

Automatic recognition of anatomic features on cephalograms of preadolescent children

Chihiro Tanikawa^a; Taku Yamamoto^b; Masakazu Yagi^c; Kenji Takada^d

ABSTRACT

Objective: To develop a system that automatically recognizes the dentoskeletal traits on cephalograms recorded for preadolescent children and to examine performance reliability.

Materials and Methods: We obtained 859 lateral cephalograms and divided them into group P (400 films taken from orthodontic patients having permanent dentition) and group M (459 films taken from those having mixed dentition). Fifty-nine cephalograms in group M were reserved for system test, and the remaining cephalograms in groups M and P were used for system development. Using a previously reported method (Yagi and Shibata, 2003), systems S_M and S_{P+M} were developed with the knowledge generated from groups M and P+M (combined sample of groups M and P), respectively. The system S_P that had been developed for cephalograms of permanent dentition in our previous report was also employed for comparison. To evaluate performance reliability, the systems examined the 59 reserved cephalograms. The areas of each system-identified anatomic structure surrounding the anatomic landmarks and the positions of each system-identified landmark were compared with the norms in the form of confidence ellipses. The success rates were calculated for S_P , S_M , and S_{P+M} .

Results: The systems successfully identified all of the specified anatomic structures in all of the images. The systems S_P , S_M , and S_{P+M} determined the landmark positions with a mean success rate of 69% (range, 38–98%), 82% (range, 50–100%), and 82% (range, 58–100%), respectively.

Conclusions: Systems S_M and S_{P+M} were confirmed to be accurate and reliable in recognizing the anatomic features on the cephalograms of preadolescent children. (*Angle Orthod.* 2010;80:812–820.)

KEY WORDS: Cephalograms; Children; Recognition

^a Assistant Professor, Department of Orthodontics and Dentofacial Orthopedics, Graduate School of Dentistry, Adjunct Assistant Professor, Center for Advanced Medical Engineering and Informatics, Osaka University, Osaka, Japan.

^b Former Doctoral Student, Department of Orthodontics and Dentofacial Orthopedics, Graduate School of Dentistry, Osaka University, Osaka, Japan.

^c Associate Professor, Center for Advanced Medical Engineering and Informatics, Osaka University, Osaka, Japan.

^d Professor and Chair, Department of Orthodontics and Dentofacial Orthopedics, Graduate School of Dentistry, Professor, Center for Advanced Medical Engineering and Informatics, Osaka University, Osaka, Japan.

Corresponding author: Kenji Takada, DDS, PhD, Department of Orthodontics and Dentofacial Orthopedics, Graduate School of Dentistry, Osaka University, 1-8 Yamadaoka, Suita, Osaka, Japan 565-0871
(e-mail: opam@dent.osaka-u.ac.jp).

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INTRODUCTION

Human recognition of anatomic features on cephalograms is more difficult in preadolescents than in adolescents/adults. There are two major reasons for this. First, radiolucent images are more likely to be obtained on cephalograms of preadolescent children, because their bone density is relatively lower, as their bones are immature and, thus, thin.¹ Accordingly, the exposure dose used for children is usually low.² Further, it is often difficult to project certain landmarks clearly. Under the aforementioned conditions, the soft tissue images projected on the films are more accentuated,³ yielding obscure images with complicated overlaps.

Second, in the spatial relationship between the anatomic features, there is a great biological variation that stems from the development. Dentofacial development involves development in not only the size but

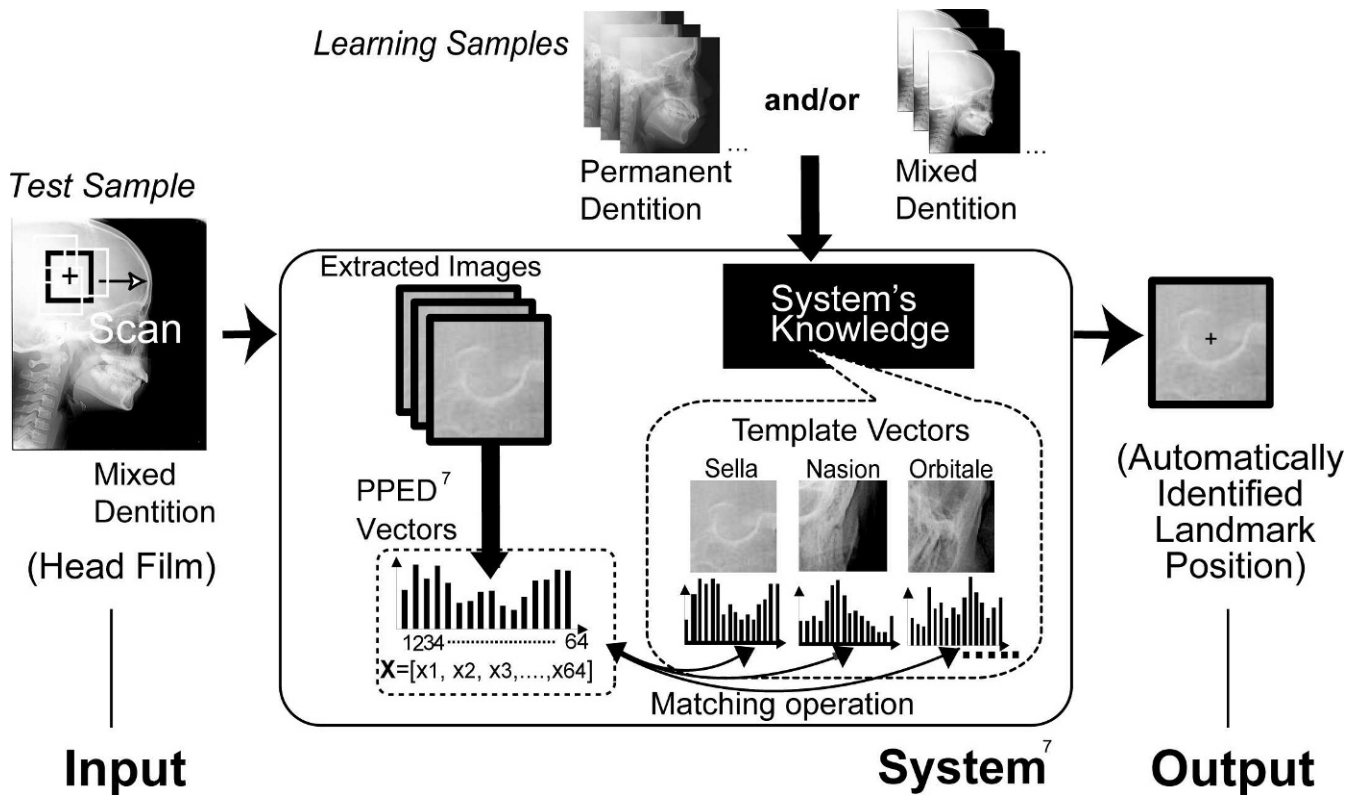


Figure 1. Schematic illustration of the system employed in the present study.

also the shape, wherein the developing pattern varies according to the anatomic regions.^{4,5} Additionally, relationships between the primary and permanent tooth germs show relative variability in tooth development. To recognize the landmarks having great variations in the anatomic features on the cephalograms, dentists are required to have extensive past experience in recognizing the target. This implies that the recognition of the anatomic features surrounding the landmarks in the cephalogram of a preadolescent with large variation is more difficult than that in the cephalogram of an adult having relatively small variation.

On the other hand, in our laboratory, we previously developed an automatic recognition system for the anatomic features on the cephalograms and confirmed its effectiveness and potential in clinical application.⁶ However, it has yet to be proved whether the proposed system can be applied to the records of preadolescent children. The principle underlying the operation of the system is a matching process; it is used to assess whether the dentoskeletal–soft tissue relationships in the cephalograms used for testing the system’s performance are similar to those observed in the record set employed for the system’s learning. The system proposed in the previous study did not provide any information in terms of the preadolescent’s anatomic features on cephalograms, which would

probably result in low success rates for recognition when cephalograms of preadolescent children were tested using the previous system.

The aims of the present study were as follows: (1) to examine the practical accuracy of the existing automatic recognition system that was optimized for cephalograms of adolescents/adults, when applied to the cephalograms of preadolescent children, and (2) to optimize the system for cephalograms of preadolescent children and examine its practical accuracy.

MATERIALS AND METHODS

System Architecture

Figure 1 presents the system architecture employed in this study. The system performs automatic recognition of the anatomic landmarks on the lateral cephalograms. A detailed description of the system has been reported elsewhere.^{6,7} In short, the system is composed of two major phases (ie, the “knowledge generation [system learning]” phase and the “recognition” phase). In the knowledge generation phase, image data extracted from learning samples are converted into Principal Projected Edge Distribution (PPED) vectors consisting of 64 variables that feature contours of the anatomic structures.⁷ From these vectors, template vectors (ie, the principal information

for identifying the landmarks) are generated using a generalized Lloyd algorithm⁶ for each landmark. The template vectors are stored on the system as the system's knowledge. In the recognition phase, the system performs pixel-by-pixel film scanning with template-matching operations between the PPED vectors that are generated from an input film and template vectors stored on the system. The system recognizes the most matched position as a landmark position.

Samples

A total of 859 pretreatment digital lateral cephalograms that had been obtained from Japanese orthodontic patients who had visited the university dental hospital between 1998 and 2005 were employed consecutively. Two orthodontists examined the cephalograms and divided them into the following two groups based on their dental development stages⁸: (1) group P, 400 patients having full permanent dentition (mean age, 23.6 years; age range, 11.9–60.0 years; 119 males and 281 females) and (2) group M, 459 preadolescent children having mixed dentition (mean age, 8.9 years; age range, 5.0–16.3 years; 200 males and 259 females). For testing the systems' performance, 59 cephalograms were reserved from group M at random. For knowledge generation, the remaining cephalograms in group M and all cephalograms in group P were used.

Data Processing

Each film was scanned (300 dpi; image data), and 18 landmark positions^{4,6} (Table 1), which were identified visually and cross-marked on a traced paper, were recorded (landmark position data) using the method reported previously.⁶ The degree of certainty was recorded for each landmark using the following three subjective judging scores: (1) absolutely correct, (2) probably correct, and (3) difficult to recognize. Positions assigned to the degrees of certainty 2 and 3 were exempted from the data set for system learning. Positions assigned to the degrees of certainty 3 were exempted from the data set for the performance test.

Knowledge Generation

From the image and position data of groups P and M, the following two sets of template vectors were generated as the systems' knowledge: (1) template vectors for the knowledge of the mixed dentition period alone (obtained from group M) and (2) template vectors for the knowledge of both the permanent dentition and the mixed dentition periods (obtained

Table 1. The 18 Anatomic Landmarks Employed in the Present Study

Landmark	Definition
S	The center of sella turcica
N	The junction of the frontonasal at the most posterior point on the curve at the bridge of the nose
Or	The lowest point on the inferior margin of the orbit
Po	Point on the upper margin of the porus acusticus externus
Ba	Point where the median sagittal plane of the skull intersects the lowest point on the anterior margin of the foramen magnum
ANS	The tip of the anterior nasal spine
PNS	The posterior limit of the palatine bone
Point A	The most posterior point on the curve between ANS and Prosthion
Point B	The point most posterior to a line from Infradentale (Id) to Pog on the anterior surface of the symphyseal outline of the mandible
Pog	A tangential to the anterior contour of the symphysis and passing through Id
Me	The most inferior point of the symphysis to the line Id-Pog
Gn	Intersection between the perpendicular bisector of Pog-Me and the anterior contour of the symphysis
Go	External angle of the mandible, located on the lateral radiograph by bisecting the angle formed by tangents to the posterior border of the ramus and the inferior border of the mandible
Ar	Intersection of the lateral radiographic image of the posterior border of the ramus with the base of the occipital bone
Cd	The top of the head of the condyle
U1	The upper central incisal tip
L1	The lower central incisal tip
Ptm	The most anterior inferior confluence of the curvatures, which is a bilateral, upside-down, teardrop-shaped area of radio-lucency, the anterior surfaces of which are taken as the posterior surfaces of the maxilla

from groups P and M). Two separate systems, S_M and S_{P+M} , were designed to employ these template vector sets, respectively.

Systems' Performance Test

In the present study, to examine the practical accuracy of the existing system when it is applied to the cephalograms of preadolescent children, we employed a system, S_P , that was previously developed⁸ and that offered prior knowledge obtained from the permanent dentition alone.

The systems S_P , S_M , and S_{P+M} were instructed to identify 59 cephalograms that had been reserved for the system's performance test. To evaluate the systems' performance reliability, we employed confidence ellipses that were developed in our previous report,⁶ which were designed to represent errors for manual landmark identification.

Table 2. Criteria for Classifying the Landmarks

	Criterion
I	When the E_P^l was greater than 80%, the landmark was assigned a value of 1; otherwise, it was assigned a value of 0
II	When the E_M^l or E_{P+M}^l was statistically greater than E_P^l , the landmark was assigned a value of 1; otherwise, it was assigned a value of 0
III	When the E_M^l or E_{P+M}^l was greater than 80%, the landmark was assigned a value of 1; otherwise, it was assigned a value of 0

First, for each landmark, the systems computed an area that was the most probable location of the anatomic structure surrounding a given landmark as a minimum rectangular area that included the first 50 candidate positions of the landmark (hereafter referred to as “search area”) in 1/16-downscaled targeted images. If the fiducial zone, designated by a confidence ellipse with $\alpha = .01$, was found to overlap the search area, recognition of the “anatomic structure” was considered to be successful.

Second, for each landmark, the systems computed the most probable position of the landmark by examining the targeted images with original resolution in the search area. The success or failure of the assessment by the system was evaluated using confidence ellipses with $\alpha = .01$. In short, when a system-identified point was located within a confidence limit of $\alpha = .01$, the “landmark identification” was considered to be successful.

The anatomic structure surrounding that landmark (E_P^a , E_M^a , and E_{P+M}^a) and the success rates for the recognition of the landmark (E_P^l , E_M^l , and E_{P+M}^l) were defined as the proportions of the total samples that could be successfully recognized by the systems S_P , S_M , and S_{P+M} , respectively. The success rates for all the landmarks were calculated. All of the procedures were carried out on a workstation (Sun Blade 2000, Sun Microsystems Inc, Palo Alto, Calif).

Analysis of the Success Rates E_P^l , E_M^l , and E_{P+M}^l

To determine the landmarks that showed significantly higher recognition performance when using the present systems E_M^l and E_{P+M}^l , relative to the existing system E_P^l , the following two analyses were performed. First, to assess whether the success rate E_M^l or E_{P+M}^l was significantly different from E_P^l (ie, E_{P+M} vs E_P and E_M vs E_P), the success rates E_M^l and E_P^l were statistically evaluated by a test for equal or given proportions for each landmark ($P \leq .05$).⁹ Second, to clarify the patterns of success rates E_P^l , E_M^l , and E_{P+M}^l for each landmark, the landmarks were classified into eight patterns using the three criteria shown in Table 2. The patterns were represented as {1 or 0 for criterion I, 1 or 0 for criterion II, and 1 or 0 for criterion III}.

Table 3. Success Rates of the Recognition of Anatomic Structures and the Landmark Positions Obtained Using the Systems

Landmark	Success Rate of the Anatomic Structures, %			Success Rate of the Landmark Positions, % ^a		
	E_P^a	E_M^a	E_{P+M}^a	E_P^l	E_M^l	E_{P+M}^l
Ptm				98	100	100
Pog				96	98	98
Point B				94	98	94
Me				86	88	88
Gn				84	90	92
PNS				78	92	86
Point A				78	90	92
Po				72	78	80
Cd				72	86	88
Ba	100	100	100	64	74 (74)	68
S				62	84	80
Or				62	76	82
ANS				62	84	92
U1				54	72 (72)	72
L1				50	78 (80)	78
Go				50	68 (82)	64
Ar				40	72 (72)	58
N				38	50	60 (70)
Average	100	100	100	69	82	82

^a Parenthetical numbers represent the success rates when including the second candidate for the identification of Ba, U1, L1, Go, Ar, and N.

RESULTS

The E_P^a , E_M^a , and E_{P+M}^a had success rates of 100%. In other words, the systems successfully recognized all the anatomic structures surrounding all the landmarks (sella turcica, naso-frontal junction, infraorbital area, mandibular symphysis, etc) when determined using a 62 × 62-pixel (range, 36 × 36-pixel to 84 × 84-pixel) search area.

The E_P^l , E_M^l , and E_{P+M}^l values are listed in Table 3. The mean E_P^l was 69%, with a range of 38% (N) to 98% (Ptm). The mean E_M^l was 82%, with a range of 50% (N) to 100% (Ptm). The mean E_{P+M}^l was 82%, with a range of 58% (Ar) to 100% (Ptm). When either E_M^l or E_{P+M}^l that achieved higher success rates for each landmark was evaluated, the mean success rate was 84%, with a range of 60% (N) to 100% (Ptm). The *P* values that were obtained by the test for equal or given proportions are provided in Table 4.

The landmarks classified into each pattern are shown in Figure 2. The number of landmarks assigned to the pattern {1, 0, 1} was five (Ptm, Pog, Point B, Me, and Gn). In other words, these five landmarks achieved greater than 80% success rates with both the previous and the present systems. On the other hand, the numbers of landmarks assigned to the patterns {0, 1, 1}, {0, 1, 0}, {0, 0, 1}, and {0, 0, 0} were six (PNS, Point A, Cd, S, Or, and ANS), three (L1, Ar, and N), one (Po), and three (Ba, U1, and Go), respectively. In other words, these 13 landmarks could

Table 4. P Values Obtained by the Test for Equal or Given Proportions

Landmark	P Value	
	E_P^I vs E_M^I	E_P^I vs E_{P+M}^I
Ptm	0.31	0.31
Pog	0.56	0.56
Point B	0.31	N/A ^a
Me	0.77	0.77
Gn	0.37	0.22
PNS	0.05*	0.30
Point A	0.10	0.05*
Po	0.49	0.35
Cd	0.09	0.05*
Ba	0.28	0.67
S	0.01*	0.05*
Or	0.13	0.03*
ANS	0.01*	0.00*
U1	0.06	0.06
L1	0.00*	0.00*
Go	0.07	0.15
Ar	0.00*	0.07
N	0.23	0.03*

^a N/A indicates not applicable.

* $P \leq .05$.

not achieve greater than 80% success rates using the previous system. Of these 13 landmarks, six (PNS, Point A, Cd, S, Or, and ANS) showed significant improvements and success rates greater than 80% using the present systems; three landmarks (L1, Ar, and N) showed significant improvements but did not show success rates greater than 80% with the present systems; and four landmarks (Po, Ba, U1, and Go) showed no significant improvement with the present systems. There were no landmarks assigned to the groups {1, 1, 1}, {1, 1, 0}, and {1, 0, 0}. The positions of the 18 landmarks identified are exemplified in Figure 3.

DISCUSSION

The confidence ellipse was designed to represent the variation among manual landmark identifications performed in 10 cephalograms by 10 experienced orthodontists.⁶ Thus, the success rate reflected the system's recognition ability with the same precision as manual identifications by the experienced orthodontists.

There are mainly two types of landmarks: those related to teeth and those related to bones. The timing of tooth emergence and skeletal maturation varies among individuals, and the correlation between them is weak.¹⁰ In the present study, we attempted to divide the learning and test samples into two groups to minimize the image variations caused by at least one factor of these skeletal or dental development stages. The stage of dental development was chosen in this study because dental development could be judged more clearly, compared with skeletal development, on cephalograms.

This is the first report to examine the practical accuracy of the automatic recognition system when it is applied to the cephalograms of preadolescent children. The results indicate that the system that previously reported, whereby cephalograms of preadolescent children are employed as inputs, cannot achieve a recognition ability that can be used in the routine clinical setting.

In the present study, to optimize the existing system for cephalograms of preadolescent children, we employed two kinds of "knowledge" generated from the cephalograms of the mixed dentition period alone and from those of both the mixed and permanent dentition periods. The reason for generating the two types of knowledge was the various overlaps between knowledge obtained from preadolescents and that

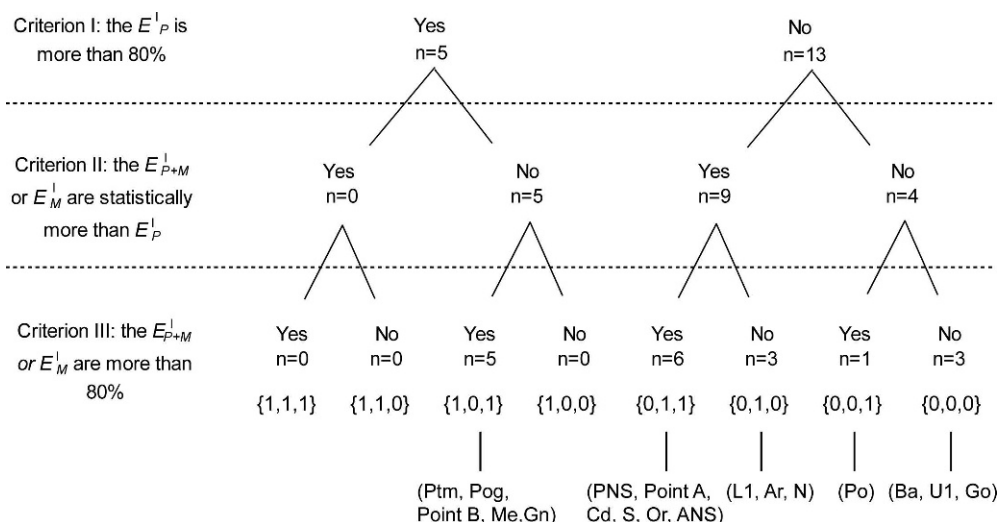


Figure 2. Classification of the recognition results of the landmarks. Each number shows the number of landmarks that satisfied each criterion.

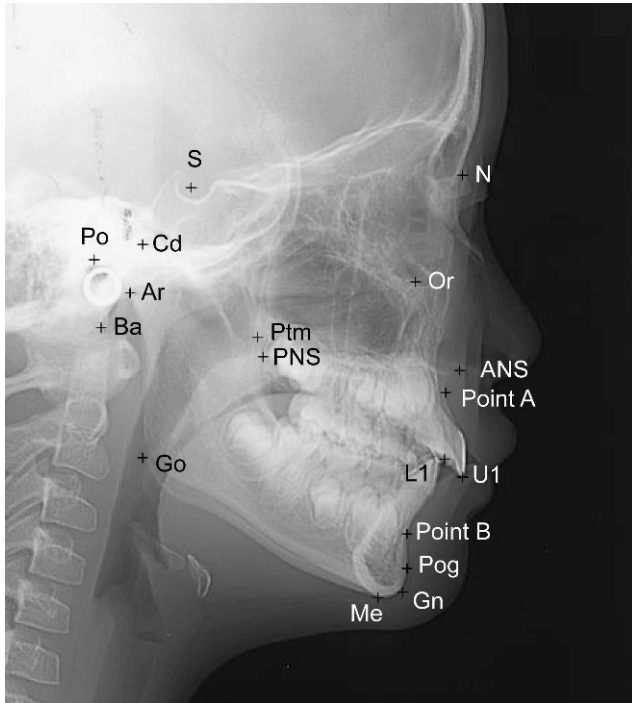


Figure 3. Example of the positions of the 18 cephalometric landmarks identified by the proposed system.

obtained from adolescents/adults, which were assumed to be dependent on the landmarks. For example, as skeletal development does not always match dental development,¹⁰ the viewing images of the skeletal structure at the later phase of the mixed dentition and those at the prophase of the permanent dentition are similar, indicating large knowledge overlaps. Thus, for the skeletal landmarks, it was assumed that the recognition performance would be improved if the system contained knowledge of both mixed and permanent dentition periods. Figure 4 shows an example of the relationships of the two types of knowledge and their corresponding probable recognition performance when a combined group was used for knowledge generation (see patterns 1, 2, and 3 in Figure 4 and Appendix).

Generally, it can be postulated that recognition performance varies according to variations in the knowledge obtained from preadolescent children and from adolescents/adults, as well as according to their positioning. These variations correspond to disparity in viewing images of the anatomic features near the landmarks of cephalograms in the mixed and permanent dentition periods and to the similarity of viewing images of those in the two periods.

In the present study concerning the four landmarks (Point A, Cd, Or, and N), the success rates of the landmarks obtained when using the system construct-

ed from the records of the two dentition stages were significantly higher than those obtained using the existing system. With regard to the three landmarks (S, ANS, and L1), both systems—having knowledge with and without permanent dentition—achieved significantly higher success rates when compared with the existing system. Furthermore, with regard to the two landmarks (PNS and Ar), the success rates obtained using the system constructed from the mixed dentition alone were significantly higher than those obtained using the existing system. This result is likely due to the fact that the knowledge of these landmarks belongs to patterns 1, 2, and 3, respectively (for details, see Table 5).^{4,5,10-13}

With regard to the five landmarks (Ptm, Pog, Point B, Me, and Gn), the success rates were greater than 80% with both the previous and present systems. The confidence ellipse was larger for these landmarks than for the others, and, thus, a high success rate was probably obtained when using the existing system as well.

On the other hand, six landmarks (N, Ba, Go, Ar, U1, and L1) showed success rates that were below 80% in the existing system and any of the present systems. In geometrical terms concerning Nasion and Articulare, which are intersections or branch points, the recognition performance may be improved in the future by incorporating the method of tracing the outline into the present system.¹⁴ With regard to Basion and Gonion, there may be greater variations in the anatomical structure as a result of the shaded image of the pharyngeal region overlapped with the adjacent cervical vertebrae. This led to fewer images that corresponded to those used for performance tests in the learning samples, which probably caused the lower success rate. In this case, the success rate can be improved by increasing the amount of data for learning.

In the present study, when observing recognition results only for patients with anomalies ($n = 19$), as a preliminary examination, the present system achieved greater than 80% of the success rate even for landmarks that were expected to be difficult to recognize as a result of the anomalous structure (84% [ANS], 95% [Point A], and 89% [PNS]). Thus, the system can possibly be applied to patients with congenital anomalies as well.

Finally, the system can be used for clinical application, as follows: For four landmarks (Point A, Cd, Or, and N), the knowledge generated from the combined subjects of the mixed and the permanent dentitions should be employed. As for the two landmarks (PNS, Ar), the knowledge generated from the mixed dentition subjects alone should be employed. Regarding the remaining landmarks, either or both kinds of knowl-

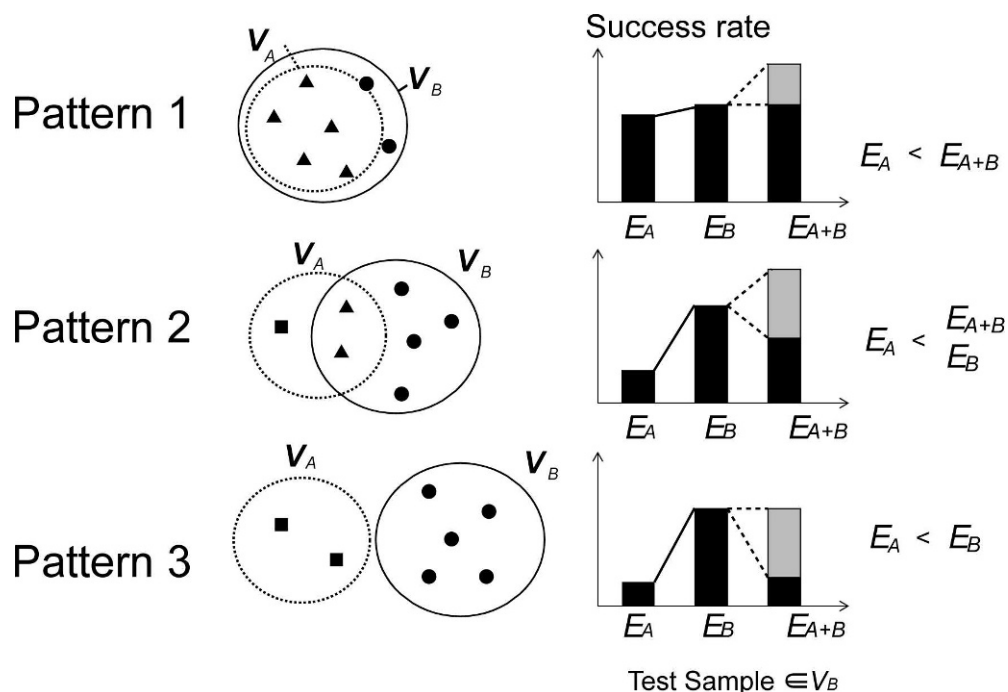


Figure 4. Left: An example showing the variations and relationships of knowledge in a PPED vector space. Open circles of V_A and V_B indicate vector groups in the PPED vector space (ie, the sizes of V_A and V_B represent the variations in viewing image of the anatomic features, and their relationships in the positioning represent the differences in anatomic features). The closed square, circle, and triangle represent the template vectors that correspond to vector groups V_A , V_B , and both of them, respectively. Right: An example showing the rates of success corresponding to patterns 1, 2, and 3. E_A , E_B , and E_{A+B} indicate the rates of success when template matching is conducted using an input having the attributes of the vector group V_B with the systems generated from V_A , V_B , and V_{A+B} . Gray; assumed ranges of the success rate. For details, see Appendix.

edge can be employed. By having both kinds of knowledge, the system is able to output multiple candidates based on the two kinds of knowledge. In the present study, all the anatomic features near the landmarks were found to be correctly recognized. Thus, it seems to be possible to develop an interface, such that dentists will be able to visibly check and select a candidate using auto-magnified images near the landmarks and correct the candidate's position, if necessary. This will likely lead to a considerable reduction in the dentist's workload. Furthermore, it is expected that the same schemes for developing and optimizing the system that were described in the present study are applicable to the current trend toward three-dimensional records; this will facilitate more accurate and automatic identification using transverse information.

In summary, the system optimized in the present study for cephalograms of mixed dentition was confirmed to be more accurate and reliable in recognizing the anatomic features on the cephalograms of preadolescent children, when compared with the existing system, for which knowledge was obtained from the adolescent/adult sample alone. The present system will offer increased efficiency during clinical applications.

CONCLUSIONS

- For the recognition of the anatomic features surrounding the landmarks in the cephalograms of preadolescent children, the previous system (optimized for adolescents/adults) and the present systems (optimized in the present study for preadolescent children) achieved success rates of 100%.
- For the identification the landmark positions in the cephalograms of preadolescent children, five landmarks (Ptm, Pog, Point B, Me, and Gn) achieved greater than 80% success rates with both the previous and the present systems. Out of the remaining landmarks, six landmarks (PNS, Point A, Cd, S, Or, and ANS) showed significant improvements and success rates greater than 80% using the present systems; three landmarks (L1, Ar, and N) showed significant improvements, but did not show success rates greater than 80% with the present systems; and four landmarks (Po, Ba, U1, and Go) showed no significant improvement with the present systems.
- These results reveal that the systems optimized in the present study for cephalograms of mixed dentition were more accurate and reliable in recognizing the

Table 5. Comparative Success Rates of E_P^I , E_M^I , and E_{P+M}^I , the Knowledge Relation Pattern Presumed from the Result, and its Description of the Anatomic Features in Cephalograms of Permanent and Mixed Dentition Periods

Landmark	E_P^I vs E_M^I	E_P^I vs E_{P+M}^I	Presumed Knowledge Relation Pattern	Description of the Anatomic Features in the Cephalograms of the Permanent and Mixed Dentition Periods
Point A	$E_P^I = E_M^I$	$E_P^I < E_{P+M}^I$	Pattern 1: Large knowledge overlap among the permanent and mixed dentition periods	The view of the image near the anterior boundary of the maxilla is affected by the existence of tooth germs and the roots on the maxillary anterior teeth. ¹⁰ However, as the anterior teeth erupt earlier than the molars, it is assumed that there are large overlaps among cephalograms of the permanent and mixed dentition periods.
Cd				Because the distance between the shade of the ear rod and the landmarks of the cephalogram of the mixed dentition period is shorter than that of the permanent dentition period, variations of anatomical features near landmarks by the effect of the image of the ear rod differ. However, because the distance between Cd and ear rod is longer, it is assumed that there are large overlaps among cephalograms of the permanent and mixed dentition periods.
Or				Because growth of the anatomical structure of the area surrounding Or is complete at around the age of 7 years, ¹¹ it is assumed that there are large overlaps among cephalograms of the permanent and mixed dentition periods.
N				The frontal sinus existing nearby appears around the prophase of the mixed dentition period, ⁹ parallelism of the inside of the cortical bone and the outside of the frontal bone is furthermore lost by growth, ¹² and growth ends at prophase of the mixed dentition period. Therefore, at the later phase of the mixed dentition period and the prophase of the permanent dentition, the view as an image of the anatomical structure near the measuring point is similar, and recognition precision is thought to be enhanced when knowledge is generated from cephalograms of both mixed and permanent dentition periods.
S	$E_P^I < E_M^I$	$E_P^I < E_{P+M}^I$	Pattern 2: Small knowledge overlap among the permanent and mixed dentition periods	Formation of soft tissue near the sella turcica exhibits a growth pattern that differs according to the individual. ^{4,11} It is therefore considered that the image of anatomical features is viewed in the area surrounding landmarks and differs between cephalograms of the mixed and permanent dentition periods, and the disparity of anatomical features in the area surrounding S in cephalograms of the mixed dentition period is large.
ANS				The overlap of the shade of fat in cephalograms of children is more pronounced, ¹³ so there is even more disparity in anatomical features near the landmarks than with adults. As the anterior nasal spine is thinner for children, it is more easily penetrated by X-rays, and the anatomical features in the area surrounding landmarks differ in cephalograms of the mixed and permanent dentition periods.
L1				The upper incisors (L1) erupt prior to the lower incisors (U1). ¹⁰ In other words, at the point in time when identification of landmark L1 becomes possible as a result of eruption of the mandibular incisors, in some cases, the maxillary incisors are deciduous teeth and in some cases they are permanent teeth. As identifiable landmarks were used as data for the research described herein, there was more disparity in the anatomical features in the area surrounding L1 than for U1. Disparity among anatomical features in the area surrounding landmarks in cephalograms of the mixed dentition period is also large.
PNS	$E_P^I < E_M^I$	$E_P^I = E_{P+M}^I$	Pattern 3: No knowledge overlap among the permanent and mixed dentition periods	In cephalograms of the mixed dentition period, as tooth germs of the upper first and second molars sometimes exist, there is a lot of disparity in the anatomical features near the landmarks when compared with the cephalogram of the permanent dentition period, and cephalograms of the two dentition periods have different anatomical features.
Ar				Because the distance between the shade of the ear rod and landmarks of the cephalogram of the mixed dentition period is shorter than that of the permanent dentition period, there is a lot of disparity in anatomical features near the landmarks due to the effect of the ear rod, and, thus, cephalograms of the two dentition periods have different anatomical features for Ar.

anatomic features on the cephalograms of preadolescent children, compared with the previous system.

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APPENDIX

Consider that there are two vector groups V_A and V_B in the PPED vector space; the template vectors are generated from the combined group of the two (V_{A+B}); and an input with attributes of V_B was employed. Generally, if overlaps of V_A and V_B are larger, then there will be more template vectors that correspond to V_B . This leads to higher recognition performance because of the large number of corresponding knowledge for matching (“recognition”). In addition, if variation of V_B is greater than that of V_A , there will be more knowledge that corresponds to V_B , which also leads to higher recognition performance.

As shown by Pattern 1 in Figure 4, if vectors of both are observed to match or overlap, in other words, with regard to landmarks where no difference is observed in the anatomical features near the landmarks of mixed and permanent dentition periods, recognition performance does not vary or is enhanced by the combination of knowledge from the mixed and the permanent dentition periods. In contrast, as shown by Pattern 3, the knowledge of the two does not overlap, ie, with regard to landmarks where the anatomical features near the landmarks of the mixed and permanent dentition periods differ, because cephalograms of mixed dentition period are used for the performance test and recognition performance declines due to the combination of mixed and permanent dentition periods. As shown in Pattern 2, when knowledge of the two overlaps in one place (i.e., concerning landmarks, while anatomical features near landmarks of mixed dentition period and permanent dentition period are similar in some cephalograms, there also exist some cephalograms with anatomical features differing for mixed dentition period and permanent dentition period), recognition performance does not vary or is enhanced by combining knowledge from mixed and permanent dentition periods.