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Generative Adversarial Networks (GANs) 2D imaging optimization in image–J for estimation of endodontic filling material measurement: A review

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Abstract

Background: Root canal treatment (RCT) remains the most common clinical intervention in dentistry, treating a wide range of pulp-related conditions and structural tooth injuries. RCT begins by partially removing the crown to access and remove the infected pulp through a meticulous process of cleaning, reshaping, and irrigating the canal. This prepared canal is filled with gutta-percha as the endodontic filling material (EFM), and adhesive cement is used to seal the canal before final restoration with a crown. The success of RCT, however, hinges on accurately measuring and applying the EFM volume within the canal. Current measurement practices using 2D radiographic imaging fall short in accuracy due to operator limitations and the inherent lack of depth and clarity in 2D images, which contribute to high variability in EFM application. CBCT has emerged as a viable alternative, offering comprehensive 3D imaging for a more accurate EFM volume assessment, yet its high radiation levels, cost, and accessibility issues pose challenges. Thus, with increasing demand for safer and cost-effective alternatives, AI-driven enhancements in 2D imaging are being explored to achieve CBCT-level accuracy without its drawbacks, marking a significant step forward in RCT reliability and success rates.

Purpose: To explore the potential of GANs and Image–J integration on 2D images for estimation of EFM measurement.

Method: A literature review of studies published within the past five years from sources like ResearchGate, ScienceDirect, PubMed, and Google Scholar.

Result: This study explores the integration of artificial intelligence, specifically convolutional neural networks (CNN) and generative adversarial networks (GANs), to enhance the accuracy of endodontic filling material (EFM) measurements in root canal treatments (RCT). CNN's structure, comprising multilayered networks with pooling layers, has shown potential in medical imaging by segmenting anatomical details for EFM measurement. However, challenges remain due to CNN's reliance on extensive datasets and its susceptibility to misinterpretation when faced with complex anatomical variations. GANs, combining a generator and discriminator, address these limitations by enabling unsupervised learning, allowing the generation of photorealistic data samples for more precise EFM measurement. This bidirectional learning system refines measurement accuracy through continuous feedback between the generator and discriminator, achieving superior outcomes across parameters like radiopacity, dimensional consistency, classification performance, and sealing ability. Furthermore, the AI model is enhanced by integrating Image-J, a Java-based image

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analysis software with precise 2D measurement capabilities. Despite its effectiveness in analyzing length and volume, Image-J has limitations due to its dependence on the operator's interpretation, especially with low-quality 2D images. The combined use of GANs with Image-J allows for automated, detailed border detection of the pulp anatomy, improving measurement accuracy even with complex root canal forms. The results suggest that this integrated AI approach can advance clinical practices by providing precise, rapid, and consistent EFM measurements, potentially overcoming the limitations of traditional 2D radiographic methods and addressing CBCT's drawbacks in radiation exposure and accessibility.

Conclusion: The integration of generative adversarial networks (GANs) with Image-J offers a promising advancement in the measurement of endodontic filling materials (EFM) for root canal treatments based on 2D imaging. GANs enhance Image-J's measurement precision and accuracy by utilizing bidirectional deep learning, which enables continuous learning and refinement without requiring extensive external inputs. This approach not only improves EFM estimation but also presents a viable alternative to cone-beam computed tomography (CBCT), reducing potential health risks and economic burdens associated with CBCT. The combined GANs and Image-J system thus supports a more accessible, efficient, and precise methodology for EFM assessment in clinical dentistry.

Keywords: Bacteria; Chlorhexidine; Cytotoxicity; Dental caries; Extract

1. Introduction

Root canal treatment (RCT) is the most utilized clinical treatment in dentistry as at least 55.7% of the worldwide population have at least one tooth that has been done with RCT (1). RCT has been started with access formation of the tooth by partial removal of crown so the infected pulp removal could be done with the process of recleaning, reshaping, and also irrigation to disinfect the root canal. After that, the well–prepared root canal will be filled with gutta–percha as endodontic filling materials (EFM) and sealed with adhesive cement as sealer to prevent further infection before being restored with new restorative crown to give mechanical supports to the whole tooth (2). Therefore, indications of RCT are versatile since it can be utilized to treat necrotic pulp, periapical cyst, apical periodontitis, and injury by luxation and avulsion (3,4). By these advantages, RCT has been done as the most commonly used treatment but it is also linear with the prevalence of the treatment failure reaching out to 30.4% of all RCT that have been conducted (5). 73.8% of the failures have been due to EFM volume in the root canal which overfilling and underfilling play the biggest role for these failures (1,6–7).

Usually before the root canal filling process with EFM, the EFM volume must be measured and estimated until getting a certain length and volume of the EFM. Measurement of the EFM itself is usually based on volumetric and density which may lead to accurate determination of EFM filling capacity (8,9). These two aspects were measured using a two–dimensional (2D) radiographic method but it didn't manage a significant improvement of RCT success rate since the imaging results are not proper and detailed enough for the diagnosis besides the operator sights limitation itself also playing massive roles in resulting high– deviated measures compared to realm (10). This led to technology utilization into the most futuristic and realistic cone beam–computed tomography (CBCT) which may result in more detailed and reliable results of imaging since it is taken in three–dimensional ways. However, the radiation dose resulted by CBCT is quite big, even the biggest than all dental radiographic techniques that have been existed until this moment, also expensive price and availability in underdeveloped and developing countries, triggering new question that comes down to the root of reliability and realistically aspects of CBCT utilization just for estimating EFM measure to be applied into root canal (11). According to long–term disadvantages, less prospect of CBCT and seeking 2D imaging potency while the details could be enhanced, artificial intelligence (AI) utilization could be bold options to achieve CBCT ability level but also could overcome the negative impacts of CBCT.

2. Material and methods

A literature review exploring the potential of neural networks, specifically GANs and Image–J, as integration methods of 2D imaging for estimation of EFM measurement, was conducted by searching and compiling scientific articles and data. These form the foundation and provide supporting evidence for arguments favouring the use of avocado seeds in caries treatment. Articles and data were sourced from reputable scientific databases, such as PubMed, ScienceDirect, ResearchGate, and supplementary databases like Google Scholar, to gather research findings relevant to the situation in Indonesia, which aligns with the objectives of this literature review.

Several key phrases were used to aid the search process, including terms related to GANs, 2D imaging, Image–J, EFM measurement, their mechanism and processes. Another aspect considered during the collection process was ensuring

that the articles and data were up-to-date. Only articles published within the last five years were selected, with the oldest articles being from 2018.

A total of 1.082 articles were retrieved through the search process and were gradually filtered based on their relevance to the objectives of the literature review. Ultimately, 18 related articles were used in the preparation of this review.

3. Results and discussion

In terms of AI utilization, convolutional neural networks (CNN) would be tremendously discussed as its impressive ability of deep learning plays a key role for an accurate automated measurement of the EFM. Basically, CNN is a single system of multilayered neural networks divided into many pooling layers with a fair–and–square size for detailing items by magnifying and segmenting before the process of augmentation as the fundamental process of the CNN (12). The idea was excellent but the implementation at many experimental studies in medicine and dentistry a long time ago still cannot conclude the practical way and certain architecture design or even exact procedures to conduct it clinically. The problems are rooted to the aspects of requirements of big data frequency and combination, indeed also unidirectional mechanism of the system causing CNN to become pragmatic in interpreting new images with a little bit modification so the results could be undesired results as mislocalization to lead mismeasurement could happen (13). However, the concept of CNN was tremendously good but the enhancements or modifications could deliver the improvement of AI utilization for EFM measures more accurately and rapidly–processed to be applied clinically. The improvement of CNN has emerged in this 21st century which comes with a single system consisting of two pieces of CNN that integrated to each other playing different roles as generator and discriminator named generative adversarial networks (GANs).

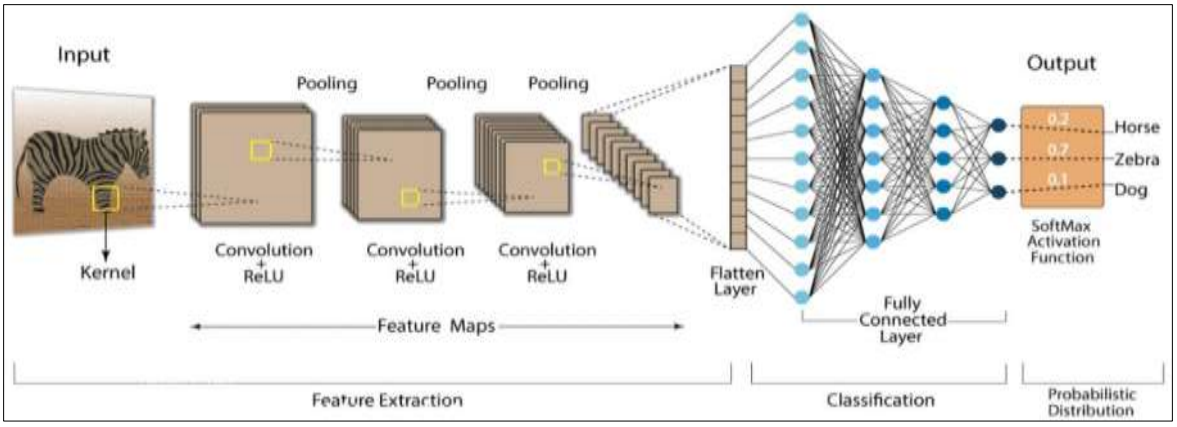

Figure 1 Mechanism Workflow of CNN

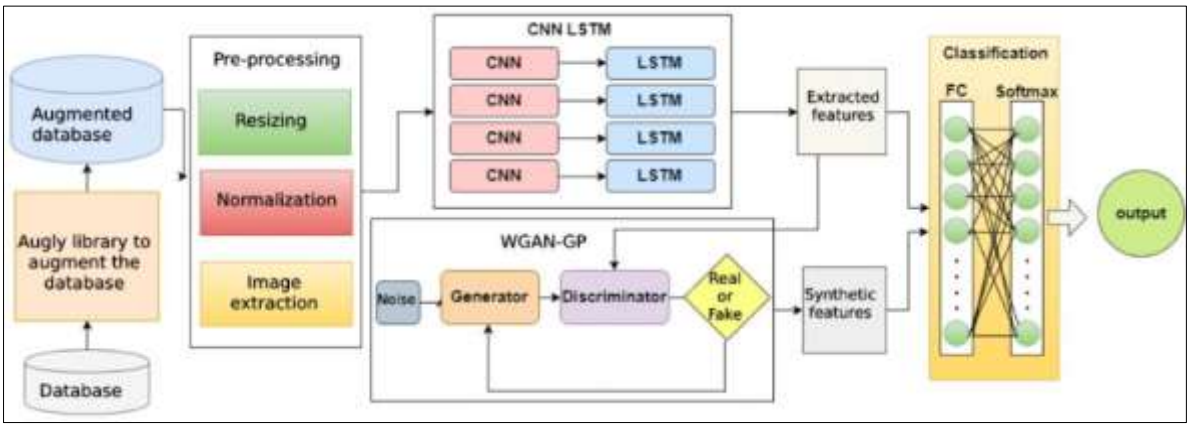

Figure 2 Mechanism Workflow of GANs

This system could be very useful in EFM measurement which needs a high–level of detail and accuracy to determine the border of the pulp anatomical structures since this package has been designed to unlock and enable unsupervised learning which is not provided by CNN since its dependence of the dataset inputted. Generators could generate new data samples from data inputted by automated augmentation so an estimated measure of EFM could be defined effectively and rapidly for the next stage of training by supportive discriminator system which will evaluate the estimated measure and distinguish it from actual size (14,15). By this integration, all new data samples generated that have been checked by discriminator could be more photorealistically so the unsupervised learning could be unlocked at this moment and enormous training datasets could be run in millions of cycles like *'zero–sum game theory'* to train and improve GANs ability of estimating EFM measure by only a minimal of datasets that have to be validated by CBCT (14–16). These will differ GANs with CNN old–fashioned deep learning since this bidirectional deep learning mechanism has complete features that all systems should have such as feedback mechanism between generator– discriminator and discriminator–generator which could play massive roles in resulting and outcoming the estimated EFM measure accurately, precisely, rapidly, and more consistently than its predecessors which the outcome parameters could be classified into parameter of radiopacity measurement, dimensional consistency, classification performance, and sealing ability that some researchers have revealed GANs ability to reach excellent for all of these parameter values (14). This feedback really supports the whole system for the adversarial process, which generator interaction that may fool discriminator, will trigger discriminator to evaluate and distinguish the interpret size to actual size (16).

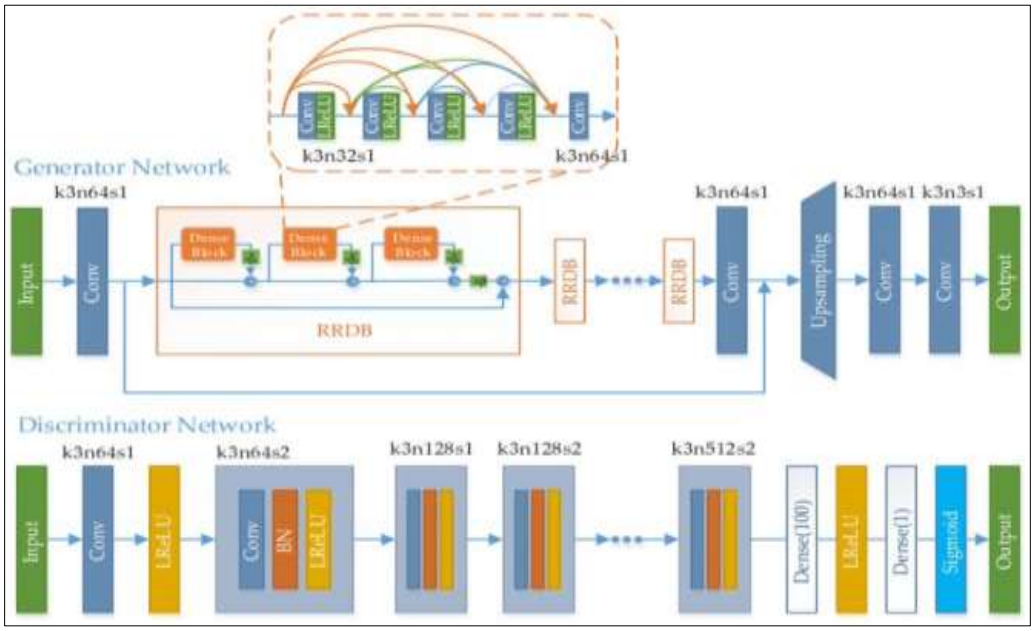

Figure 3 Specification of Generator and Discriminator Network of GANs

Figure 4 Undefined Anatomical Border of Root Canal from RCT Preoperative Radiograph Interpretation which Leads to Underfilling of Root Canal with EFM

GANs are more fitted than CNN to help the precise interpretation and detailed determination in case of EFM measure estimation in the root canal, even if the root canal has quite complex form, especially if it is combined with nowadays–hyped software named Image– J. Image–J is an image processing program based on Java configuration that has an open architecture so the features of editing and analyzing pictures are enabled (17,18). In just decade of its occurrence, Image–J itself has been well–known for its excellent ability in measuring length, area, and even volume by being very detailed at 2D imaging, although the image quality was so–so, since it has ability on annotating images into highlighted specific region of interests (ROI) and enabling lookup tables to support its measurement (17). This statement will state that GANs could not stand by itself for the measurement process but it needs numerical and quantitative evidence which could be shown based on 2D based–measurement gold standard named Image–J. Image–J itself needs some support based on AI to enhance their ability of measurement since Suzuki et al. (2021)(18) revealed that Image–J measurement could be very biased over 0.8 in several moments because of low–quality 2D images which causes the anatomical border operators to determine correctly becoming less–precise since it is known that Image–J usually is being used manually by an operator. By optimization of GANs on Image–J, it could bring multiple advantages by automated system configured to deliver spectacular results by resulting more detailed anatomical pulp root border determination, especially if bigger and more variative datasets could be given to add some boost to supervised learning process acceleration of GANs for estimating measure process of the EFM (12).

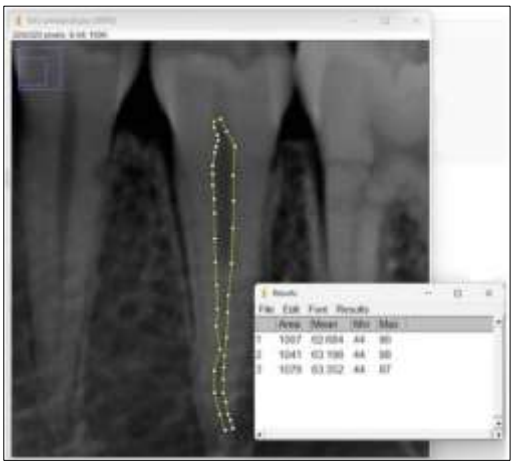

Figure 5 Bias of root canal measurement by manual-operated Image–J

4. Conclusion

GANs could be utilized in potentiation of Image–J works for estimating measure of EFM in root canal based on 2D imaging to prevent negative impacts of CBCT, either health or economic aspects, since its bidirectional mechanism of deep learning that may trigger the system to keep learning without dependence of external input and enabling more precise and accurate of Image–J measurement of the root canal.

Compliance with ethical standards

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Disclosure of conflict of interest

Authors have declared no conflict of interests.

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