UNIVERSITY OF THE PACIFIC
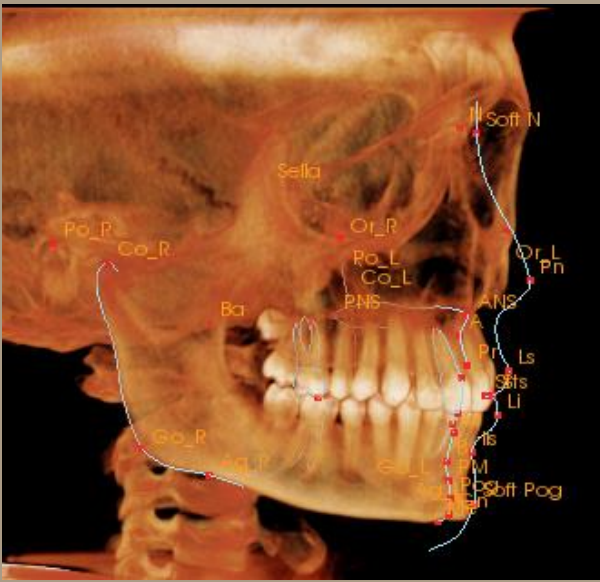Arthur A. Dugoni
School of Dentistry

# Accuracy of 3-D automated landmark identification on cone-beam computed tomography

**Joyce Choi, Jake Nealon, Richa Roy, Young Eun Jung, Hanisha Pasupulate, Heeyeon Suh, Joorok Park, Heesoo Oh**
**Department of Orthodontics, University of the Pacific, Arthur A. Dugoni School of Dentistry, San Francisco**

## OBJECTIVE

Recent advancements in computing power have led to the development of automatic landmark identification (ALI), which could greatly benefit clinicians and researchers. However, the accuracy of these tools needs to be evaluated against the gold standard. This study aims to evaluate the accuracy of an automatic landmark identification software compared to human landmark identification on CBCTs.
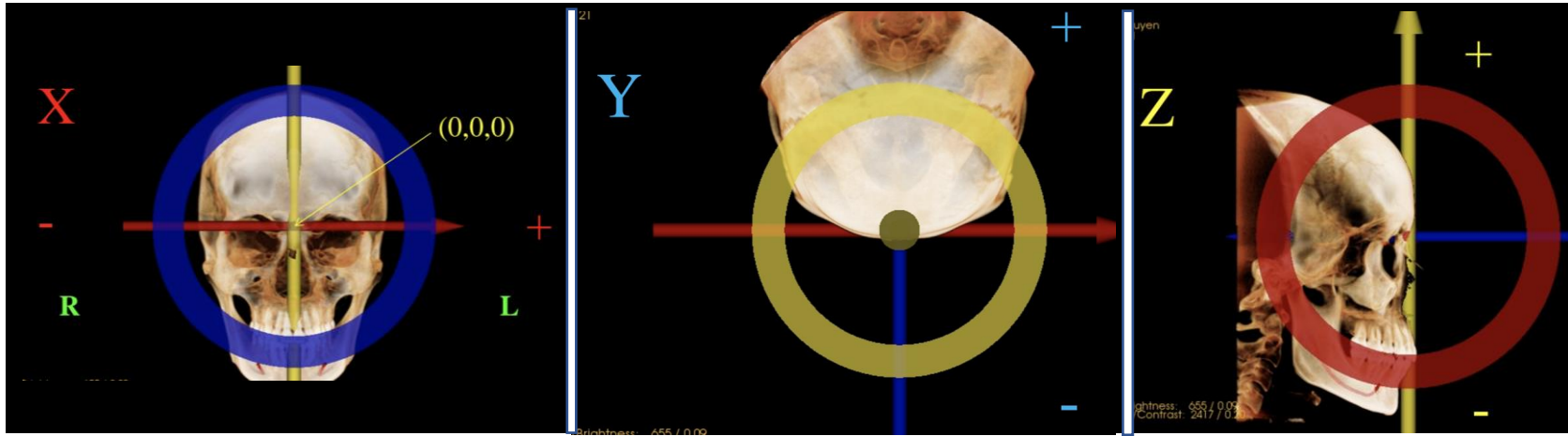


Figure 1. x, y, and z coordinate planes.

## METHODS

A total of 76 cone-beam computed tomography (CBCT) images were collected. After the calibration procedure, two human judges identified 23 landmarks (13 hard tissue, 4 dental, 6 soft tissue) in the x, y, and z coordinate planes on CBCTs using Invivo software (Fig 1). The ground truth was created by averaging landmark coordinates identified by two human judges for each landmark.

The accuracy of ALI was evaluated by:

(1) the mean absolute error (mm) at the x, y, and z coordinates

$$Mean\ Absolute\ Error = \frac{1}{n}\sum_{i=1}^{n}|Software\ Coordinate_i - Human\ coordinate_i|$$

(2) mean error distance (mm) between the human landmark identification and the ALI

$$Mean\ Error\ Distance\ (MED) = \frac{1}{n}\sum_{i=1}^{n}ED_i$$

$$Error\ Distance\ (ED) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

(3) successful detection rate (SDR)

The percentage of images in which each landmark was located within a precision range. Common error distance ranges of ≤2 mm, 2.5 mm, 3 mm, and 4 mm were used.

## RESULTS

(1) The ALI's mean absolute error for all coordinates was 1.4 mm on average. Across all three coordinate planes, 99% of the landmarks had a mean absolute error of less than 3 mm (Table 1).

(2) The mean error distance for all 23 landmarks was 2.9 ± 0.9 mm (Table 1).

(3) When applied to 23 landmarks on 76 CBCTs, the ALI system showed a 78% success rate in detecting landmarks within a 4-mm error distance range (Table 2).

Table 1

| | Mean Absolute Error | | | Error Distance (mm) | |
|---|---|---|---|---|---|
| | x | y | z | mean | sd |
| Nasion | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Left Orbitale | 1.66 | 1.19 | 1.54 | 2.87 | 1.75 |
| Right Orbitale | 2.42 | 1.44 | 1.50 | 3.54 | 1.92 |
| Left Porion | 4.51 | 1.67 | 1.92 | 5.63 | 2.06 |
| Right Porion | 4.57 | 1.24 | 1.50 | 5.24 | 2.44 |
| Basion | 0.26 | 1.19 | 1.88 | 2.58 | 2.69 |
| Sella | 0.98 | 0.76 | 1.61 | 2.35 | 1.57 |
| A point | 0.96 | 0.71 | 1.66 | 2.32 | 1.49 |
| ANS | 1.09 | 1.01 | 1.39 | 2.42 | 1.30 |
| PNS | 0.88 | 1.33 | 2.17 | 3.06 | 5.39 |
| B point | 1.47 | 1.02 | 1.75 | 2.91 | 1.23 |
| Pogonion | 1.69 | 1.12 | 1.73 | 3.11 | 1.60 |
| Menton | 1.78 | 1.43 | 1.31 | 3.10 | 1.47 |
| Soft tissue Nasion | 0.50 | 0.55 | 2.25 | 2.53 | 1.88 |
| Pronasale | 1.11 | 0.72 | 1.98 | 2.68 | 1.74 |
| Labrale superior | 1.19 | 0.86 | 1.46 | 2.44 | 1.48 |
| Labrale inferior | 1.20 | 0.96 | 1.67 | 2.65 | 1.31 |
| Soft tissue Pogonion | 1.39 | 1.14 | 4.13 | 4.80 | 2.15 |
| Lower labial sulcus | 1.21 | 1.09 | 1.56 | 2.67 | 1.52 |
| Upper right incisor root | 1.02 | 0.84 | 1.75 | 2.52 | 1.48 |
| Lower right incisor root | 1.47 | 1.14 | 1.36 | 2.71 | 1.23 |
| Upper right first molar cusp | 0.93 | 0.93 | 1.44 | 2.26 | 1.51 |
| Lower right first molar cusp | 1.13 | 0.86 | 1.48 | 2.37 | 1.46 |

Figure 2. Envelope of error with 95 % confidence ellipse of right Porion.
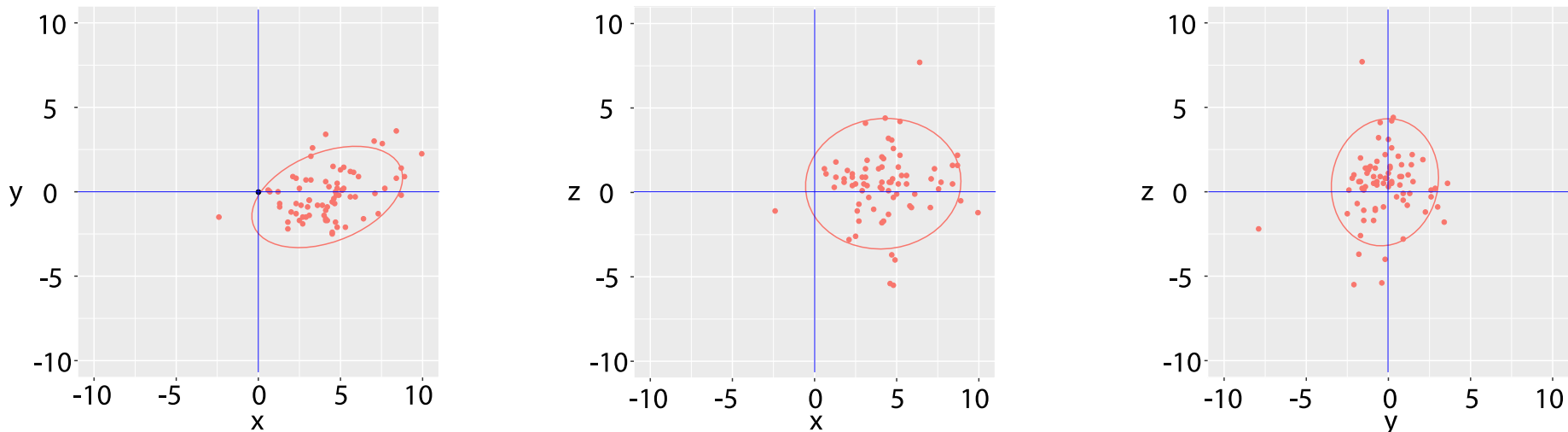


ALI is considered correct if ALI-Ground truth difference < 2mm, and acceptable if < 4mm. Error distribution is not spherical (Fig 2) and clinically acceptable error varies. For example, Porion has large x-axis error (Fig 2), but x-axis error of Porion is less critical in orthodontic analysis.

Table 2

| | SDR (%) | | | |
|---|---|---|---|---|
| | 2 mm | 2.5 mm | 3 mm | 4 mm |
| Nasion | 100 | 100 | 100 | 100 |
| Left Orbitale | 30 | 50 | 63 | 82 |
| Right Orbitale | 20 | 29 | 49 | 71 |
| Left Porion | 0 | 0 | 1 | 22 |
| Right Porion | 5 | 8 | 17 | 33 |
| Basion | 49 | 61 | 74 | 86 |
| Sella | 55 | 70 | 79 | 88 |
| A point | 51 | 64 | 82 | 89 |
| ANS | 45 | 63 | 72 | 91 |
| PNS | 45 | 61 | 71 | 87 |
| B point | 21 | 42 | 64 | 82 |
| Pogonion | 24 | 49 | 59 | 79 |
| Menton | 22 | 42 | 59 | 78 |
| Soft tissue Nasion | 50 | 63 | 70 | 84 |
| Pronasale | 34 | 55 | 72 | 86 |
| Labrale superior | 53 | 70 | 72 | 88 |
| Labrale inferior | 34 | 57 | 68 | 87 |
| Soft tissue Pogonion | 5 | 14 | 20 | 37 |
| Lower labial sulcus | 41 | 55 | 67 | 87 |
| Upper right incisor root | 38 | 55 | 67 | 86 |
| Lower right incisor root | 26 | 45 | 61 | 79 |
| Upper right first molar cusp | 47 | 66 | 75 | 86 |
| Lower right first molar cusp | 46 | 62 | 74 | 86 |

## CONCLUSION

The automatic landmark identification (ALI) software showed clinically acceptable mean error distances in most landmarks, except for a few. This study highlights the potential of ALI in assisting clinicians with landmark identification on CBCTs.

## REFERENCES

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