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Dental Panoramic Radiography in Age Estimation for Dental Care using Dark-Net 19

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A rapidly increasing human lifespan has led to population aging with growing demands for healthcare, including dental healthcare services. The oral cavity plays a crucial role in mastication and speech. Furthermore, artificial intelligence (AI) has extensively developed, and automated diagnostic technology continues to evolve. Therefore, it is necessary to integrate objective AI, automatic diagnosis, and dental care to reduce errors resulting from subjective diagnosis. This study used 15,000 dental panoramic X-ray images to train an AI algorithm and estimate dental age, using Darknet-19 for the AI model. The accuracy was about 84 % and 96 %, respectively, when the dental estimate acceptable range was ± 5 and ± 10 years. Based on this model, patients could evaluate their oral condition and improve their quality of life using appropriate treatment and prevention methods.

Keywords : Artificial Intelligence (AI), Electromagnetic radiation (X-ray), age estimation, dental care, dark-Net

1. Introduction

In recent years, the average life expectancy of humans has increased, and people are taking better care of themselves to maintain good health [1]. Preventive and restorative dental care is crucial, regardless of age and sex, because a functional dentition preserves mastication, speech, and esthetics [2].

People want healthy teeth as they age because tooth loss produces significant discomfort in the quality of daily life. Chewing disability alters dietary patterns and leads to a nutritional imbalance. Moreover, poor pronunciation impacts conversation and limits communication [3]. Finally, it can cause more damage to gums. It can lead to additional oral diseases [4]. These problems negatively influence human life and reduce life satisfaction [5]. Therefore, dental care is a vital requirement for improving the quality of life.

High costs and prolonged treatment of oral diseases create a significant patient burden [6], which can be minimized by preventive dental care. The most appropriate method is establishing a customized diagnosis according to the patient and the oral conditions based on specialized dentistry. After diagnosis, the patient can evaluate the situation and prioritize dental care [7]. Preventive dentistry promotes oral health in individuals by preventing or alleviating the occurrence of oral diseases and their related symptoms. Oral diseases include dental caries, periodontal disease, acquired oral disorders, and hereditary diseases. An oral hygiene regimen based on preventive care ensures long-lasting oral health [8]. Thus, patients who receive periodic check-ups and appropriate interceptive have a lower incidence of oral diseases and better quality of life [9]. Moreover,

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interceptive dental care can reduce the burden of long-term treatment and high costs [10] and increase patient satisfaction by preventing various problems that may appear in everyday life. Oral health awareness improves dental health attitudes, and professional intervention ensures continued dental care and healthy practices (good quality toothpaste, toothbrush, and oral cleaner).

Moreover, the dentist can provide nutritional counseling for oral health [11] and render customized services tailored to patient needs. As the importance of dental examinations increases, more accurate and prompt diagnosis is required. Today, AI is extensively used in many fields, including the automatic diagnosis of oral diseases [12]. The advantages of AI over conventional diagnosis are less time, lower costs, and objective diagnosis [13]. This study enables patients to obtain an objective and accurate assessment of their oral condition and determine prevention strategies in the future.

Currently, studies are underway to apply AI to the dental field. The age estimation algorithm is based on panoramic radiography [14]. Previous research classified the teeth of young and old individuals with high accuracy using dental radiography data. However, the study lacked adequate dental radiography data to train AI. When estimating the dental age, there was a limit to dividing into simple (decade) age groups, not precise figures.

We developed an algorithm to evaluate dental age using the Darknet-19 model to overcome the drawback of Dthe previous study. Therefore, this study presented the estimated dental age by age group as a more specific figure and used 15,000 dental radiograph data to obtain high accuracy and low error.

2. Materials and Methods

The Darknet-19, a convolutional neural network model with 19 layers, has an input size of 256 × 256. Pre-trained Darknet-19 categorizes the input images according to the human age; this network learns the various characteristics of a wide range of images. Then, each feature is extracted from the input image. The Darknet-19 model can detect specific objects using extracted features [15]. In this study, the characteristics of various categories in the dental panoramic images collected using the Darknet-19 model were trained, and the age of patients was estimated. The study was approved by the Kangwon National University (KNU) Institutional Review Board (KWNUIRB-2020-12-004-002, Chuncheon, South Korea).

To train and validate age and gender information on the dental images, 13,000 images of patients with actual age were used among 15,000 image data (Fig. 1). For more

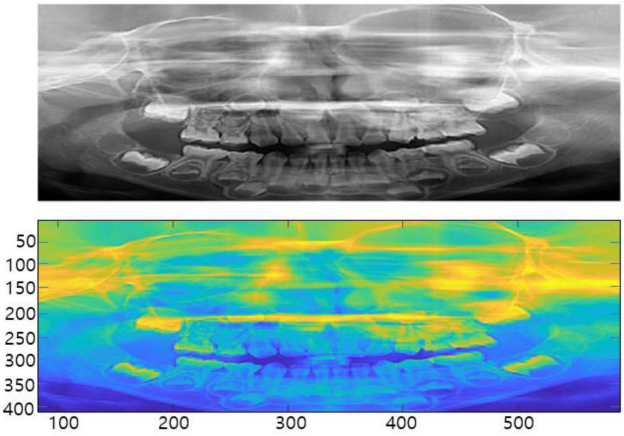

Fig. 1. (Color online) Dental image based on panoramic radiograph and the actual age with heat map of patient. According to lower image, the image size was composed of 712 by 408.

accurate results, the dental panoramic image in the training dataset was well-distributed (Fig. 2). The age distribution of dataset was largely even, as shown in Fig. 3. The size of the dental X-ray panoramic images was 2147 × 1012. Images were cropped and down-sampled by 712 × 408. The input re-size of Darknet-19 was 256 × 256; hence, the image sizes were changed. The features of the dental panoramic images were extracted by a convolution layer consisting of 19 layers and an average-pooling layer consisting of 5 layers (Fig. 4). Based on the selected features, the Darknet-19 model was trained by inputting the estimated dental age, accuracy, and error as parameters and tested with 2,000 dental images. Matlab R2021b (Mathworks, USA) software was used for training.

3. Results

The estimated age error range for teeth was set to ± 5 and ± 10 years using the Darknet-19 model and shown as a scatterplot (Fig. 5). In the scatterplot, the horizontal axis shows the actual age of patients, and the vertical axis shows the estimated age at a gap of 10 years from 20 to 60 years. The red dotted line running diagonally in the graph represents an ideal result value with the same value on the horizontal and longitudinal axes. The blue "+" mark represents the estimated and actual patient age. The closer the blue "+" is to the red dotted line, the less the difference between the actual age and estimated age of the patient. Therefore, the "+" mark is gathered in the place where there is a red dotted line.

The results were limited from 20 to 60 years (an appropriate age group to predict) using 2,000 test data.

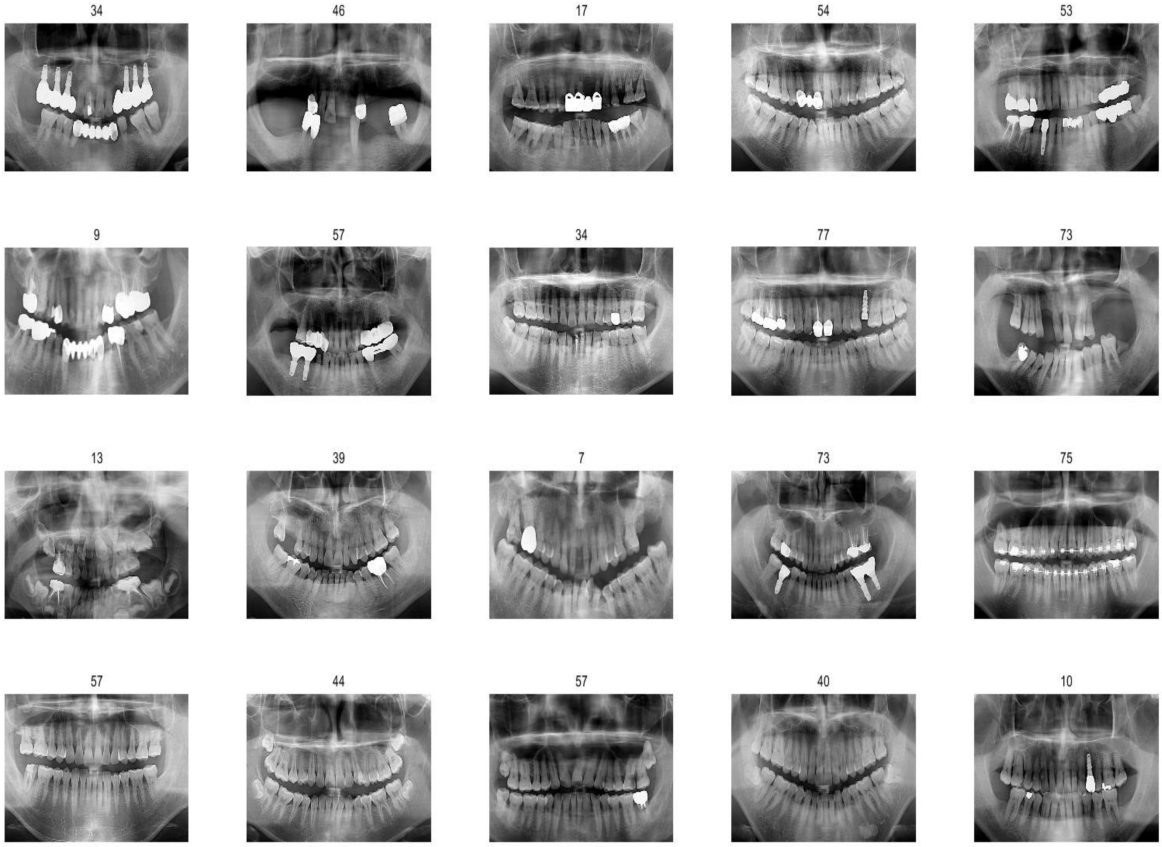

Fig. 2. The 20 images with actual age of the patients were randomly displayed. Upper number is actual age. Lower image showed tooth condition.

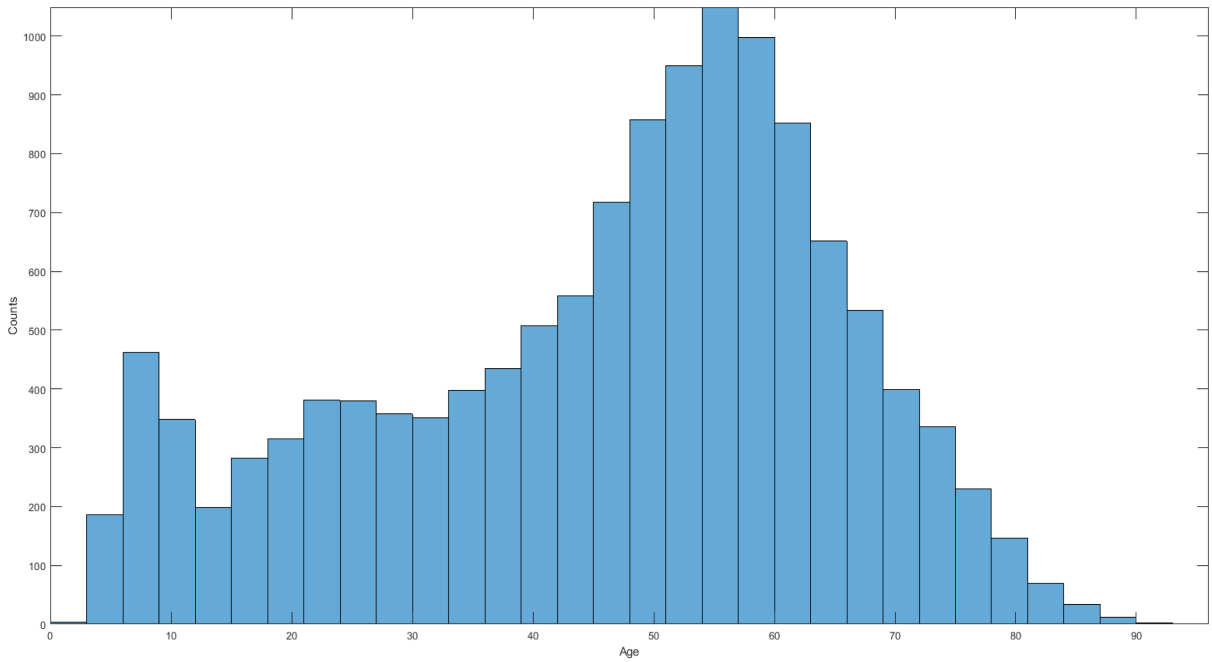

Fig. 3. (Color online) The Histogram of acquired images form dental clinics. There is relatively higher density in their 50s and 60s. However, it is generally evenly distributed.

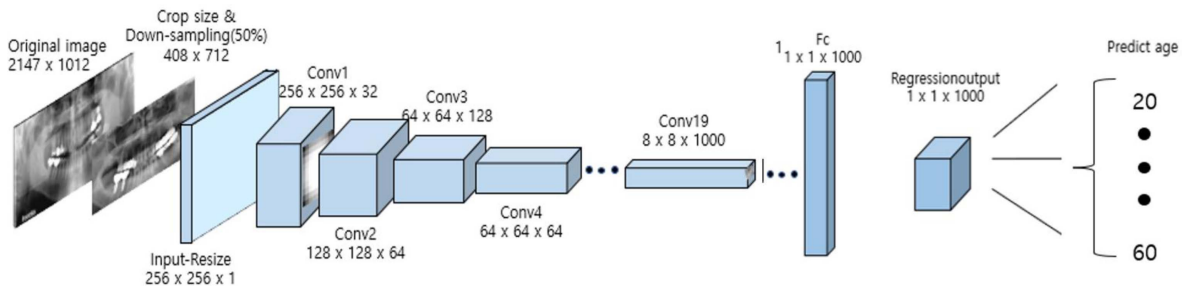

Fig. 4. (Color online) The employed AI model comprised of Convolution layer and MaxPooling layers. In order to estimate the age of dental radiography, the regression model was employed.

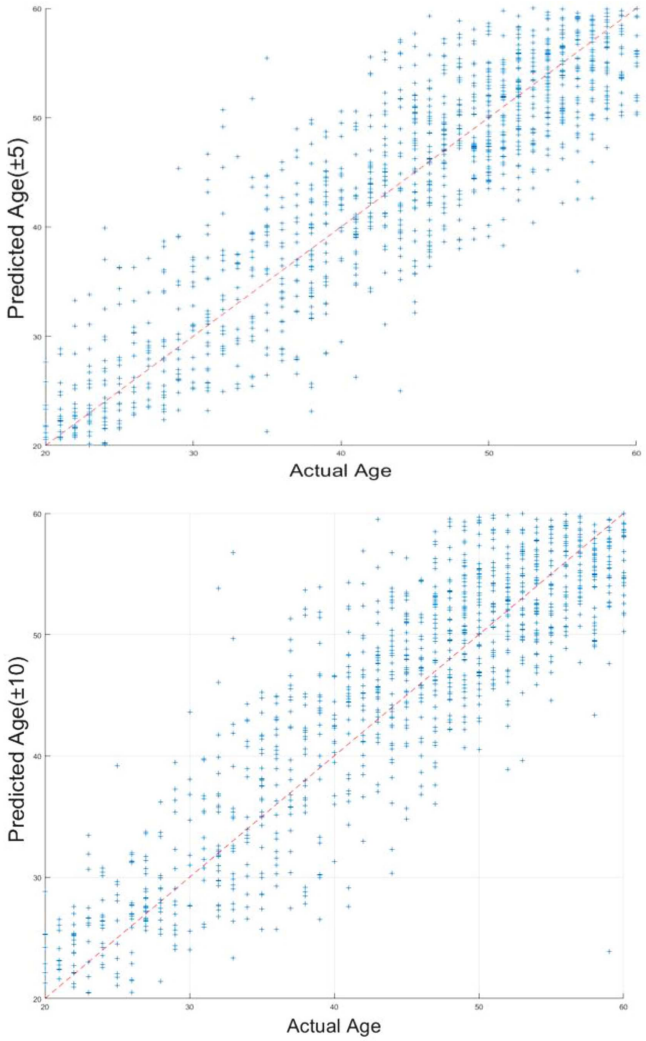

Fig. 5. (Color online) A scatter shows the actual age and the predicted age when estimated error range is ± 5 years (top) and ± 10 years (bottom). Overall, the estimated aged is distributed in proportion to the red dotted line.

The Darknet-19 model was used to calculate the average and standard deviation of accuracy and error. The error means the absolute value subtracts the estimated age from the actual age. Error, mean, and standard deviation of error in this paper, we didn't set in the specific predicted age range, but also set in the whole estimated age range by Darknet-19. When the estimated age error permitted limit was set at ± 5, the accuracy of the total age was 87.5 %. The accuracy of age estimation was 84 % in the 20s, 66 % in the 30s, 59 % in the 40s, 67 % in the 50s, and 66 % in the 60s (Table 1). The average error was 2.74 years in the 20s, 4.40 years in the 30s, 5.05 years in the 40s, 4.13 years in the 50s, and 4.21 years in the 60s. The standard deviation of error was 2.21 years in the 20s, 3.77 years in the 30s, 4.21 years in the 40s, 3.38 years in the 50s, and 3.18 years in the 60s. However, when the range was designated as ± 10, the accuracy of the whole age was 99 %, 96 % in the 20s, 91 % in the 40s, 93 % in the 60s, and 49 % in the 80s (Table 2). The average error was 3.49 years in the 20s, 4.79 years in the 40s, 4.12 years in

Table 1. Accuracy and error between actual age and predicted age (± 5 years error).

Age (years)	Accuracy (%)	Error (±5 years)	
		Mean	Std
20s	84	2.74	2.21
30s	66	4.40	3.77
40s	59	5.05	4.21
50s	67	4.13	3.38
60s	66	4.21	3.18

Table 2. Accuracy and error between actual age and predicted age (± 10 years error).

Age (years)	Accuracy (%)	Error (± 10 years)	
		Mean	Std
20s	96	3.49	2.73
40s	91	4.79	3.98
60s	93	4.12	3.27
80s	49	10.81	4.19

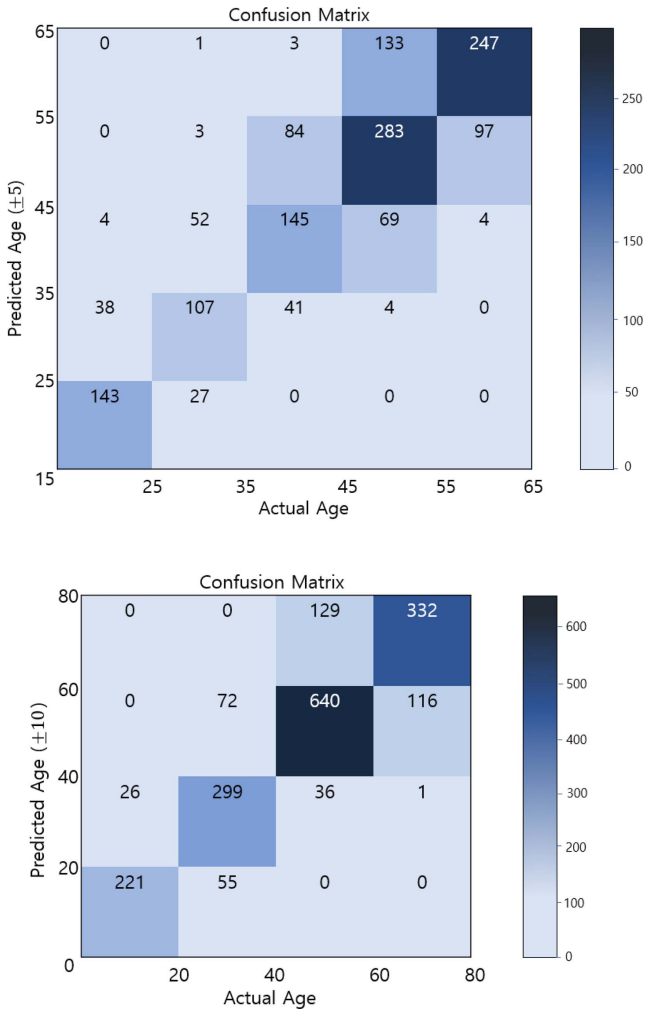

Fig. 6. (Color online) A confusion matrix that sets the predicted age and actual age from 20 to 60 years to ± 5 years (top) and ± 10 years (bottom). According to two figures, the actual age and the estimated age match well.

the 60s, and 10.81 years in the 80s. The standard deviation of the error was 2.73 years in the 20s, 3.98 years in the 40s, 3.27 years in the 60s, and 4.19 years in the 80s. In a previous study based on forensics, the error range was set to ± 10 years when estimating age [16]. However, this research considered that the accuracy and error values for each age group were excluded from the patients under 20 and over 60 years old.

The error permitted limit of each dental age estimation was set to ± 5 and ± 10 years, and the prediction performance of the trained Darknet-19 algorithm was visualized and shown as a Confusion Matrix (Fig. 6). When the error within the allowable range of dental age estimation was ± 5 years, the actual age was 143 times in the 20s, the estimated number of times was the same age, 38 times in the 30s, 4 times in the 40s, 0 times in the 50s and 60s. When the actual age was in the 30s, the estimated number of times was 107, 27 times in the 20s, 52 times in the 40s, 3 times in the 50s, and 1 time in the 60s. The following went through a similar process. When the actual age was in the 60s, the estimated number of times was 247 times, 0 times in the 20s and 30s, 4 times in the 40s, and 97 times in the 50s. the details of the results was described in Tables 1 & 2.

4. Discussion

Oral health is a part of general health and an essential element in social life and daily life with physical, mental, and social implications [17]. The increase in life expectancy has led to an increased interest in quality of life and oral health (related to diet). In a study, 19.8 % of participants in their 20s, 41.7 % in their 40s, and 64.5 % in their 60s or older perceived oral health as a more important domain for overall quality of life than any other health problem [18]. In addition, the increase in missing values (easily seen with increasing age) can cause eating disorders and lower overall health, thus affecting the daily quality of life [19]. Despite the awareness of the importance of oral examinations, the oral examination rate in 2018 was 31.8 %, which was less than half of the examination rate for general health examinations (78.5 %) [20]. Oral examination can aid the detection of oral diseases at an early stage, enable follow-up treatment, and promote disease prevention by reinforcement of oral hygiene [21].

A comprehensive examination of the oral cavity includes visual inspection and radiographic evaluation. Radiographs provide information on previous treatment, untreated lesions, and anatomical changes; they help understand disease progression, plan treatment, and improve the value of diagnosis [22]. Panoramic radiographs provide useful diagnostic information during dental visits. The imaging procedure is relatively simple, the shooting time is short, and the radiograph allows visualization of the teeth, the upper and lower jaws, and surrounding tissues [23].

Interest in artificial intelligence has increased due to the 4th industrial revolution, and research continues to converge with existing information and communication technologies with applications in various fields [24]. Deep learning algorithms show excellent performance in the medical imaging field, and deep learning technology using imaging in healthcare can increase the accuracy and efficiency of diagnosis [25]. However, research on deep learning analysis has not systematically focused on dentistry, unlike the medical field. Artificial intelligence

applications to dentistry can aid comprehensive dental analysis and provide appropriate patient guidance.

Most studies using AI in the dental field have focused on disease diagnosis [12, 26], and few studies have attempted to estimate age. Age estimation is used for various purposes, and recently its importance has increased due to social welfare benefits, job search, and social-interpersonal relationship problems [27]. Among data that help age estimation of an unidentified cadaver or living person, teeth are preserved the longest in human tissues, and change according to age is relatively gradual; thus, they can provide reliable data for age estimation [28]. Therefore, accurate age estimation of individuals in forensics and medico-legal domains plays a crucial role based on biometric functions [29].

Age estimation can be confirmed by tooth eruption, tooth loss, degree of calcification, pulp size, and changes in the degree of dental agility and microstructure [30]. These features can be evaluated using dental radiographs, which have been proven significant as an index of age estimation in several studies [31]. Therefore, AI used for age estimation can aid in accurate and rapid diagnosis. Kim et al. developed a standard for AI reading that could distinguish young and old groups based on dental panoramic radiographs [14] and confirmed the possibility of age estimation. However, a limitation of the study was that it relied on small data of 117 people and only suggested the potential use of AI. Also, the study showed that age estimation error could be reduced by estimating the age group by analyzing the top, bottom, left, and right 4 first molars in the panoramic images of 1586 people across all age groups [32]. However, the accuracy of tooth estimation with imaging data of 1586 individuals was 89.05-90.27 %. Noteworthy that the amount of data and accuracy are lower than this study, which secured 15,000 imaging data and built an AI database for accurate and quick age prediction.

Based on the Darknet-19 model, the study estimated the dental age of patients and found new points in the error of each dental age. Before the study, we thought older people had poorer dental conditions than younger age groups and received inadequate dental care, resulting in high error rates, probably because the dentition of older adults is more affected by food habits, smoking, drinking, chewing, and oral products than that of young people [33]. However, the error of dental age estimates of patients in the 10s and 40s was the highest, but it was a slight difference. We think this result could be due to higher exposure to periodontal disease than tooth decay compared to other age groups. This study estimated the dental age using the AI model based on panoramic images. Therefore, it is considered that the error of the dental age of patients aged 30 to 50 who have suffered the most periodontal disease is occurred for such a reason. However, the differences were insignificant when comparing age-specific accuracy and error. The results of this study will increase patient awareness of dental care and help compare the estimated and actual age. The results can be used as objective data in clinical practice. Future research should aim to improve the performance of AI models to achieve high accuracy and low error in a wide age range.

We have developed an AI algorithm with excellent performance that can accurately predict oral diseases and dental age for the prevention and treatment of oral disease. Furthermore, this study provides oral health awareness and emphasizes the need for regular management by increasing the attention

5. Conclusions

The dental age of patients was estimated using the Darknet-19 model with panoramic radiography. The collected data showed an even age distribution. Based on this algorithm, we compared the actual dental age of the patients and the dental age predicted by the Darknet-19 model with the ideal result value. The accuracy of the dental age was the highest in the 20s at ± 5 and the highest in the 20s at ± 10. The average error and the standard deviation of error were the highest in the 40s. The average error and the standard deviation of error were the highest in the 80s at ± 10. Table 2 shows no noticeable difference between the average and standard deviation values of age accuracy and error, except for the 80s at ± 10. Therefore, this study met the purpose of estimating the dental age of patients using the Darknet-19 model.

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