

INTRODUCTION

Clinical motivation

- Fetal Growth Restriction impairs fetal development, leading to **preterm delivery**^[1].

Why fetal lung?

- Fetal lung matures late and is vulnerable to **developmental impairment in FGR**^[2].

Why MRI + DL?

- IVIM-MRI enables non-invasive assessment, but current analysis is **labour-intensive**^[3,4].

METHODOLOGY

- Strategy: 3D full-resolution nnU-Net^[5];
- Fusion strategies** for representative lung mask: **OLP, AVG, LC**;
- IVIM fitting**: voxel-wise two-step least-squares (MATLAB).
- The IVIM mathematical model^[6]:

$$S(b) = S_0 [f \exp(-D^*b) + (1 - f) \exp(-Db)]$$

b: diffusion weighting (b-value);
S(b): signal at *b*;
S₀: signal at *b* = 0;
f: perfusion fraction;
*D**: pseudo-diffusion coefficient;
D: tissue diffusion coefficient.
 IVIM model separates the effect of pure diffusion (*D*) and blood perfusion (*f*)
- Total lung volume (TLV) was the **only significant parameter** distinguishing FGR from controls (**p = 0.003**).
- The expected TLV was calculated using a reported TLV-GA relationship^[7]:

$$TLV_{expected} = -0.0132 \cdot GA^3 + 1.14 \cdot GA^2 - 27.38 \cdot GA + 207.50$$
 where GA is the gestational age in weeks.
- FGR Classification using observed-to-expected total lung volume (oeTLV):

$$\frac{TLV_{measured}}{TLV_{expected}} \rightarrow \text{standardised} \rightarrow \text{Z-score} \xrightarrow{\text{ROC Analysis}} \text{Youden-index Threshold} \xrightarrow{\text{To test set}} \text{Prediction}$$

Fig 1. Procedure of FGR Classification using IVIM Parameters.

DATA DESCRIPTION AND EXPERIMENTS

- Dataset: 95 4D diffusion-weighted MR images from 30 pregnant women.

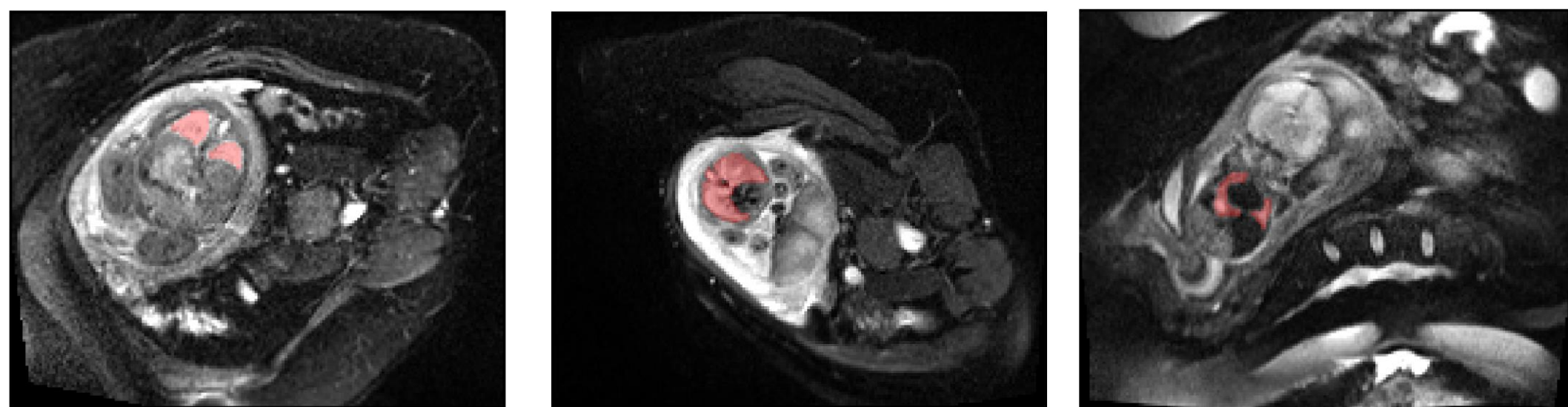


Fig 2. Fetal lung visibility in different views. (A) Coronal and (B) axial views show clear boundaries, while (C) sagittal view has poor definition.

- GA: 20-36 weeks (median: 27+6 weeks)
- b-values (Strength of diffusion gradients) : 0 to 600 s/mm²
- Repetition time (TR) = 3700 ms
- Echo time (TE) = 73 ms
- Slice thickness = 6 mm
- Inter-slice spacing = 7.2 mm
- Acquisition matrix = 148 × 128

- Data preprocessing:

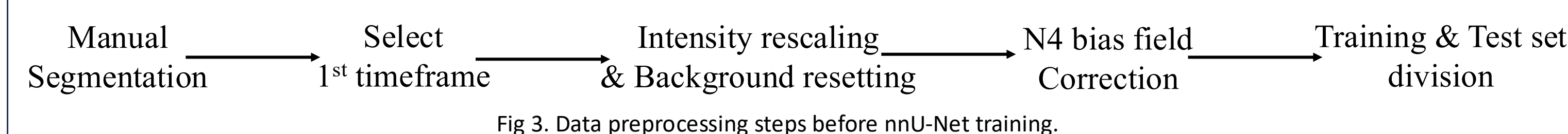


Fig 3. Data preprocessing steps before nnU-Net training.

- Data split: 80% training / 20% testing
- Balanced for GA, FGR/control ratio, orientation, and image intensity

RESULT

- Auto-segmentation result:
Test set: 18 images(6 fetuses)
Mean Dice: 82.14 ± 6.68%

- Factors affecting segmentation accuracy:
 - No group effect;
 - No view effect;
 - Improved with GA.

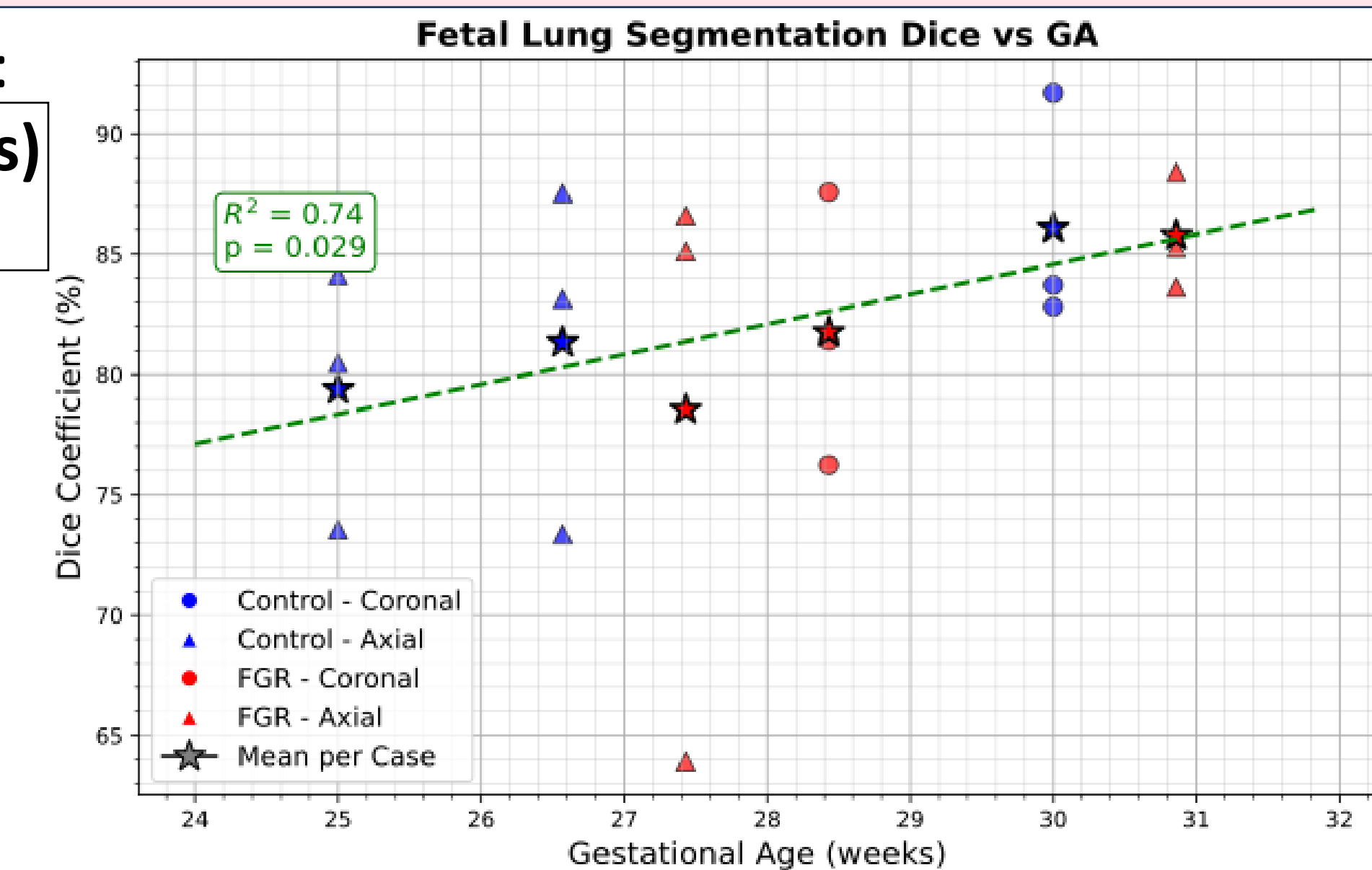


Fig 4. Relationship between GA and the Dice coefficient

- Manual vs Auto IVIM Parameters
 - No significant differences across all fusion strategies (all **p ≥ 0.1603**)
 - No significant differences in variability metrics (all **p ≥ 0.0851**)
 - AVG showed the best overall agreement**

Parameter	Mean Parameter p-values			Intra-Mask Variability p-values			
	AVG	OLP	LC	Variability	AVG	OLP	LC
Volume	0.6181	0.4394	0.5334	S_0^{cv}	0.5907	0.3821	0.6355
S ₀	0.9770	0.4987	0.5068	f^{cv}	0.3933	0.6804	0.6518
f	0.8924	0.6556	0.7055	D^{*cv}	0.4222	0.3133	0.2038
D*	0.1810	0.3748	0.1603	ADC_{cv}	0.5315	0.3049	0.7741
ADC	0.1963	0.3936	0.4396	$f_{entropy}$	0.8121	0.3766	0.9619
Residual	0.5631	0.4335	0.2276	$D^*_{entropy}$	0.7570	0.0851	0.2745
				$ADC_{entropy}$	0.4017	0.6709	0.3256

Table 1. Paired t-test p-values comparing Manual vs. Automatic segmentations for mean parameters and intra-mask variability metrics.

- Coefficient of variation (CV) analysis:
 - Higher inter-subject variability in FGR than controls
 - AVG showed the smallest CV difference (28.4%)

Parameter	AVG Fusion		OLP Fusion		LC Fusion							
	Manual	Automatic	Manual	Automatic	Manual	Automatic						
	Ctrl	FGR	Ctrl	FGR	Ctrl	FGR						
Volume	0.3142	0.2399	0.3147	0.3280	0.5984	0.1124	0.7712	0.3200	0.1425	0.4109	0.1141	0.5157
S ₀	0.1374	0.3371	0.1579	0.3099	0.1386	0.3545	0.1681	0.3063	0.1708	0.3752	0.1849	0.3122
f	0.0837	0.1337	0.1383	0.1138	0.1091	0.1749	0.1322	0.1000	0.0604	0.0628	0.0784	0.2434
D*	0.1137	0.1429	0.1706	0.2361	0.1761	0.1531	0.1664	0.1886	0.0394	0.1288	0.0361	0.1091
ADC	0.0320	0.0558	0.0102	0.0482	0.0161	0.0873	0.0166	0.0491	0.0097	0.0300	0.0168	0.0862
Residual	0.4102	0.8862	0.3957	0.8871	0.4641	0.8998	0.4123	0.9188	0.3661	0.9519	0.3720	0.9207

Table 2. Intra-group Coefficient of Variation (CV) for IVIM Parameters, comparing fusion strategies, Manual vs Automatic segmentations and control vs FGR.

- FGR classification: The oeTLV analysis achieved an AUC of 0.9924 in the 23-case training set and showed consistent separation between FGR and controls in the test set.

CONCLUSION

- We achieved **automated fetal lung segmentation of fetal DWI-MRI**.
- DL segmentation achieved **manual-grade IVIM quantification**.
- oeTLV-based model demonstrated **strong potential for FGR classification**.

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Let's connect!

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