Application of artificial intelligence in dental crown prosthesis: A scoping review

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Research Article

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Abstract

Background
This scoping review aims to present the applications and performance of artificial intelligence (AI) in dental crown prostheses and related topics.

Methods
We conducted a literature search of PubMed, Scopus, Web of Science, Google Scholar, and IEEE Xplore databases from January 2010 to January 2024. The included articles addressed the application of AI in various aspects of dental crown treatment, including fabrication, assessment, and prognosis.

Results
The initial electronic literature search yielded 393 records, which were reduced to 315 after eliminating duplicate references. The application of inclusion criteria led to analysis of 12 eligible publications in the qualitative review. The AI-based applications included in this review were related to detection of dental crown finish line, evaluation of AI-based color matching, evaluation of crown preparation, evaluation of dental crown designed by AI, identification of a dental crown in an intraoral photo, and prediction of debonding probability.

Conclusions
AI has the potential to increase efficiency in processes such as fabricating and evaluating dental crowns, with a high level of accuracy reported in most of the analyzed studies. However, a significant number of studies focused on designing crowns using AI-based software, and these studies had a small number of patients and did not always present their algorithms. Standardized protocols for reporting and evaluating AI studies are needed to increase the evidence and effectiveness.

Background
Artificial intelligence (AI) is a broad term indicating the capability of computers to execute tasks typically associated with intelligent human behavior. Within the realm of medicine, AI finds application in tasks such as identifying and categorizing pathologies present in various forms of imagery, including radiographs and photographs [1, 2]. Additionally, AI is employed for event prediction and the simulation of interactions between drugs and their respective targets [3]. The field of dentistry has seen a parallel surge in AI research, mirroring advancements in medicine [4, 5, 6]. AI exhibits considerable potential for diverse diagnostic applications in dentistry, including the identification of dental caries [7, 8] from radiographs, evaluating the complexity of endodontic cases [9, 10], automating the localization of cephalometric landmarks [11], and classification of dental implant systems [12, 13, 14]. The majority of AI applications is based on machine learning, a methodology where mathematical models are trained to recognize statistical patterns within datasets to perform predictions. A subset of machine learning known as deep learning employs multi-layered neural networks with intricate architecture, allowing deep learning algorithms that often surpass other machine learning strategies in discerning patterns within vast and varied datasets [15]. This is particularly advantageous in the field of dentistry, where datasets often encompass images, proteomic information, and clinical data [16].

Prosthodontics stands at the intersection of artistic expression and scientific principles within the field of dentistry [17]. It constitutes the art and science involved in the diagnosis, strategic planning, rehabilitation, and preservation of the functional, comfortable, aesthetically pleasing, and healthy aspects of the oral structures in patients. Its primary objective is the replacement of absent teeth and related structures through the integration of artificial substitutes. The application of AI holds considerable promise across various therapeutic modalities within this domain [18].

The implementation of AI is significantly impacting the creation of dental crown prostheses, a fundamental component of prosthodontic dentistry. The dental crown prosthesis plays an integral role in reinstating both the structural integrity and functionality of teeth affected by damage or decay, offering patients solutions that are both visually appealing and durable. The integration of AI in this field holds the potential to transform the processes involved in designing, manufacturing, and placing dental crowns.

Despite an increasing volume of publications on deep learning in dental crown prosthesis, there is ambiguity regarding the prevalence of specific tasks, the types of deep learning methods favored for these tasks, and the performance variations among approaches for distinct
tasks. Additionally, the resilience of the overall body of evidence remains uncertain. Thus, the objective of this scoping review was to assess and evaluate studies that used deep learning in the context of dental crown prosthesis.

**Methods**

**Protocol**

We followed the reporting recommendations specified in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) guidelines [19] to convey the findings of this investigation. The specific review question was the applications and performance of AI in dental crown prostheses. Our literature exploration was based on the PICO (problem/patient/population, intervention/indicator, comparison, and outcome) elements [20].

1. Population: Images and other data types for dental crown prostheses used in prosthodontic rehabilitation.

2. Intervention/Comparison: AI models for diagnosis, prognosis assessment, and treatment procedures compared to reference standards.

3. Outcome: Any type of performance measurement.

**Literature search**

In January 2024, an electronic literature search was conducted across PubMed, Scopus, Web of Science, Google Scholar, and IEEE Xplore databases. No supplementary manual searches were conducted. Considering the timing of application of deep learning in dentistry, only literature published after 2010 was searched.

Each category consists of a combination of Medical Subject Headings (MeSH) Terms and related dental terms with conjunctions: (“dental crown” OR “crown preparation” OR “fixed prosthesis” OR “prosthodontic” OR “dental prosthesis”) and (“artificial intelligence” OR “machine learning” OR “deep learning” OR “neural network”).

**Eligibility criteria**

The following inclusion criteria were employed in the selection of articles:

1. Articles related to AI applications in dental crown prosthesis

2. Articles composed in English and released between January 2010 and January 2024

Our exclusion criteria were:

1. Articles that used AI for conditions not related to dental crown prosthesis

2. Articles that did not report performance metrics such as accuracy

3. Articles without the full text available

4. Review articles and letters to the editor

Two reviewers (H.J.K. and Y.L.K.) assessed the titles and abstracts of articles based on pre-established inclusion and exclusion criteria. When titles and abstracts were deemed insufficient in providing necessary information, a thorough analysis of the entire text was conducted. Both reviewers diligently examined articles that were potentially relevant and collaboratively selected papers for further analysis. Any discrepancies in opinions were resolved through discussion.

**Results**

**Selection of sources**

The flowchart in Fig. 1 outlines the article selection process adhering to PRISMA-ScR for this scoping review. Initially, a search of electronic literature produced 393 records, which was decreased to 315 after eliminating duplicate references. Following the examination of titles and abstracts, 26 studies underwent a more detailed review, after which 14 records were excluded for not meeting the inclusion criteria. Finally, 12
eligible publications were included in the qualitative review (Table 1). The evaluators unanimously agreed on the literature selection and categorization of publications.

### Table 1
Summary of each included article on artificial intelligence applications in dental crown prosthesis.

<table>
<thead>
<tr>
<th>Author</th>
<th>Aim</th>
<th>Main AI architecture</th>
<th>Authors Suggestions/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chau et al. 2023 [21]</td>
<td>To investigate the accuracy of AI in designing single dental prostheses</td>
<td>3D GAN</td>
<td>An AI system successfully designed a dental prosthesis for a single molar, replicating the morphology of a natural tooth.</td>
</tr>
<tr>
<td>Tian et al. 2022 [22]</td>
<td>To design a dental crown surface using a two-stage GAN</td>
<td>DCPR-GAN</td>
<td>DCPR-GAN demonstrates superior performance overall, affirming the efficacy of two-stage GAN.</td>
</tr>
<tr>
<td>Choi et al. 2023 [23]</td>
<td>To compare the accuracy of a AI hybrid method that extracts finish lines</td>
<td>CNN</td>
<td>The hybrid method outperformed existing commercial software.</td>
</tr>
<tr>
<td>Takahashi et al. 2021 [24]</td>
<td>To identify dental prostheses and restorations through deep learning</td>
<td>CNN</td>
<td>Deep learning exhibits high accuracy in recognizing dental prostheses and restorations with metallic color but achieves only moderate accuracy with normal tooth color.</td>
</tr>
<tr>
<td>Liu et al. 2024 [25]</td>
<td>To design various dental restorations using AI system</td>
<td>AI software</td>
<td>Compared to conventional wax-up and CAD approaches, AI design proves more time-efficient and enhances overall production efficiency.</td>
</tr>
<tr>
<td>Ueki et al. 2020 [26]</td>
<td>To develop an AI-based color evaluation system</td>
<td>CNN</td>
<td>The first candidate produced accurate outputs for 6 of 22 images, representing a 27% success rate. The second and third candidates demonstrated improved performance, correctly identifying 12 images (55%) and 15 images (68%) of the total 22.</td>
</tr>
<tr>
<td>Han et al. 2023 [27]</td>
<td>To evaluate SAE compared with a human-based DAE</td>
<td>AI software</td>
<td>SAE has the potential to reduce inaccuracies and offer more dependable and accurate assessments compared to human-based DAE.</td>
</tr>
<tr>
<td>Chen et al. 2020 [28]</td>
<td>To compare the occlusal morphology and fracture behavior of lithium disilicate crowns designed by AI and CAD software</td>
<td>AI software</td>
<td>Differences in occlusal morphology are present between AI-generated crowns and CAD-designed crowns, with the latter showing greater adherence to the natural shape of the original teeth.</td>
</tr>
<tr>
<td>Ding et al. 2023 [29]</td>
<td>To develop an AI algorithm for dental crown design</td>
<td>3D-DCGAN</td>
<td>3D-DCGAN exhibited minimal deviation from the natural teeth.</td>
</tr>
<tr>
<td>Yamaguchi et al. 2019 [30]</td>
<td>To evaluate a deep learning method to predict the probability of debonding of CAD/CAM CR crowns</td>
<td>CNN</td>
<td>The CNN approach displayed notable efficacy in predicting the probability of debonding for a CAD/CAM CR crown.</td>
</tr>
<tr>
<td>Cho et al. 2023 [31]</td>
<td>To evaluate the time efficiency, occlusal morphology, and internal fit of dental crowns designed using AI software compared to conventional software</td>
<td>AI software</td>
<td>AI software exhibited enhanced efficacy in contrast to the non-AI approach employing conventional CAD software.</td>
</tr>
<tr>
<td>Cho et al. 2024 [32]</td>
<td>To compare the tooth morphology, internal fit, occlusion, and proximal contacts of dental crowns generated by AI software with those of conventional software</td>
<td>AI software</td>
<td>Deep learning-based software for crown design resulted in optimized outcomes concerning tooth morphology, internal fit, cusp angle, and the number of occlusal contact points.</td>
</tr>
</tbody>
</table>

The AI-based applications included in this review were related to detection of dental crown finish line, evaluation of AI-based color matching, evaluation of crown preparation, evaluation of dental crown designed by AI, identification of dental crowns in intraoral photos, and prediction of debonding probability (Fig. 2). While the search was initially planned to encompass articles published between January 2010 and January 2024, the findings indicate a surge in the popularity of AI applications starting in 2019.

**Datasets**

The dataset size exhibited a wide range owing to the diversity in inputs and outcomes across study types (Table 2). Dataset size for included studies ranged from 12 to 8640. Studies using AI software included a small number of data (mean = 24.25). Since these studies do not learn new models, they do not require large datasets like existing deep learning studies. The most common types of data used were scanned digital images of the jaw and casts (n = 10), and two studies used intraoral photographs.
Table 2
AI architecture, overall dataset size, and outcome metrics of reviewed studies

<table>
<thead>
<tr>
<th>Study category</th>
<th>AI architecture</th>
<th>Overall dataset type and size</th>
<th>Outcome metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of dental crown designed by AI (n = 8)</td>
<td>AI software</td>
<td>Scanned image for 15 dental study samples</td>
<td>Root Mean Square Error (RMS)</td>
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<td>Time spent</td>
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<td>Mean margin gap</td>
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<td></td>
<td>AI software</td>
<td>Scanned image for 12 dental resin samples</td>
<td>Average profile discrepancy</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Root Mean Square Error (RMS)</td>
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<td></td>
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<td></td>
<td>Volume discrepancy failure mode</td>
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<td></td>
<td></td>
<td></td>
<td>SEM examination</td>
</tr>
<tr>
<td></td>
<td>3D GAN</td>
<td>Scanned image for 612 digital casts</td>
<td>Cusp angle</td>
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<tr>
<td></td>
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<td></td>
<td>Mean deviation</td>
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<td></td>
<td>Root Mean Square Error (RMS)</td>
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<td>Occlusal contact</td>
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<td>Finite element analysis</td>
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<td></td>
<td>3D GAN</td>
<td>Scanned image for 169 digital casts</td>
<td>Hausdorff distance</td>
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<td>Intersection over union</td>
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<td></td>
<td>3D GAN</td>
<td>Scanned image for 780 crowns</td>
<td>Peak Signal Noise Ratio (PSNR)</td>
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<td>Root Mean Square Error (RMS)</td>
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<td>Structural Similarity Index Measure (SSIM)</td>
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<td></td>
<td>Feature Similarity Index Measure (FSIM)</td>
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<tr>
<td></td>
<td>AI software (CNN and GAN)</td>
<td>Scanned image for 30 jaws</td>
<td>Root Mean Square Error (RMS)</td>
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<td></td>
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<td>Time spent</td>
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<td></td>
<td>AI software (CNN and GAN)</td>
<td>Scanned image for 30 jaws</td>
<td>Root Mean Square Error (RMS)</td>
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<td>Mean deviation</td>
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<td>Cusp angle</td>
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<tr>
<td>Detection of dental crown finish line</td>
<td>CNN</td>
<td>Scanned image for 182 jaws</td>
<td>Hausdorff distance</td>
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<td></td>
<td></td>
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<td>Chamfer distance</td>
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<tr>
<td>Evaluation of crown preparation</td>
<td>AI software</td>
<td>Scanned image for 35 dental resin teeth</td>
<td>Inter-rater agreement between human-based evaluation</td>
</tr>
<tr>
<td>Evaluation of AI-based color matching</td>
<td>CNN</td>
<td>1024 color data from 62 intraoral photographs</td>
<td>Average of the output probability scores</td>
</tr>
<tr>
<td>Identification of dental crown in intraoral photo</td>
<td>CNN</td>
<td>1904 intraoral photographs</td>
<td>Mean average precision</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Mean intersection over union</td>
</tr>
<tr>
<td>Prediction of debonding probability</td>
<td>CNN</td>
<td>Scanned images for 8640 crown</td>
<td>Accuracy</td>
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<td>Precision</td>
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<td>Recall</td>
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<td>F-measure values</td>
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</table>

Three types of AI architecture were used in this body of literature. AI software was used most often (5 times). CNN was used four times, and GAN was used three times. Among AI software, CNN and GAN algorithms were used in two studies. However, in the remaining three documents, the name of the software was provided, although the specific algorithm was not disclosed.

Excluding studies where the algorithm could not be confirmed, in designs using AI, the program used only 3D-GAN or used it in combination with CNN. In other types of studies, CNNs, which are widely used in image classification and object detection, were used. In two studies using a combination of CNN and GAN, CNN was used to extract the preparation tooth and set the margin line, and then GAN was used to create the outer surface.

**Outcome metrics**

With a scoping review, there is considerable heterogeneity in data forms and methodologies, leading to diverse outcome metrics. In studies evaluating AI design, RMS was used as an evaluation indicator in six of the studies. In these studies, mean deviation to evaluate positional accuracy and cusp angle to evaluate crown shape were used as evaluation indicators. Working time was also included in two studies to compare with existing programs or traditional methods. When an object detection algorithm was used, Intersection over union (IoU) was used as an evaluation index. Accuracy, precision, recall, and F-score were used in one prediction study.

**Discussion**

According to this scoping review, an increasing number of studies have employed AI for various tasks related to dental crown prostheses. To align with the rapid evolution of digital technologies, the investigation focused on the most recent 14 years. The application of AI in the fabrication and evaluation of dental crowns can contribute to increased efficiency for prosthodontists, raising expectations for improved productivity. The application of AI to the following fields related to dental crown prosthesis was reviewed.

**Dental crown prosthesis designed by AI**

The production of crown prostheses has been separated into traditional wax-up methods and digital approaches using CAD/CAM systems. Recently, there has been a widespread adoption of CAD/CAM methodologies, particularly in conjunction with the popularization of zirconia usage. Notably, these methods report high levels of accuracy and success rates [33]. In the CAD/CAM process, there have been efforts to enhance the speed and precision of prosthesis design through the application of AI [34].

Seven studies evaluated the feasibility of AI models to design dental crown prostheses [21,22,25,28,29,31,32]. Four studies used AI software [25, 28, 31, 32], while three studies [21, 22, 29] employed 3D-GAN algorithms for model training. In six studies, integration of AI into the fabrication process demonstrated higher accuracy compared with traditional CAD or manually designed methods. One study [28] reported that knowledge-based AI, compared to human-designed CAD software, exhibited a higher occlusal profile discrepancy.

Two studies [25, 31] reported high time efficiency of AI-based programs. While traditional CAD work does not involve adding and modifying wax, it requires human thinking. Both wax-up and CAD processes are heavily influenced by the accumulated experience of dental technicians [35, 36]. However, AI-based operations minimize human intervention using automated calculations. Therefore, designing with AI significantly reduces the time spent on the design process, especially in cases with extensive restoration requirements.

Among the seven studies, four used commercially produced AI software, with two of them lacking specific mention of the program's algorithm [25, 28]. The absence of detailed information on the algorithms and metrics used for training the models in these studies acts as a limitation, emphasizing the need for transparency in the application of AI in dentistry, especially with commercially available software. Additionally, studies employing software had datasets ranging from 12 to 30 cases, posing a limitation in detecting statistical significance due to the potentially insufficient sample size. Despite these limitations, AI for dental crown design has the potential to significantly increase production efficiency by saving time. Considering the performance demonstrated in aspects such as morphology, internal fit, and occlusion, there is a promising outlook for the future utilization of AI in dentistry.

**Detection of dental crown finish line**

Choi et al. [23] compared the accuracy of hybrid software combined with deep learning with existing traditional CAD software in detecting the crown finish line. An accurate marginal fit is crucial for preventing microgaps. This, in turn, lowers the risk of caries and ensures that the restoration retains its function [37]. Recently, finish lines have been extracted and processed manually using CAD programs, but this is a repetitive and time-consuming process [38]. In Choi et al., as a result of evaluation using Hausdorff distance and chamfer distance, the hybrid system showed statistically more accurate results. This implies that a hybrid approach, integrating both deep learning and computer-aided design methods, may allow robust and precise extraction of finish lines with minimal adjustments required.

**Evaluation of crown preparation**
One of the most fundamental aspects in dental prosthodontics education is understanding and practicing the principles of tooth preparation [39]. However, evaluating students' tooth preparation outcomes in dental education can lack consistency due to factors such as subjective grading scales and insufficient inter-rater agreement. This difficulty hinders the provision of ongoing and reliable feedback [40, 41].

Han et al. [27] assessed the viability of software-based automated evaluation (SAE) with AI to evaluate abutment tooth preparation for single crowns. This was done through a comparison with a human-based digitally-assisted evaluation (DAE), which showed perfect intra-rater agreement and almost perfect inter-rater agreement with SAE. The findings of this study substantiate the credibility of SAE within prosthodontics education and propose its potential clinical utility for evaluating tooth preparation.

Evaluation of AI-based color matching

A crucial aspect of the dental technician's role is replicating the natural color of teeth in dental prostheses. An experienced dental technician possesses the ability to precisely assess the authentic color. However, this proves to be a challenging task for a less-experienced dental technician [42].

Ueki et al. [26] extracted 62 images of patient teeth, which were annotated by experienced dental technicians. They then used a neural network to estimate the true color. The accuracy of the first candidate's output was six of 22 (27%), considerably lower than the desired level. However, the outputs for the second and third candidates encompassed 12 (55%) and 15 (68%) of the total 22 images, respectively. This affirmed accurate classification of certain colors.

One notable limitation of this study is the relatively small size of the image dataset used. To more accurately assess the potential of AI in shade selection, a substantial amount of training data is required.

Identification of dental crown in intraoral photo

In clinical situations, it is crucial for dentists to gather intraoral information about patients—a process that demands time and effort. Additionally, the effectiveness of this procedure relies on the dentist's knowledge and experience. Consequently, there is a demand for an automated system that can rapidly assess the intraoral situation.

Takahashi et al. [24] used a deep learning object detection method to recognize dental prostheses and restorations. In their study, 'You Only Look Once version 3' (YOLOv3) was used for object detection because it has shown high performance in other dental deep learning studies [43, 44, 45].

A satisfactory level of performance is typically associated with an IoU exceeding 0.7 [46, 47]. In the present investigation, the IoU was 0.76. Consequently, the proficiency of this learning system was high. In assessing the accuracy of the object detection model, the mAP is employed, with values above 0.7 considered favorable in previous research [48]. The mAP achieved in the present study was 0.80, supporting the learning system's commendable performance from a mAP perspective.

Irrespective of the overall count of objects across all images, there was a tendency for higher average precision (AP) scores in cases of metallic-colored prostheses, while tooth-colored prostheses exhibited a tendency toward lower AP scores. These findings suggest that the identification was influenced by the color distinctions between the natural teeth and prostheses.

Prediction of debonding probability

CAD/CAM composite resin (CR) crowns cemented to dentin often exhibit a propensity for debonding within one year, and the reported debonding rate for CAD/CAM CR crowns cemented on implant abutments stands at 80% within one year [49]. Inadequate preparation has been identified to contribute to debonding [50, 51].

Yamaguchi et al. [30] aimed to predict the debonding probability of CAD/CAM CR crowns using scanned images of prepared models employing convolutional neural networks. The reported prediction accuracy was 98.5%. Despite the good performance, this study acknowledges a limitation in explaining the primary factor contributing to debonding, stating that it was difficult to pinpoint the main cause.

Conclusions

The number of studies applying AI to dental crown prostheses is gradually increasing. According to the results of this review, AI has the potential to increase efficiency in processes such as fabricating and evaluating dental crowns, with a high level of accuracy reported in most of the included studies. However, a significant number of studies focused on designing crowns using AI-based software, and these studies have limitations in that the study size was small and the algorithms used were sometimes not disclosed. The small number of AI-related studies means that AI application to dental crowns is needed in more diverse aspects. Additionally, research involving a large number of
patients and data in various clinical situations is needed. AI study, by its nature, uses a variety of methods and evaluation metrics. Therefore, standardized protocols for reporting and evaluating AI studies are needed to increase the evidence and effectiveness.

**Abbreviations**


**Declarations**

**Ethical approval**

Not applicable.

**Consent for publication**

Not applicable.

**Availability of data and materials**

All data generated or analysed during this study are included in this published article

**Competing interests**

The authors declare that they have no competing interests

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**Authors' contributions**

HJK conceived the study. All authors developed the review protocol. HJK and YLK did the literature search and assessed the quality of included studies. All authors read, commented critically and approved the final manuscript.

Corresponding author: Hyun Jun Kong

**Acknowledgements**

Not applicable

**References**


Figures
Figure 1

PRISMA-ScR flowchart of study selection

Figure 2

Graph showing the number of articles published each year with various categories of research topics.
Number of included articles by publication year and purpose of artificial intelligence application