Fully Automated CBCT-based Bone Loss Estimation: A Validation Against Conventional Periapical Radiography

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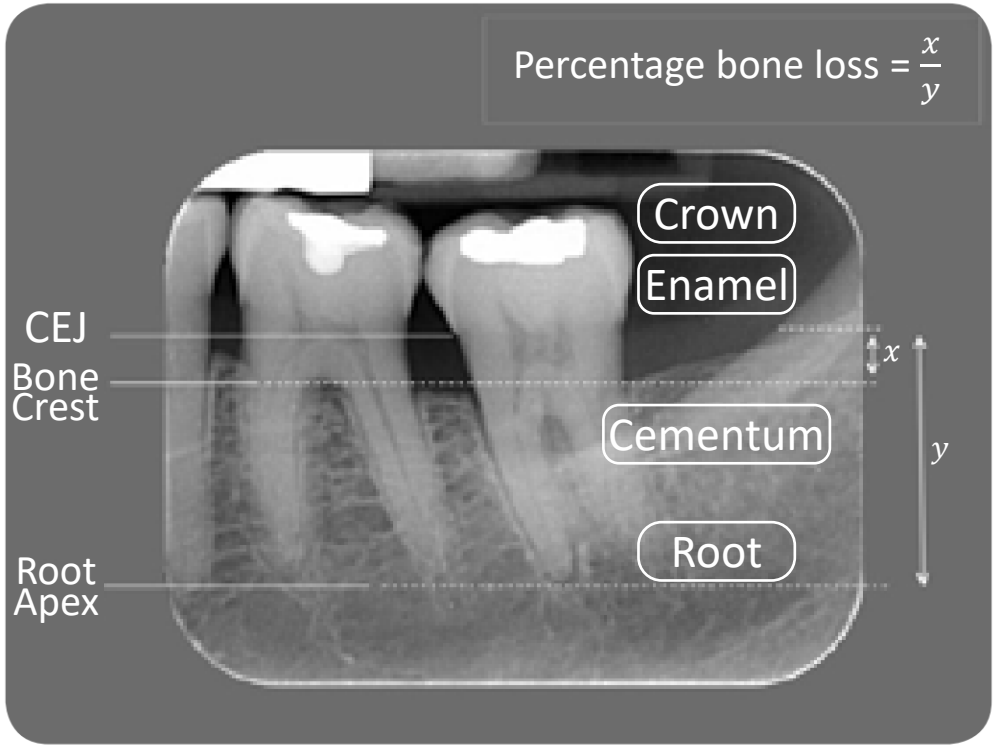
Project supervised by Dr. Yunpeng Li, Prof Owen Addison

Bellairs Workshop

Motivation

- **Critical**: Estimation of Tooth Bone Loss from Medical Imaging

Current Paradigm (BSP Guidance[1])



British Society of Periodontology's Guidance[1] on How to Estimate Bone Loss

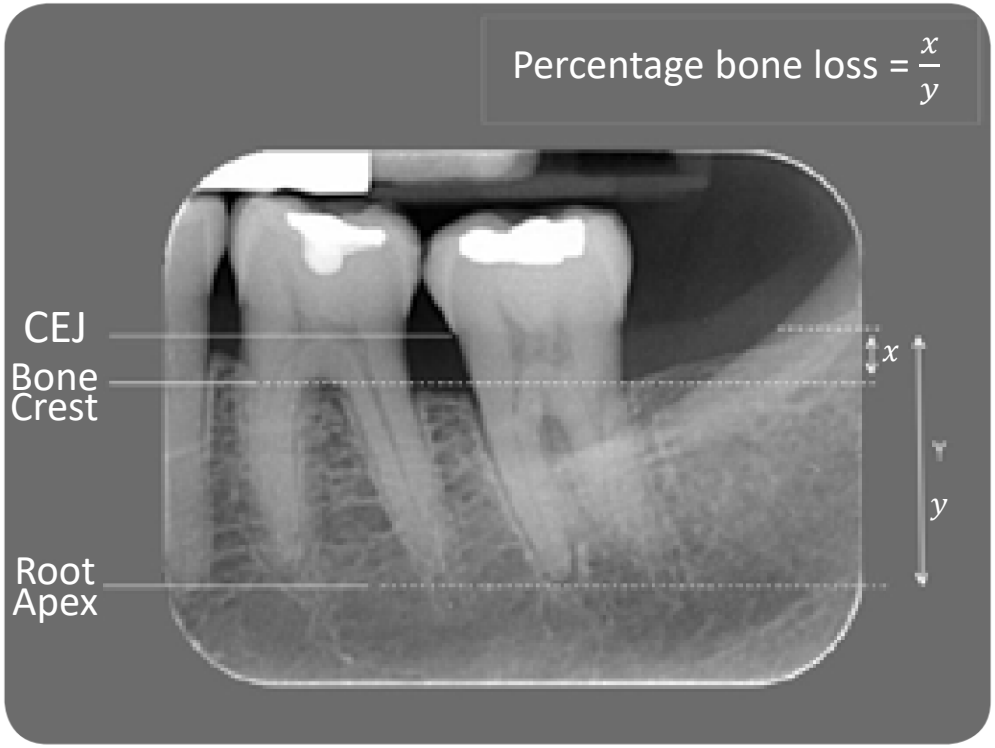
- Data Source: Periapical (PA) Imaging
- Measurement: Distances between Three Parallel Lines
- Measurement Point: Left & Right Side

Quite Naïve but Efficient for Carrying on

[1] Needleman, I. (2016). The good practitioner's guide to periodontology. Br Soc Periodontol, 10, 4.

Motivation

- **Critical**: Estimation of Tooth Bone Loss from Medical Imaging
- **Question for Current Paradigm**: **Accurate Enough**?



British Society of Periodontology's Guidance[1] on How to Estimate Bone Loss

- Data Source: Periapical (PA) Imaging

  Orientations of PA Radiographs are adjusted by the clinical Dentists

- Measurement: Distances between Three Parallel Lines ?

  Inter-operator Inconsistency

[1] Needleman, I. (2016). The good practitioner's guide to periodontology. Br Soc Periodontol, 10, 4.

Motivation

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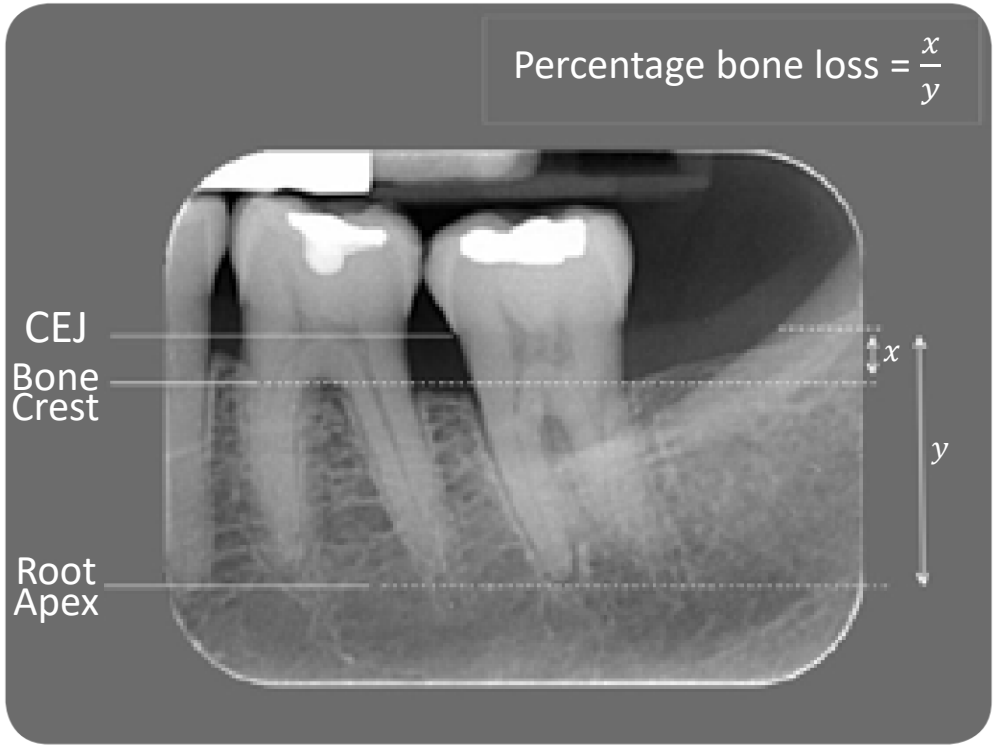


British Society of Periodontology's Guidance[1] on How to Estimate Bone Loss

- Data Source: Periapical (PA) Imaging

PA Intensity $I = I_0 \cdot e^{-\int \mu(x)dx}$

Range of x cover the whole tooth

↓

- Measurement Point: Left & Right Side?

Cannot Reveal the Bone Loss Condition of face-facing and tongue-facing sides

[1] Needleman, I. (2016). The good practitioner's guide to periodontology. Br Soc Periodontol, 10, 4.

Target

- Research Target:

1. A ***Standard*** and ***Comprehensive*** Method for Bone Loss Estimation

↓ *Automatic & Generalized*

↓ *Reveal Whole Tooth Condition*

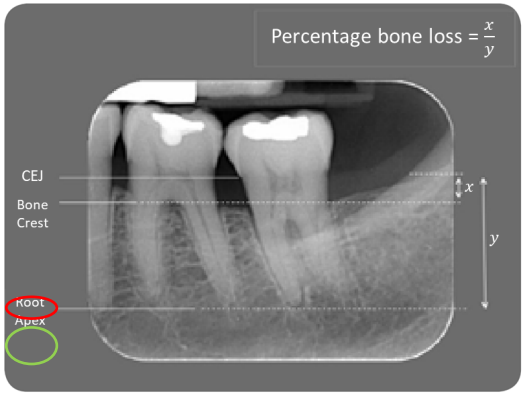
2. ***Validate***: Compare Proposed Method & Current Naïve Paradigm

↓

Formulate clinically significant recommendations

Methodology - Framework

- **Framework**: CBCT Segmentation and Bone Loss Estimation Pipeline

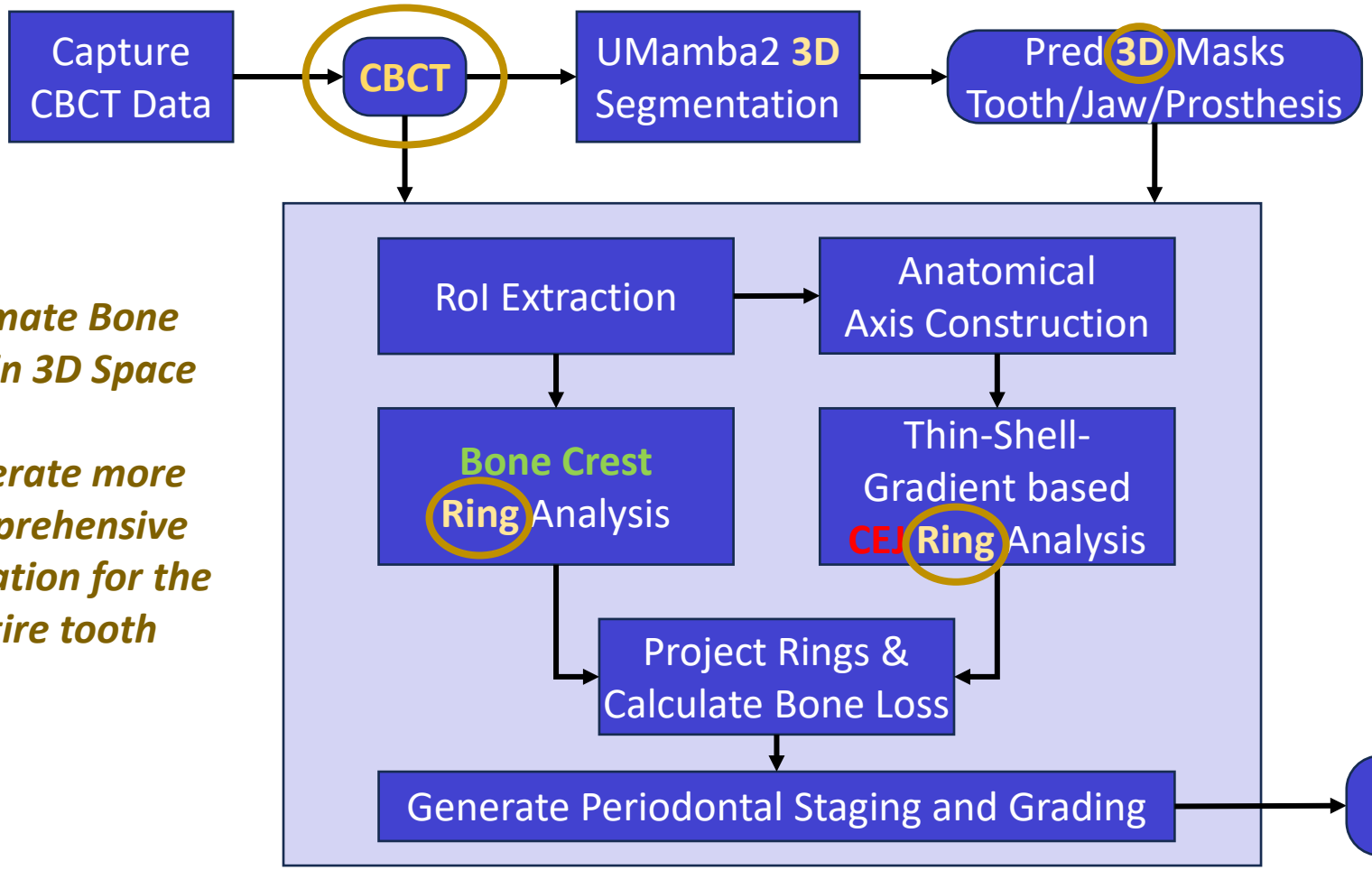


Fully-Automatic Pipeline without clinician involvement

Generalizable to any non-prosthetic teeth

Methodology - Framework

- **Framework**: CBCT Segmentation and Bone Loss Estimation Pipeline

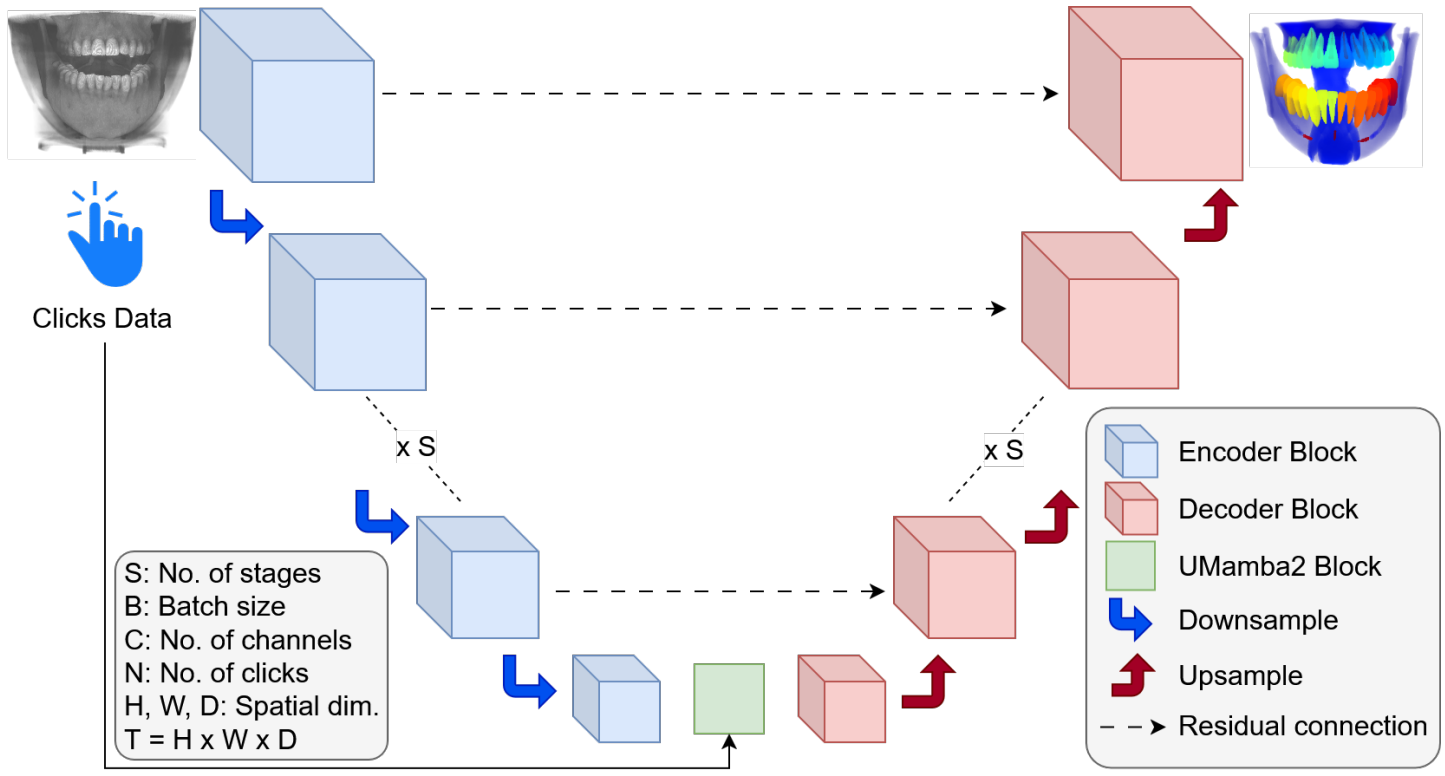


Estimate Bone Loss in 3D Space

Generate more Comprehensive Estimation for the entire tooth

Methodology - 3D Segmentation

- **UMamba2**: SOTA CBCT 3D Segmentation method[1]



Framework of Umamba2

[1] Tan, Z. Q., Zhu, X., Addison, O., & Li, Y. (2025). U-mamba2: Scaling state space models for dental anatomy segmentation in CBCT. MICCAI ODIN workshop

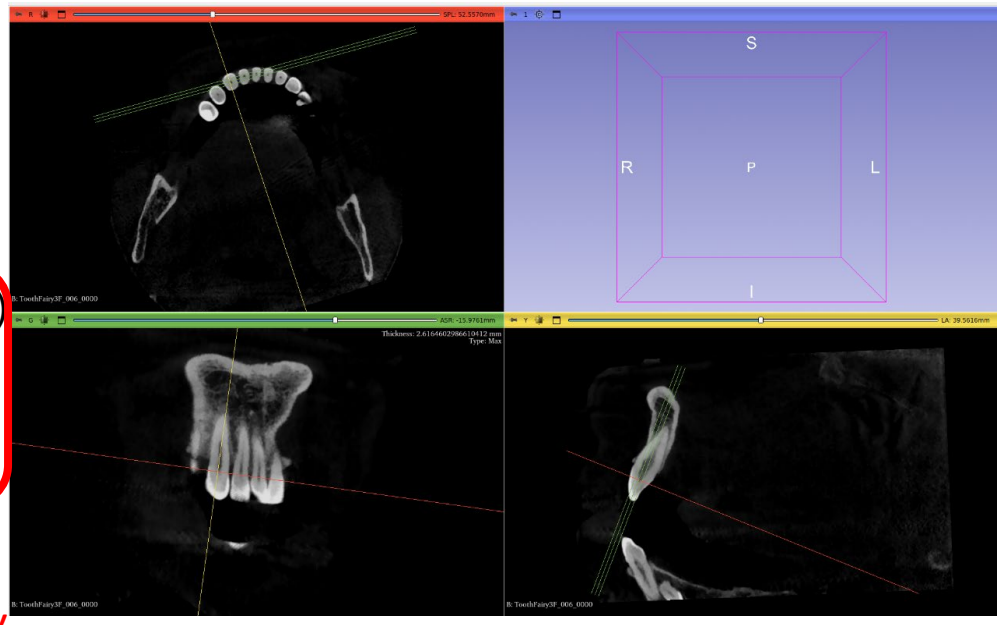
Methodology - Bone Loss Estimation

- **Input**: Segmented masks (Tooth/Jaw/Prosthesis) & Original CBCT data
- **Output**: Bone Loss & Corresponding Report
- Essential Dental Knowledge:

the Jaw&Tooth Junction

1. Bone Crest Ring ✓
2. CEJ (Cementum Enamel Junction)
   a. Enamel (High CT Intensity)
   b. Cementum (lower CT Intensity)

No Enamel Mask Generated
Only the CBCT Intensity Value & Anatomy



Methodology - Bone Loss Estimation

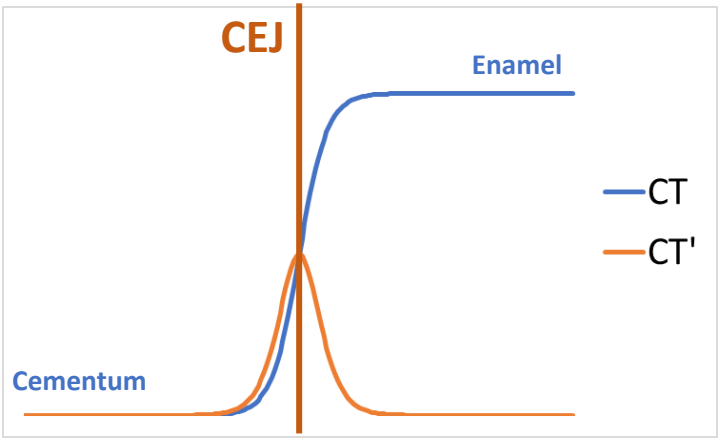
- **Degraded Challenging Issue**: Generate CEJ Ring
- CEJ Knowledge Guidance and Possible Solutions
  - Threshold by CT Intensity (Fixed) ✗ Not stable for diverse Age/Gender/Person
  - Segment by CT Intensity (Otsu/Li/KMeans) ✗
  - Segment by CT Intensity & Position (Kmeans/Slic) ✗
  - Segment by CT Intensity Gradient (Otsu/Li/KMeans) ✗

  Adaptive Clustering or Thresholding Not Stable (Especially inside the Tooth) in Large-Scale Date

  - **Thin-Shell-Gradient based CEJ Ring Analysis Method** ✓ **Robust & Effective**

Methodology - Bone Loss Estimation

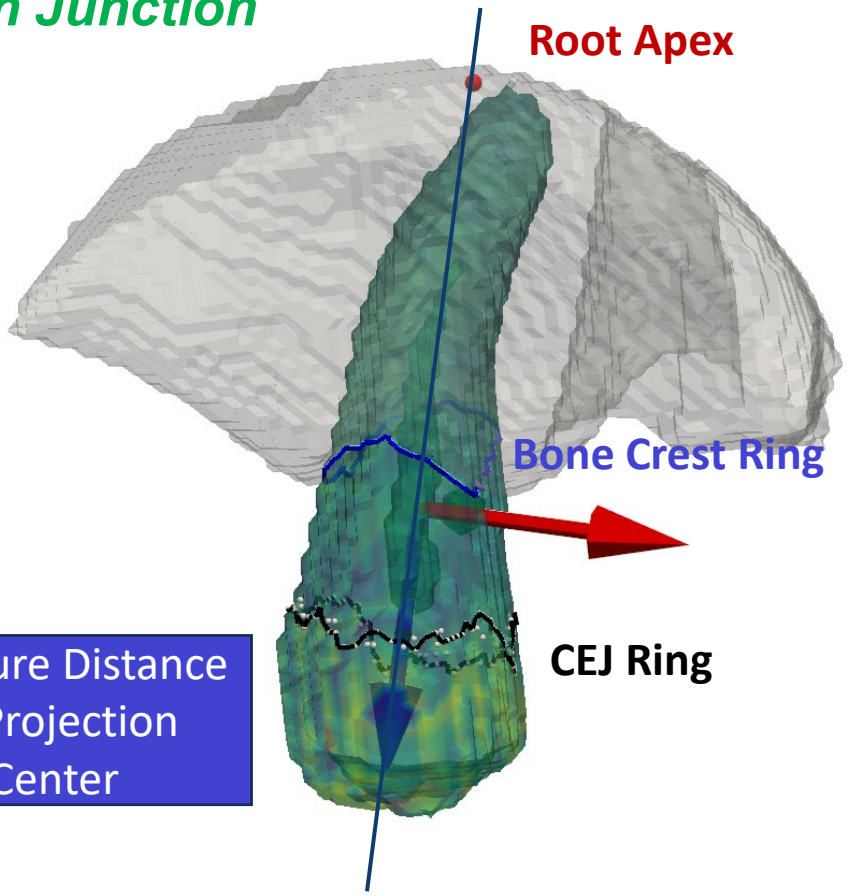
- **Degraded Challenging Issue**: Generate CEJ Ring
- **Thin-Shell-Gradient based CEJ Ring Analysis Method**
  - Stay Focus: Surface Thin Shell
    More Stable for Mask Boundary
  - Larger Neighborhood: Dilated Gradient
    Smooth Local CT Variation
  - Find Gradient Ridges: Watershed Algorithm[1]
    More Stable for Local Gradient Variation
  - Roots Selection: Consider CT Value & Position
    More Stable for Structure Initialization

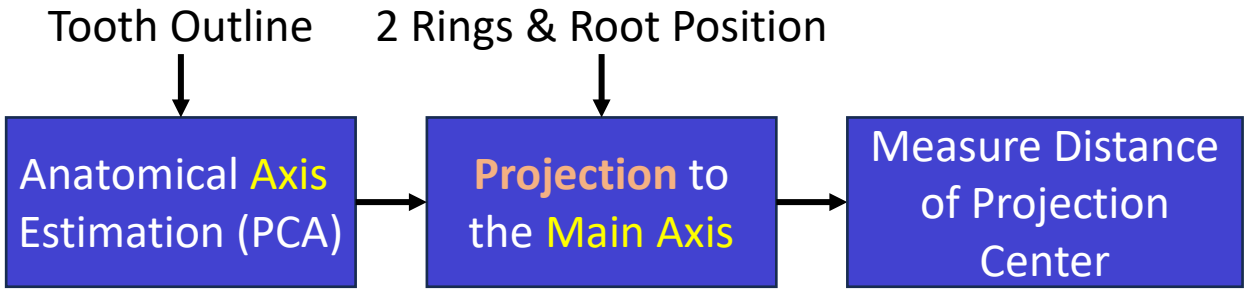


[1] Vincent, L., & Soille, P. (1991). Watersheds in digital spaces: an efficient algorithm based on immersion simulations. IEEE TPAMI, 13(06), 583-598.

Methodology - Bone Loss Estimation

- Generate Bone Crest Ring and Calculate **3D Bone Loss**
  - Bone Crest Ring - ***the Jaw&Tooth Junction***
  - **3D** Bone Loss
    - Conventional (PA): 2 Side **Bone Loss**
    - Current (CBCT): 3D **Bone Loss**





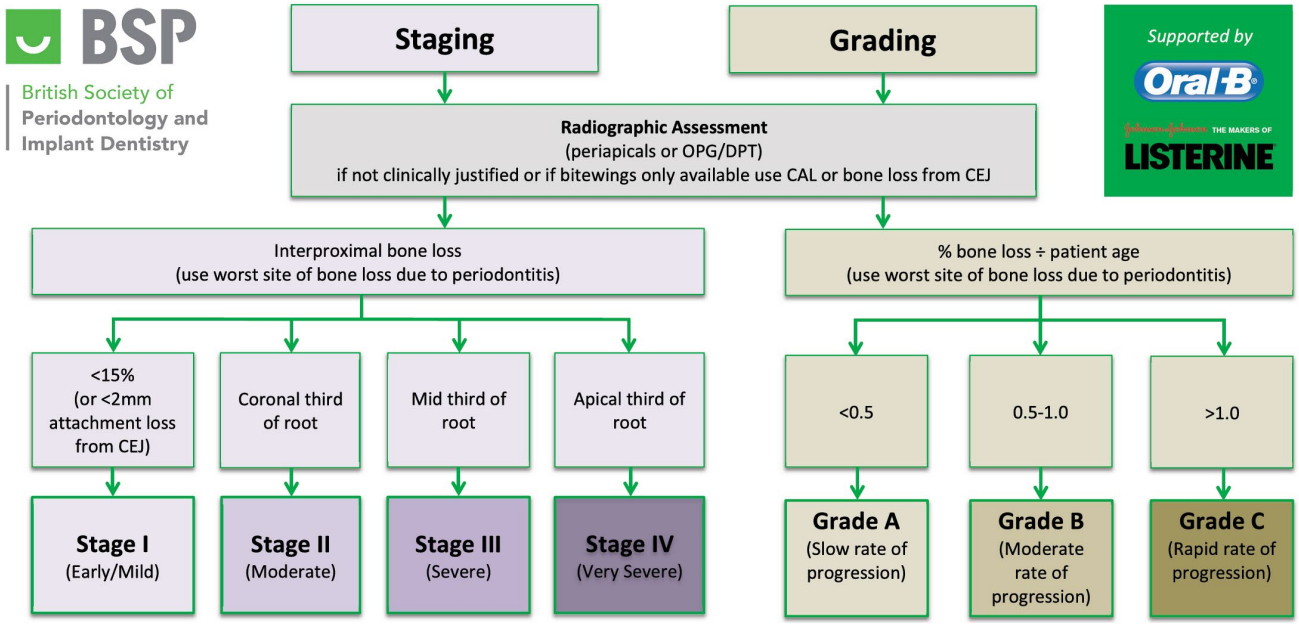
Methodology – Stage & Grade Report

- Generate Periodontal Staging & Grading Report

3D Bone Loss →

Age →

Staging & Grading Periodontology Report ←

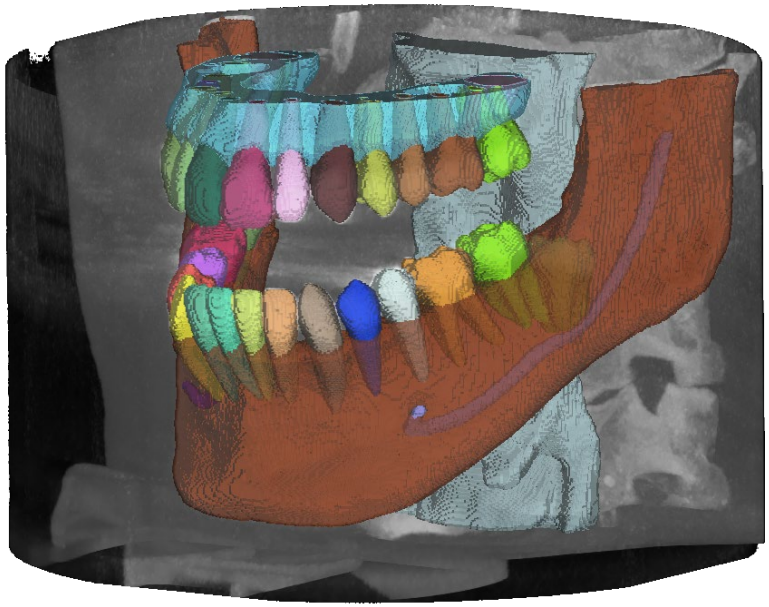


British Society of Periodontology's Guidance[1] on How to evaluate Staging and Grading

[1] British Society of Periodontology and Implant Dentistry. (2018). BSP flowchart implementing the 2018 classification.

Validation - Dataset

- **ToothFairy3 Dataset**[1]
  - **Most Comprehensive 3D Annotation** (Tooth/Jaw/Prosthesis)
  - **Largest Scale (532 Samples)**



Key Categories:

- Each Tooth
- Jaw Bone → Not Included in other CBCT Datasets Affecting **Crest GT**
- Bridge
- Crown
- Implant

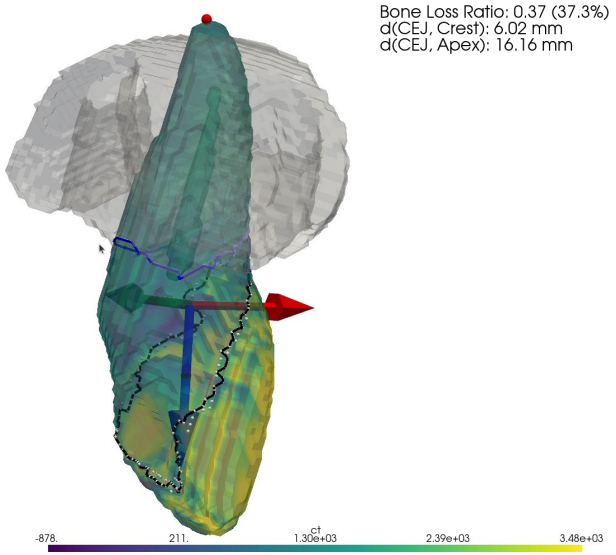
} Prosthesis

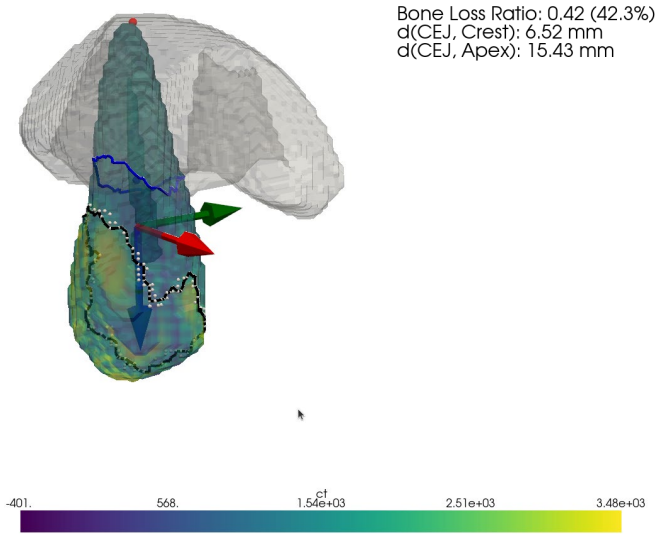
Spacing:
[0.3,0.3,0.3]mm

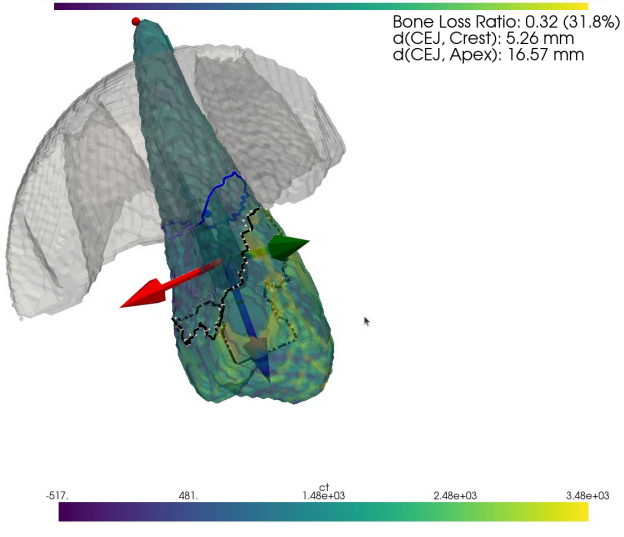
[1] Bolelli, F., Marchesini, K., van Nistelrooij, at al. (2025). Segmenting Maxillofacial Structures in CBCT Volumes. In *CVPR* (pp. 5238-5248).

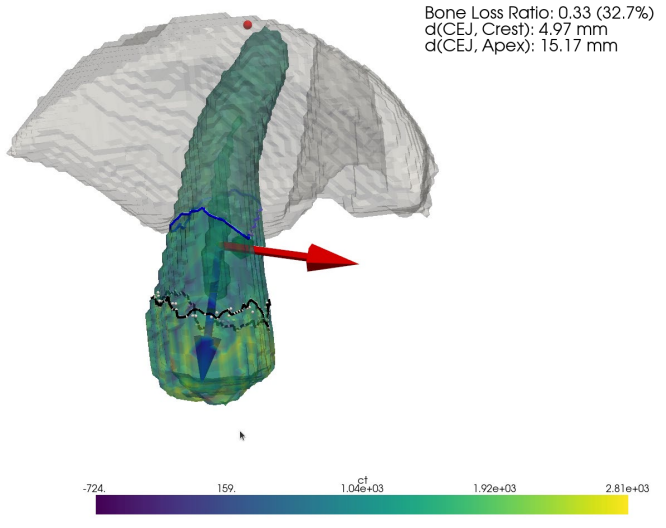
Validation - Intuitive Visualization

- **Performance Illustration**



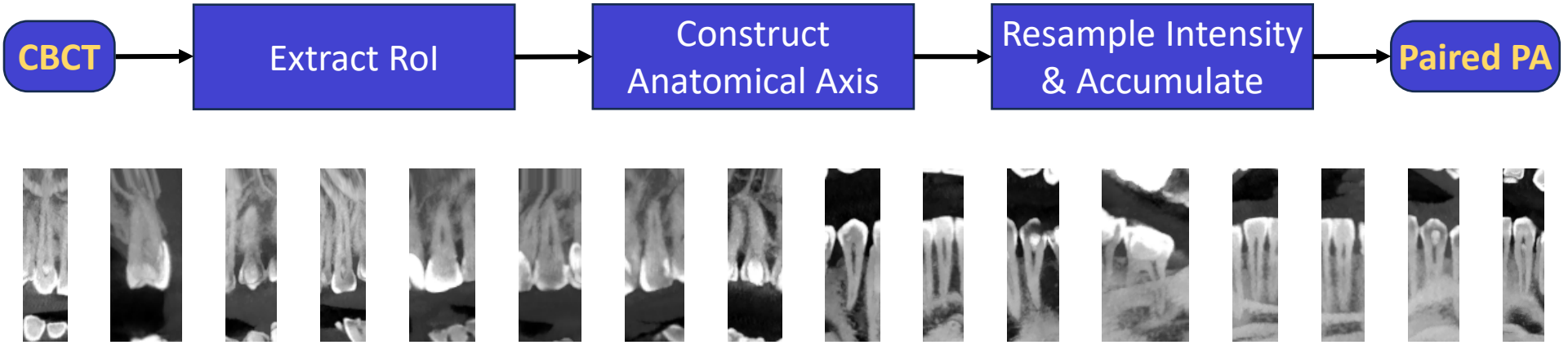






Validation - Performance Comparison

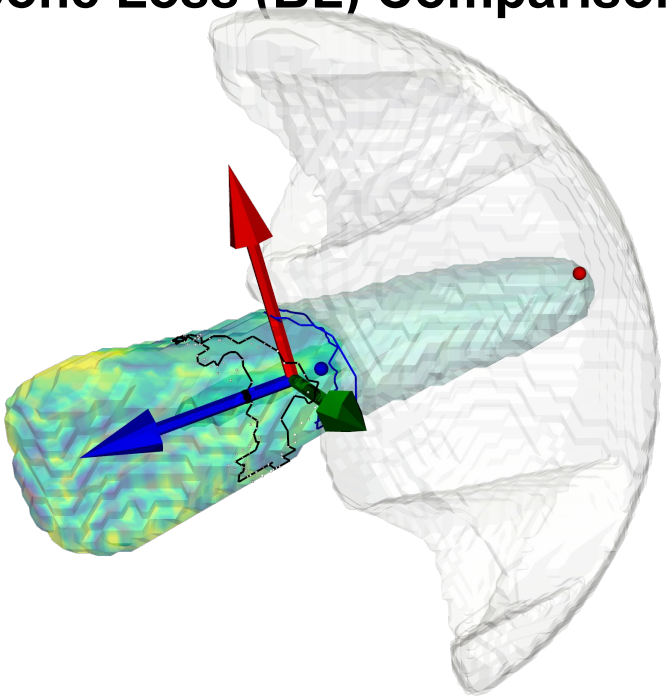
- **Conventional 2D PA Imaging Generation**
  - No Paired PA imaging data Included in ToothFairy3 Datasets
  - **Reconstruct the Paired PA from CBCT Data**



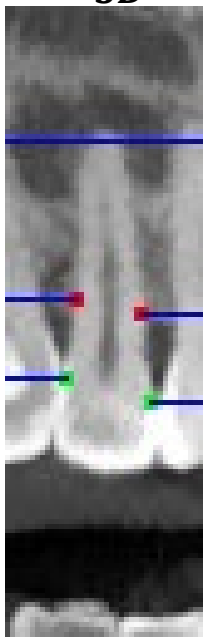
Reconstructed PA Images

Validation - Performance Comparison

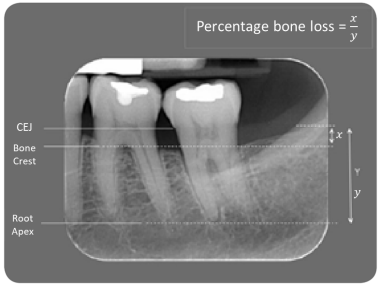
- **Bone Loss (BL) Comparison: BL_{2D} vs. BL_{3D}**



$BL_{3D} = 21.6\%$



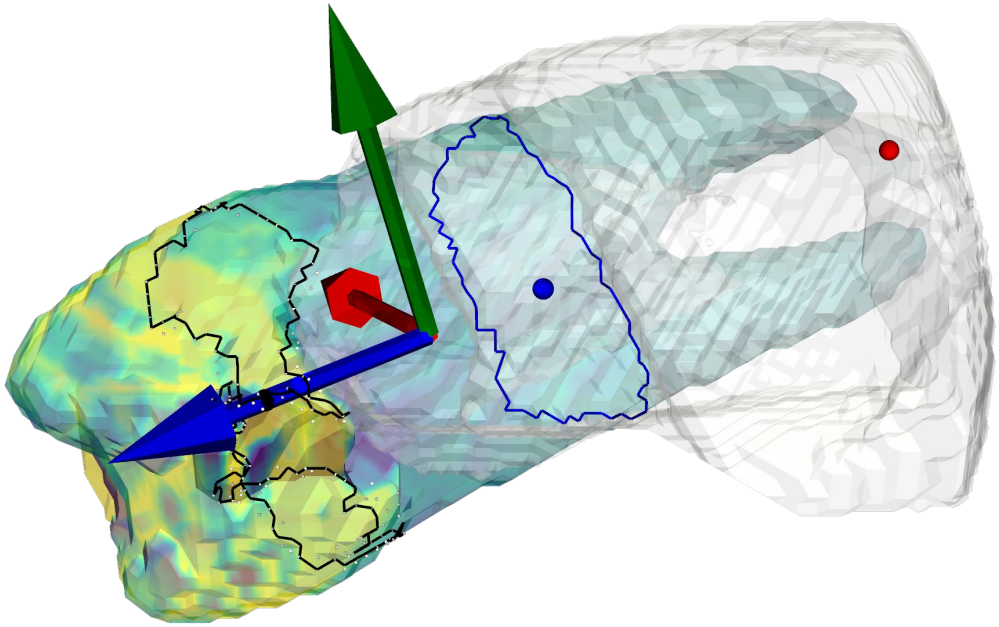
$BL_{2D}^{L} = 33.3\%$
$BL_{2D}^{R} = 34.0\%$



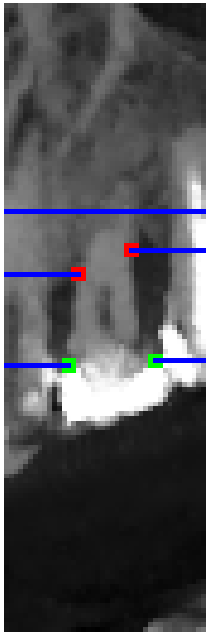
3D Rings Provided more Comprehensive Evaluation, not Just Two Points

Validation - Performance Comparison

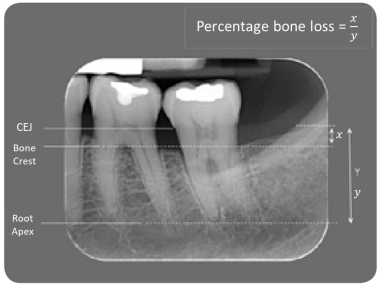
- **Bone Loss (BL) Comparison: BL_{2D} vs. BL_{3D}**



$BL_{3D} = 42.2\%$



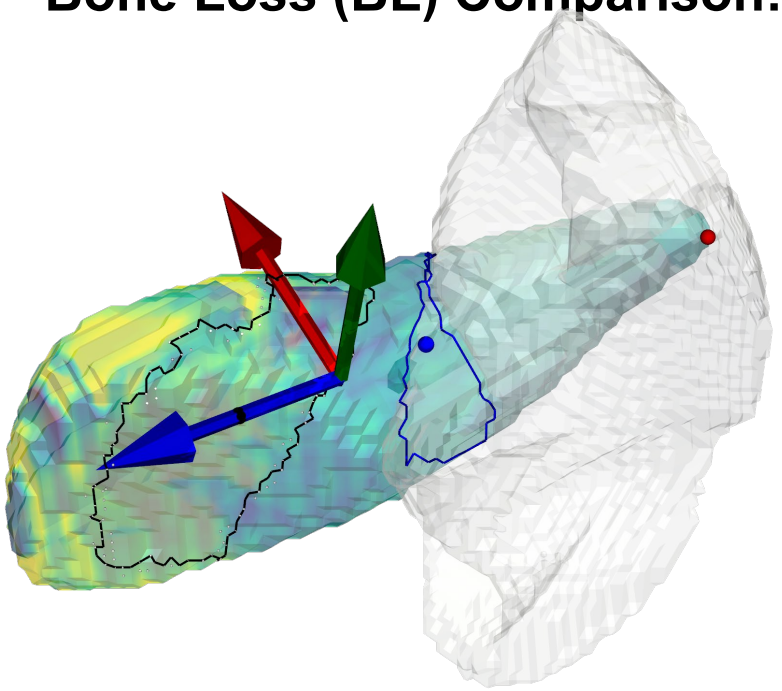
$BL_{2D}^{L} = 59.4\%$
$BL_{2D}^{R} = 74.2\%$



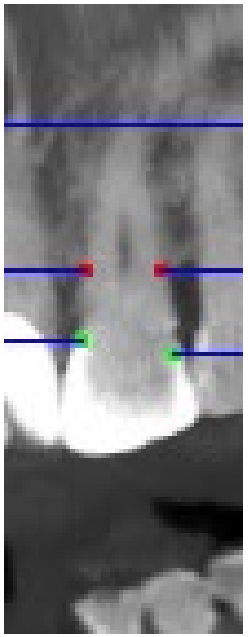
3D Rings Provided more Comprehensive Evaluation, not Just Two Points

Validation - Performance Comparison

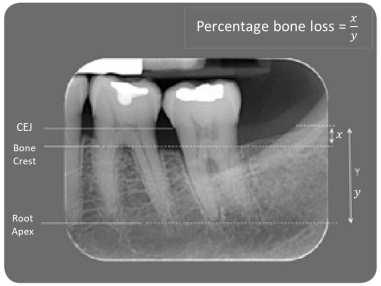
- **Bone Loss (BL) Comparison: BL_{2D} vs. BL_{3D}**



$BL_{3D} = 37.3\%$



$BL_{2D}^{L} = 32.7\%$
$BL_{2D}^{R} = 36.5\%$



3D Rings Provided more Comprehensive Evaluation, not Just Two Points

Validation - Performance Comparison

- **Bone Loss (BL) Comparison: BL_{2D} vs. BL_{3D}**

Population-Level Evidence

Type	%	Error Measurement	AVG	STD	MAX
		2D current paradigm underestimate the overall severity			
$BL_{3D} > \max(BL_{2D}^{L}, BL_{2D}^{R})$	24.7%	$BL_{3D} - \max(BL_{2D}^{L}, BL_{2D}^{R})$	3.2%	3.0%	12.5%
		2D current paradigm overestimate the overall severity			
$BL_{3D} < \min(BL_{2D}^{L}, BL_{2D}^{R})$	36.5%	$\min(BL_{2D}^{L}, BL_{2D}^{R}) - BL_{3D}$	6.2%	5.9%	36.7%
		2D current paradigm provide an interval but not a comprehensive estimate			
$Others$	38.8%	$\lvert BL_{3D} - \text{avg}(BL_{2D}^{L}, BL_{2D}^{R}) \rvert$	2.0%	1.7%	8.4%

3D Rings Provided more Comprehensive Evaluation, not Just Two Points

Future Work

- **More Sub-metrics for 3D Bone Loss**
- **Dataset & Evaluation: Real-world Paired CBCT & PA Images**
- **Robustness Validation: Across Devices and Acquisition Protocols**
- **Clinical Validation**

Thank you!

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