Study of Lung Shunt Fraction Using Data Acquired from 3D SPECT and 2D Planar Imaging

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Abstract

Purpose: A modified lung shunt fraction (LSF) based on conventional 2D planar imaging data was proposed. This modified LSF reduces 2D overestimation errors and yields results closer to those from 3D SPECT images.

Methods and Results: The 3D LSF from attenuation-corrected SPECT images is treated as the gold standard. A modified LSF based on 2D planar imaging data was derived, incorporating attenuation and scatter correction through a correction factor k, which depends on the planar imaging system and the patient. The factor k is typically in the range of 0.35–0.5. Results indicate that using the modified LSF instead of the 2D LSF reduces overestimation errors, especially at higher lung shunt fractions.

Conclusion: We propose a method to determine a corrected LSF from 2D planar images, termed the modified LSF. Results show it reduces overestimation and produces values closer to 3D SPECT/CT (gold standard), particularly in cases with high LSF.

Introduction

Selective internal radiation therapy using Yttrium-90 (Y90)–labeled microspheres (Y90 radioembolization) is widely used to treat primary hepatocellular carcinoma (HCC) and metastatic liver tumors. A major toxicity risk is radiation-induced pneumonitis and sclerosis due to hepatopulmonary shunting of Y90 microspheres.

Before treatment, lung shunting is estimated using 99mTc-macroaggregated albumin (99mTc-MAA) to simulate Y90 distribution. **The lung shunt fraction (LSF), defined as the fraction of microspheres bypassing the liver and entering the lungs, is used to assess eligibility and determine a therapeutic yet safe radiation dose**. It is calculated from anterior and posterior 2D planar images using the geometric mean of counts from liver and lung regions of interest (ROI).

SPECT/CT can alternatively assess particle distribution, providing 3D visualization and CT-based attenuation and scatter correction. However, planar imaging can significantly overestimate LSF compared with SPECT/CT. Reducing these errors can improve treatment planning while maintaining lung dose within safe limits.

This study proposes a modified LSF derived from 2D planar imaging that reduces overestimation and yields results closer to SPECT/CT, which is widely considered the gold standard.

Methods & Materials

In our study, 3D Lung Shunt Fraction (LSF_3) from attenuation corrected SPECT images was treated as gold standard method and is given by:

$$\boldsymbol{LSF_3} = \frac{C_1}{C_1+C_2} \qquad (1)$$

where C_1 is the total activity counts from lungs, C_2 is the total activity counts from liver. In routine clinical practice, LSF from a 2D planar image is given by:

$$\boldsymbol{LSF_2} = \frac{G_1}{G_1+G_2} \qquad (2)$$

where G_1 and G_2 are the geometric mean of the counts on the anterior and posterior 2D planar images and are given by $G_i = \sqrt{I_{i_{anterior}} I_{i_{posterior}} e^{-\mu d_i}}$, when anterior and posterior 2D planar images were used for LSF estimation, LSF_2 can also be described as following:

$$\boldsymbol{LSF_2} = \frac{C_1 B_1 e^{-\mu d_1/2}}{C_1 B_1 e^{-\mu l_1/2} + C_2 B_2 e^{-\mu d_2/2}} = \frac{C_1}{C_1+kC_2} \qquad (3)$$

where B_1 and B_2 are the buildup factors due to Compton scatter, d_1 and d_2 are the patient's effect thicknesses in lungs and liver regions, $e^{-\mu d_1}$and $e^{-\mu d_2}$ are the attenuation factors in lungs and liver regions, $k = (B_2/B_1)e^{-\mu(d_2-d_1)/2}$, is a planar imaging system and patient dependent factor. In our study, first, k was determined by using a group of test data set of LSF_2 and LSF_3:

$$\boldsymbol{k} = \frac{LSF_2 \times (1-LSF_3)}{LSF_3 \times (1-LSF_2)} \qquad (4)$$

After determining the k value, the modified LSF is calculated by using LSF_2 from a verification data set:

$$\boldsymbol{LSF_m} = \frac{k \times LSF_2}{1+(k-1) \times LSF_2} \qquad (5)$$

Finally, these modified LSF_m were analyzed and compared with the traditional LSF_2.

Results

Based on equation (4), k was calculated from a 12-patient test dataset, yielding a mean value of $k = 0.45$. Using equation (5), the modified LSF was then determined for a 64-patient verification dataset. The results show that:

(1) across all patients, the average difference between LSF_2 and LSF_3 was 3.0%, compared to 1.2% for LSF_m vs. LSF_3;

(2) for $LSF_2 \geq 5\%$, the differences were 6.6% and 1.6%, respectively; and

(3) for $LSF_2 \geq 10\%$, the differences were 10.1% and 1.9%, respectively.

These results demonstrate that replacing LSF_2 with the modified LSF reduces overestimation errors, particularly at higher lung shunt fractions, and yields results more closely aligned with SPECT/CT.

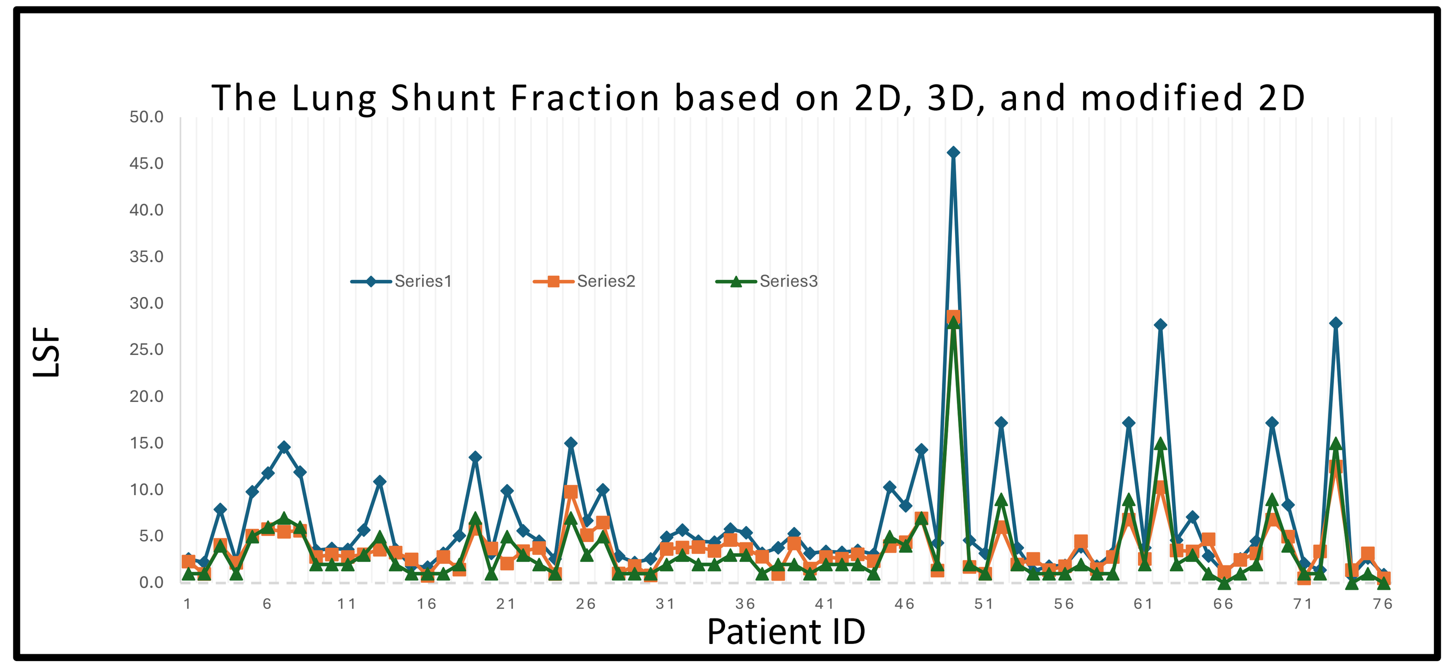

Figure 1: The results of LSF based on planar images LSF_2, based on SPECT LSF_3, and modified LSF_m and LSF_3 for all 76 cases.

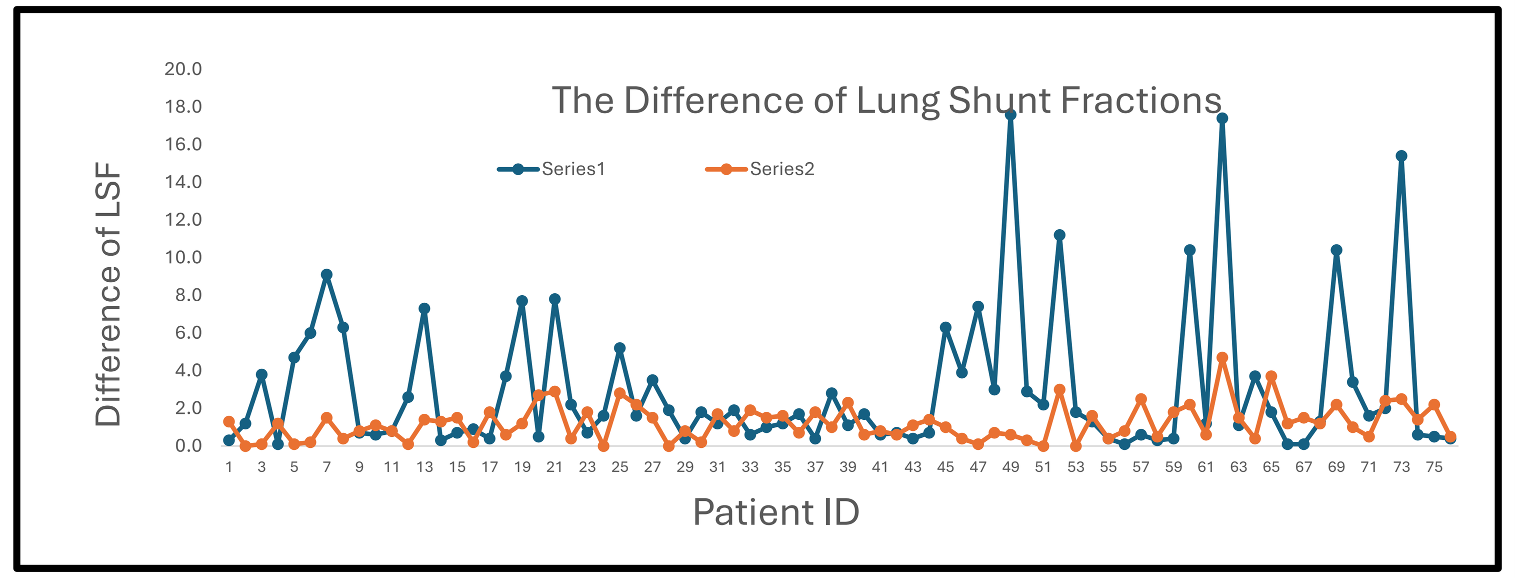

Figure 2: The comparison of the difference between LSF_2 and LSF_3, and the difference between modified LSF_m and LSF_3 for all 76 cases.

Discussion

The present study demonstrates that planar imaging consistently yields higher LSF values than SPECT/CT. We propose a method to estimate LSF from planar imaging data, in which the system- and patient-dependent factor k is empirically determined from a test dataset. This factor typically ranges from 0.3 to 1.0, with $k = 1$ corresponding to no attenuation difference between lung and liver regions. In this study, $k = 0.45$ was the mean value obtained.

Our results show that high LSF values are often associated with large overestimation bias, which can lead to overestimation of lung dose based on planar imaging and may exceed safety thresholds (30 Gy for a single treatment or 50 Gy cumulative).

In addition to attenuation and buildup effects, several factors may contribute to discrepancies between planar imaging and SPECT/CT. Overlap of the liver and lung bases in anterior and posterior projections can introduce liver activity into lung ROIs, increasing planar LSF. Scatter from 99mTc-MAA activity, despite collimation, may also cause liver-originating counts to be recorded in lung ROIs.

This study is limited by its retrospective design and small sample size. Further studies with larger patient cohorts are warranted.

Conclusions

This study proposes a method to determine a corrected LSF from 2D planar images, referred to as the modified LSF.

Results demonstrate that this approach reduces overestimation errors and produces values more consistent with those obtained from 3D SPECT/CT, the gold standard, particularly in cases with high lung shunt fractions, where overestimation is most pronounced.

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