# Artificial intelligence - based prediction of jaw cyst recurrence using serial panoramic radiographic images

Namkyung Kim

The Graduate School
Yonsei University
Department of Dentistry

# Artificial intelligence - based prediction of jaw cyst recurrence using serial panoramic radiographic images

Directed by Professor Kee-Deog Kim

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Namkyung Kim

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This certifies that the Master's thesis of
Namkyung Kim is approved.

Thesis Supervisor: Kee-Deog Kim

Thesis Committee Member: Wonse Park

Thesis Committee Member: Nan-Sim Pang

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# 감사의 글

지금 이 글을 쓰기까지 정말 많은 분들의 도움과 응원 그리고 격려가 있었기에 가능했다고 생각합니다.

통합치의학과 수련을 시작하고 개원가에 나온 지금까지 끝없는 가르침과 함께 항상 응원해 주시고 격려해 주시는 존경하는 김기덕 지도교수님께 큰 감사의 인사 드립니다. 단소리 보다 쓴소리가 더 많지만 늘 애정으로 가르침 주시는 박원서 교수님, 학위 논문을 준비하며 생각하지 못한 부분까지 세심하게 알려주신 방난심 교수님 진심으로 감사 드립니다. 항상 가까이서 자잘한 부탁까지 흔쾌히 도움을 준 정지은 교수님과 통합치의학과를 위해 항상 애써주시는 정복영 교수님 감사 드립니다. 막힐 때 마다 친절하게 안내해 준 김영우 교수님 정말 감사 합니다.

무너지는 순간마다 또 다시 일어날 수 있게 버팀목이 되어준 조윤형 교수님께도 진심으로 고맙다는 말 전하고 싶습니다.

그리고 부족한 엄마한테 늘 괜찮다 말해주는 세상 가장 귀한 내 보물 로빈. 정말 사랑한다.

부족한 저를 믿고 격려와 응원을 아끼지 않은 모든 분들께 감사의 마음을 전하며 이 논문을 바칩니다.

2023 년 12 월

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# Abstract

## Artificial intelligence - based prediction of jaw cyst recurrence using serial panoramic radiographic images

Namkyung Kim

*Department of Dentistry*
*The Graduate School, Yonsei University*

(Directed by Professor Kee-Deog Kim, D.D.S., M.S.D., Ph.D.)

Detecting and predicting cyst recurrence after removal requires long term follow-up along with enough experience of practitioner. In this study, a jaw cyst recurrence prediction system was developed based on AI model and serial panoramic images. The system consists of cyst tracking algorithm and recurrence prediction algorithm. Three panoramic radiographic images were labeled and utilized as ground truth data for both algorithm across 160 patient cases. Compared to manual cyst drawing by practitioner, the cyst tracking algorithm has demonstrated an accuracy of 88.2%. When compared to clinical diagnosis, the recurrence prediction algorithm has demonstrated an accuracy of 78%. Along with the performance test of each algorithm, the correlation between geometrical factors and cyst recurrence is also analyzed, including size, position, and eccentricity of deformation. Each indicator has demonstrated a significant correlation with the cyst recurrence ratio, offering valuable insights for predicting cyst recurrence through geometric analysis.

**Keywords**

Jaw cyst, artificial intelligence, tracking algorithm, recurrence prediction, serial panoramic radiograph, geometric features.

# Artificial intelligence - based prediction of jaw cyst recurrence using serial panoramic radiographic images

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## I. Introduction

Detection of jaw cyst by unexperienced practitioner is not an easy process[1]. The majority of cyst lesions can be identified at an earlier stage in dental clinics through a routine radiographic exam called panoramic radiograph. In fact, cystic lesions are often identified as incidental findings on panoramic radiographs, with no apparent symptoms regardless of patient's chief complaint[2]. The accuracy of cyst detection from radiography with bare eyes are limited to 74%[3].

Due to these reasons, it was natural that many researchers tried to use artificial intelligence (AI) for detection of cyst. For example, Sivasundaram *et al*. applied convolutional neural network to classify and segment jaw cyst from panoramic image[4]. Karthika *et al*. tried hybrid algorithm to guarantee high calculation speed and accuracy for extracting cyst[5]. Veena Dicka *et al*. performed texture analysis of X-ray image to reduce error and defect of image for detecting cyst[6]. Most of these studies have successfully detect or extract jaw cyst from a single image, providing high quality of diagnostic aid.

The main problem with jaw cysts is not just their detection but also their potential for recurrence after removal. The hollow space left after the cyst removal gradually reduces as the healing process takes place. During this time, there is a risk of a cyst reforming within this cavity if it's not entirely healed or if some cells were left behind. X-ray imaging may not easily distinguish between the remnants of the previous cyst and the normal healing process. The post-removal cavity might look similar to the original cyst on an X-ray, making it difficult to differentiate them. This means that a single image cannot provide any information on sign of cyst recurrence.

Yet there are no attempts to detect or predict cyst recurrence with the aid of AI. Therefore, this prediction of cyst regrowth is still dependent to the practitioner's experience. In clinical field, practitioners can only predict cyst recurrence by comparing past and current images.

The purpose of this study is to develop AI based system to aid diagnosis process in predicting cyst recurrence. Fig. 1 shows the scheme of overall system. This system is based on analyzing geometrical change between multiple images taken from each patient at different time period. This system consists of two main algorithms: The first algorithm is to track cyst and extract geometrical information of cyst. Second algorithm is to compare the geometrical changes of cyst and predict the possibility of cyst recurrence.

Along with the performance test of each algorithm, the correlation between geometrical factors and cyst recurrence is also analyzed, including size, position, and eccentricity of deformation. This analysis might provide additional indicators besides the cyst size for predicting the recurrence.

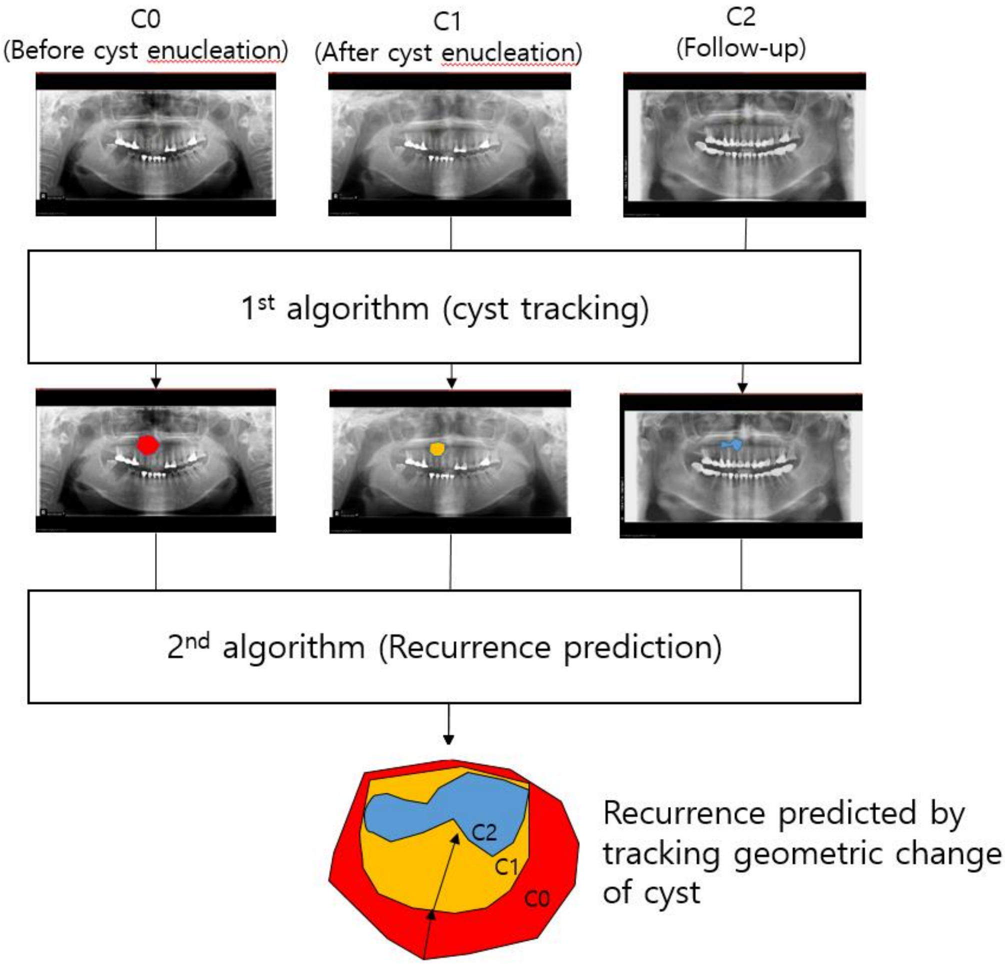


Fig. 1. Scheme of cyst recurrence prediction system using two algorithms.

## II. Materials and Methods

### 1. Dental photographic image acquirement

Every dental photographic image used in this study is from Yonsei University Dental Hospital and has been permitted by the institutional review board. The target patients were those who suffered from a jaw cyst on anterior maxilla and underwent cyst removal, followed by a diagnosis follow-up period ranging from 1 to 10 years. Panoramic radiography was performed for each patient at least three times: before the cyst enucleation, after the cyst enucleation, and during follow-up. As a result, 160 patient cases were selected for the study.

### 2. Image pre-processing

Images from the same patient can differ due to slightly different conditions when taking pictures. Uniformly resizing these images is required to properly calculate changes in the size and position of the cyst boundary.

Therefore, as part of the pre-processing, an image adjustment algorithm was used. An example of image adjustment is shown in fig. 2. The boundary of the image is selected from anatomic reference lines that can be easily distinguished in the images. For the width direction, anterior border of ramus of mandible was used as the reference line. For the height direction, posterior border of hard palate and inferior border of mandibular symphysis were selected.

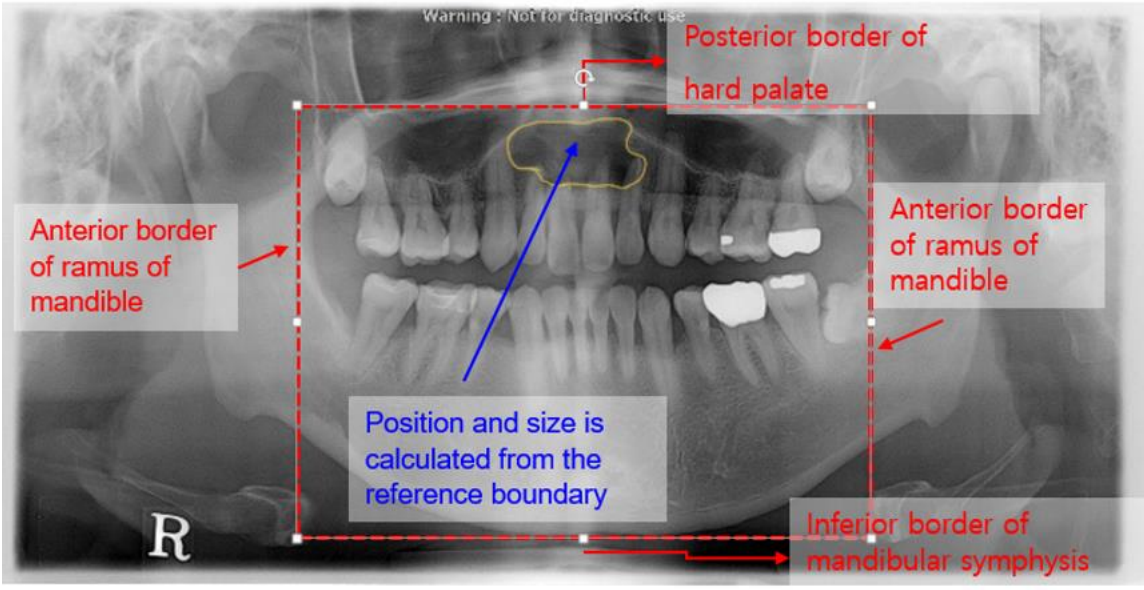


Fig. 2. The boundary of pre-processing image

## 3. Cyst tracking algorithm

The purpose of first algorithm is to automatically track the cyst and extract geometric information. For the ground truth data, 480 cyst-labeled images were used. To be precise, three images of each of the 160 patients were labeled manually by practitioner. Among the labeled images, 320 images were used as the training set and 160 images were used as the performance test set.

Two types of AI models (artificial neural network (ANN), multilayer perceptron (MLP)) and three types of machine learning algorithms (random forest, AdaBoost, K-nearest neighbors (KNN)) were tested. The performance of each algorithm was compared by the area of the cyst in terms of mean absolute error (MAE) and $R^2$score. In this test, the area of the cyst is used as reference value for calculating MAE. The test results are shown in table 1. As a result, ANN model has shown highest performance, which is selected as the final model for the study.

Table 1. Performance comparison of each base models.

| **Algorithm** | **MAE** | **$R^2$ score** |
|---|---|---|
| ANN | 9.14 | 0.724 |
| MLP | 11.89 | 0.659 |
| Random forest | 9.96 | 0.701 |
| Adaboost | 13.11 | 0.603 |
| KNN | 14.38 | 0.587 |

ANN, artificial neural network; MLP, multilayer perceptron; KNN, K-nearest neighbors; MAE, mean absolute error; $R^2$score, R-squared score

## 4. Recurrence prediction algorithm

The purpose of second algorithm is to estimate the possibility of the cyst recurrence analyzing changes in the cyst. Not only geometric information but also the period between images was used as input data.

Eighty patient datasets were used to train the algorithm and another 80 datasets were used to test the algorithm. These datasets did not include manually labeled data but instead contained calculated data from the first algorithm to evaluate the accuracy of the entire system.

Similar to the first algorithm, ANN was selected as base model. As explained previously, each patient’s data consists of three images: before the cyst enucleation, after the cyst enucleation, and during follow-up. While the image before the cyst enucleation was used as reference, the after-enucleation image and the follow-up image were compared in the algorithm.

The evaluation of geometric feature correlation followed the algorithm performance test. Geometrical features considered in this study were the size, center position, and eccentricity of deformation.

# III. Results

### 1. Cyst tracking algorithm performance test

The accuracy of the tracking algorithm is analyzed in terms of both area accuracy and ratio of high-accuracy cases. Area accuracy is determined by comparing the cyst's area from in the labeled image with that in the estimated image. An example of accuracy calculation is presented in Fig. 3. High-accuracy cases are defined as those with an accuracy higher than 80% in this study. The primary cause is that the algorithm does not accurately distinguish between normal anatomical structures and cyst boundaries, where the root of the tooth or the sinus floor is mistakenly identified as a cyst, as demonstrated in Fig. 4.

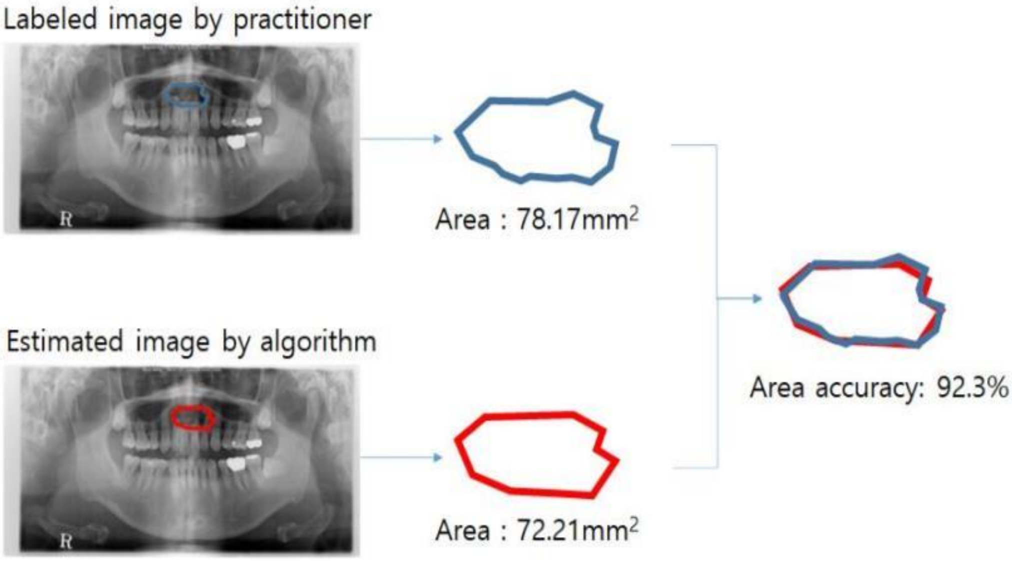


Fig. 3. Example of area accuracy calculation for a single patient case.

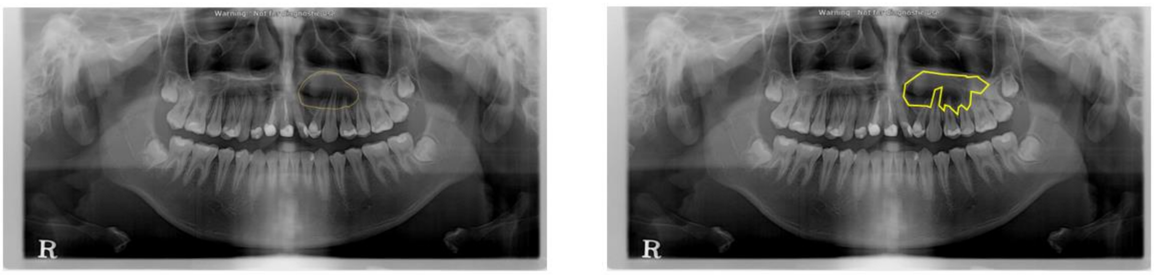

Fig. 4. Example of low accuracy case.

## 2. Recurrence prediction algorithm performance test

The performance test for recurrence prediction, utilizing data from 80 patients, is presented in Table 2. Overall, the algorithm demonstrated an accuracy of 78%. The sensitivity was 70%, signifying that out of the 20 patients with regrown cysts, 14 cases were correctly identified. The specificity was 81%, indicating that among the 60 patients whose cysts were fully cured, 49 were correctly identified.

Table 2. Performance test result of recurrence prediction algorithm

| | **Cured case** | **Recurred case** | **Total case** |
|---|---|---|---|
| **Number of cases** | 60 | 20 | 80 |
| **Correctly predicted cases** | 49 | 14 | 63 |
| **Percentage (%)** | 81 | 70 | 78 |

### 3. Correlation analysis of geometric features

Three major geometric features are analyzed in terms of their correlation with recurrence. Cyst size is defined as the decrease in the area of the cavity, the center position is defined as the movement of the cyst's center of mass, and eccentricity is defined as the change in apsis ratio—the ratio between the longest boundary and the shortest boundary from the center of mass.

Firstly, the accuracy of each geometric feature by the first algorithm is calculated. Subsequently, the correlation between geometric features and recurrence is analyzed, and the summarized results are presented in Table 3. The accuracy of cyst size, center position, and eccentricity was reported as 88.2%, 91.2%, and 62.7%, respectively. Additionally, the correlations were found to be 0.72, 0.41, and 0.47.

Cyst size has demonstrated both high accuracy and correlation. This result is expected since a larger reduction in cyst size indicates proper curing. However, the correlation value is insufficient to determine recurrence based solely on the decrease in cyst size. Therefore, to increase accuracy in determining recurrence, other geometric features must also be considered.

The center position showed the highest accuracy because, in most cases, the movement of the cyst is small. However, based on the correlation value, this feature cannot be ignored for predicting recurrence. Specifically, a few cases of cyst recurrence showed a drastic change in center position, while cyst size appeared to decrease normally.

Eccentricity represents abnormal changes in cyst shape. Eccentricity can be a good indicator for predicting recurrence, but low accuracy can be a problem. The apsis ratio is sensitive to even a small change in cyst geometry, indicating that any defects during the cyst detection process or changes in cyst boundaries can result in miscalculation. Eccentricity is worth considering in predicting recurrence, as it shows a higher correlation than center position despite its low accuracy.

Table 3. Accuracy and correlation of each geometric features

| Geometric features | Description | Accuracy | Correlation |
|---|---|---|---|
| **Cyst size** | Reduction of cyst size | 88.2 | 0.72 |
| **Center position** | Movement of center of cavity | 91.2 | 0.41 |
| **Eccentricity** | Change of apsis ratio | 62.7 | 0.47 |

## IV. Discussion

The chance of jaw cyst recurrence can be up to 30%[7] and it can be caused by various factors, including incomplete removal of cystic lesions or the association of nevoid basal cell syndrome.[8,9] As a result, many patients who have undergone cyst removal revisit dental clinics or hospitals for follow-up diagnoses. Approximately 75% of cyst recurrence occurs within 4 years, although some cases have shown recurrence after more than 10 years[8]. This extended duration of follow-up can be unexpected and tiresome. Furthermore, as cyst diagnosis still relies on practitioners' experience, detecting cyst recurrence in the early stage can be challenging, leading to delayed action.[10]

There are few other methods for cyst diagnosis. CT imaging has been the focus of most research on recurrent imaging. However, it is difficult to predict the impact of cumulative radiation dose on patients from repeated high-dose imaging during the follow-up period. The most accurate method involves microscopic analysis by extracting tissue[11]. Microscopic examination can clearly distinguish hidden or vague cysts[12]. Various studies have performed this method in case of severe or abnormal cases[13-16]. There are even recent few studies adopting AI in microscopic image analysis to identify and classify the exact type of cyst or tumors[17]. However, considering the incidence and period of cyst recurrence, it is not realistic to perform microscopic examinations for every follow-up diagnosis.

Most cyst diagnoses are conducted in dental clinics where only panoramic radiographic images are accessible. This, along with the requirement for practitioners' experience, may increase the chance of misdiagnosis for various reasons.

Cyst size alone is not sufficient to predict cyst recurrence. The position of the cyst and the shape of its boundary are also crucial, and these factors are not easily comparable with the naked eye. Additionally, the decreasing speed of cyst size should be considered, as abnormally slow closure of a cyst may indicate recurrence. Therefore, both the size ratio and the time between images taken should be considered.

The main purpose of the system in this study was to aid in cyst recurrence diagnosis, considering that only panoramic images are accessible. Predicting cyst recurrence at an early stage can reduce the unnecessary duration of follow-up diagnoses and provide timely treatment for reoccurred cysts. While experienced practitioners can identify cyst recurrence quickly, inexperienced practitioners might have a hard time making judgments independently. The system introduced in this paper, if utilized by these practitioners, could improve both efficiency and accuracy.

The value of the cyst recurrence prediction system is not limited to assisting practitioners with a lack of experience. In most cases, a decrease in cyst size is used as the primary indicator, as it is the only information that practitioners can intuitively gain. However, other geometric features such as center position or eccentricity might also provide critical information. The correlation analysis performed in this study demonstrated that these features can also be used as indicators.

The challenge with these features is the difficulty in quantitatively measuring or tracking changes in them. This is why there are not enough studies related to geometric analysis on cysts. An AI algorithm can be helpful in judging the effect of various geometric features based on ground data.

The comparative system of follow-up dental images itself can be applied to other dental diseases. Until now, various AI studies have focused on detecting symptoms or defects from a single dental image.[18,19] Common examples of AI-based image diagnosis include detecting dental caries[20], root fracutres[21], or periodontal bone loss[22].

However, there were a few limitations to the study, mostly due to the constraints of X-ray images. While a cyst is considered a 3D object, X-ray images can only show a projected 2D image of the cyst. This might provide inaccurate information about cyst geometry. Although changes in cyst size might be accurate enough, the shift of the cyst center or boundary distortion might be different from what is seen in a 2D image. Nevertheless, as mentioned above, using a more precise method such as microscopy was not an option in this study. It might be wiser to focus on other indirect methods to improve the accuracy of geometrical images, such as implying other biometric information of patient or estimating depth by shadow density.

Another problem is the accuracy of the labeled image itself. The practitioner's manually drawn cyst boundary is used as ground truth data for the algorithm. Regardless of the practitioner's precision, it is impossible to be 100% sure that the labeled image is accurate, as it is directly drawn from the X-ray image. Moreover, there is no specific method to validate labeled images. This might disturb data uniformity to some extent.

Also, the number of cured patient cases was higher than the number of recurred patients, with a ratio of about 4:1. This might have caused an imbalance in the ground data, resulting in a high difference between sensitivity and specificity.

The ultimate aim of this study is to assist practitioners in conducting comprehensive diagnoses and predictions through the comparative analysis of serial panoramic radiographic images. To achieve this, based on the limitations mentioned above, the follow-up study will focus on increasing ground data and improving model stability.

## V. Conclusion

In this study, an AI-based jaw cysts recurrence prediction system was developed. The system consisted of cyst tracking algorithm and recurrence prediction algorithm. Compared to manual cyst drawing by practitioner, the cyst tracking algorithm has demonstrated an accuracy of 88.2%. When compared to clinical diagnosis, the recurrence prediction algorithm has demonstrated an accuracy of 78%. Along with the performance test of each algorithm, the correlation between geometrical factors and cyst recurrence is also analyzed, including size, position, and eccentricity of deformation. Each indicator has demonstrated a significant correlation with the cyst recurrence ratio, offering valuable insights for predicting cyst recurrence through geometric analysis.

# References

1. Putra, Ramadhan Hardani, et al. "Current applications and development of artificial intelligence for digital dental radiography." Dentomaxillofacial Radiology 51.1 (2022): 20210197.

2. Choi,J.-W.Assessment of panoramic radipgraphy as a national oral examination tool: Review of the literature. Imaging Sci.Dent.2011,41,1.

3. Syrjänen, S., et al. "Radiological interpretation of the periapical cysts and granulomas." Dentomaxillofacial Radiology 11.2 (1982): 89-92.

4. Sivasundaram, Sivagami, and Chitra Pandian. "Performance analysis of classification and segmentation of cysts in panoramic dental images using convolutional neural network architecture." International Journal of Imaging Systems and Technology 31.4 (2021): 2214-2225.

5. Karthika Devi, R., Arumugam Banumathi, and G. Ulaganathan. "An automated and hybrid method for cyst segmentation in dental x-ray images." Cluster Computing 22 (2019): 12179-12191.

6. Jatti, Anand, and Revan Joshi. "Characterization of dental pathologies using digital panoramic X-ray images based on texture analysis." 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE, 2017.

7. Jafarian, Amir Hosein, Amin Rahpeyma, and Saeedeh Khajehahmadi. "Recurrent Glandular Odontogenic Cyst of Maxilla-A Case Report." Iranian Journal of Pathology 10.2 (2015): 160.

8. Giuliani, Michele, et al. "Conservative management of a large odontogenic keratocyst: report of a case and review of the literature." Journal of oral and maxillofacial surgery 64.2 (2006): 308-316.

9. Santosh, Arvind Babu Rajendra. "Odontogenic cysts." Dental Clinics 64.1 (2020): 105-119.

10. Jung, Hwi-Dong, et al. "Appropriate follow-up period for odontogenic keratocyst: a retrospective study." Maxillofacial plastic and reconstructive surgery 43 (2021): 1-6.

11. Endres, Michael G., et al. "Development of a deep learning algorithm for periapical disease detection in dental radiographs." Diagnostics 10.6 (2020): 430.

12. Austin, Ryan P., and Brenda L. Nelson. "Sine qua non: dentigerous cyst." Head and neck pathology 15.4 (2021): 1261-1264.

13. Daley, Tom D., and George P. Wysocki. "The small dentigerous cyst: a diagnostic dilemma." Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 79.1 (1995): 77-81.

14. Damante, José Humberto, and Raul Negrão Fleury. "A contribution to the diagnosis of the small dentigerous cyst or the paradental cyst." Pesquisa Odontológica Brasileira 15 (2001): 238-246.

15. Lopez-Arranz, J. S. "Adenomatoid odontogenic tumor arising in a dental cyst: report of unusual case." The Journal of clinical pediatric dentistry 23.1 (1998): 55-58.

16. Fowler, Craig B., et al. "Glandular odontogenic cyst: analysis of 46 cases with special emphasis on microscopic criteria for diagnosis." Head and neck pathology 5 (2011): 364-375.

17. Rao, Roopa S., et al. "Deep learning-based microscopic diagnosis of odontogenic keratocysts and non-keratocysts in haematoxylin and eosin-stained incisional biopsies." Diagnostics 11.12 (2021): 2184.

18. Ossowska, Agata, Aida Kusiak, and Dariusz Świetlik. "Artificial intelligence in dentistry—Narrative review." International journal of environmental research and public health 19.6 (2022): 3449.

19. Khanagar, Sanjeev B., et al. "Developments, application, and performance of artificial intelligence in dentistry–A systematic review." Journal of dental sciences 16.1 (2021): 508-522.

20. Lee, Jae-Hong, et al. "Detection and diagnosis of dental caries using a deep learning-based convolutional neural network algorithm." Journal of dentistry 77 (2018): 106-111.

21. Fukuda, Motoki, et al. "Evaluation of an artificial intelligence system for detecting vertical root fracture on panoramic radiography." Oral Radiology 36 (2020): 337-343.

22. Krois, Joachim, et al. "Deep learning for the radiographic detection of periodontal bone loss." Scientific reports 9.1 (2019): 8495.

국문요약

# 연속 파노라마 방사선 영상을 이용한 인공지능 기반 악골 낭종의 재발 예측

<지도교수 김기덕>

연세대학교 대학원 치의학과

**김 남 경**

낭종 제거 후 재발 여부를 진단하고 예측하려면 의료진의 충분한 경험과 함께 장기간의 추적관찰이 필요하다. 본 연구에서는 상악 전치부에 낭종 제거를 받은 환자의 연속 파노라마 방사선 영상을 이용하여 인공지능 모델을 기반으로 악골 낭종의 재발 예측 시스템을 연구하였다. 각 성능을 평가하여 ANN(artificial neural network)이라는 인공지능 모델을 이용하였으며 낭종 추적 알고리즘과 재발 예측 알고리즘으로 각각 나누어 분석하였다. 160 명

환자의 낭종 제거 전과 후, 추적 관찰 시 촬영된 3 개의 연속 파노라마 방사선 영상을 이용해 두 알고리즘에 대한 실제 데이터로 사용하였다. 의사가 수동으로 낭종의 경계를 그린 것과 비교하여 낭종 추적 알고리즘은 88.2%의 정확도를 나타내었다. 재발 예측 알고리즘은 임상진단과 비교했을 때 78%의 정확도를 보였다. 각 알고리즘의 성능 테스트와 함께 크기, 위치, 변형의 편심 등 기하학적 요인과 낭종 재발 사이의 상관관계도 분석하였다. 낭종 중심의 위치 변화와 경계 변형의 편심과 같은 기하학적 요인은 낭종의 크기 감소와 더불어 재발 예측 알고리즘의 개발에 유의미한 결과를 나타내었다.

**핵심단어**
악골 낭종, 인공지능, 낭종 추적과 재발 예측 알고리즘, 연속 파노라마 방사선 영상, 기하학적 요소