Automating Periodontal Bone Loss Measurement via Dental Landmark Localisation

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Periodontal Disease and Periodontal Bone Loss (PBL)

Periodontal disease

Microbially-associated inflammation

6th most common disease worldwide

Periodontal Bone Loss

Bone around the tooth degrades

Indicates severe periodontal disease

DETECTION: Radiographic assessment

DEFINITION: Ratio of tooth supported by bone

CONSEQUENCE: Leading cause of adult tooth loss

TREATMENT: Antibiotics, root planning, periodontal surgery

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Radiographic Assessment – Why Automation?

TWO MAIN TYPES OF RADIOGRAPHS USED

Panoramic – All teeth displayed

Holistic viewpoint

Superior Accuracy

Periapical – Intraoral, focussed radiograph

Research in this application domain remains limited

Limitation

- Radiographic assessment exhibits substantial interobserver errors

Solution

- Computer-assisted Diagnosis
- Calibrated to multi-expert assessments
- Objectively & consistently detect small changes in PBL

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Contributions

- **1st paper to use Deep Learning for Landmark Localisation on Periapical Radiographs**
- Introduces ***Interstitial Spatial MixUp (ISM)*** as novel data augmentation
- Extensive qualitative evaluation on numerous ***root morphologies***
- *Introduces a clinical pipeline that automatically **emulates current interobserver error** for PBL measurement*

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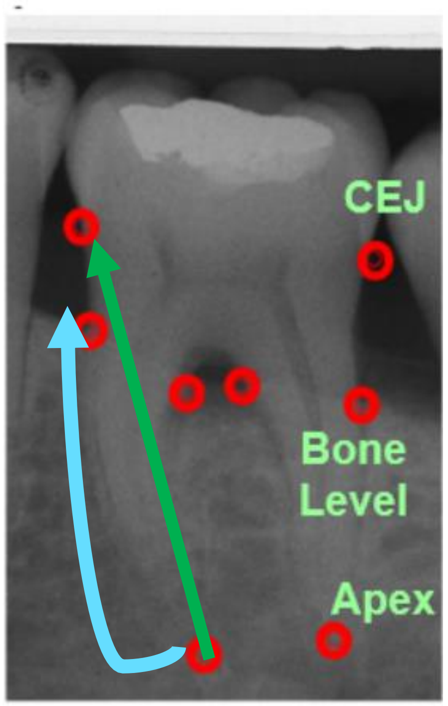
Measuring Periodontal Bone Loss



Given the landmarks, PBL is calculated:

- **Length of tooth** = Apex to CEJ
- **Tooth supported by bone** = Bone level to CEJ
- **PBL** = Ratio between both

Single, double and triple rooted teeth assessed:

- Single = 5 landmarks
- Double = 8 landmarks
- Triple = 9 landmarks

Acronym	Meaning
CEJ_(L/R)	Cemento-Enamel Junction, Left/Right side
BL_(L/R/LC/RC)	Bone Level, Left/Right/Left Centre/Right Centre
A_(L/C/R)	Apex, Left/Centre/Right

Clinical Categorisation of Periodontal Bone Loss

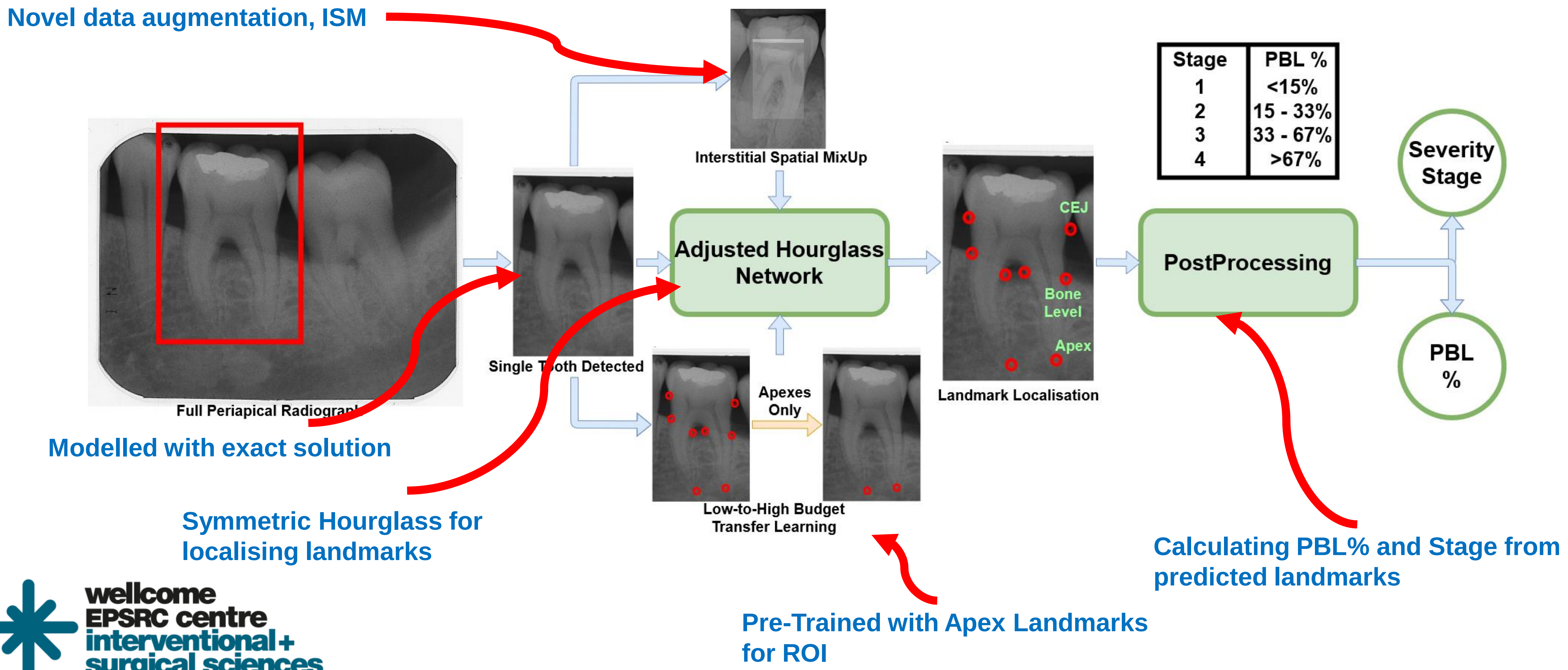
Four **Severity Stage (SS)** groups

Stage	PBL%
1	<15%
2	15 – 33%
3	33 – 67%
4	>67%

PBL stage informs
interventional decision

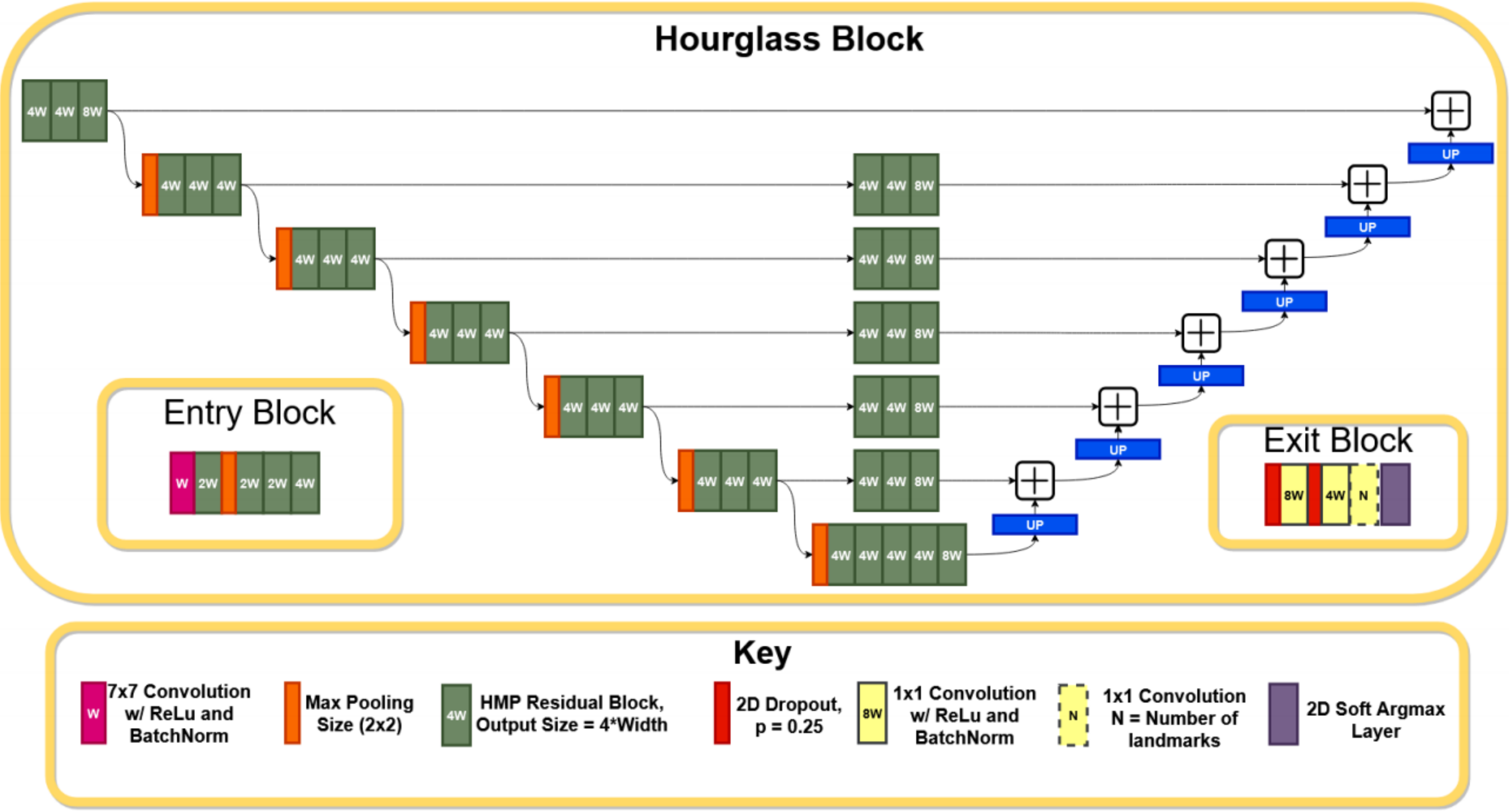
Proposed Solution

- An end-to-end pipeline that uses deep learning to measure PBL via landmark localisation



Proposed Network – Landmark Localisation

- Convolutional Neural Network (CNN)
- Symmetric Hourglass for localising landmarks
- Hierarchical, Multiscale Parallel (HMP) residual blocks
- Each root morphology has separate network



Network adapted from [1]

[1] - Tiulpin, A., Melekhov, I., Saarakkala, S.: KNEEL: Knee anatomical landmark localization using hourglass networks. In: 2019 IEEE/CVF International Conference on Computer Vision Workshop (ICCVW), pp. 352–361 (2019)

Interstitial Spatial MixUp (ISM)

Assess the relationship between pixel interpolation and in-place multi-scale analyses

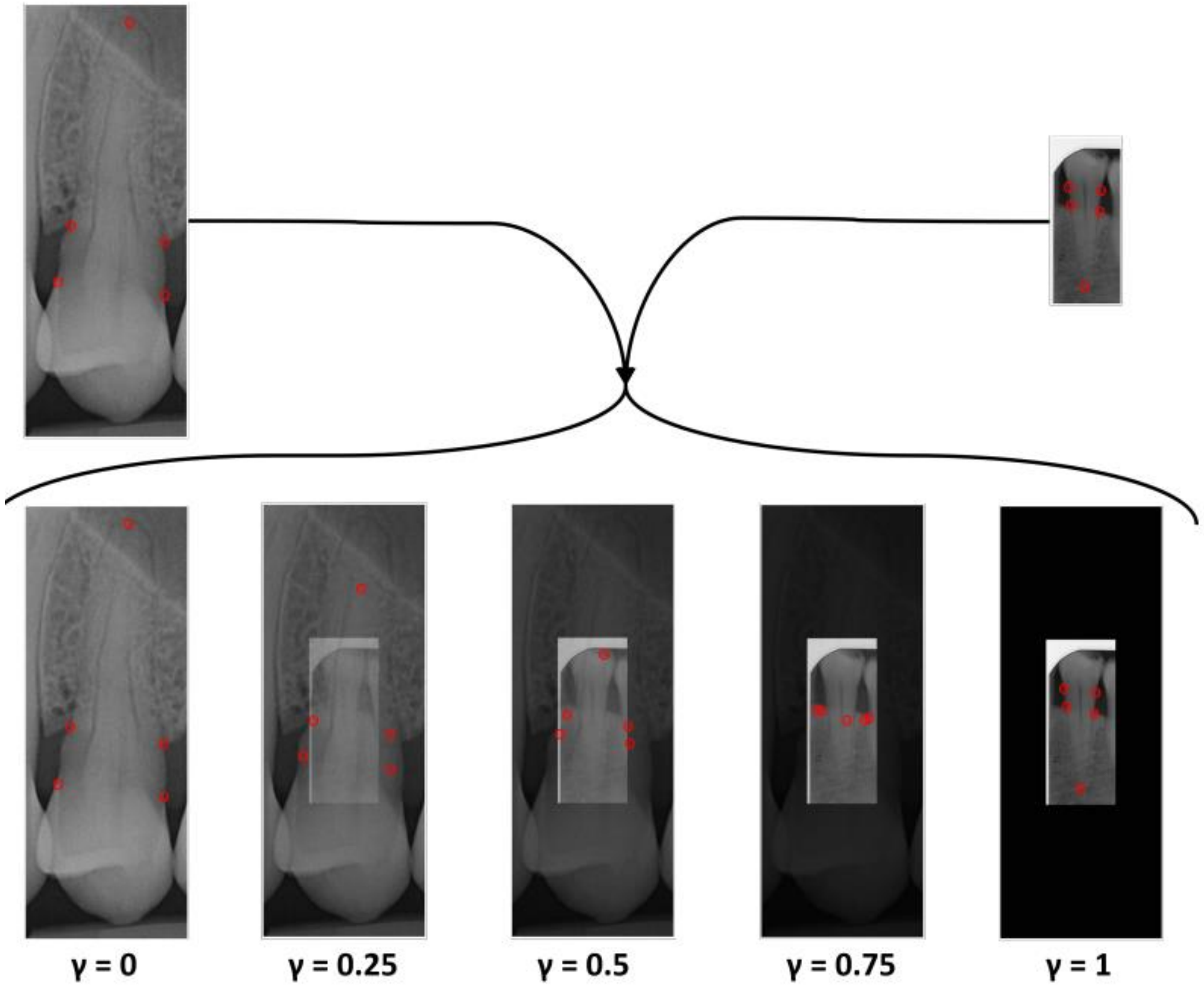
<u>THE PROCESS</u>

1. 2 differently-sized images; place smaller one in centre

2. Interpolation w/ random γ

$$ISM = \gamma * I_1 + (1 - \gamma) * I_2$$

3. Landmarks and pixels are interpolated as above



ISM Hypothesis

With a sufficiently small feature map and sufficiently large filter, it is hoped that ISM will encourage the creation of **robust** confidence mappings via convolution.

- Small feature maps conducive with Hourglass
- **Encourages invariance to noise** – interpolation between **images** and black space have same weighting

0	0	0	0	0
0	Equal Prediction	0	0	0
0	0	Correct Label	0	0
0	0	0	Equal Prediction	0
0	0	0	0	0

Methodology to calculate PBL

- **PBL estimation** from the predicted landmarks:

$$PBL\% = max(\frac{||CEJ_L - A_C|| - ||BL_L - A_C||}{||CEJ_L - A_C||}, \frac{||CEJ_R - A_C|| - ||BL_R - A_C||}{||CEJ_R - A_C||}) \times 100$$

- **Severity Stage (SS) prediction** from the estimated PBL

- **PBL** and **SS** compared to clinical diagnosis in two ways:
  - PBL calculation using clinician-labelled landmarks
  - Clinicians' direct estimation of entire periapical radiograph (2-4 teeth)

Dataset Description

Dataset mainly weighted towards **single rooted teeth:**

	No. Images	CEJ_L	CEJ_R	BL_L	BL_R	BL_{LC}	BL_{RC}	A_L	A_R	A_C
Single	463	463	463	463	463	-	-	-	-	463
Double	115	115	115	115	115	115	115	115	115	-
Triple	56	56	56	56	56	56	56	56	56	56

Key:
CEJ – Cemento-Enamel Junction
BL – Bone level
A – Apex
L – Left
R – Right
C - Centre

- BL_L, BL_{RC}, A_L and A_R least featured landmarks
  - Impacts double rooted teeth mostly
- Triple rooted teeth aligned spatially
- Images resized to 256x256

63 patient cases

340 periapical radiographs

2 postgraduate specialist trainee labellers

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Results – Landmark Localisation

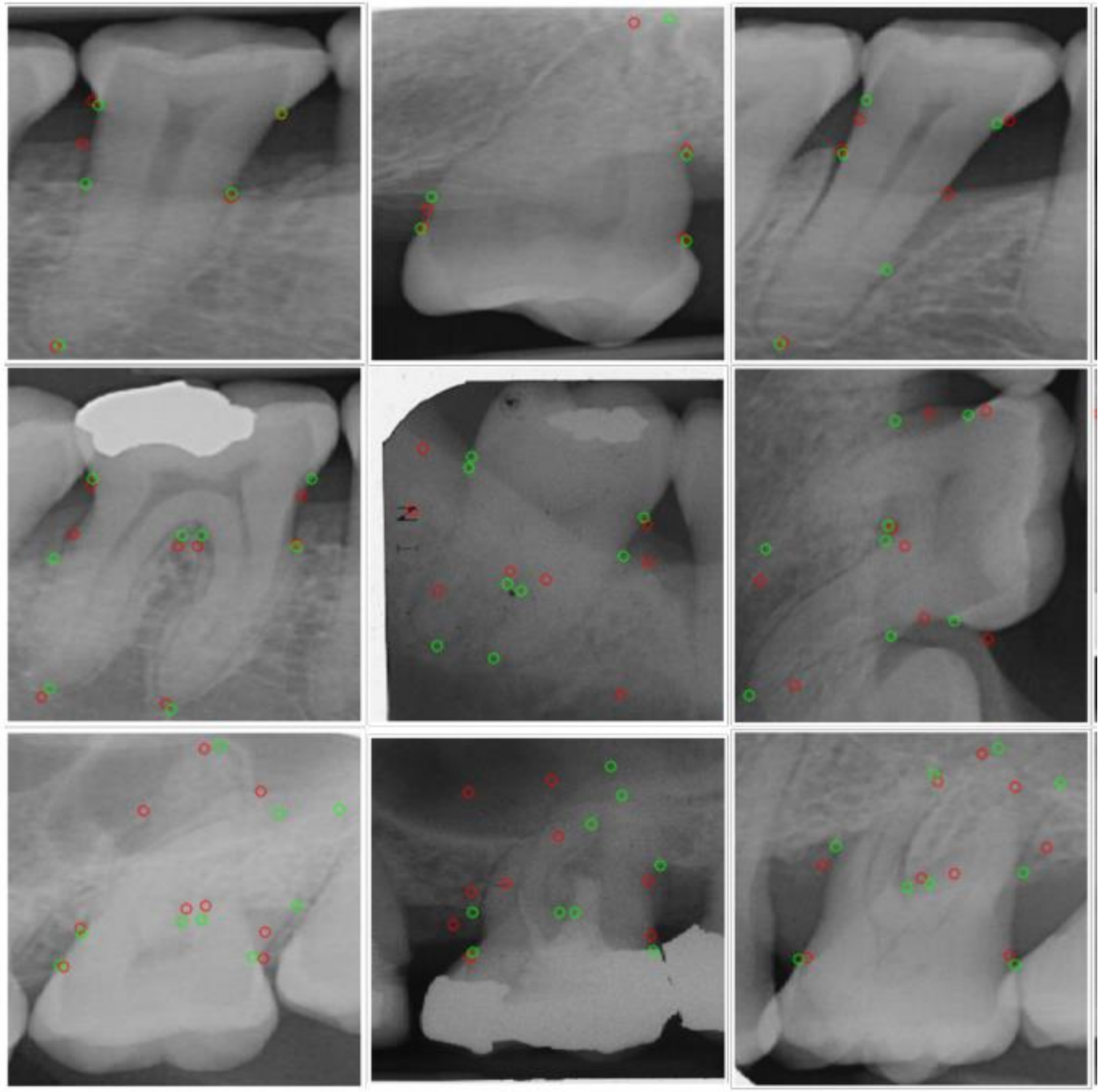
3-fold cross-validation

- Our method outperforms all when weighted by dataset size
- ISM outperforms MixUp with the same additions and model
- Asymmetric hourglass outperforms our model for double and triple roots
- Central Apex is more accurately localised with our model

Model	Root	STD-M Mean ± Std	STD-M Outliers
Asymmetric Hourglass W/ Proposed ISM Additions	Single	12.12 ± 11.08	2.29%
	Double	**18.03 ± 17.77**	**4.02%**
	Triple	**15.53 ± 13.34**	**3.17%**
	W-Mean	13.49 ± 12.49	N/A
Symmetric Hourglass W/ Proposed ISM Additions	**Single**	**10.85 ± 10.13**	**2.20%**
	Double	18.07 ± 17.04	4.67%
	Triple	17.23 ± 14.12	3.57%
	W-Mean	**12.72 ± 11.74**	N/A
Symmetric Hourglass W/ MixUp Additions	**Single**	12.54 ± 11.59	2.59%
	Double	17.73 ± 16.47	4.02%
	Triple	17.94 ± 14.68	2.98%
	W-Mean	13.96 ± 12.75	N/A
Asymmetric Hourglass No Additions	Single	11.75 ± 11.24	2.76%
	Double	20.59 ± 19.08	4.35%
	Triple	19.43 ± 13.93	3.37%
	W-Mean	14.03 ± 12.90	N/A
Symmetric Hourglass No Additions	Single	12.69 ± 11.85	2.46%
	Double	22.56 ± 18.78	4.57%
	Triple	19.48 ± 15.07	3.57%
	W-Mean	15.08 ± 13.39	N/A

Qualitative Landmark Results

- Single root teeth show impressive performance.
    - Percentage Correct Keypoints = 88.9%
- Model shows variance with radiography conditions.
- Triple rooted teeth all aligned spatially
- CEJ accurately predicted and bone level errors are logical



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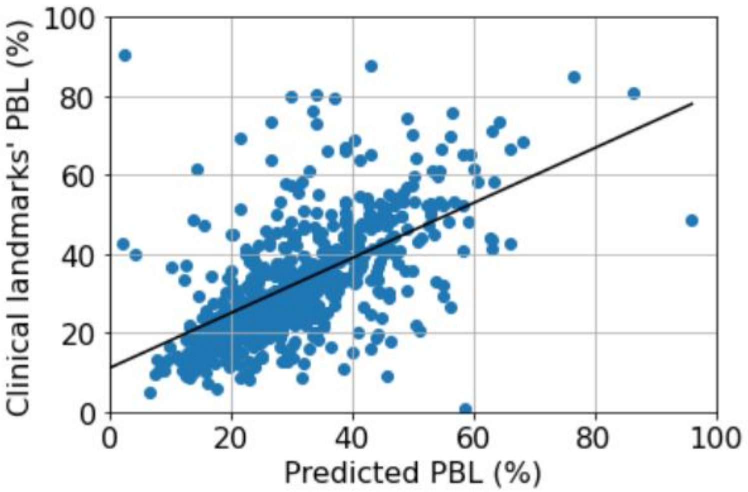
Comparison with clinical measurements

PBL predicted vs PBL calculated clinicians' labelled landmarks

- PBL% error = 6.82 ± 6.43
- Severity Stage accuracy = 68.30%
- Consistency in lower % but overall underestimation



Predicted vs clinically diagnosed stage from the entire radiograph

- PBL% error = 10.69 ± 9.15
- Severity Stage accuracy = 58%
- Most errors are from central class mispredictions
- Labels are an estimate by clinicians

Actual Stage \ Predicted Stage	1	2	3	4
1	1%	2%	2%	0%
2	0%	21%	12%	0%
3	0%	18%	36%	0%
4	0%	4%	4%	0%

Conclusions

Performance: Periodontal bone loss error **emulates** current interobserver error

Interstitial Spatial MixUp shows promise in increasing **robustness** and **accuracy**

Future Research

- **Increasing** the size of datasets, **improving** data processing (STNs) and the **variety** of (cross-) labellers

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