3D Virtual RibCage Implant Generation

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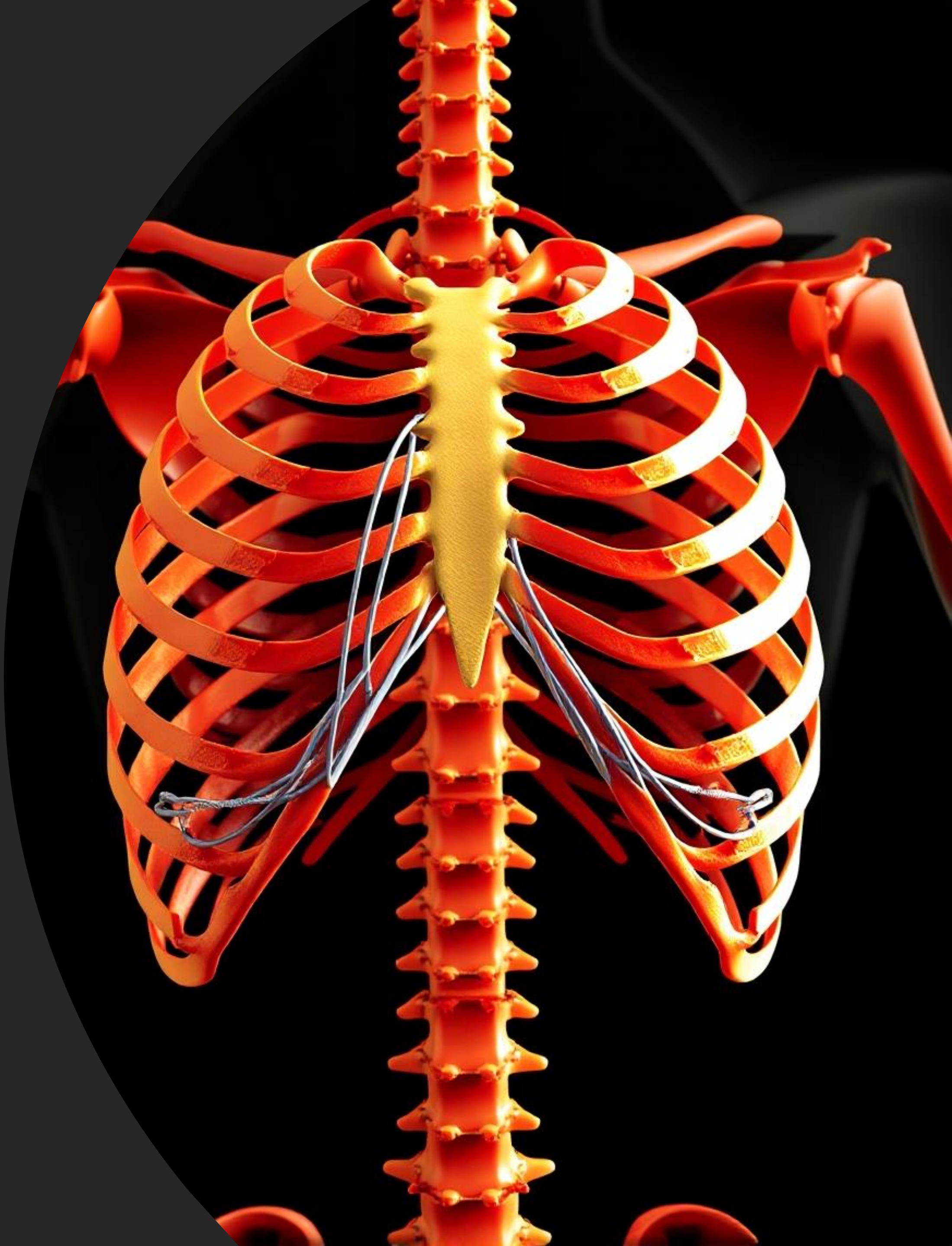
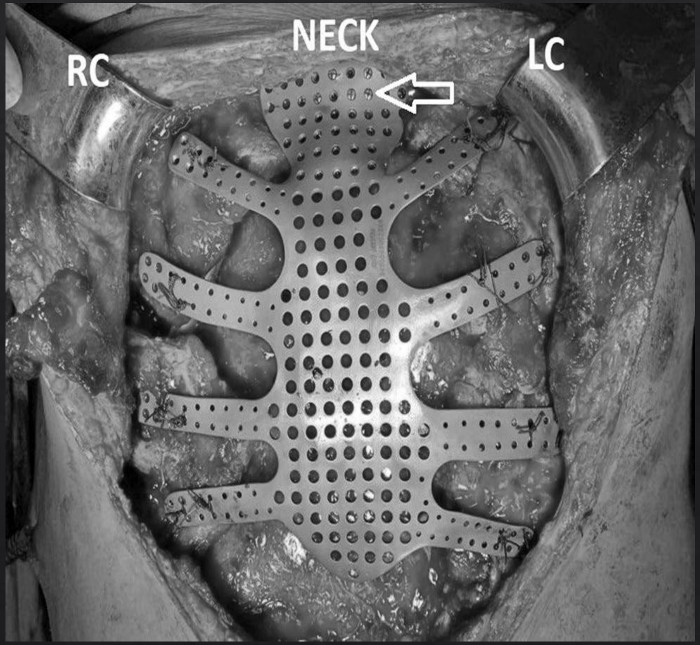
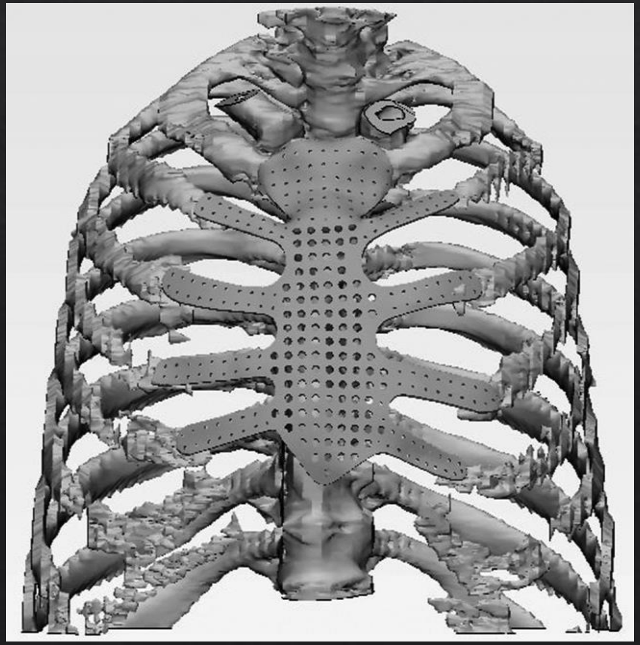


Existing Methods of Ribcage Implant

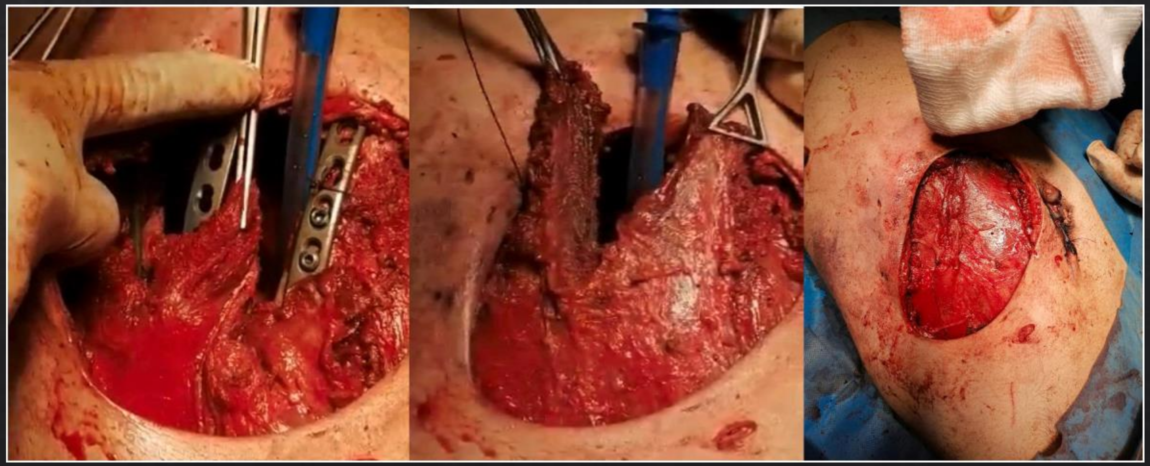
- Haskan Isiki et al, had presented another paper in 2021 for chest wall reconstruction as a case study for two patients. In this also titanium-alloy metal is used for the implant. They designed 3D digital model for implant and transferred to Selective metal laser sintering (SLS) machine for the construction.

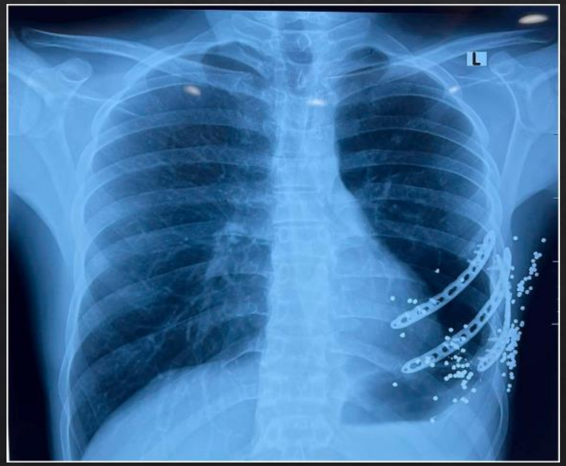




Existing Methods of Ribcage Implant

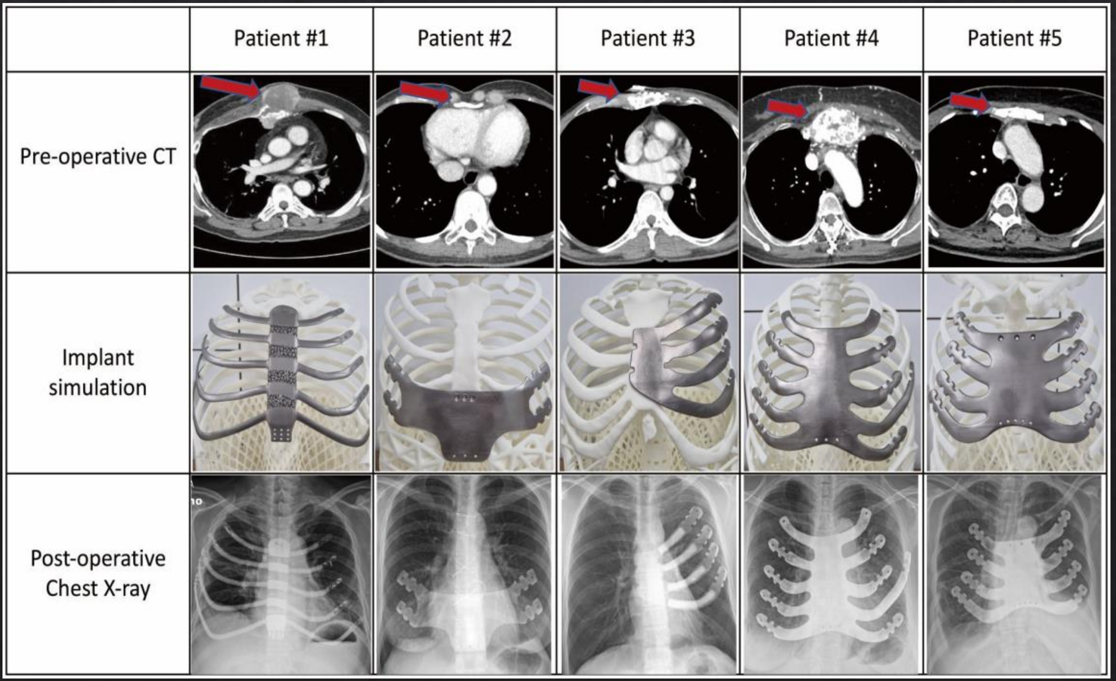
- Rawand Abdul Rahman Essa et al. has presented in 2022, a case study of a patient had got bullet injury for which chest wall have been reconstructed using the Titanium based metal and 3D printing technology.





Existing Methods of Ribcage Implant

- In 2024, Doong Yoong et al, has reconstructed 3D printed pure titanium implementation for the chest wall reconstruction involving sternum and ribs. They have used the CT scan and specific measurements of rib structure and 1:1 simulation for each patient to generate the implant. This implant generation takes **2-3 days** for design process.



What is the need of Ribcage Implant design using Learning based Approach?

- Overcome Limitations of Manual/CAD Methods
  - Traditional methods are time-intensive and require specialized expertise.
  - Learning-based methods streamline the process, reducing the need for manual input.
- Improved Design Speed and Consistency
  - Automated model-driven design reduces the time required for implant creation.
  - Consistent quality across patients, minimizing variability seen in manual approaches.
- Higher Anatomical Precision
  - Deep learning captures complex ribcage geometries and unique patient anatomy.
  - Ensures implants align precisely with each patient's thoracic structure.
- Scalable Solution for Personalized Medicine

RibCageImp: A Deep Learning Framework for RibCage Implant Generation

The Problem Statement

- Let R represent the ribcage, and R_d be a portion of the ribcage with a defect created by a removed section due to fracture or surgical resection.
- Let I_g represent the ground truth implant corresponding to the removed portion.
- Objective: To generate a 3D implant I_p that, when combined with R_d, reconstructs the complete ribcage $\hat{R}$, Mathematically

$$\hat{R} = R_d + I_p$$

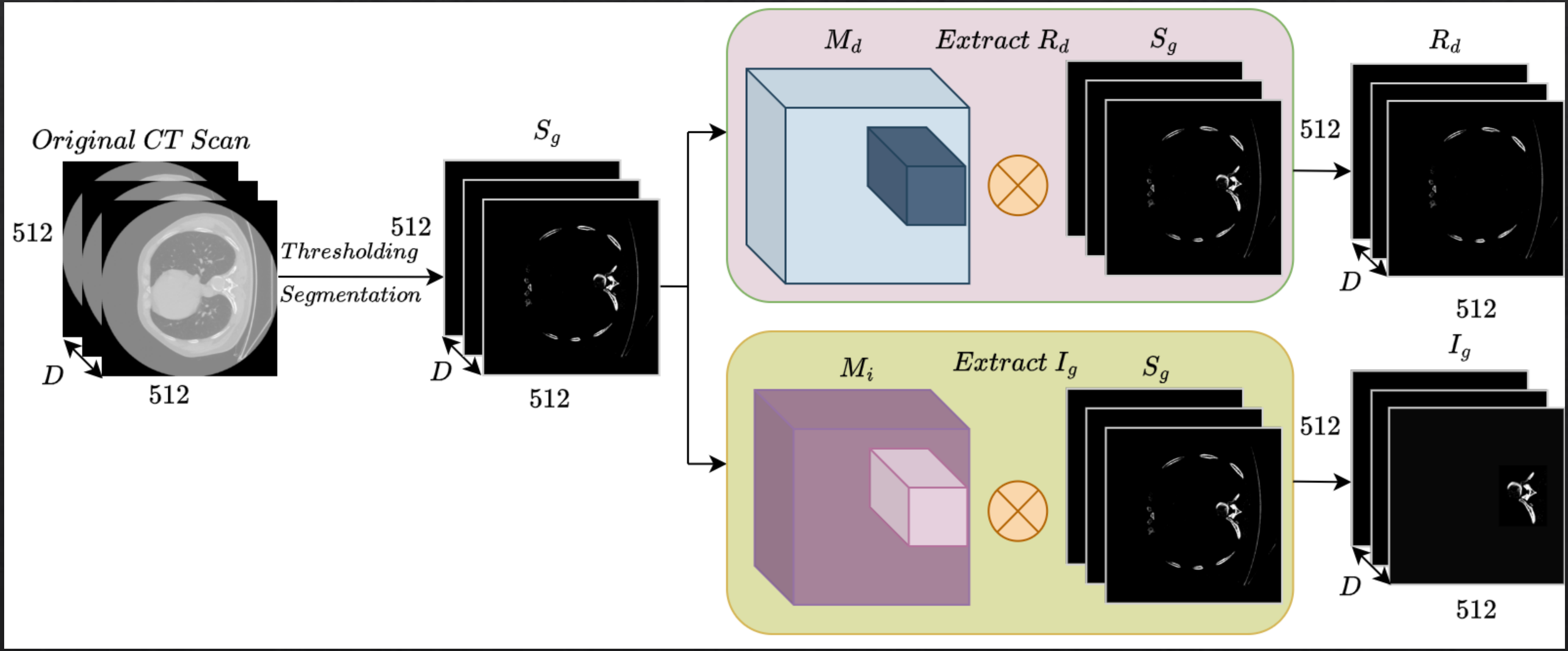
- Challenge: Find I_p so that $\hat{R}$ closely matches the original ribcage R. The problem can be formalized as:

$$\min_{R_d} \mathcal{L}\left(I_g, I_p\right) \; subject\ to \hat{R} = R_d + I_p$$

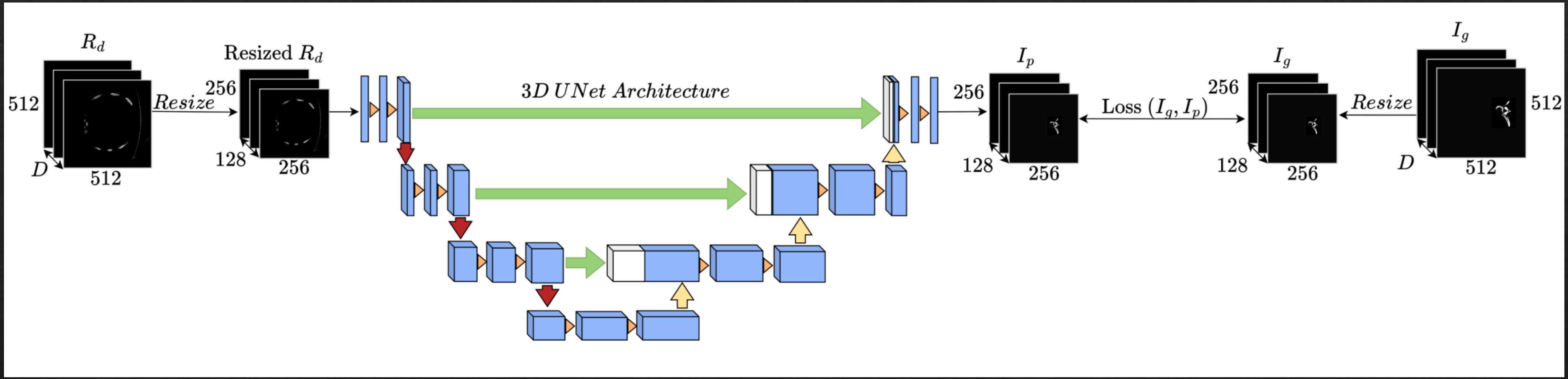
- Here, $\mathcal{L}$ is a loss function evaluating similarity between predicted implant I_p and ground truth implant I_g.

The Goal

How we have prepared data ?



Model Architecture and Training Pipeline



What are Loss Functions used ?

- **DICE Loss:** Gives volumetric overlap between the I_g and I_p.

$$\mathcal{L}_{Dice}(I_p, I_g) = 1 - 2.\frac{|I_p \cap I_g|}{|I_p| + |I_g|}$$

- **MSE Loss**: quantifies the voxel-wise accuracy of prediction, it ensures precise voxel level alignment

$$\mathcal{L}_{MSE}(I_p, I_g) = \frac{1}{n}\sum_{i=1}^{n}(I_p(i) - I_g(i))$$

What are Loss Functions used ?

- **Extra Region Removal**: penalizes any extraneous predictions E_R outside the ground truth region in the predicted implant I_p by computing the elementwise product with the inverse of the ground ${I_g}^{-1}$ truth and subtracting to a zero matrix.

$$E_R = {I_g}^{-1} . I_p$$

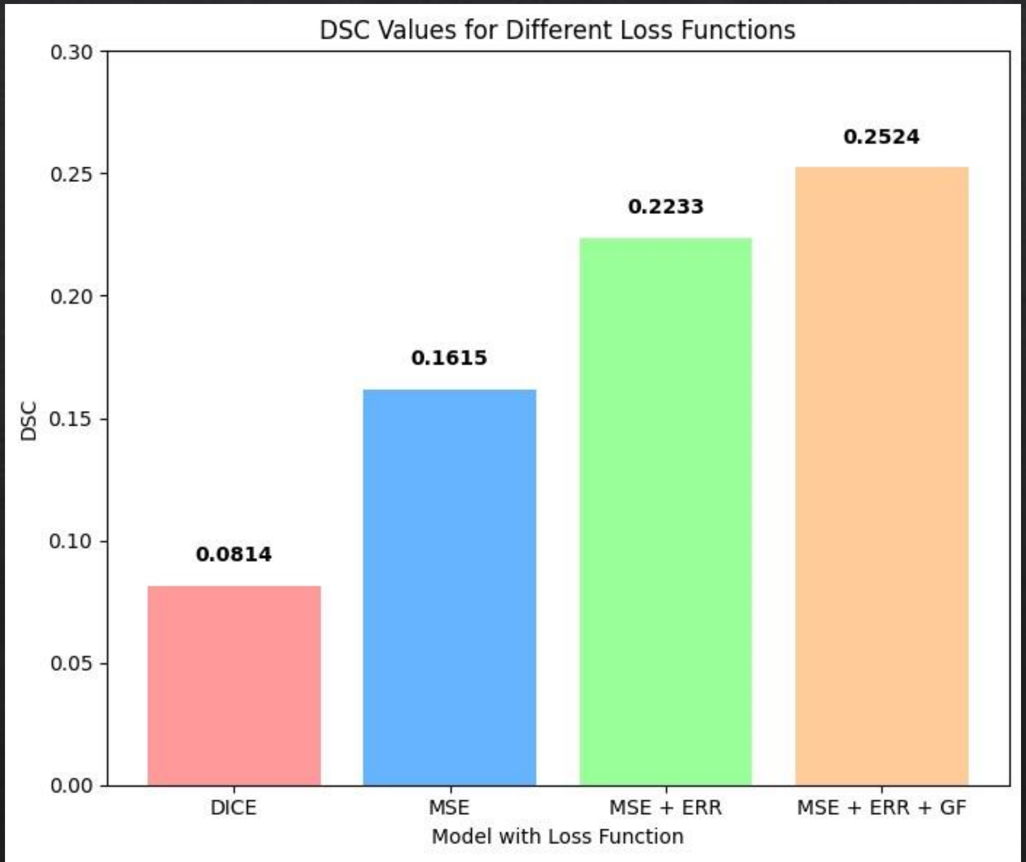
$$\mathcal{L}_{ERR}(E_R, 0) = \frac{1}{n}\sum_{i=1}^{n}(E_R(i) - 0(i))^2$$

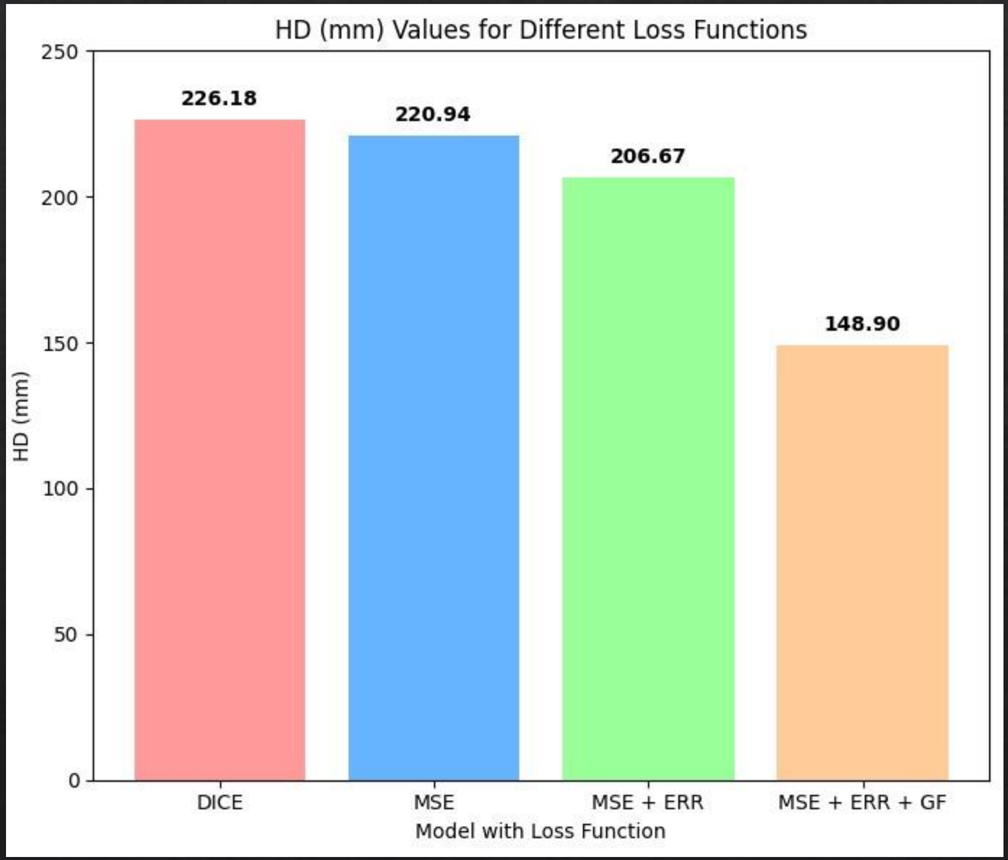
- **Gap Filling**: addresses structural discontinuities, penalizing missing regions in the prediction

$$G_F = {I_p}^{-1} . I_g$$

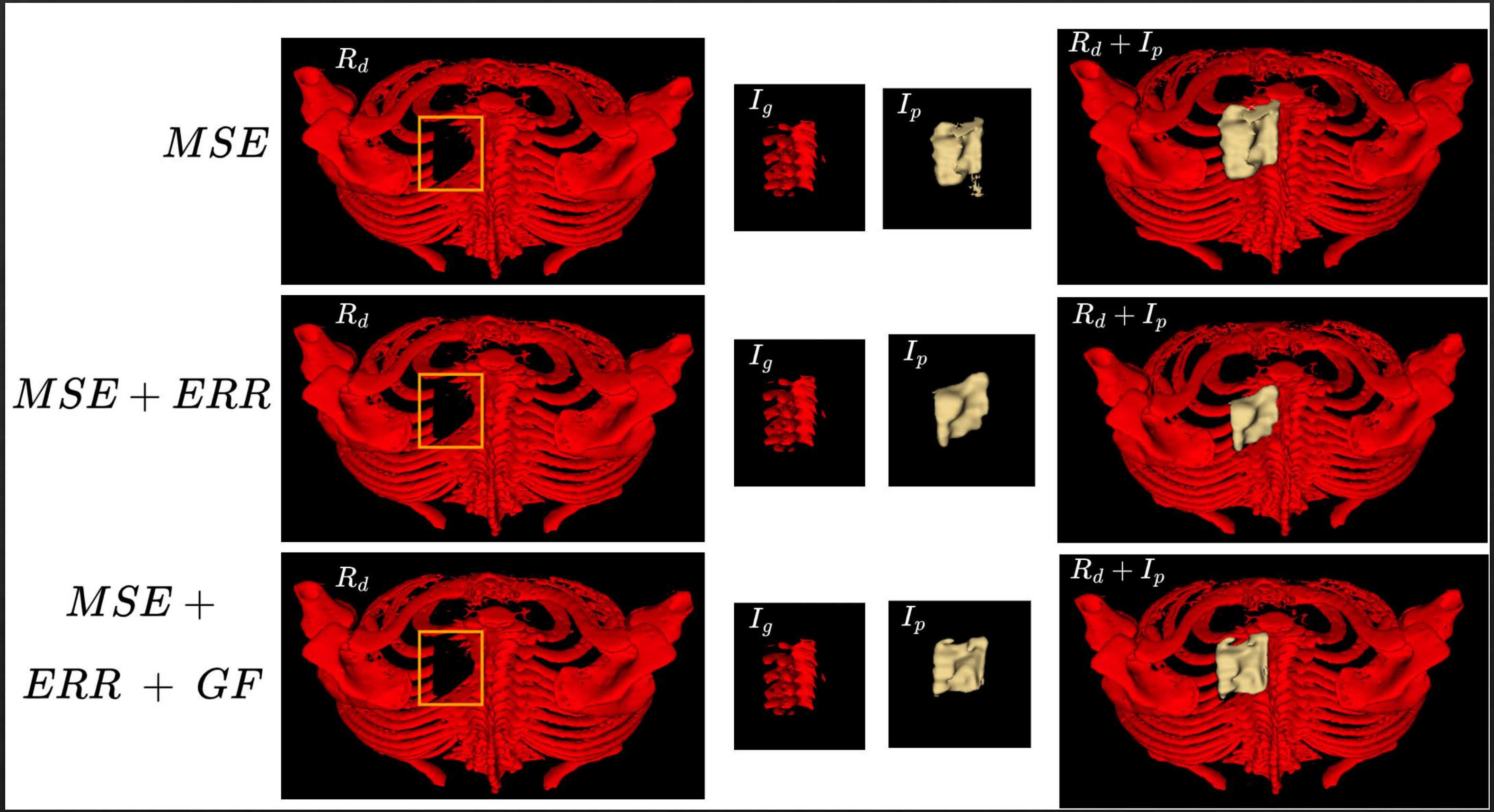
$$\mathcal{L}_{GF}(G_F, 0) = \frac{1}{n}\sum_{i=1}^{n}(G_F(i) - 0(i))^2$$

Quantitative Results

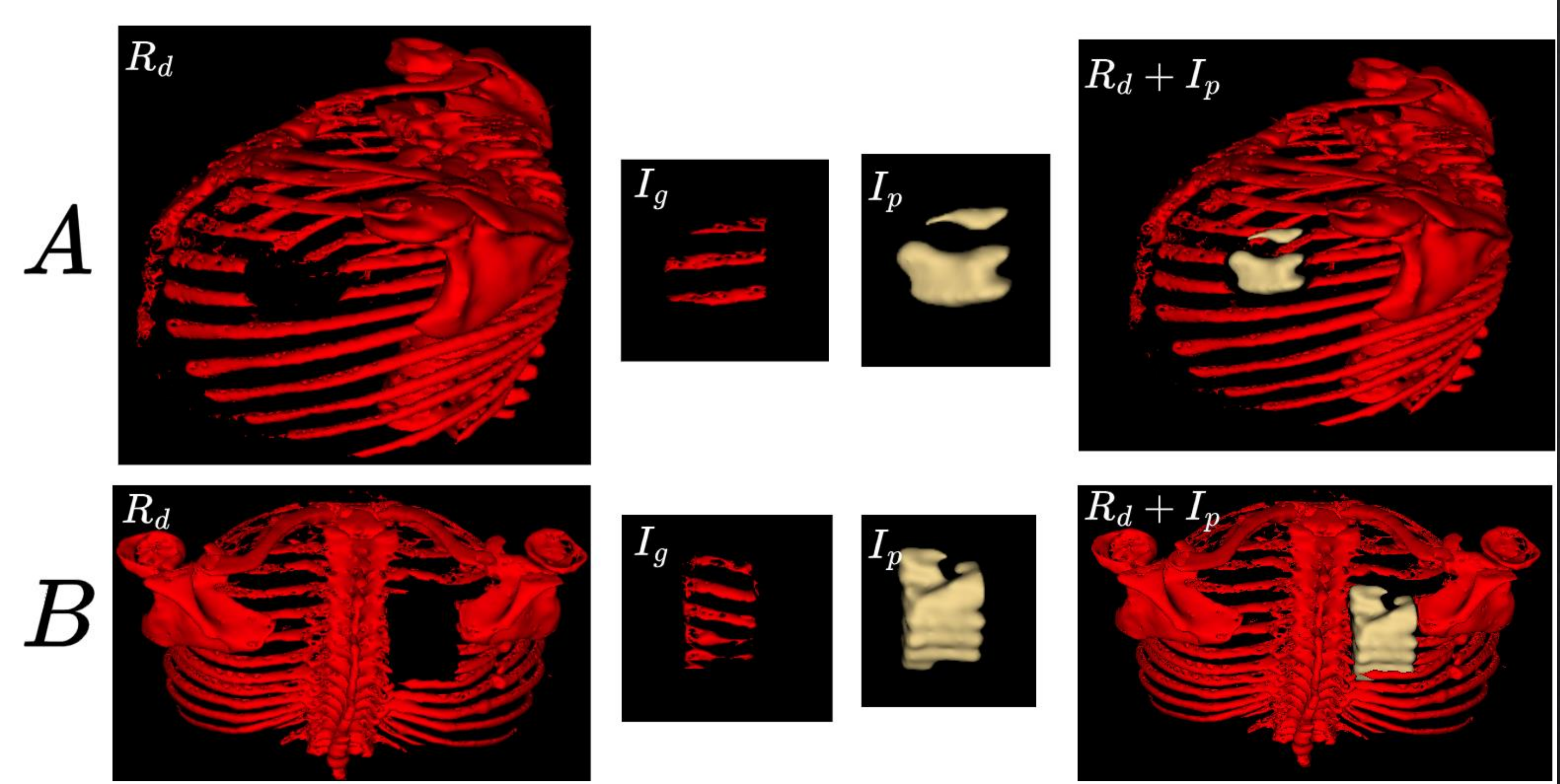




Qualitative Results



Failure Cases of Model



Challenges we have faced

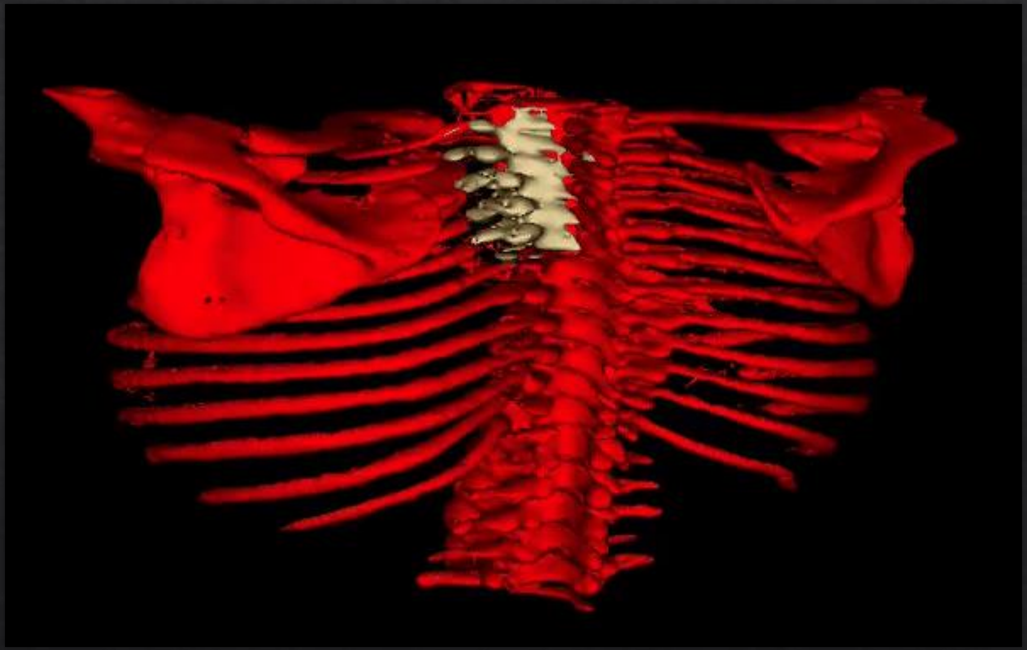
- Complexity in Ribcage Geometry
- Data Limitations
- Designing efficient loss function
- High Computational Demands

Future Directions

- Development of more sophisticated approaches to achieve better implant design
- Incorporating Anatomical Constraints in Loss Function Design

Augmented Reality (AR) Integration for Implant Simulation

- The integration of Augmented Reality (AR) in the 3D virtual ribcage implant process will enable doctors to simulate and visualize the design of implants directly on a virtual model of the patient's anatomy. This approach allows for a more precise assessment of fit and positioning before fabrication. By simulating the implant in AR, doctors can gain confidence that the 3D-printed implant will accurately fit within the body, potentially reducing the need for adjustments post-surgery and improving patient outcomes.



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many more…

Questions/Suggestions ?