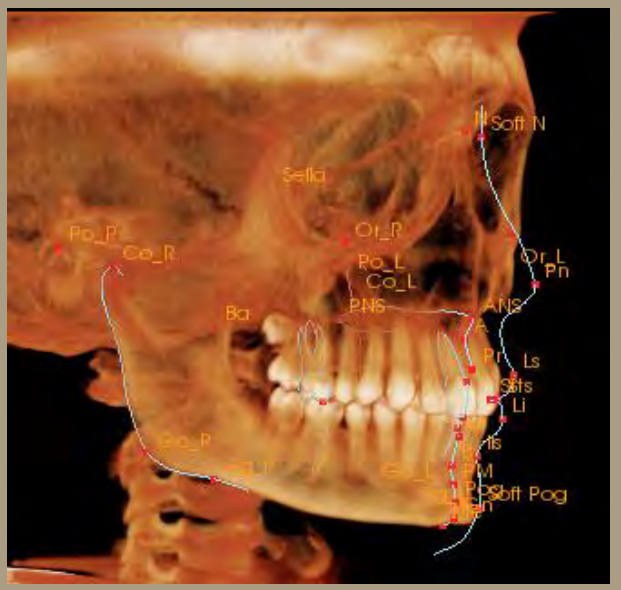


Accuracy of 3-D automated landmark identification on cone-beam computed tomography

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.

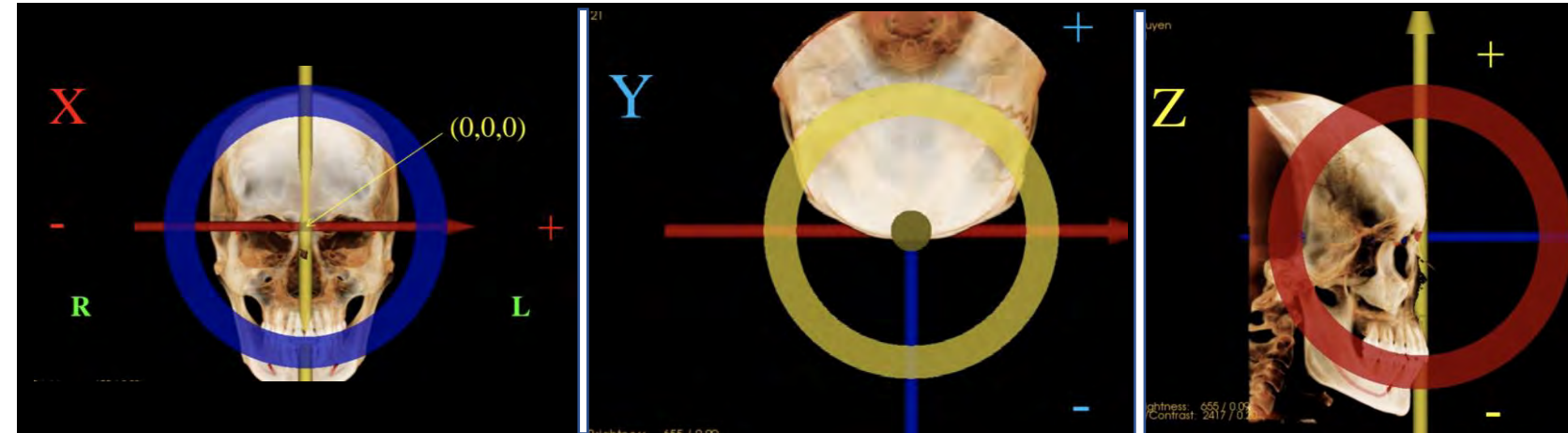


Figure 1. x, y, and z coordinate planes.

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

$$\text{Mean Absolute Error} = \frac{1}{n} \sum_{i=1}^n |\text{Software Coordinate}_i - \text{Human coordinate}_i|$$

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

$$\text{Mean Error Distance (MED)} = \frac{1}{n} \sum_{i=1}^n ED_i \quad \text{Error Distance (ED)} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

- (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.

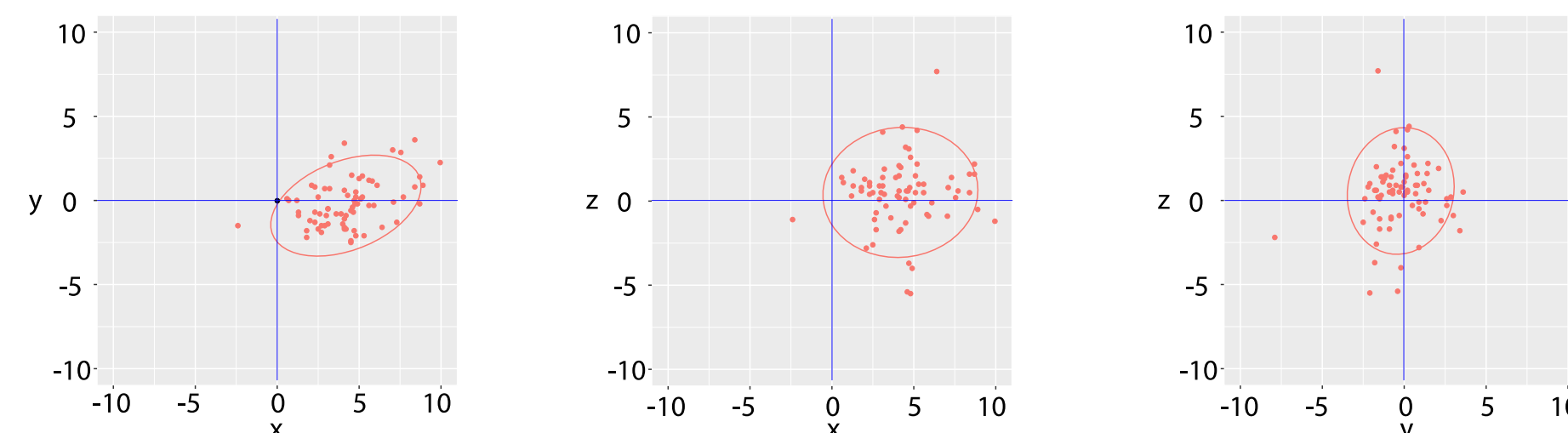
RESULTS

- (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 < 2 mm, and acceptable if < 4 mm. 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.

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