Placental Flattening via Volumetric Parameterization

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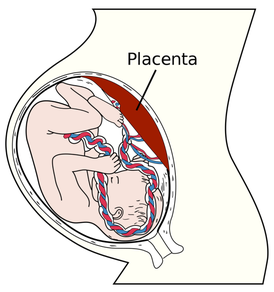
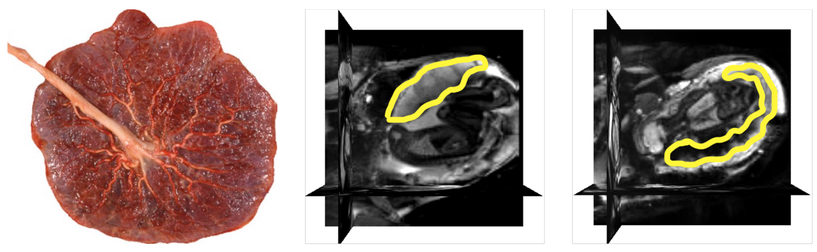
Goal

Improve visualization of placenta function, anatomy



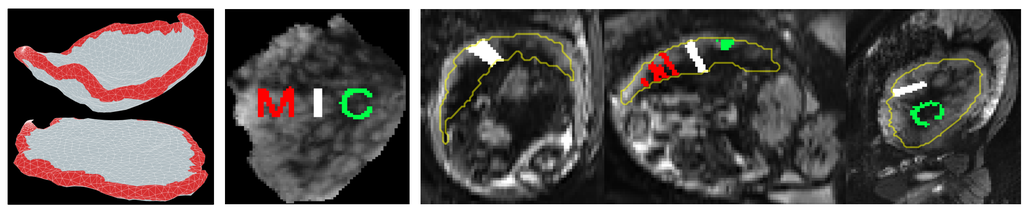
Clinical Motivations

- Prevent pregnancy complications: assess placental function by fetal MRI
- Difficult to visualize, study function: variable and curved placental shape

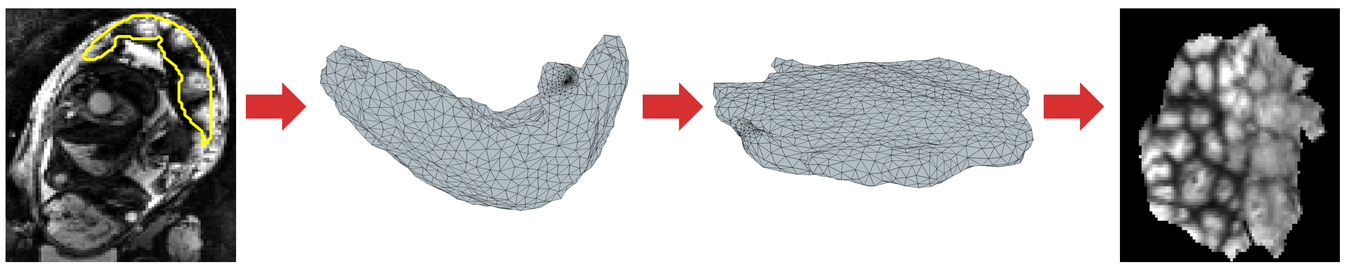


Approach

Map the placenta volume to a flattened template to resemble the well-studied post-birth shape.

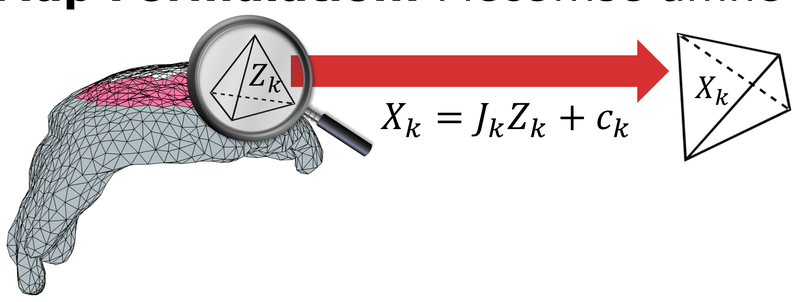


Original, Flattened Mesh | Flattened MRI | Original MRI



Fetal MRI | Tetrahedral mesh | Flattened mesh | Flattened image

1. Map Formulation: Piecewise affine to a template



Z_k: tet. k (original)
X_k: tet. k (flattened)
J_k: Jacobian of transform
x_i: vertex i (flattened)

2. Mapping Objective Function

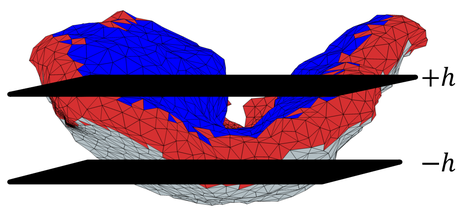
$$\phi(X,h) = \underbrace{\sum_{m:\, x_m \in \partial Z} Area_m T(x_m,h)}_{\text{Template Match } (T)} + \lambda \underbrace{\sum_{k=1}^{K} Vol_k \mathcal{D}(J(X_k))}_{\text{Volumetric Distortion } (\mathcal{D})}$$

- Distortion: Symmetric Dirichlet Energy

$$\mathcal{D}(J) = \|J\|_F^2 + \|J^{-1}\|_F^2 = \sum_{i=1}^{3} (\sigma_i^2 + \sigma_i^{-2})$$

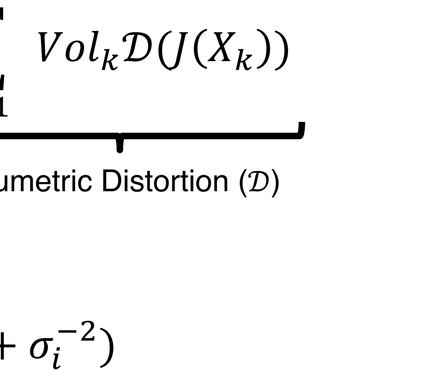
- Template: Uniform thickness

$$T(x,h) = \begin{cases} (x^{(3)} - h)^2, & \text{if } x \in \mathcal{F}(\partial Z) \\ (x^{(3)} + h)^2, & \text{if } x \in \mathcal{M}(\partial Z) \\ 0 & \text{otherwise} \end{cases}$$



  - Boundary parcellation: Spectral clustering to find boundary vertex labelling $\boldsymbol{l}$ that minimizes

$$E(\boldsymbol{l}) = \textstyle\sum_{ij} w_{ij} (l_i - l_j)^2;$$
subject to $\|\boldsymbol{l}\|_2^2 = 1, \sum_i l_i = 0,$
where, $w_{i,j} = \exp\{\gamma(\hat{n}_i^T \hat{n}_j)\}$



3. Optimization

- Gradient descent over vertex locations with line search
- Invertible map: Prevent tet. volume sign change per iteration

$$X_k^{(n+1)} = X_k^{(n)} - \eta \nabla_X \phi(X)$$

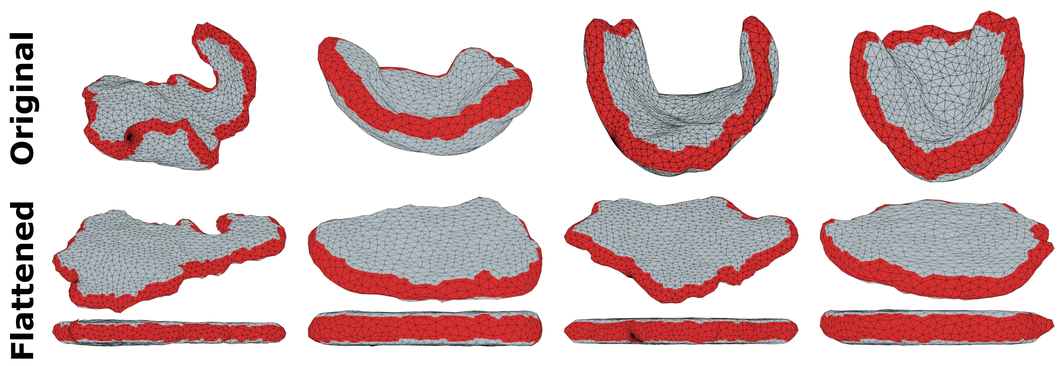
$$Vol_k(\eta) = \frac{1}{6} \det\left((X_k - \eta \nabla_X \phi(X_k))B\right)$$

Dataset:

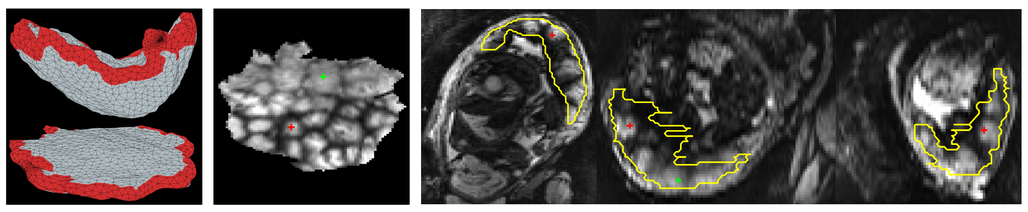
- 78 subjects, gestational age: 27-38 weeks
- 111 segmentations; 59 singleton (35 in supine and lateral positions), 17 twin pregnancies
- MRI: GRE-EPI 3mm isotropic

Results:

- Mapping is robust to shape variation



- Enables Contextual Visualization



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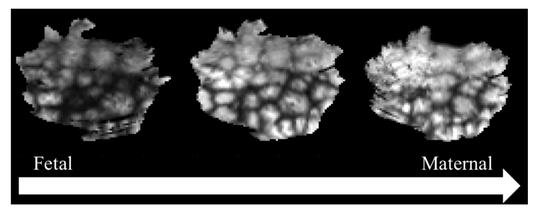
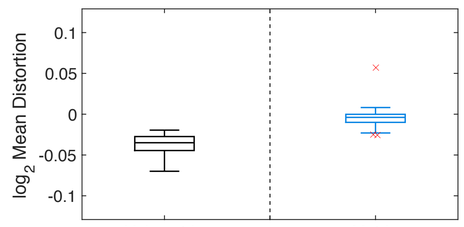
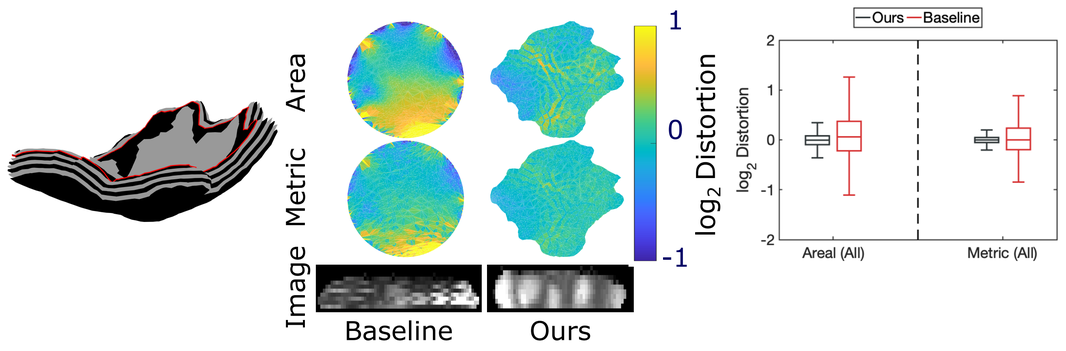


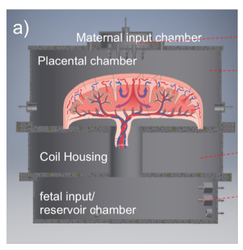
- Shape distortion: 4.1±1.9%
- Template mismatch 0.26±0.05 voxels



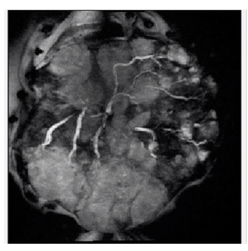
- Improved distortion, visualization over 2D baseline[1]



- **Next Steps:** *ex vivo* analysis and comparison



Placenta Chamber



Perfused Placenta

1. Miao et al., "Placenta Maps…", IEEE TVCG: 23(6), 2017
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