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AI-Assisted CBCT-Based Palatal Bone Assessment for Bicortical Orthodontic Mini-Screw Planning

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Abstract: Accurate placement of orthodontic mini-screws is important for skeletal anchorage and orthodontic treatment planning. Inappropriate placement may damage adjacent anatomical structures. Cone Beam Computed Tomography (CBCT) provides three-dimensional information that can assist in assessing palatal bone anatomy. This paper presents a preliminary image-analysis workflow for examining palatal bone thickness and displaying regions above and at or below a selected 5 mm threshold. The ToothFairy2 resource contains 480 publicly available training CBCT volumes and 50 private test volumes; however, the present implementation did not analyse all 480 training cases. The reported experiment concerns Patient 1, for which 668 slices were processed. The latest Patient 1 dashboard output classified 76.28% of the analysed region as greater than 5 mm and 23.72% as 5 mm or less, with a dashboard-reported segmentation score of 84.36%. The 5 mm value is treated as a study-defined operational threshold, not as a universal clinical safety rule. Expert review and further validation are required before clinical use.

Keywords: CBCT, palatal bone thickness, orthodontic mini-screws, image analysis, threshold-based assessment, segmentation

1. INTRODUCTION

Orthodontic mini-screws, also known as temporary anchorage devices (TADs), provide additional anchorage for controlled tooth movement. Their placement requires assessment of the available bone and nearby anatomical structures. The palate is a commonly considered region for orthodontic mini-implant placement, but bone thickness varies by location and between individuals. Published CBCT studies report this anatomical variation and emphasize individualized imaging assessment.

CBCT imaging provides multiplanar views of the maxillary region and can support preoperative anatomical assessment. Image-processing and segmentation methods can help identify regions of interest and represent bone thickness. The purpose of this project is to develop a preliminary digital workflow that visualizes palatal bone thickness and classifies the analysed region according to a selected threshold. The output is intended to support review and planning by dental professionals; it does not independently determine clinical suitability.

1A. RELATED WORK

CBCT-based studies have examined palatal bone depth, cortical thickness, and mucosal thickness to identify anatomical variation relevant to orthodontic mini-implant placement. These studies indicate that the available bone is not uniform across the palate and that measurements depend on the anatomical location and the individual patient [8], [9]. This supports the use of patient-specific image review rather than relying on a single assumed thickness value.

Digital planning and guided insertion have also been investigated to improve the positioning of orthodontic mini-screws. Research on digitally planned and guided insertion reports the importance of planning accuracy and verification of the final screw position [1]–[5]. These studies provide context for developing image-based assessment tools, but the present project does not claim to have designed or clinically tested a surgical guide.

Artificial-intelligence methods have been explored for the detection and segmentation of oral and maxillofacial structures in CBCT images. Reviews report growing use of automated image-analysis approaches while also highlighting the need

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for appropriate datasets, reference annotations, and validation [6]. The present implementation is at a preliminary stage and should be distinguished from a fully trained and independently validated segmentation model.
The ToothFairy2 challenge provides a public resource for multi-structure segmentation research in CBCT volumes [7]. Although the dataset description reports 480 public training volumes and 50 private test volumes, the experiment reported here is limited to one patient scan. The dataset size is therefore included to describe the available resource, not to imply that all cases were processed.

2. AIM AND OBJECTIVES

The aim is to develop a preliminary CBCT-based image-analysis workflow for assessing palatal bone thickness in support of bicortical orthodontic mini-screw planning.

- To import and visualize maxillary CBCT data in DICOM format.
- To examine the palatal region in axial, sagittal, and coronal views.
- To identify the palatal region and obtain bone-thickness measurements at selected locations.
- To classify analysed regions using a study-defined 5 mm threshold.
- To display the threshold-based results and provide a preliminary quantitative summary.

3. DATASET AND SCOPE

ToothFairy2 is a public CBCT segmentation challenge dataset. Its published description reports 530 volumes in total: 480 publicly available training volumes and 50 held-out private test volumes [7]. These figures describe the available dataset and must not be interpreted as the number of cases used in the present experiment. The current project output is based on Patient 1 only. The dashboard identifies 668 processed slices for that scan.
Accordingly, the experimental scope reported in this paper is one patient scan (Patient 1; 668 processed slices). The other ToothFairy2 cases are part of the available dataset resource and are not claimed as analysed in this work.

3A. STUDY DESIGN AND EXPERIMENTAL SCOPE

This work is presented as a preliminary, single-patient image-analysis study. Patient 1 is used to demonstrate the sequence of importing a CBCT volume, reviewing orthogonal planes, identifying the palatal region, displaying thickness-related information, and summarizing the region according to a selected threshold. The study is exploratory and does not provide population-level estimates.
The unit of analysis in the current report is the analysed region represented in the Patient 1 dashboard. The dashboard also records 668 processed slices. A slice count describes the amount of image data processed; it should not be interpreted as 668 independent patients or as 668 independent experimental observations.
The public dataset count and the analysed case count are reported separately to avoid ambiguity. The 480 training volumes are available within the ToothFairy2 resource, while only Patient 1 is included in the current experimental output. Any future multi-patient evaluation should report the number of scans successfully processed, excluded scans, and reasons for exclusion.

4. METHODOLOGY / PROPOSED SYSTEM

A. CBCT Image Acquisition

The upper-jaw CBCT scan is obtained in DICOM format and imported into 3D Slicer for visualization and analysis. The scan provides three-dimensional information about the maxillary palate and surrounding structures.

B. Image Preprocessing

The scan is reviewed in axial, sagittal, and coronal planes. Preprocessing and visualization are used to support clearer inspection of the anatomical region. The processed slice count recorded for Patient 1 is 668.

C. Anatomical Region Identification

The maxillary and palatal regions are identified for further examination. Relevant anatomical landmarks, including the mid-palatal suture and incisive foramen, may be used as reference points during assessment. The region of interest is then used for bone-thickness evaluation.

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D. Bone-Thickness Assessment

Bone thickness is assessed at selected locations using the measurement and visualization tools available in the image-analysis workflow. A colour-coded thickness representation is used to show spatial variation. The measurements must be interpreted in the context of the individual scan and its image calibration.

E. Threshold-Based Classification

For this project, 5 mm is used as an operational threshold: regions with measured thickness greater than 5 mm are placed in the above-threshold category, while regions measuring 5 mm or less are placed in the at-or-below-threshold category. A published CBCT study discusses a preferred palatal bone thickness in the range of approximately 4–5 mm for orthodontic mini-implant placement [9]. This provides background for selecting a 5 mm study threshold, but does not establish 5 mm as a universal bicortical-placement safety cutoff. The threshold requires confirmation by the collaborating dental professional.

F. Results Visualization

The dashboard presents multiplanar CBCT views, a bone-thickness map, a threshold-based anatomical map, and a numerical summary. The displayed categories are computational labels based on the selected threshold. They should not be treated as a clinical diagnosis or as an automatic recommendation to insert a screw.

5. IMPLEMENTATION

The current implementation uses 3D Slicer to import and inspect the Patient 1 DICOM scan. The maxillary palatal region is reviewed in multiplanar views, and the analysis output is summarized in a dashboard. The dashboard records 668 processed slices and reports the percentage of the analysed region above and at or below the 5 mm threshold.

5A. IMAGE-ANALYSIS WORKFLOW AND REPRODUCIBILITY

The workflow begins with loading the DICOM series and confirming that the images correspond to the intended maxillary scan. The axial, coronal, and sagittal reconstructions are reviewed together because each plane provides a different view of the anatomy. The orthogonal-view figure in this paper documents the scan orientation used for Patient 1 and provides anatomical context for the later dashboard output.

After import, the region of interest is restricted to the palatal area selected for analysis. This step is important because measurements from unrelated structures, teeth, air spaces, or other parts of the maxilla would not represent palatal bone thickness. The region selection and any manual interaction should be recorded in a repeatable protocol if the analysis is to be reproduced by another operator.

Thickness values are represented spatially using a colour-coded map. The colour map is a visualization aid: it allows the reader to observe relative variation across the selected region. The numeric scale and physical units must be linked to the original DICOM voxel spacing and calibration. If spacing metadata are missing or altered during export, measurements in millimetres may be unreliable and must be checked before publication.

For threshold-based reporting, each analysed measurement or region is assigned to one of two categories. Values strictly greater than 5 mm are assigned to the above-threshold category; values equal to or below 5 mm are assigned to the at-or-below-threshold category. The threshold is an operational rule for this analysis and is not a stand-alone clinical decision rule.

To improve reproducibility, a future version of the workflow should record the software version, DICOM series identifier, voxel spacing, region-of-interest definition, measurement locations, threshold value, preprocessing settings, and the exact calculation used to generate the dashboard percentages. These details make it possible to repeat the same analysis and compare outputs across scans.

The project is described as an AI-assisted image-analysis workflow. However, the current evidence provided for this paper does not document a fully trained and independently validated machine-learning model for automatic palatal segmentation or clinical screw-position prediction. Therefore, the paper does not claim that a clinically validated AI system or a fabricated CAD-CAM guide has been completed. Such functions may be considered future extensions after appropriate implementation and validation.

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6. RESULTS AND DISCUSSION

The latest dashboard output for Patient 1 reports the following threshold-based distribution and segmentation score:

6A. CALCULATION OF THRESHOLD DISTRIBUTION

The dashboard divides the analysed region into the above-threshold and at-or-below-threshold categories. The percentage for each category is calculated as the amount of analysed region assigned to that category divided by the total analysed region, multiplied by 100. The exact denominator (for example, number of pixels, voxels, or sampled measurement points) should be stated in the implementation record and confirmed before final submission.

For Patient 1, the reported percentages are 76.28% above 5 mm and 23.72% at or below 5 mm. The two categories sum to 100.00%, indicating that the dashboard presents them as complementary parts of the analysed region. These percentages describe the dashboard's selected region and should not be interpreted as the percentage of the entire palate or as the percentage of patients who are suitable for mini-screw placement.

The three displayed measurements—6.82 mm in the axial view, 6.37 mm in the sagittal view, and 6.11 mm in the coronal view—are individual location-specific examples. They demonstrate how measurements are presented in the three orthogonal planes, but they do not replace a systematic measurement protocol across predefined anatomical sites.

Output parameter	Reported value
Region above 5 mm	76.28%
Region at or below 5 mm	23.72%
Processed slices	668
Reported segmentation score	84.36%

The latest dashboard reports 76.28% of the analysed region above the selected 5 mm threshold and 23.72% at or below the threshold. These values replace the earlier dashboard results in this paper. The accompanying CBCT views show example measurements of 6.82 mm in the axial view, 6.37 mm in the sagittal view, and 6.11 mm in the coronal view. These are location-specific measurements shown in the dashboard and should not be interpreted as measurements for the entire palate. The orthogonal slice views are included to document the scan orientation and anatomical context; they do not independently establish the threshold percentages or segmentation score.

The dashboard reports a segmentation score of 84.36%. The calculation method and ground-truth comparison for this score have not been documented in the supplied material. It is therefore described as a dashboard-reported segmentation score, not independently verified model accuracy. Validation against expert-reviewed annotations is required before making a verified accuracy claim.

The threshold-based distribution is specific to Patient 1 and should not be generalized to other patients. A region above 5 mm is not automatically clinically safe: screw trajectory, cortical engagement, soft-tissue thickness, adjacent anatomy, and patient-specific factors must also be assessed by a qualified dental professional.



Fig. 1. Orthogonal CBCT slice views of Patient 1 showing axial, coronal and sagittal planes.

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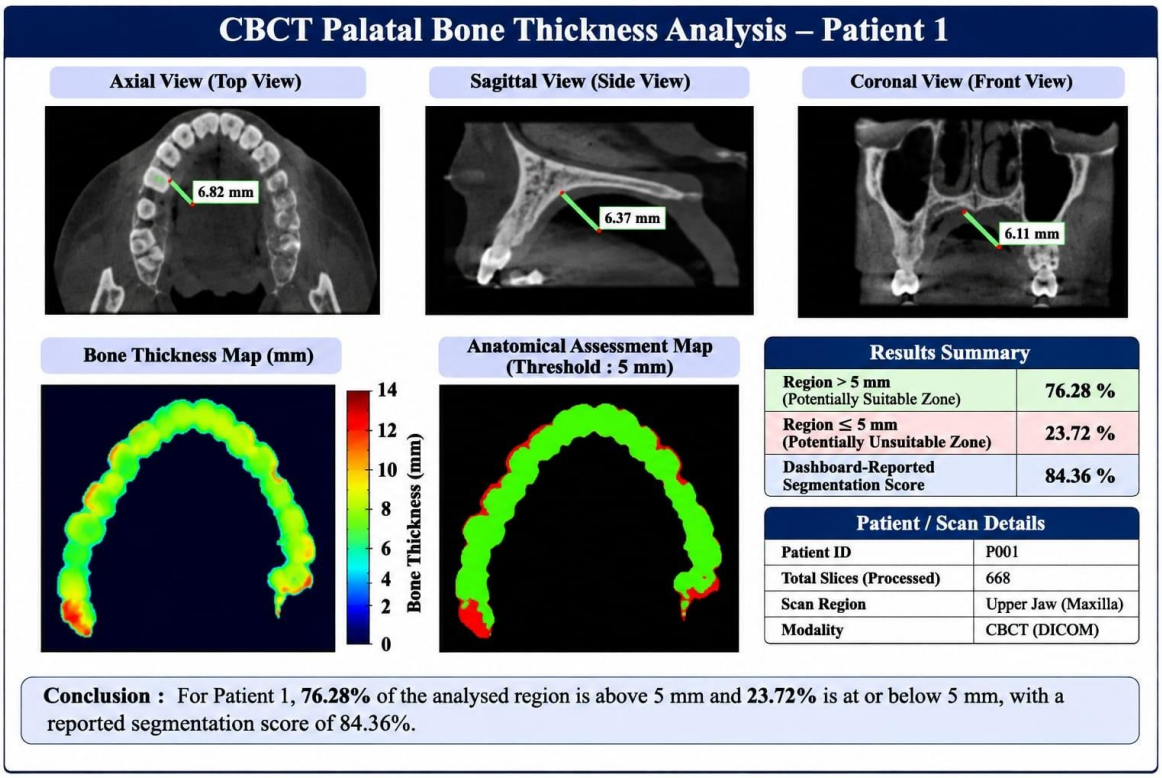


Fig. 2. Latest Patient 1 CBCT dashboard showing axial, sagittal, and coronal measurements, bone-thickness and anatomical assessment maps, threshold distribution, and the dashboard-reported segmentation score.

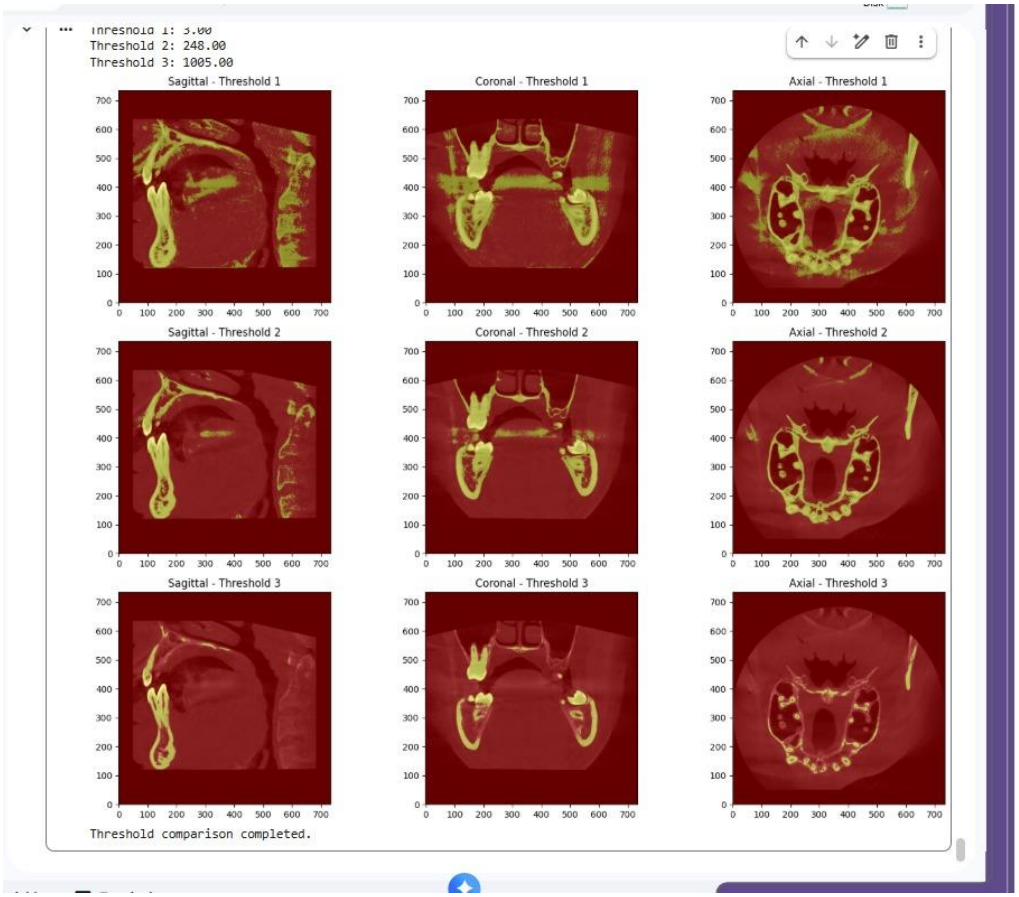


Fig. 3. Threshold comparison views in sagittal, coronal, and axial planes.

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6B. DISCUSSION

The Patient 1 dashboard demonstrates how CBCT information can be organized into a visual summary for preliminary anatomical review. The combination of orthogonal slice views, a thickness map, a threshold-based map, and a numerical summary provides complementary information: the slice views show anatomical context, the thickness map represents spatial variation, and the summary communicates the distribution generated by the selected threshold.

The reported 76.28% above-threshold region suggests that a substantial portion of the analysed region exceeded the study's 5 mm criterion in this scan. However, the result alone cannot establish that a screw can be placed safely at every above-threshold location. Clinical planning also considers the intended screw trajectory, cortical engagement, soft-tissue thickness, root proximity, anatomical structures, insertion angle, and the treatment objective. These factors require assessment by a qualified dental professional.

The dashboard-reported segmentation score of 84.36% requires particular care in interpretation. A score can only be called accuracy when the metric definition, reference labels, and comparison procedure are known. For segmentation, commonly used evaluation measures include Dice similarity coefficient and intersection over union, but the present paper does not assign either name to the 84.36% value because the calculation details have not yet been supplied. Until those details are verified, the value is retained as a dashboard-reported segmentation score.

The present work should therefore be viewed as a demonstration of an image-analysis and reporting workflow rather than proof of clinical effectiveness. A stronger evaluation would compare the automatically or semi-automatically identified palatal region with annotations prepared by dental experts, quantify agreement, and repeat the workflow across multiple independent scans.

7. LIMITATIONS

- The reported experiment covers Patient 1 only; the full set of 480 public ToothFairy2 training volumes was not analysed.
- The 5 mm threshold is an operational criterion for this project and requires clinical confirmation, particularly for bicortical placement.
- The dashboard-reported 84.36% segmentation score requires a documented metric definition and comparison with expert-validated ground truth before it can be presented as verified model accuracy.
- The current output is a preliminary image-analysis aid and is not a clinically validated decision-support system.
- CAD-CAM guide design, fabrication, and post-placement accuracy assessment are not claimed as completed in the present implementation.

7A. FUTURE WORK

Future work will focus on expanding the analysis from one patient to a larger, clearly documented set of CBCT scans. Each scan should be checked for image quality, correct anatomical coverage, and valid voxel-spacing metadata before inclusion. The number of scans processed and the number successfully analysed should be reported separately.

A dental expert should define the palatal region of interest and provide reference measurements or segmentation annotations. The analysis can then be evaluated using clearly specified metrics, such as Dice similarity coefficient for segmentation overlap, intersection over union, and measurement error in millimetres. The chosen metrics, formulas, reference labels, and evaluation protocol should be documented before reporting a model accuracy value.

Further development may include automated palatal-region segmentation, localization of predefined anatomical landmarks, and a reproducible measurement grid. Any proposed safe-zone visualization should remain an aid for professional review and should not generate an autonomous screw-placement recommendation without clinical validation.

If bicortical engagement is a central objective, future validation should specifically examine both cortical plates along the proposed screw trajectory and compare planned engagement with expert assessment or post-placement imaging where ethically and clinically appropriate. This is distinct from measuring palatal thickness at isolated points.

7B. ETHICAL, PRIVACY, AND DATA-HANDLING CONSIDERATIONS

CBCT scans are health-related imaging data. Before any wider research use or publication, the project team should confirm that the scans were obtained and processed under the applicable institutional permissions, consent or waiver requirements, and data-protection procedures. Direct identifiers should be removed from images and metadata, and access to source scans should be restricted to authorized project members. The paper should state the actual approval or consent status only after it has been confirmed by the institution; no approval number is assumed in this draft.

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8. CONCLUSION

This paper presents a preliminary CBCT-based workflow for visualizing palatal bone anatomy and classifying the analysed region using a study-defined 5 mm threshold. For Patient 1, the latest dashboard reports 76.28% of the analysed region above 5 mm and 23.72% at or below 5 mm, based on 668 processed slices. The dashboard-reported segmentation score is 84.36%, but its metric definition and reference comparison require confirmation. The available ToothFairy2 resource contains 480 public training volumes; these were not all used in the present experiment. The orthogonal CBCT views and dashboard provide a structured visual record of the single-patient analysis. Further work should include expert-validated annotations, reproducible measurement procedures, multiple independent scans, and dental review of the threshold and bicortical-planning criteria. The workflow is intended for preliminary research support and does not replace clinical judgment.

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