Journal of Information Systems Engineering and Management
2025, 10(48s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Systematic Literature Review: Classification of Skeletal Malocclusion Using Deep Learning A Review

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ARTICLE INFO

Received: 15 Dec 2024

Revised: 18 Feb 2025

Accepted: 25 Feb 2025

ABSTRACT

Skeletal malocclusion is a medical condition in which there is a misalignment between teeth that can be caused by genetic and bad habits. The untreated condition can lead to a variety of functional, psychological, and long-term effects on health. Early diagnoses are essential to prevent complications and improve the patient's quality of life. This study aims to systematically review studies related to the classification of skeletal malocclusion using traditional to deep learning methods. Each class of skeletal malocclusion requires a different way of handling. Traditional classifications used to classify three malocclusion classes. Recent research tries to use deep for skeletal malocclusion classification. This research uses the PRISMA method with the keywords "skeletal malocclusion classification" and "deep learning", this study is searched into four databases. The analyzed literature must be published between 2019-2024, discuss classification of skeletal malocclusion, and be free access. The results of this analysis will be used to answer three research questions. This research has analyzed 31 articles, it was found that before using deep learning, classification was done manually with the Angle's classification technique but it has many drawbacks. Previous research has shown that deep learning techniques can significantly improve medical analysis capabilities in accuracy, speed, and can provide a second opinion for medical decision-making. This research concludes that deep learning has significant impact for the classification of skeletal malocclusion. With deep learning, classification can be done faster and more accurately, as well as support clinical medical decision-making.

Keywords: Deep Learning, Skeletal Malocclusion, Medical Image Classification, Systematic Literature Review.

INTRODUCTION

Skeletal Malocclusion is a condition where there is a misalignment of teeth when the jaw is closed. This condition has negative effects both physically and mentally for a person who experiences it, and this condition sometimes requires serious medical treatment such as surgery[1]. Skeletal malocclusion is on average caused by genetics to bad habits such as sucking the thumb or other objects excessively. In Indonesia, malocclusion has become a common dental health problem, reaching 80% of the population, so this is a concern of this study[2]. Malocclusion conditions that are not treated properly can result in various physical and functional problems such as difficulty chewing, speaking, and jaw pain. Dental health problems can also arise such as dental disease, tooth erosion, eroded and broken teeth. A person who experiences this condition usually experiences psychological and social problems such as lack of confidence and anxiety. Worse, this condition can cause long-term effects on health, such as digestive problems and chronic pain. The Malocclusion skeletal can be classified into three classes, namely class 1, class 2, and class 3 based on the position of the upper and lower molars with the position of the jaw.[3]. Each class has a different way of handling and to determine a class requires several steps of statistical analysis and manual labelling which takes quite a long time and often results in bias[1].

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In general, classifying medical images is quite difficult. Malocclusion classification using the angle's classification method is still widely used today because it is the most convenient method to use[2]. However, classification methods with these techniques often give subjective results from the clinicians. This can lead to variation in results resulting in biased results, category limitations into three main categories and inability to capture smaller complexity.

Several research articles have conducted research using deep learning methods to classify skeletal malocclusion. Some studies reveal the use of deep learning can be the basis of classification so that the results of classification do not produce much bias or variation in results that lead to errors in medical action decision-making. By using deep learning algorithms, these algorithms can automatically extract and retrieve the most important features in the data so that they can perform better classification[4]. Deep learning can analyze medical images quickly and precisely, there are several deep learning techniques that have been tested using malocclusion skeletal data and give quite good results.

Table 1: Research Question

RQ	Questions	Purpose
1	How skeletal malocclusion is classified without involving deep learning?	To find out how to classify skeletal malocclusion before the use of deep learning
2	How deep learning classifies skeletal malocclusion data	To find out how deep learning works in classifying malocclusion skeletal data
3	How does the implementation of deep learning in the medical world affect the skeletal field of malocclusion?	To find out the influence of deep learning implementation on the medical world in the field of malocclusion.

This study will review studies related to skeletal malocclusion classification systematically using the PRISMA method to find out how skeletal malocclusion classification is carried out without using deep learning and how deep learning techniques perform skeletal malocclusion classification and find out what impact that deep learning has in the medical world, precisely in the case of skeletal classification malocclusion.

This research is expected to provide deeper insights into the use of deep learning technology in the field of dentistry and its benefits in improving the quality of diagnosis and patient care. With a better understanding of how deep learning can be used for skeletal classification of malocclusion, it is expected that this technology will be increasingly adopted in everyday medical practice. The implementation of deep learning can help dentists and orthodontists in diagnosing malocclusion conditions more quickly and accurately, reducing misdiagnosis caused by the subjectivity of manual methods. Additionally, deep learning can speed up the treatment planning process, allowing for more timely and effective interventions for patients. As such, this research not only makes a theoretical contribution in the field of dental science but also has the potential to have a significant practical impact, helping to improve patients' quality of life through better and more efficient care.

RESEARCH METHODS

This research is a systematic literature review using the principles of PRISMA 2020 Guideline published by Page[5]. This study aims to review several previous studies so that this study can be a reference for secondary studies. The steps of the systematic literature review method of this study have been documented below.

Research Question

Based on **Table 1**, the study has three questions to answer. First, how skeletal malocclusion is classified without using deep learning methods. This question aims to find out what the malocclusion classification techniques are and find out the disadvantages of using non-deep learning classification. Second, how deep learning techniques can classify malocclusion skeletal data (images) which aims to find out how deep learning works can classify malocclusion

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data. Second, how the implementation of deep learning affects the medical world which aims to understand how the influence of deep learning implementation on the medical world.

Search Process

The process of searching for reference sources in this study is carried out by directly accessing the database through the Scopus website, Google Schoolar, PubMed, Semantic Schoolar. To answer the formulation of the problem in this study, data search was carried out in four databases using the keywords "Skeletal Malocclusion Classification" and "Deep Learning" contained in the title and abstract of the study with the year of publication 2019-2024. The number of journals obtained from several databases can be seen in **Table 2**.

Criteria

The articles obtained will be filtered based on several criteria such as duplicates, accessibility, to the focus of classification discussion using deep learning. Then a re-screening was carried out based on the title and abstract of the research to annul papers that did not meet the criteria that can be seen in **Table 3**. These study articles will be screened again to select articles that can be accessed directly. Articles that meet the criteria will be used in this study to answer the research question in this study.

Table 2: Database Journal Search Result

Database Journal	Article(s) Count
Google Schoolar	27.900
PubMed	161
Scopus	517
Semantic Schoolar	14.400

Table 3: Criteria of Previous Research Acceptance

In/Ex	Criteria
Inclusion	1. The article discusses the classification of skeletal malocclusion (deep learning and non-deep learning)
	2. Publication year range of the last 5 years (2019-2024)
	3. Free Access
Exclusion	1. Similar articles between databases (duplicate)
	2. Articles that do not address the skeletal malocclusion classification
	3. Non-Accessible

Data Analysis

In data analyzing process, the information to be analyzed is based on the points that exist in data collection, precisely in the summary and conclusion. Data analysis is used to strengthen the answers to the research questions contained in this study.

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Experiment

Outside of the direction of PRISMA 2020, this research will conduct experiments on the data collection and analysis process. This experiment was carried out to expand the scope of the research. Some of the experiments carried out are as follows:

1) Include articles related to this study even if they are not included in the criteria with certain requirements.
2) The article can support this research arguments.

Based on **Fig. 1**, there are quite a lot of studies that discuss the study of skeletal classification of malocclusion using deep learning. Based on the flow diagram above, this study searched into four databases and found 24,978 previous studies. From 42,978 studies, there are 119 studies that are eligible for in-depth analysis and review in this study.

RESULT AND DISCUSSION

This study has analyzed the data obtained from previous research and will answer research questions using the data with the aim of obtaining research results.

Result

How skeletal malocclusion is classified without involving deep learning?

From several studies that have been analyzed, there are several ways to classify skeletal malocclusion. **Table 4** contain research analysis data that discusses the classification of skeletal malocclusion without the use of deep learning.

Based on **Table 4**, it can be concluded that there were many classification methods that existed before the use of deep learning. The most common classification method is angle's classification, which is still the most popular method for -

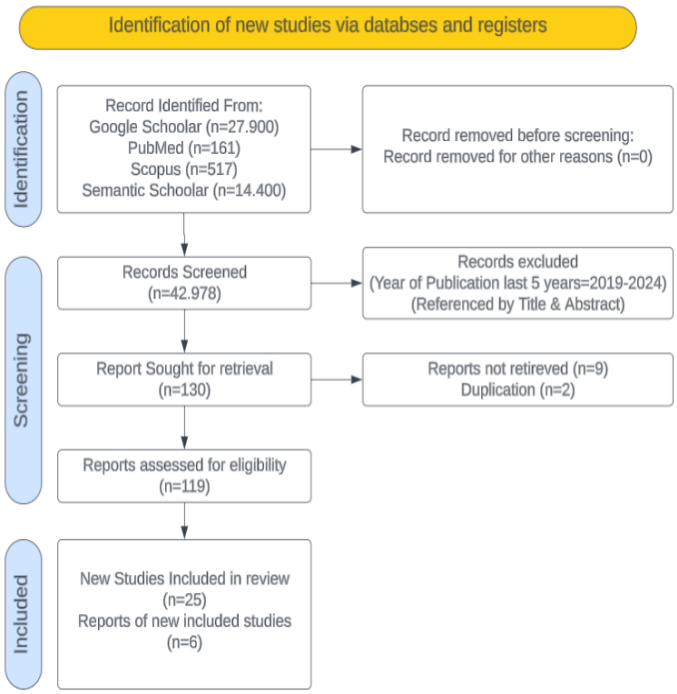

Figure 1. PRISMA 2020 Flow Diagram

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Table 1: Classification Method Before Deep Learning

Classification Method	ArticleCount	Identification
Angle Classification, BSI Classification, Katz Classification, Incisor's, Canine, and Molar classification,	2	[2], [6]
Occlusal Classification	1	[6]
Katz Classification	1	[6]
Lateral Cephalometric + Steiner Analysis	1	[3]
Lateral Cephalometric + Angle's Classification	7	[2], [7], [8], [9], [10], [11], [12]
Pell and Gregory, Winter, and Archer classification Method	1	[13]

- classifying malocclusion although the disadvantage of this method is that it cannot classify 7% of the 4309 samples owned by the Broadbent-Bolton study[6]. The classification technique with the angle classification method is still often used today, this method is still used because this technique is the easiest way to practice[2].

Fig. 2. shows the anatomy of normal human teeth and an example of the skeletal malocclusion class. Basically, angle classification uses the calculation of the relationship between the upper and lower aligned molars and the position of the jaw. Simply put, in class I (normal) the first upper molars (maxilla) are aligned or slightly ahead of the first lower molars (mandibles). In grade II, the mandibles are far behind their normal position. In grade III, the mandibles are further forward than their normal position. The angle's classification method has been modified a lot, this modification of the method has created various new models such as incisor, canine, and molar classification which are not much different from the classification method.

A study uses the lateral cephalometric analysis technique, namely the Steiner analysis method to classify the malocclusion class, this analysis technique utilizes cephalometric lateral radiographic images to examine the structure of the jawbone[3]. This technique has three main components, namely landmark points as reference points on the skull, then axes and reference lines drawn between landmark points, and angles and linear measurements measured between points and reference lines to analyze the structural relationships between bone structures.

Occlusal classification is a classification technique for the relationship between the upper and lower teeth when the jaw is closed using the angle classification or Katz classification technique. This technique helps dentists to diagnose and decide on the right treatment technique [6].

The British Standard Institute (BSI) classification is a classification standard used to classify malocclusion based on its severity assessed by whether it requires orthodontic treatment or not.

The BSI classification uses the index of orthodontic treatment need (IOTN) which has two main components, namely the dental health component (DHC) which is divided into five severity classes and the aesthetic component (AC) which provides a score on the aesthetic appearance of the teeth. BSI classification is more accurate in performing malocclusion grouping, BSI and Katz techniques have proven to be easier to use than angle classification[6].

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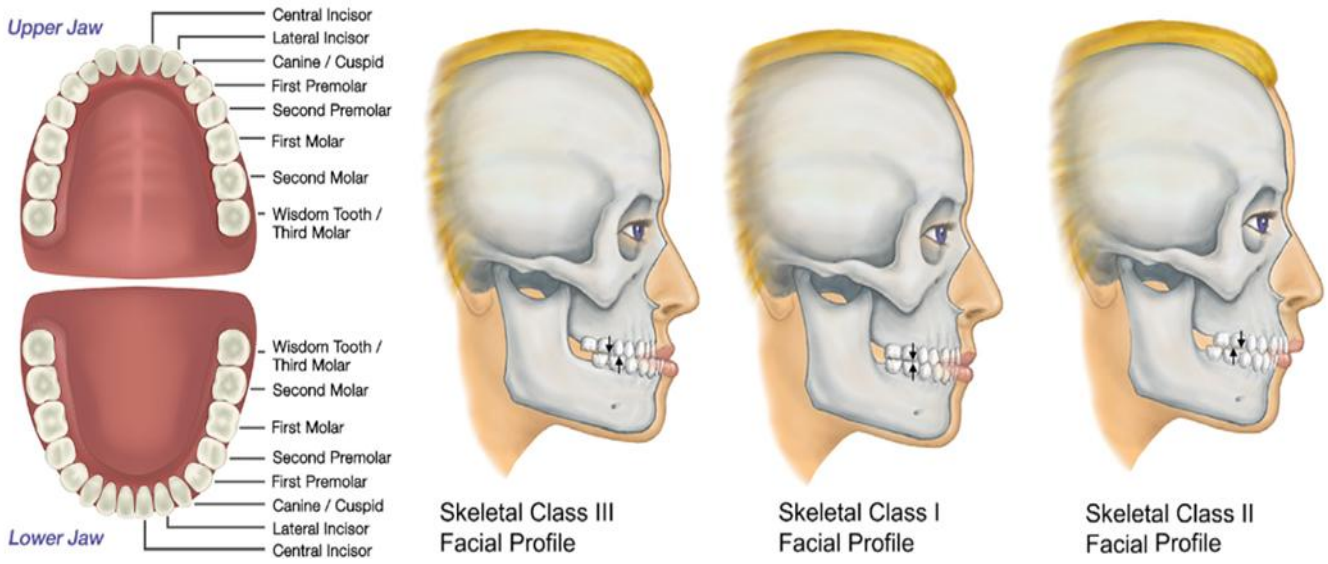

(a) (b) (c)

Figure 1. Tooth Anatomy and Skeletal Malocclusion Class

Table 5: Deep Learning Method in Classification of Skeletal Malocclusion

DL Classification Method	Article(s) Count	Identification
CLAHE + CNN	1	[1]
CNN	5	[4], [15], [16], [17], [18]
Combined CNN	1	[14]
DNN	2	[19], [20]
CNN + Resnet50	1	[21]
CNN + DenseNet	3	[22], [23], [24]

The Pell and Gregory classification is a commonly used method to assess the impact by classifying the mandibular ramus and the depth of the alveolar bone. Then Archer's classification focuses more on the relationship between the wisdom teeth and the occlusal line of the second molars. while the Winter classification is used to describe the direction or angle of the incisional impact of wisdom teeth based on the angle formed by the crown of the tooth relative to the occlusal line of the other teeth[13].

How Deep Learning classifies the Skeletal Malocclusion data?

Based on **Table 5**, it can be concluded that the CNN-based method is the most widely applied deep learning method. The CNN method is even better if it has a large sample of data, previous studies have examined that the accuracy and precision using contour transformations and classified using CNNs are better than the usual lateral cephalogram technique. In this study, CNN focused on the contour features that have been confirmed[1]. With the results of the F1-Score calculation, where using CNN produces a higher score of 7.69%, it proves that the use of deep learning provides better results.

Previously, there had also been a study that tested the use of CNN to predict malocclusion so that it could perform the right surgical action. The use of deep learning in this study provides very high accuracy, namely 0.954, 0.844, and 0.993[4].

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Deep learning is also capable of automatically identifying and calcifying skeletal malocclusion based on 3-Dimensional craniofacial CBCT images. This can improve the accuracy of decision-making on malocclusion cases[14].

The research by Zhang aims to develop a deep learning model to predict the outcome of mandibular growth using cephalometric radiographs. The CNN model was built on ResNet50 and trained using 256 cephalometric radiographs data. This model produces a good accuracy of 85%, higher than junior orthotists which is 54.2%. This model can predict the growth of the lower jaw in children with relatively high accuracy using cephalometric images. This model performs classification by identifying the characteristics of the chin area, the lower edge of the lower jaw, the incisors area, airway and condyle in cephalometric images[15].

There is a study that uses the DNN method, this method is also compared with the machine learning method and rule-based classification. The model uses an "Adam" optimizer and cross-entropy, with a 4-layer structure i.e. input with "ReLU", two hidden layers that use the "Sigmoid" activation function, and an output layer. At the end of the study, the model produced an accuracy of 70% with a sensitivity of 64% for classification[19]. DNN models can be useful in clinical practice, as DNNs can provide objective and valuable additional opinions for cephalometric imaging diagnosis[20].

The combination of artificial-intelligence and dentistry-orthodontics builds three deep learning models with the CNN method using 339 cephalometric data resulting in a high accuracy of 89.9%. This model architecture has six layers with the sequence ReLU-Tanh-ReLU-Tanh-ReLU-ReLU[16].

The study using lateral cephalograms and patient photos was classified using a CNN deep learning model with ResNet50 as the framework. This study built 5 CNN models, one of which produced a good accuracy of 84.50%. This deep learning model is much better when compared to the results of class predictions by specialists who are at 0.57%[21].

The CNN model built with 5,890 lateral cephalograms produced a very high accuracy value of 96.40%, this model uses a modified CNN architecture with DenseNet and then optimized using transfer learning and data augmentation techniques. The results of this study show that this model can diagnose specific face types without the need for additional cephalometric information and analysis[22].

Deep learning has good classification performance, but deep learning methods require a large amount of data to optimize the model to the maximum. As well as the model can be enhanced with high-quality images incorporated into the model. High-quality images can provide more accurate details and information to assist doctors in diagnosing[25][26].

In the medical world, the CNN model that is most often used for medical image segmentation is CNN in the form of Fully Convolutional Networks (FCNs). These FCNs are CNNs designed to perform segmentation tasks that only use directly connected layer layers[27].

Table 6: The Influence of Deep Learning in the Classification of Skeletal Malocclusion

The Influence of Deep Learning	Article(s) Count	Identification
Improve the accuracy and efficiency of Classification	9	[29], [1], [4], [14], [30], [22], [31], [25], [26]
Providing additional assistance	7	[29], [20], [21], [23], [24], [29], [17]
Reducing classification result bias	2	[1], [4]

How does the implementation of Deep Learning in the medical world affect the skeletal field of malocclusion?

Table 6 shows the benefits of using deep learning in Classifying skeletal malocclusion. Based on Table 4, this study can highlight three main impacts, namely improving the accuracy and efficiency of classification, providing additional assistance, and reducing bias in classification results.

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Deep learning is a technology that can imitate the way of thinking of humans to make decisions that can be applied[28]. With deep learning, the accuracy and efficiency of malocclusion skeletal diagnosis can be improved[29][30]. Deep learning has been widely used including its use against the classification of medical images[25].

The use of deep learning will not only benefit oral, maxillofacial and orthodontists but also general dentists. With deep learning, the decision-making process will have standardization[4] So that this will avoid bias from the classification results.

In recent decades, deep learning methods have given a significant boost to medical image analysis. Deep learning models are able to learn the features in medical images directly and efficiently, which can increase the speed of analysis. Deep learning is also able to improve the accuracy of complex classification tasks that cannot be solved by traditional image processing algorithms[31].

Object detection is important in medical applications. Deep learning allows automated detection to identify suspicious objects in medical images such as CT, MRI or AS results. Deep learning can also do classification so that it can help radiologists and provide important information[29].

Deep learning can be a promising tool for screening skeletal malocclusion. Deep learning can provide an important insight into monitoring and early detection in the surrounding environment[21].

Deep learning shows potential for skeletal diagnosis of malocclusion. Deep learning can make diagnoses without going through steps that require complicated diagnostic procedures, increasing speed[22].

Convolutional neural network (CNN) is one of the deep learning models that successfully learns patterns from data with many layers of CNNs[26], [27]. There are studies that try to identify cranio-spinal differences using CNNs and DenseNet as feature extractors. The discovery found something interesting: deep learning can still perform skeletal classification of malocclusion even if the jawbone image is covered. By using cranio-spinal area images, deep learning can still classify even with a high accuracy value of 90.43%[23].

The use of computer-vision that can analyze images has the potential to provide useful results, as it can reveal important correlations between images based on parameters that cannot be perceived by humans. CNN can be used as an additional aid in providing a second opinion in complex clinical questions. Additionally, CNNs are intrinsically unaffected by factors such as fatigue, individual beliefs, or hierarchy issues, thus minimizing inter- and intra-individual variability when accomplishing specific tasks. CNNs can contribute to optimizing routine tasks and have the potential to have a positive impact[24].

DISCUSSION

Based on the studies that have been mentioned, there are various methods to classify skeletal malocclusion, including Angle Classification, BSI Classification, Salzmann Classification, Occlusal Classification, and classification based on Incisor, Canine, and Molar. These classification models are done manually and have been widely used before deep learning.

Table 4 contains information on various research articles that discuss the skeletal classification method of malocclusion without using deep learning. For example, Angle's Classification is one of the most used methods. Then the lateral cephalometric technique involves the use of CBCT, this technique calculates the distance between the root of the maximal central incisor and the incisive canal manually. Another study combined the classification methods of Pell and Gregory, Winter, and Archer to determine the impact of malocclusion on the lower third molar.

The classification method without using deep learning is still used today, but this technique has a drawback, to determine a class requires several steps of statistical analysis and manual labelling which takes quite a long time and often results in bias[1]. And this classification method often has subjective results from the clinician which causes variation resulting in bias, as well as the limitation of categories into three categories and cannot capture smaller complexity.

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It can be seen in **Table 5** which contains research information using deep learning methods to classify skeletal malocclusion. Convolutional Neural Networks (CNNs) are the most applied deep learning methods in these studies. The CNN method is getting better as the number of samples increases, providing higher accuracy and precision compared to traditional cephalogram techniques. Deep learning models such as CNNs combined with ResNet50 and DenseNet improve the automatic identification and classification of skeletal malocclusion from 3D craniofacial CBCT images, improving diagnostic accuracy.

A study using DNNs, compared to machine learning methods and rule-based classification, achieved an accuracy level of 70% with a sensitivity of 64% for classification. Another study combining artificial intelligence and dental orthodontics created three deep learning models using CNNs on 339 cephalometric datasets, achieving an accuracy rate of 89.9%.

Table 6 contains information related to the influence of deep learning on the medical world, precisely on the classification of skeletal malocclusion. With the use of deep learning, the accuracy and efficiency of classification can be improved, deep learning can provide significant support in clinical decision-making. This technology reduces classification bias and helps medical professionals make standardized decisions. For example, automatic object detection through deep learning is essential in medical applications, assisting radiologists by providing critical information from CT, MRI, or AS images.

Deep learning shows great potential in skeletal malocclusion screening, providing important insights for monitoring and early detection. This technology simplifies the diagnosis process without the need for complex procedures. A study that used CNN with DenseNet as a feature extractor identified skeletal malocclusion even though images of the jawbone were covered, showed a high accuracy rate of 90.43% even with images of the cranio-spinal area.

Overall, the implementation of deep learning in the classification of skeletal malocclusion significantly improves the ability of medical analysis, both in terms of accuracy and speed. However, deep learning technology requires a higher cost compared to traditional classification techniques. Still, the use of deep learning can have a significant positive impact. Therefore, this technological advancement has a positive impact on the medical world, especially in cases of malocclusion.

CONCLUSION

This study highlights the importance of deep learning, particularly Convolutional Neural Networks (CNNs), in improving the classification of skeletal malocclusion. The transition from traditional manual classification, such as Angle's classification, to deep learning has demonstrated significant advancements in accuracy, efficiency, and reliability. CNNs have proven to be highly effective in extracting crucial features from medical images, reducing subjective bias, and enhancing diagnostic precision.

The findings of this study emphasize the potential of deep learning in transforming medical decision-making, enabling faster and more standardized classifications. Future research should focus on expanding datasets to improve model robustness, exploring hybrid models for increased accuracy, and integrating deep learning with emerging medical technologies such as 3D imaging and augmented reality. These advancements can further refine the classification process and improve patient outcomes.

Interdisciplinary collaboration between medical and technology experts is essential for maximizing the impact of deep learning in clinical practice. By continuing to develop and integrate these technologies, the medical community can enhance diagnostic capabilities and provide more effective treatment solutions for skeletal malocclusion.

Acknowledgements

This research is the result of collaboration between Bina Nusantara University, Universiti Sains Islam Malaysia, and Universiti Teknologi Malaysia. We extend our sincere gratitude to all parties who have contributed to this study. We also express our appreciation for the support and funding from the Bina Nusantara University Grant Program, which

has made this research possible. The support and collaboration from all parties have been invaluable in the completion of this study.

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