Towards Autonomous Pre-surgical Planning: Deep Learning Segmentation of the Maxillary Sinus in CBCT

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Background and Clinical Needs:

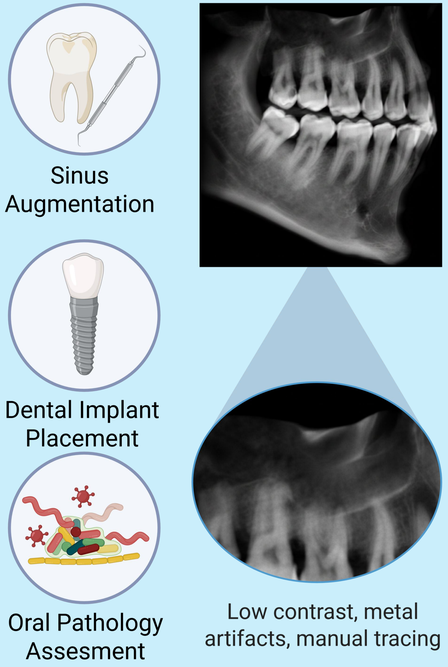
Maxillary sinus anatomy is critical for:

- Implant placement
- Sinus augmentation
- Pathology assessment

CBCT is the standard, but **manual sinus segmentation is**:

- Time-consuming
- Operator-dependent
- Error-prone with artifacts & anatomic variation

Clinical risk:
Inconsistent segmentation → Compromised planning & safety

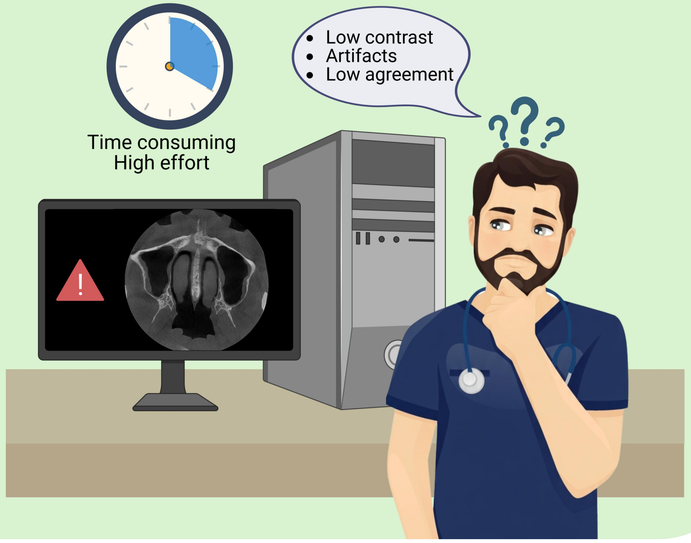


Study Objectives:

- To develop and validate an automated, uncertainty-aware deep learning model for maxillary sinus segmentation on CBCT.

Clinical Impact:

- There is a clear need for automated, reliable, and transparent sinus segmentation.

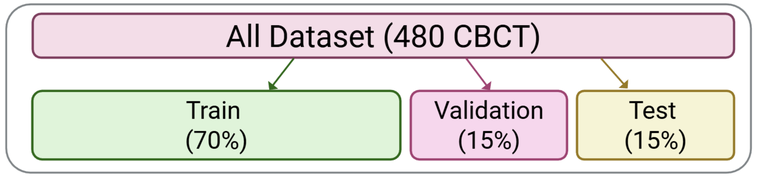


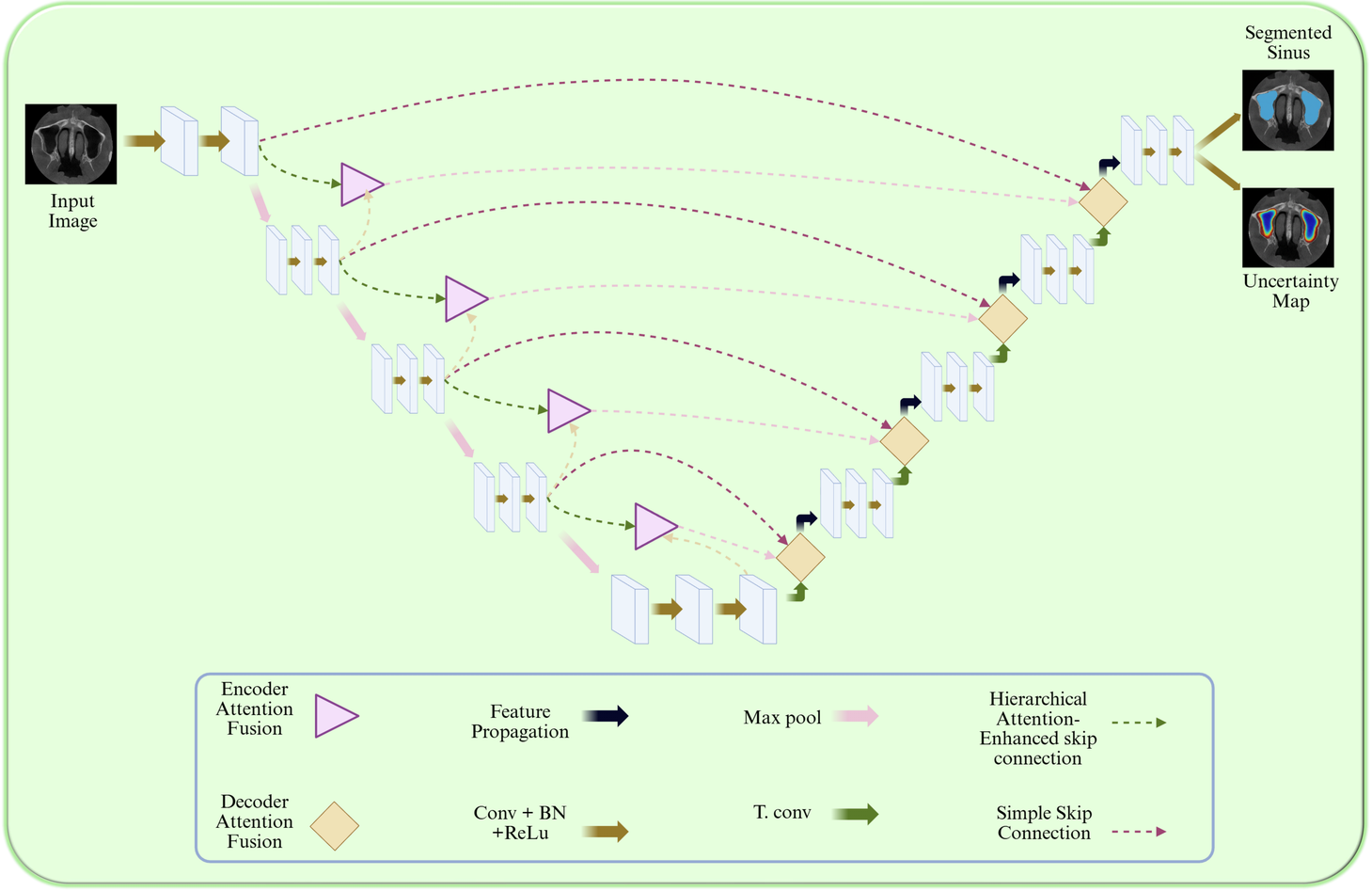
Materials and Methods:

Dataset & Training:
- 480 annotated CBCT volumes
- Tooth Fairy 2 dataset
- Expert-defined sinus ground truth

Model Architecture:
- Uncertainty-aware Attention-Guided U-Net
- Multiscale feature fusion
- Loss function: Combined Dice and Cross-entropy loss

Evaluation:
- Independent test set
- Metrics:
  - Intersection over Union (IoU)
  - Standard segmentation performance measures





Model Architecture

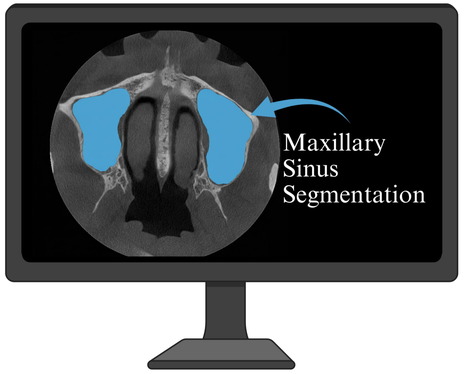
Results and Comparisons:

Quantitative Performance:
- **Mean IoU: 0.94**
- Strong agreement with expert annotations
- Consistent performance across varied cases

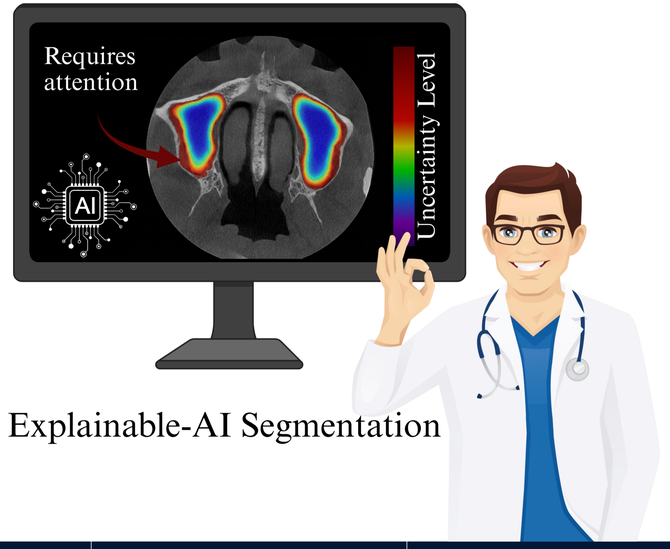
Qualitative Findings:
- Accurate sinus boundaries even in:
  - Reduced image quality
  - Complex sinus anatomy

Uncertainty maps:
- Identify low-confidence regions
- Guide clinician review

Clinical Relevance:
- Reduces operator dependency
- Enhances trust in AI-assisted planning



Traditional Segmentation



Explainable-AI Segmentation

Study	Model/ Method	Dataset Size	IoU (%)
Choi et al., 2022	U-Net	90	89.77 %
Belgin et al., 2025	CNN	1000	88.7 %
Chen et al., 2025	U-Net	600	91.6 %
Bayrakdar et al., 2024	nnU-Net v2	202	93 %
Ozturk et al., 2024	U-Net	200	92.75 %
Our Model	Attention-based U-Net	960	94.34 %

Discussion and Conclusion:

Towards safer and more standardized maxillary surgeries:

High-Precision Automation

- **0.91 Mean IoU:** Achieved high-accuracy segmentation across diverse CBCT volumes.
- **Efficiency:** Automates a labor-intensive task, providing consistent expert-level results.
- **Reliability:** Overcomes common imaging artifacts and anatomical variations.

Explainable-AI feature

- **Uncertainty Mapping:** Unlike "black box" models, this system flags areas of low confidence (e.g., thin bone or mucosal thickening).
- **Clinical Collaboration:** Directs the clinician's eye to high-risk regions for manual verification, enhancing interpreted safety.

Surgical Impact & Predictability

- **Standardization:** Reduces inter-operator variability in sinus augmentation planning.
- **Risk Mitigation:** Provides a precise anatomical "map" to help avoid intra-operative complications like membrane perforation.
- **Predictable Outcomes:** Supports more reliable implant-supported restorations through better pre-operative data.

The pixel-wise uncertainty heatmap directs the clinician's focus exactly where it is needed most.

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