Improving cross-domain brain tissue segmentation in fetal MRI with synthetic data

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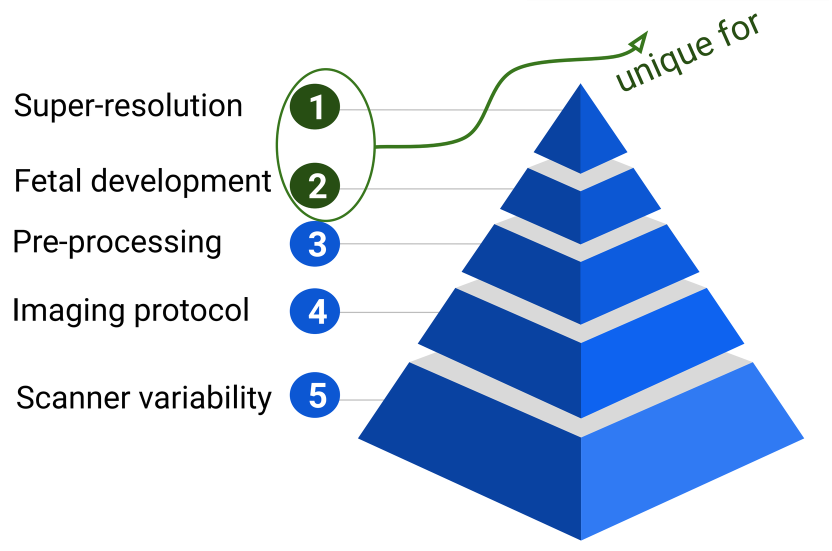
Introduction

Fetal brain MRI is an imaging technique crucial for **detection of neurodevelopmental abnormalities**[1].

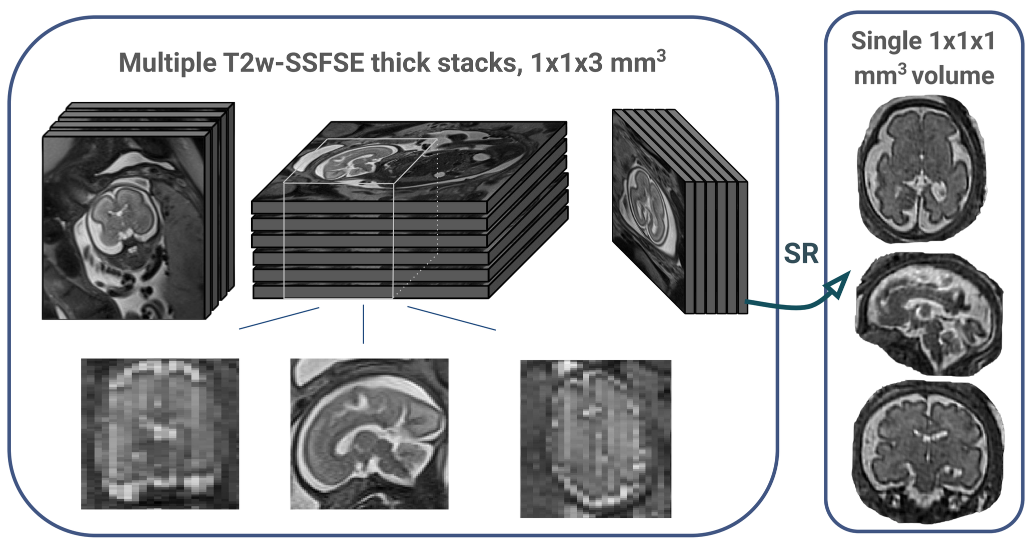
Challenges with fetal brain MRI:

- data scarcity[2]
- domain shifts

Sources of domain shifts in fetal brain MRI[3]



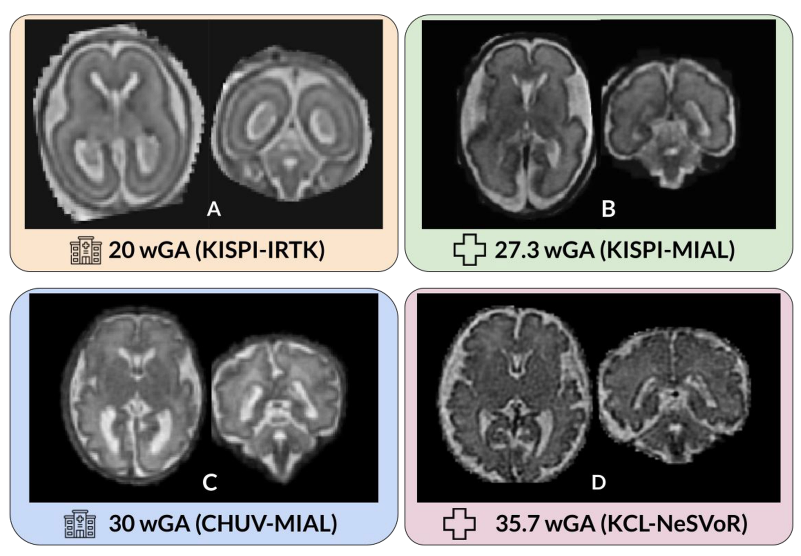
1. **Super-resolution (SR)** is needed to obtain high-resolution isotropic volumes from clinical scans. But it can also introduce artifacts.



2. **Fetal neurodevelopment is characterized by drastic anatomical changes in the brain** throughout gestation.

It significantly **alters brain morphology** and introduces **tissue heterogeneity** due to developing white and gray matter[1].

Fetal brain MRI domains



Methods

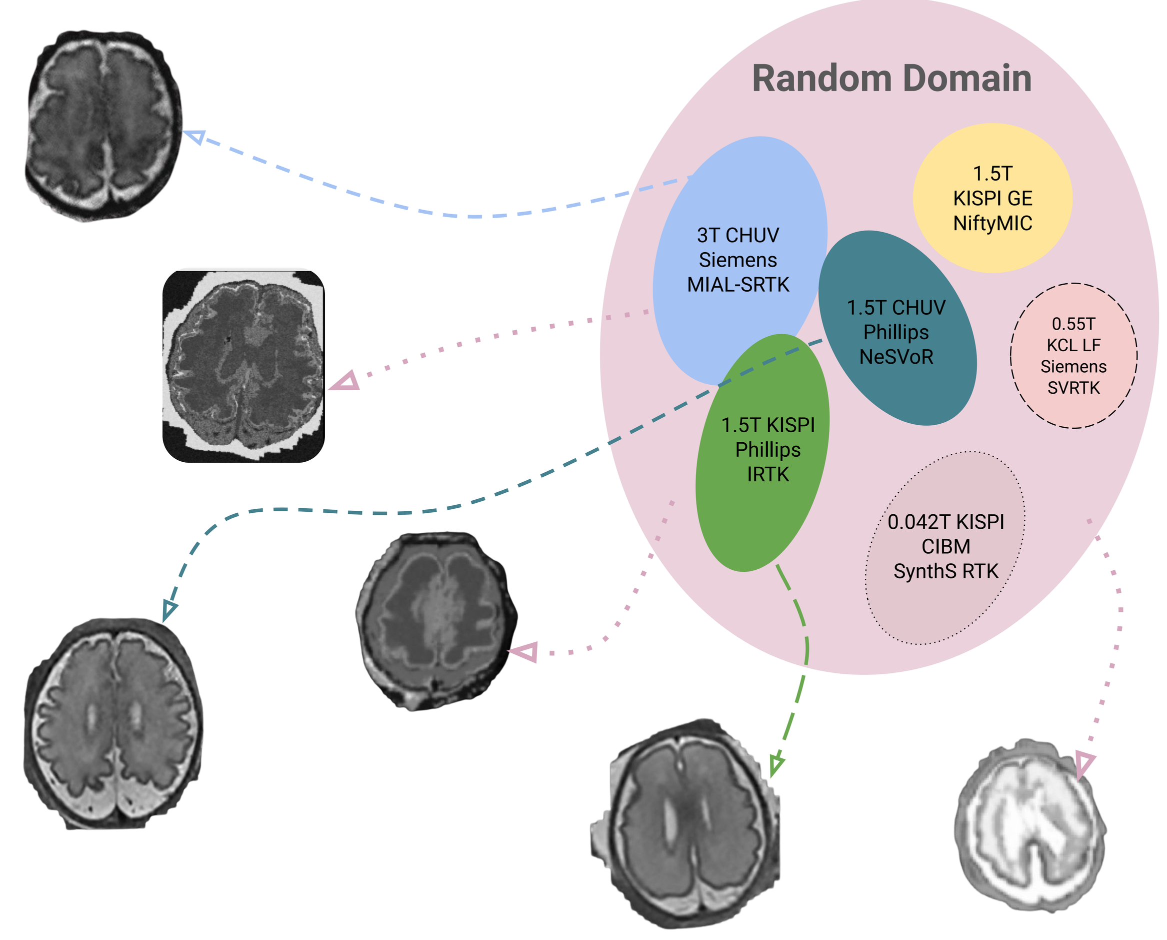
Data

We utilize **data from** the **FeTA challenge**[5], along with **private clinical** data from **two institutions.**

Table 1. Dataset properties. N_n - neurotypical, N_p - pathological. KISPI* - publically available dataset of the FeTA challenge

Site	Scanner	Acquisition Parameters	SR	Resolution (mm^3)	GA (weeks)	N_n	N_p
KISPI*	GE Signa Discovery MR450/MR750 (1.5T/3T)	ssFSE TR: 2500-3500/120 ms 0.5 x 0.5 x 3.5 mm^3	MIAL IRTK	0.5^3 0.5^3	20-34 20-34	25 24	15 16
CHUV	Siemens MAGNETOM Aera (1.5T)	HASTE TR/TE: 1200/90 ms 1.1 x 1.1 x 3 mm^3	MIAL	1.1^3	21-35	25	15
KCL	Siemens MAGNETOM FREE.MAX (0.55T)	HASTE TR/TE: 2600/106 ms 1.5 x 1.5 x 4.5 mm^3	SVRTK NeSVoR	0.8^3	21-35	40	0

Domain Randomization



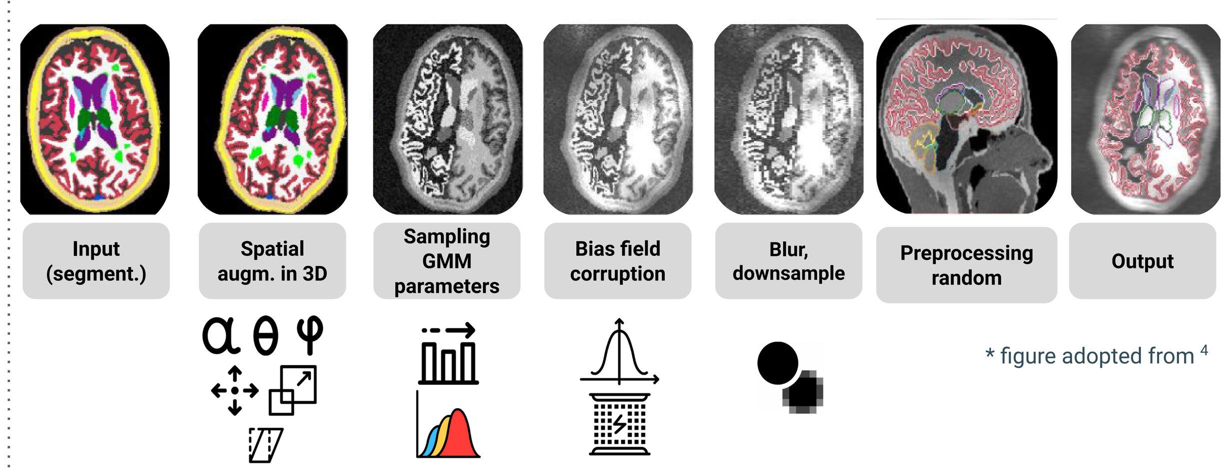
To achieve domain randomization (DR):

- simulate **wide range of image appearances, often beyond realistic**
- train a model **on synthetic images** from the random domain

In this work we focus on **single-source domain generalization (SSDG) through DR**: can we generalize to other domains using data from only one domain?

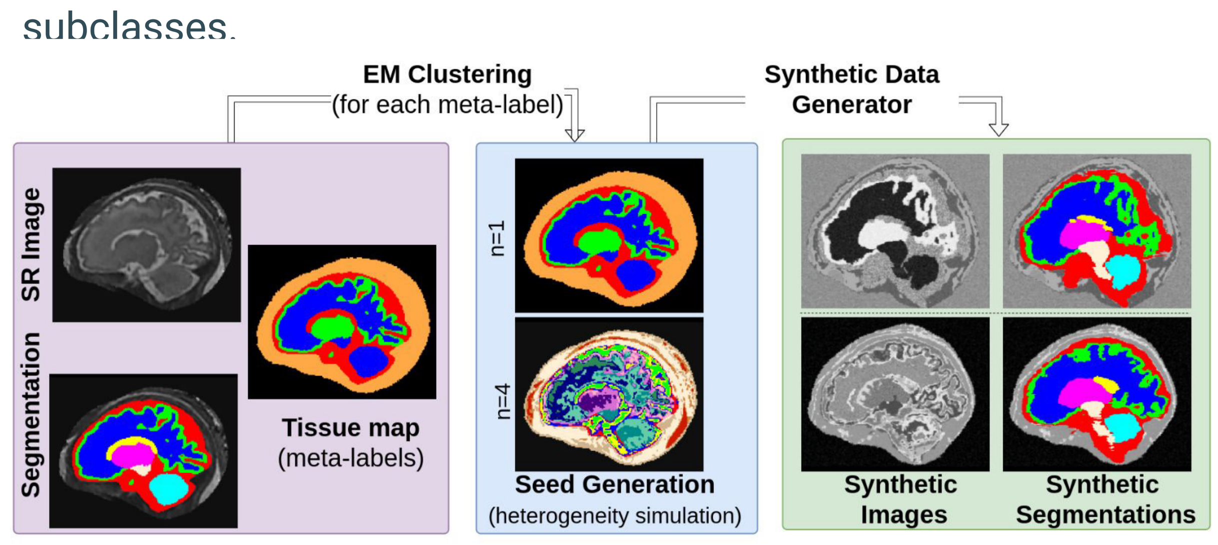
SynthSeg[4] is a popular approach for domain randomization in adult neuroimaging that we have adopted for fetal brain MRI.

SynthSeg's[4] generator for synthetic images



FetalSynthSeg incorporates domain-specific knowledge into the generation pipeline.

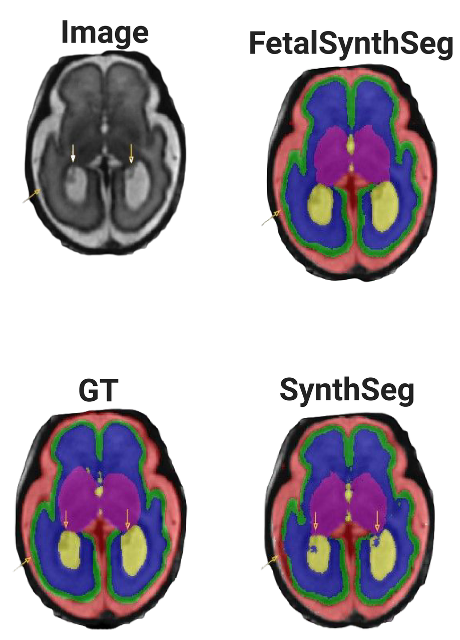
It address **fetal tissue heterogeneity** and **super-resolution artifacts** by introducing meta-label splitting strategy into subclasses.



We compare the utility of synthetic images from SynthSeg and FetalSynthSeg with real images (Baseline) by **training the same 3D U-Net for fetal brain tissue segmentation** on different data sources.

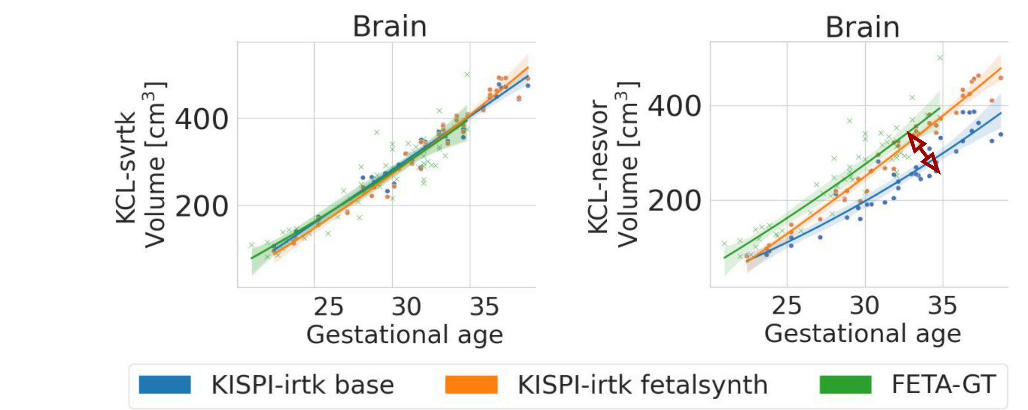
Results

SSDG



Tested	Trained	Experiment	Mean DSC ± STD
CHUV-mial	KISPI-irtk	Baseline	76.5 ± 3.2
		SynthSeg	77.9 ± 2.9
		FetalSynthSeg	**79.9 ± 2.1**
	KISPI-mial	Baseline	75.2 ± 3.5
		SynthSeg	72.9 ± 4.6
		FetalSynthSeg	**77.7 ± 2.6**
KISPI-irtk	CHUV-mial	Baseline	69.6 ± 13.6
		SynthSeg	70.9 ± 9.2
		FetalSynthSeg	**79.5 ± 8.4**
	KISPI-mial	Baseline	67.7 ± 12.9
		SynthSeg	72.0 ± 7.7
		FetalSynthSeg	**75.7 ± 7.0**
KISPI-mial	CHUV-mial	Baseline	67.2 ± 17.6
		SynthSeg	60.5 ± 15.7
		FetalSynthSeg	**69.7 ± 15.5**
	KISPI-irtk	Baseline	63.4 ± 17.0
		SynthSeg	67.5 ± 15.7
		FetalSynthSeg	**68.2 ± 15.2**

Growth charts of cerebral volume at low-field

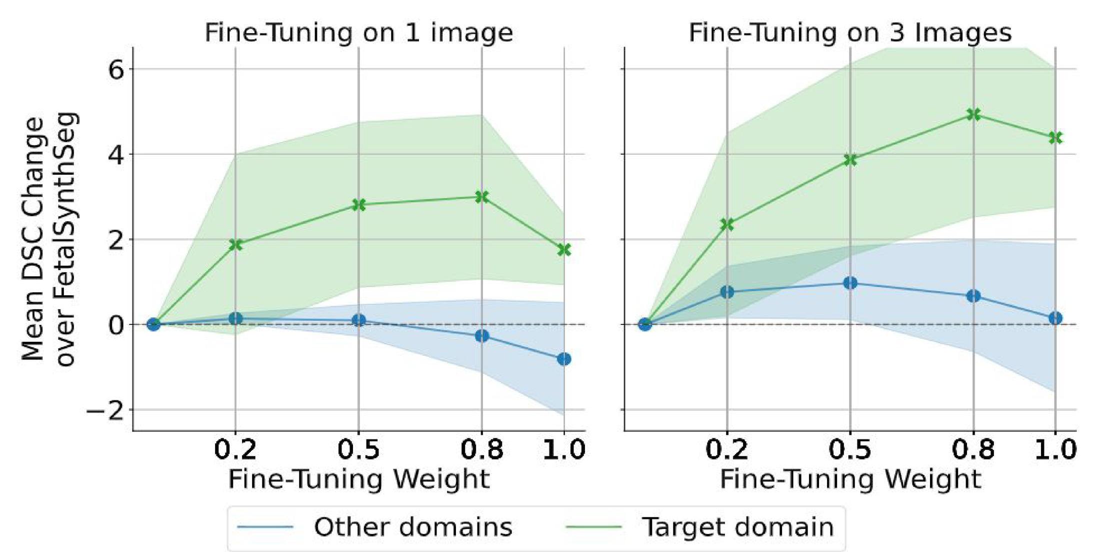


Evaluation on **two domain shifts**:

- **field strength** (trained on 3T, tested on 0.55T)
- **SR method** (trained on SR similar to SVRTK)

Using real data

Fine-tuning FetalSynthSeg **with real images** can further improve performance with the **weight-space interpolation**[6] **helping to balance** the tradeoff between in-domain performance and out-of-domain generatlization.



Conclusions

- **SR** reconstruction **poses a strong domain shift**
- DR helps to achieve SSDG in fetal brain MRI
  - **Simulating domain specific distribution shifts** is crucial for success
- Use of real data needs to be combined with **weight interpolation** to avoid overfitting

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