Jacobian-Based Biomechanical Texture Radiomics from Inspiratory–Expiratory CT for Predicting Target-Lobe Volume Reduction and Treatment Response In Endobronchial Valve Therapy

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Abstract Text:

Purpose:

Endobronchial Valves (EBV) are one of the few treatment options for patients with moderate to severe emphysema. Eligibility is typically assessed from CT image data analysis including Emphysema Score (RA950) and Fissure Integrity Score(FIS). However not all EBV candidates are responders. The purpose of this work was to develop an approach to quantify the CT texture of jacobian determinant (detJ) derived biomechanical lung expansion and contraction during lung inspiration and expiration to improve prediction of candidates who will benefit from EBV treatment.

Methods and Materials:

We performed a retrospective study using data from 48 patients with moderate to severe emphysema who underwent EBV treatment. Each patient underwent baseline (pre-treatment) CT scanning at both Total Lung Capacity (TLC) and Residual Volume (RV) breath-holds. Lung lobe segmentations were performed on CT image data to automatically identify lobar regions. RA950 was extracted for each lobe. Jacobian determinant was extracted from registered in RV-TLC images to quantify lung expansion and contraction. 72 features from first-order and 3 texture-radiomic feature sets were extracted from lobar regions. Using multiple linear regression, we evaluated if detJ radiomic features improved prediction of target-lobe volume reduction (TLVR).

Results:

Adding GLRLM Non-Uniformity to baseline predictor fissure integrity score (FIS) modestly improved model fit compared with FIS-only (ΔAIC=-1.59).

Conclusions:

Texture-based radiomics derived from Jacobian ventilation maps capture clinically relevant patterns of regional ventilation heterogeneity associated with EBV-induced lobar deflation and may provide complementary biomechanical imaging biomarkers beyond conventional CT metrics.

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INTRODUCTION

Endobronchial Valves (EBV) are one of the few treatment options for patients with moderate to severe emphysema. Eligibility is typically assessed from CT image data analysis including Emphysema Score (RA950) and Fissure Integrity Score(FIS). However not all EBV candidates are responders.

The **purpose** of this work was to develop an approach to quantify the CT texture of biomechanical lung expansion and contraction during lung inspiration and expiration using Jacobian determinant of deformation vector (DVF) to improve prediction of candidates who will benefit from EBV treatment.

Fig. 2: Responder Patient Coronal RV CT; Jacobian in RV; lobar region (target lobe RUL); RA950 in red on TLC.

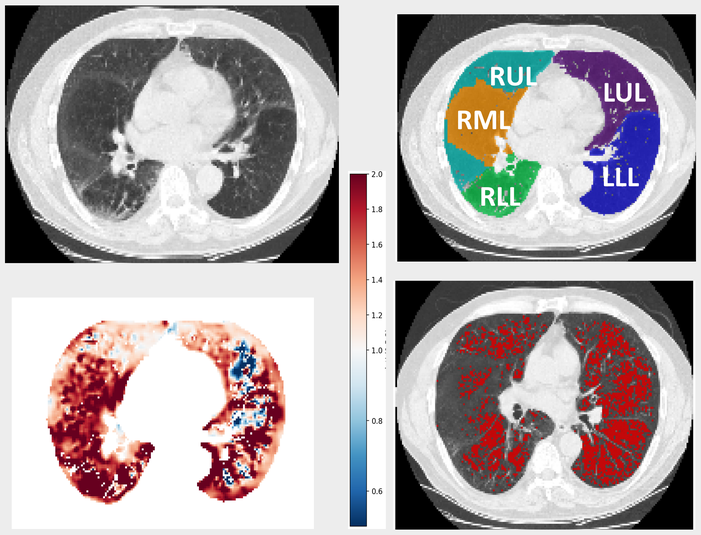


Fig. 3. Non-responder Coronal RV CT; Jacobian in RV; lobar region (target lobe RUL); RA950 in red on TLC.

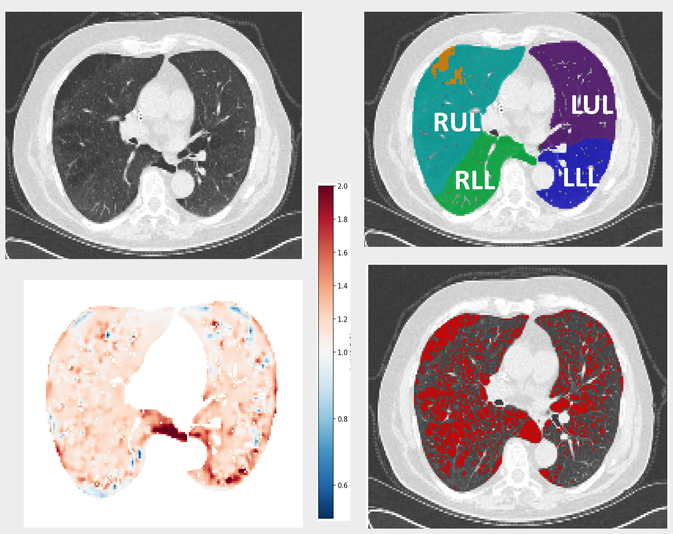


Fig 1. Workflow including Registration and Calculation of Jacobian Determinant

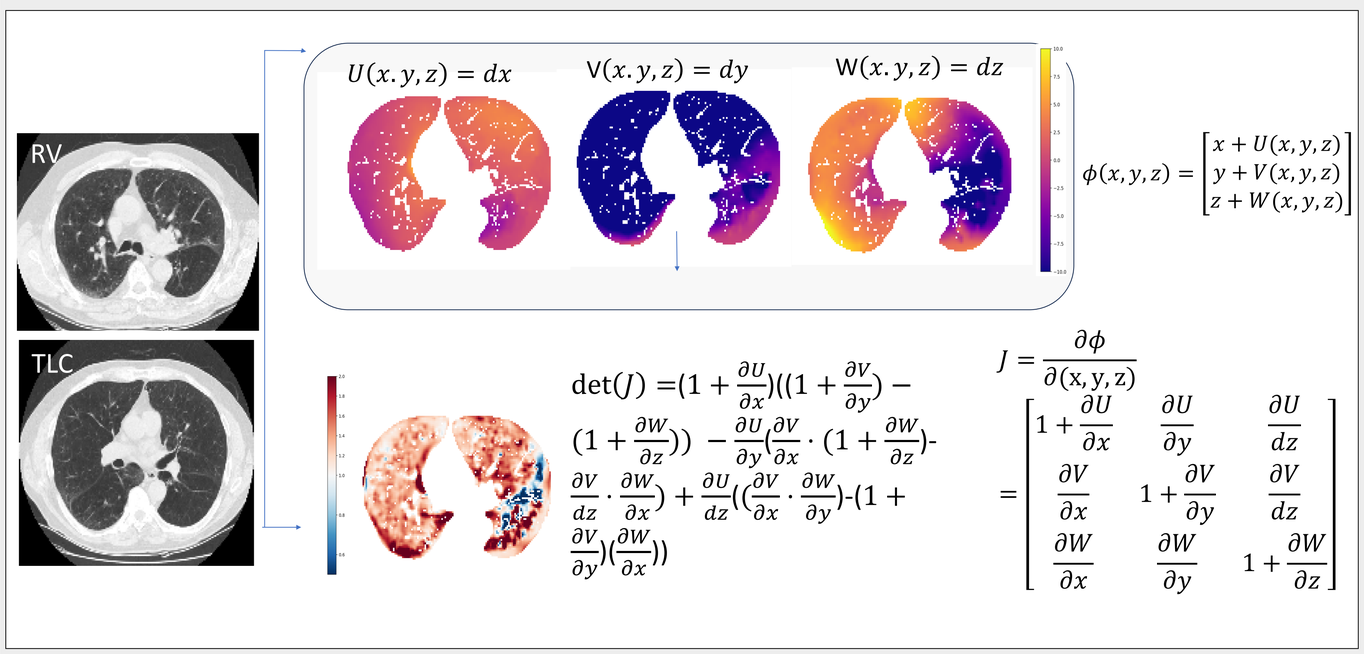
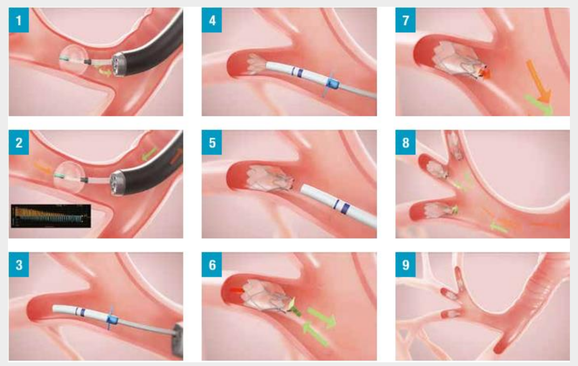


Fig 4. Valves implanted using bronchoscope. Multiple valves placed in segmental airways to completely occlude entire lobe with goal of target lobe volume reduction (TLVR).



METHODS AND MATERIALS

72 features from 4 texture-radiomic feature sets were extracted from lobar regions. We performed ordinary least squares multiple linear regression to evaluate if the addition of jacobian derived feature would improve model prediction compared to baseline prediction model which depends on fissure completeness or fissure integrity score (FIS).

Gray Level Run Length Matrix (GLRLM) features quantify the spatial organization of Jacobian determinant (detJ) values within the ROI. Each voxel reflects local tissue volume change: detJ >1 expansion; detJ <1 contraction. After discretizing the continuous detJ values into bins, the GLRLM counts consecutive neighboring voxels with the same binned detJ value along a given direction., GLRLM features describe whether deformation patterns are spatially homogeneous or heterogeneous, fragmented or contiguous, and whether regions of similar expansion or contraction occur as short or long runs**. Gray Level Non-Uniformity (GLN)** quantifies GLRLM spatial runs of similar binned Jacobian ((J)) values; lower values correlate with greater similarity in intensity values.

Table 1. Multiple Linear Regression Models for Endobronchial Valve (EBV) Treatment Prediction using Fissure Integrity and Jacobian Radiomic Features

Baseline Multiple Linear Regression Model	$\boldsymbol{TLVR = \beta_0 + \beta_1(FIS\ Comp)}$
Expanded Multiple Linear Regression Model	**TLVR**$= \boldsymbol{\beta_0 + \beta_1(FIS\ Comp) + \beta_2(Radiomic\ Feature)}$

Metric	Log-Ratio Test p-value	ΔAIC	β_2	95% CI	P-value
Target Lobe GLRLM Non Uniformity (GLN)	0.0581	--1.59	1.82E-04	[-0.000014, 0.000378]	0.068

RESULTS

We found Gray Level Run Length Matrix (GLRLM) Non-Uniformity radiomic texture from Jacobian determinant moderately improved the treatment response prediction model from the baseline. The small beta coefficient provides further motivation to increase the sample size of this study.

CONCLUSIONS

Texture-based radiomics derived from Jacobian ventilation maps capture clinically relevant patterns of regional ventilation heterogeneity associated with EBV-induced lobar deflation and may provide complementary biomechanical imaging biomarkers beyond conventional CT metrics.

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