Tracking congestion with a personalized thoracic impedance index from chest geometry and composition

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Purpose

Quantifying pulmonary congestion in heart failure (HF) patients is important for treatment and prognosis. Multifrequency trans-thoracic bioimpedance (TTI) could be used to track fluid changes in the lungs and predict onset of congestion, however, patient specific characteristics may impact the measurements.

- We investigated the effects of thoracic geometry and composition on TTI.
- This was used to calculate a personalized fluid index**.**

Methods

Simulation

Computational simulations (FEM) of thoracic bioimpedance for 125 different combinations of chest circumference, fat and muscle proportion were used to derive parameters for a linear model to estimate thoracic bioimpedance. Dielectric properties were taken from the equations provided by [Gabriel et al.] the quasi-static FEM problem was solved in COMSOL [Pettersen et al.].

Measurements

Real measurement data for model development and evaluation were taken from two trials. One on healthy subjects (control subjects) enrolled in a body-composition trial and a second one on HF patients.

1) Control subjects with normal lung fluids

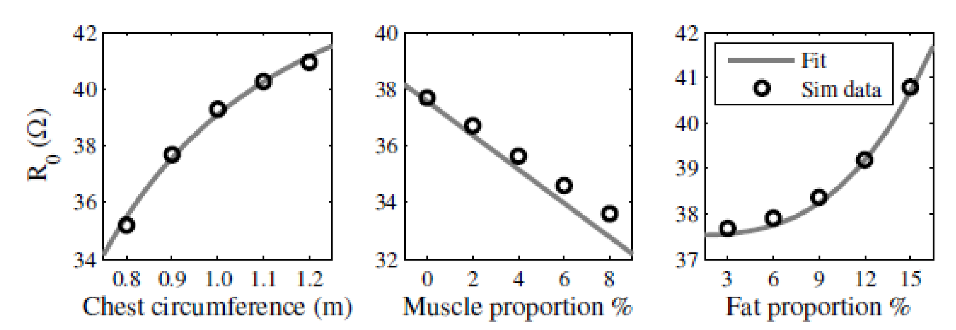
Data from 36 healthy volunteers enrolled for a day of body-composition measurements and bioimpedance measurements (Age 29.8±11.3, Height 174±7.5 cm, BMI 23.2±2.6 kg/m^2, Body fat 23.4±9.5%, Chest circumference 81.8±8.2 cm, Subscapular skinfold 12.9±4.0 mm, FFMi 17.4±2.1 kg/m^2).

2) Subjects hospitalized for acute Heart Failure

Data from 20 patients hospitalized for acute heart failure were assessed (bioimpedance and symptoms) on admission, the three subsequent days and discharge. (Age 74.7±9.5, Height 166±9.2 cm, BMI 25.8±4.4 kg/m^2, Body fat 27.2±6.4%, Chest circumference 100.0±9.2 cm, Subscapular skinfold 18.3±5.8 mm, FFMi 18.7±2.8 kg/m^2).

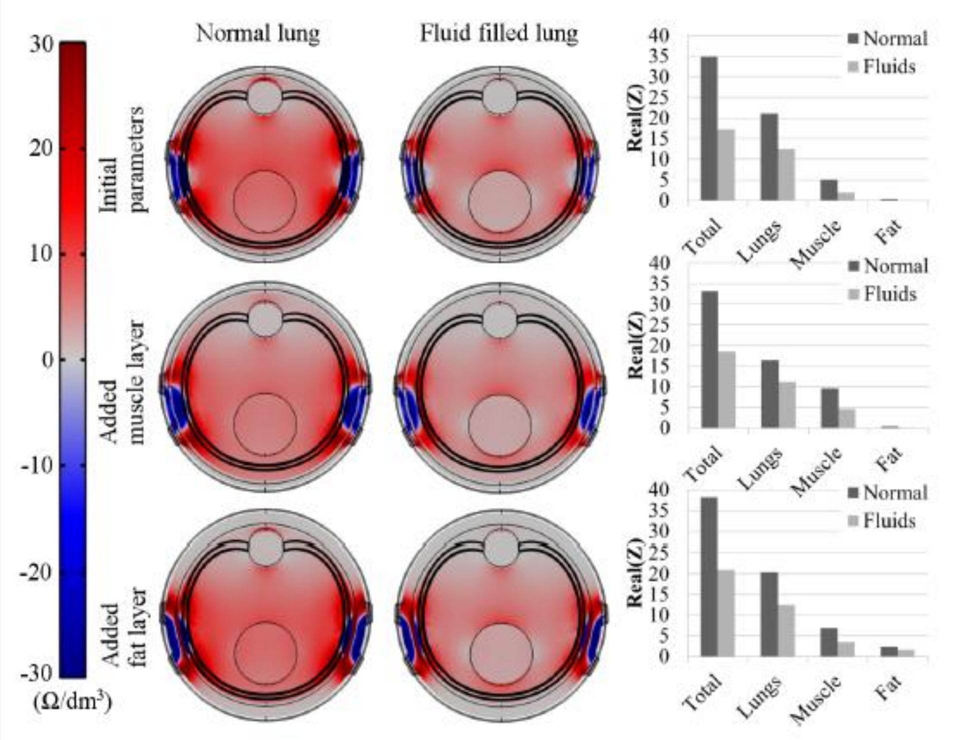
Simulation results

Figure 2: Effects of different chest compositions.



Simulated impedances together with the linear equation fitting holding two of the three parameters fixed. Increases in impedance in response to chest circumference drops off with higher values of impedance, muscle increases decreases the impedance linearly and more fat increases the impedance in an exponential fashion in the ranges explored.

Figure 3: Effects of lung fluids in simulation.



Local contribution to the total impedance for three examples of physiological parameters. Increases in both muscle and fat lowers the effect of fluids since more current is going through the unaffected layers. Muscle increase contributes to lower total impedance whereas fat increase contributes to higher total impedance.

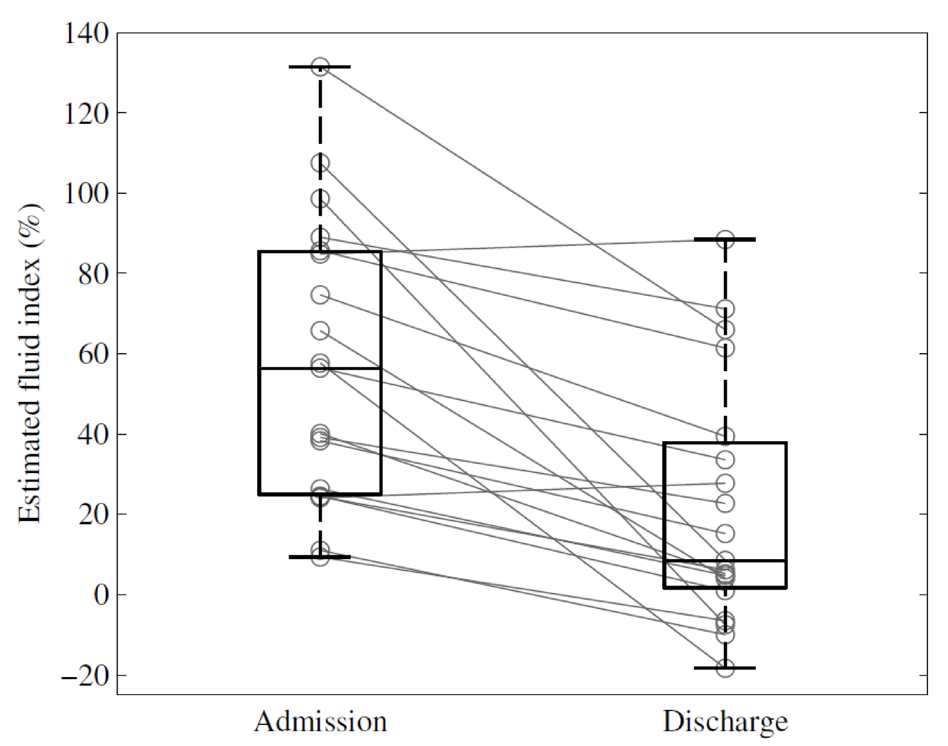
Measurement results

Table 1: Dry impedance model coefficients (normalized)

Parameter	Estimate *normalized*	SE *normalized*	T-stat	P-value
Chest circumference	3.48	1.22	2.85	0.007
Fatfreemass index	-3.54	1.22	-2.90	0.007
Subscapular fat	1.29	0.50	2.55	0.015
	RMSE	MAE	F-stat	*r*-value
Full model	2.8	8.9%	5.2	0.57

Normalized model coefficients and performance for predicting dry impedance measurements in control subjects.

Figure 4: Change in lung fluids for HF patients.



Boxplots showing the median, the range and the 25th and 75th percentile of thoracic fluid index at admission for acutely decompensated HF and discharge. Individual patient trajectories are shown as gray circles connected with lines

Statistical analysis

Fitted impedance estimates to observed measurements were evaluated using Pearson product-moment correlation coefficients (r), root mean squared errors (RMSE), and mean absolute errors (MAE), unadjusted.

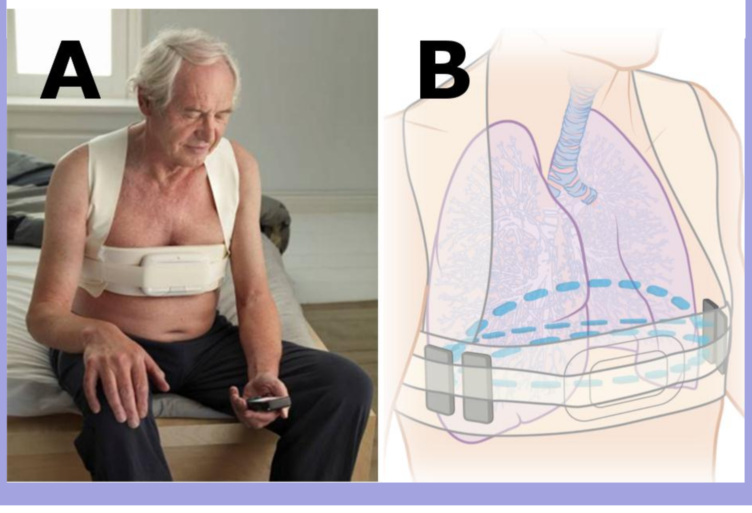
Individual symptoms were tested with uni- and multi-variate mixed-effects linear model. All mixed-effect models assumed patient specific random effects and were fitted using maximum likelihood estimation by a quasi-newton optimizer. A nominal significance level of 0.05 was assumed throughout.

All statistical and evaluation metrics were developed in a MATLAB (R2014a) environment.

Device

The wearable system was developed to provide an easy and simple method to reliably measure bioimpedance so that it could be done by patients on their own. We have previously shown that the relative measures correlates with fluid-loss during treatment and NT-proBNP levels at admission [Cuba-Gyllensten et al.].

Figure 1: Measurement vest.



Symptoms and fluid index

Table 2: Univariate and multivariate analysis [fluid index % output]

	Univariate		Multivariate	
Symptom	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Paroxysmal nocturnal dyspnea	31.3	(20.0 – 42.6)	14.1	(0.5 – 27.7)
Basal crackles	26.3	(13.3 – 39.3)	10.4	(-0.5 – 21.2)
Hepatojugular reflex	24.7	(14.1 – 35.3)	7.2	(-5.8 – 20.2)
Third heart sound	8.3	(-3.3 – 19.8)	-2.7	(-17.2 – 11.9)
Orthopnea	21.6	(12.0 – 31.2)	5.1	(-4.9 – 15.2)
Reduced exercise tolerance	16.0	(2.6 – 29.5)	-0.7	(-10.2 – 8.7)
Tachycardia	21.4	(5.9 – 36.9)	2.6	(-12.0 – 17.2)
Increased jugular venous pressure	31.5	(18.3 – 44.8)	13.5	(-3.3 – 30.2)
Hepatomegaly	7.1	(-9.9 – 24.0)	-10.6	(-23.4 – 2.3)
Peripheral edema	22.1	(13.4 – 30.9)	6.0	(-8.0 – 20.0)

Conclusion

- TTI is affected by chest geometry and composition.
- The relationship is non-linear but can be modelled to provide an estimate of dry TTI for HF patients.
- Establishing this personalized fluid index may help clinicians interpret TTI measurements

References

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Declaration of interest

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