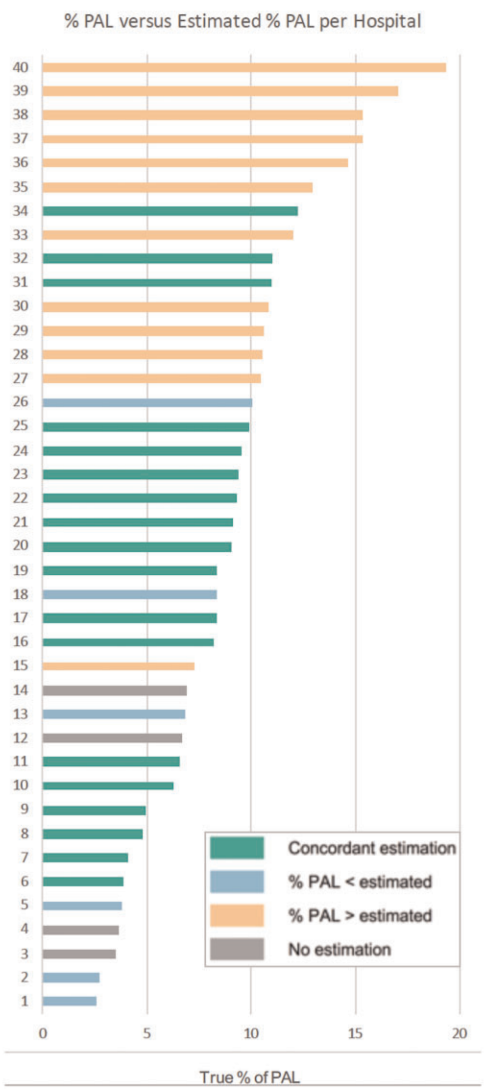

Figure 2: True percentage of PAL, derived from the Dutch Lung Cancer Audit for Surgery, versus estimated percentage of PAL, derived from the survey, per hospital. PAL: persistent air leak.

DISCUSSION

From 2012 to 2018, in the Netherlands, a PAL incidence rate of 9.0% was found with a considerable between-hospital variation. This national cohort study shows that male sex, poor lung function, low BMI, high ASA score, pulmonary comorbidity, upper lobe resection, (bi)lobectomy (vs segmentectomy), right-sided tumour and RATS are independent predictors of PAL. In addition to the variation in PAL rate, awareness and (preventive) management strategies varied considerably between hospitals. On a hospital level, postoperative water seal versus suction, immediately after surgery, was associated with 2.9% less PAL.

The incidence of PAL of 9.0% is in line with previous research. In 2016, Pompili *et al.* [4] reported, in a cohort of >5000 VATS lobectomies from the ESTS database, an incidence of 9.9% PAL. A single-centre, consecutive cohort study in lobectomies, by Brunelli *et al.* [5], found an incidence of 13% PAL. And, in a selection of lobectomies of patients in the STS database, Paul *et al.* [7] found 8.7% PAL after thoracotomy and 7.6% after VATS. Although our overall results are similar to previous studies, the variation in PAL incidence between Dutch hospitals, ranging from 2.6% to 19.3%, suggests that there is still room for improvement.

We analysed several previously identified risk factors associated with PAL. Male gender, forced expiratory volume 1 s <80% and BMI <18.5 kg/m^2 were found to be associated with PAL by Pompili *et al.* and were included in a risk score predicting postoperative PAL [5]. Earlier, Brunelli *et al.* [3] found pleural adhesions (not in our data) and upper lobe resection as predictors of PAL and made a different risk score. And in a review on PAL, Singhal *et al.* [22] additionally described diffusing capacity for carbon monoxide <80%, bilobectomy, lobectomy versus sublobar resections and steroid use as risk factors. Right-sided resections have been suggested to be a risk factor but, till now, never been found significantly associated with PAL. RATS was also identified as a risk factor for PAL. In RATS, the choice for a dissection through the fissure may play a role in causing an air leak, in contrast to a hilum first approach. But this finding should be regarded with care since learning curve may have played a role in the higher PAL rate for this relatively new technique. On the other hand, focus on the results of RATS, as a new technique, could have resulted in better registration of complications. Finally, few hospitals use this technique in the Netherlands, making it vulnerable to a hospital effect.

Despite all these previous efforts, risk models never have been successfully implemented into (Dutch) practice. Therefore, we focused on variation in real-life practice and the ability to draw lessons from treatment patterns leading to better outcomes. The survey, completed by more than half of all Dutch thoracic surgeons, showed a large variation in daily practice, suggesting that management is based on local preferences and experience, rather than on evidence. Aerostatics or seals, for example, are for some surgeons part of their surgical routine, while others never use them, or, most of them, when deemed useful. Another striking result was the lack of consensus about the postoperative drain device setting, which was 50/50 for suction versus water seal.

Table 2: Predicted effect of hospital management strategies on the incidence of PAL (%) on hospital level by linear regression using (A) the true percentages of PAL per hospital and (B) the case-mix corrected percentages of PAL.

Probability for PAL	A. Univariable linear regression			B. Univariable linear regression—case-mix corrected % of PAL	
Variables	*n*	*B* (%) (95% CI)	*P*-value	*B* (%) (95% CI)	*P*-value
Total	36				
Postoperative ward	34		0.295		0.322
Respiratory	21	Ref.		Ref.	
Surgery	13	-1.47 (-4.27 to 1.34)		-1.32 (-3.97 to 1.35)	
Use of sealants	35		0.247		0.251
On indication	23	Ref.		Ref.	
Always	6	-2.00 (-5.65 to 1.65)		-1.85 (-5.32 to 1.62)	
Never	6	-2.68 (-6.32 to 0.97)		-2.56 (-6.03 to 0.91)	
Chest drain device	35		0.134		0.116
Digital	21	Ref.		Ref.	
Analogue	5	-3.55 (-7.44 to 0.33)		-3.69 (-7.37 to -0.01)	
Both	9	0.65 (-2.46 to 3.76)		0.21 (-2.73 to 3.15)	
Drain device setting	33		**0.015**		**0.023**
Suction	17	Ref.		Ref.	
Water seal	16	**−3.27 (−5.88 to −0.67)**		**−2.92 (−5.42 to −0.43)**	

CI: confidence interval; PAL: persistent air leak. Significant of bold if p<0.05.

To take advantage of these differences, we related these management factors on a hospital level to the incidence of PAL. Despite the low numbers, limited by the number of Dutch hospitals, a correlation between drain device setting and PAL was found. When using water seal compared to suction drainage, the average incidence of PAL will decrease by 2.9%. This is in line with earlier suggestions from literature, summarized by Cerfolio and Bryant [23] and supported by the 2018 results of Holbek *et al.* [24], who compared water seal versus suction on a patient level in 228 consecutive VATS lobectomies. They concluded an advantage of 9.9% less PAL for patients receiving 'water seal' immediately after surgery. Reproducing this effect on a hospital level in our study reinforces the recommendation for postoperative water seal drainage in patients after an oncological lung resection. When applying water seal instead of suction, fear for more complications could arise, such as atelectasis or pneumonia. However, Holbek *et al.* [24] did not find significant differences in any complications in their randomized trial.

Finally, we found that in hospitals with high PAL incidence, surgeons were not aware of this and underestimated their PAL complications. As every improvement starts with awareness of the problem, benchmarked feedback to the treating surgeon on their PAL rate is very important. The DLCA-S is a key instrument in achieving this, by including PAL rates in the Codman Dashboard, which shows the surgeons (trends in) their outcomes [19].

Strengths and limitations

The main strengths of this study are the national design, covering all hospitals performing lung surgery in the Netherlands, and the conducted survey, which allowed us to combine patient-level data on PAL with hospital management strategies after an oncological lung resection. Also, the decrease in PAL using water seal compared to suction is still manifest and clinically relevant after case-mix correction, which increases the reliability of our results.

The main risk of using self-reported registry data in case of complications is under-reporting by hospitals. However, previous validation of the DLCA-S database showed only 3.3% missing or incorrectly registered complications [25]. By excluding hospitals with >5% missing data on PAL from hospital-level analysis, we minimized the effect of a potential registration bias.

Analysing data on a hospital level may lead to the phenomenon of 'ecological fallacy', i.e. the false assumption that inferences made at hospital level would apply to individual patients [26]. Because we did not have the data on individual drain device settings, we were not able to check this in our study population. However, the same relation between postoperative water seal and less PAL was reported previously in a randomized controlled trial, which endorses our results and suggests no interference by ecological fallacy [24].

CONCLUSION

This study showed that, between 2012 and 2018, the nationwide incidence of PAL after oncological lung resection in Netherlands was 9.0%. However, there was a significant between-hospital variation, and variation in management strategies by hospitals regarding postoperative (persistent) air leakage. Hospitals applying water seal had 2.9% less PAL compared to hospitals using suction drainage. With an equal number of Dutch hospitals applying postoperative water seal drainage and suction drainage, an opportunity for improvement is revealed. Underestimation of PAL rates of 30% by hospitals with a high PAL incidence highlights the importance of awareness for quality improvement. Therefore, benchmarked feedback on PAL rates will be implemented in the Codman Dashboard of the nationwide quality registry.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

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Author contributions

Fieke Hoeijmakers: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing—original draft. **Koen J. Hartemink:** Conceptualization; Resources; Supervision; Writing—review & editing. **Ad F. Verhagen:** Conceptualization; Resources; Writing—review & editing. **Willem H. Steup:** Conceptualization; Resources; Writing—review & editing. **Elske Marra:** Methodology; Visualization; Writing—review & editing. **W.F. Boudewijn Röell:** Data curation; Writing—review & editing. **David J. Heineman:** Writing—review & editing. **Wilhelmina H. Schreurs:** Writing—review & editing. **Rob A.E.M. Tollenaar:** Writing—review & editing. **Michel W.J.M. Wouters:** Conceptualization; Methodology; Resources; Supervision; Visualization; Writing—review & editing.

Reviewer information

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REFERENCES

[1] Steéphan F, Boucheseiche S, Hollande J, Flahault A, Cheffi A, Bazelly B *et al.* Pulmonary complications following lung resection: a comprehensive analysis of incidence and possible risk factors. Chest 2000;118:1263–70.
[2] Stolz AJ, Schutzner J, Lischke R, Simonek J, Pafko P. Predictors of prolonged air leak following pulmonary lobectomy. Eur J Cardiothorac Surg 2005;27:334–6.
[3] Brunelli A, Monteverde M, Borri A, Salati M, Marasco RD, Fianchini A. Predictors of prolonged air leak after pulmonary lobectomy. Ann Thorac Surg 2004;77:1205–10; discussion 10.
[4] Pompili C, Falcoz PE, Salati M, Szanto Z, Brunelli A. A risk score to predict the incidence of prolonged air leak after video-assisted thoracoscopic lobectomy: an analysis from the European Society of Thoracic Surgeons database. J Thorac Cardiovasc Surg 2017;153:957–65.
[5] Brunelli A, Varela G, Refai M, Jimenez MF, Pompili C, Sabbatini A *et al.* A scoring system to predict the risk of prolonged air leak after lobectomy. Ann Thorac Surg 2010;90:204–9.
[6] Falcoz PE, Puyraveau M, Thomas PA, Decaluwe H, Hurtgen M, Petersen RH *et al.* Video-assisted thoracoscopic surgery versus open lobectomy for primary non-small-cell lung cancer: a propensity-matched analysis of outcome from the European Society of Thoracic Surgeon database. Eur J Cardiothorac Surg 2016;49:602–9.
[7] Paul S, Altorki NK, Sheng S, Lee PC, Harpole DH, Onaitis MW *et al.* Thoracoscopic lobectomy is associated with lower morbidity than open lobectomy: a propensity-matched analysis from the STS database. J Thorac Cardiovasc Surg 2010;139:366–78.
[8] Abolhoda A, Liu D, Brooks A, Burt M. Prolonged air leak following radical upper lobectomy: an analysis of incidence and possible risk factors. Chest 1998;113:1507–10.
[9] Yoo A, Ghosh SK, Danker W, Kassis E, Kalsekar I. Burden of air leak complications in thoracic surgery estimated using a national hospital billing database. Clinicoecon Outcomes Res 2017;9:373–83.
[10] DeCamp MM, Blackstone EH, Naunheim KS, Krasna MJ, Wood DE, Meli YM *et al.* Patient and surgical factors influencing air leak after lung volume reduction surgery: lessons learned from the National Emphysema Treatment Trial. Ann Thorac Surg 2006;82:197–206; discussion 7.
[11] Varela G, Jimenez MF, Novoa N, Aranda JL. Estimating hospital costs attributable to prolonged air leak in pulmonary lobectomy. Eur J Cardiothorac Surg 2005;27:329–33.
[12] Rocco G, Brunelli A, Rocco R. Suction or nonsuction: how to manage a chest tube after pulmonary resection. Thorac Surg Clin 2017;27:35–40.
[13] Burt BM, Shrager JB. The prevention and management of air leaks following pulmonary resection. Thorac Surg Clin 2015;25:411–19.
[14] Brunelli A, Salati M, Pompili C, Refai M, Sabbatini A. Regulated tailored suction vs regulated seal: a prospective randomized trial on air leak duration. Eur J Cardiothorac Surg 2013;43:899–904.
[15] Lang P, Manickavasagar M, Burdett C, Treasure T, Fiorentino F; UK Cardiothoracic Trainees' Research Collaborative. Suction on chest drains following lung resection: evidence and practice are not aligned. Eur J Cardiothorac Surg 2016;49:611–16.
[16] Dutch Guidelines for Chest Drain Management 2011 (Richtlijn Thoraxdrainage). https://www.nvalt.nl/kwaliteit/richtlijnen/behandelkamer-operatiekamer/_/Behandelkamer%20-%20Operatiekamer/Richtlijn-thoraxdrainage%20Januari%202011.pdf (19 October 2020, date last accessed).
[17] Gao S, Zhang Z, Aragon J, Brunelli A, Cassivi S, Chai Y *et al.* The Society for Translational Medicine: clinical practice guidelines for the postoperative management of chest tube for patients undergoing lobectomy. J Thorac Dis 2017;9:3255–64.
[18] Ten Berge M, Beck N, Heineman DJ, Damhuis R, Steup WH, van Huijstee PJ *et al.* Dutch lung surgery audit: a national audit comprising lung and thoracic surgery patients. Ann Thorac Surg 2018;106:390–7.
[19] Beck N, Van Bommel AC, Eddes EH, Van Leersum NJ, Tollenaar RAEM, Wouters MWJM; Dutch Clinical Auditing Group. The Dutch Institute for Clinical Auditing: achieving Codman's dream on a nationwide basis. Ann Surg 2020;271:627–31.
[20] Fernandez FG, Falcoz PE, Kozower BD, Salati M, Wright CD, Brunelli A. The Society of Thoracic Surgeons and the European Society of Thoracic Surgeons general thoracic surgery databases: joint standardization of variable definitions and terminology. Ann Thorac Surg 2015;99:368–76.
[21] Google Forms by Google. https://docs.google.com/forms (19 October 2020, date last accessed).
[22] Singhal S, Ferraris VA, Bridges CR, Clough ER, Mitchell JD, Fernando HC *et al.* Management of alveolar air leaks after pulmonary resection. Ann Thorac Surg 2010;89:1327–35.
[23] Cerfolio RJ, Bryant AS. The management of chest tubes after pulmonary resection. Thorac Surg Clin 2010;20:399–405.
[24] Holbek BL, Christensen M, Hansen HJ, Kehlet H, Petersen RH. The effects of low suction on digital drainage devices after lobectomy using video-assisted thoracoscopic surgery: a randomized controlled trial. Eur J Cardiothorac Surg 2019;55:673–81.
[25] Hoeijmakers F, Beck N, Wouters MWJM, Prins HA, Steup WH. National quality registries: how to improve the quality of data? J Thorac Dis 2018; 10:S3490–9.
[26] Hofstede SN, van Bodegom-Vos L, Kringos DS, Steyerberg E, Marang-van de Mheen PJ. Mortality, readmission and length of stay have different relationships using hospital-level versus patient-level data: an example of the ecological fallacy affecting hospital performance indicators. BMJ Qual Saf 2018;27:474–83.