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Analysis of Dental Imageries Towards Improved Diagnosis

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Foreword

The "Clinical Assistantship to Dental Caries Detection and Assessment" has been meticulously crafted by experts in computer science and engineering as well as in dental odontology. This collaborative effort brings together a distinguished group of international specialists to offer a comprehensive, accessible, and well-illustrated guide for clinicians. The guide is thoughtfully organized to provide a logical progression, starting with the essential background needed to understand the preparation, execution, and limitations of clinical visual assessment of caries. It then explores various visual detection criteria, highlighting both their key differences and significant similarities. The book also addresses caries detection during excavation. Following this, a thorough series of chapters discusses additional detection methods that aid in caries lesion diagnosis, including radiographic film-based and digital imaging techniques. The guide also considers emerging technologies and their future potential, despite the often lengthy development timelines. Critical chapters on making treatment decisions post detection and an essential appendix on definitions round out the content. The authors and contributors are to be commended for creating such a focused and practical Clinical Guide. I believe that this book will enhance readers' confidence in managing early-stage dental caries with non-surgical approaches through more precise and objective assessment methods, ultimately improving patient care.

Kolkata, India
December 2024

Dr. Pramit Ghosh

Preface

The realm of caries detection has witnessed remarkable advancements through the integration of computer engineering principles, leading to transformative changes in how dental caries are identified and assessed. This preface delves into how the field of computer engineering has contributed to the evolution of caries detection, offering a fresh perspective on this critical aspect of dental care.

Computer engineering has played a pivotal role in developing innovative technologies and methods that enhance the accuracy and efficiency of caries detection. Through sophisticated algorithms, machine learning models, and advanced imaging techniques, computer engineering has enabled the creation of tools that provide clinicians with more precise and objective assessments of dental caries.

This book explores the intersection of computer engineering and caries detection, shedding light on how computational techniques and technological advancements are reshaping the landscape of dental diagnostics. From the development of digital radiographic systems to the implementation of artificial intelligence in image analysis, the contributions of computer engineering are integral to improving the detection and management of dental caries.

As we navigate through this guide, we will uncover the intricate ways in which computer engineering enhances traditional caries detection methods and introduces novel approaches that promise greater accuracy and reliability. This integration not only supports clinicians in their diagnostic efforts but also paves the way for more effective and personalized treatment strategies.

The fusion of computer engineering with caries detection represents a significant leap forward in dental diagnostics, reflecting a broader trend of technology-driven innovation in health care. We invite you to explore these advancements and their implications for the future of dental care, and to appreciate the transformative potential that arises from this synergy between engineering and clinical practice.

Kolkata, India — Soma Datta
Bialystok, Poland — Khalid Saeed
Kolkata, India — Nabendu Chaki

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Competing Interests Professor Nabendu Chaki is a Senior Member, IEEE.

Professor Khalid Saeed is a Senior Member, IEEE.

The authors have no conflicts of interest to declare that are relevant to the content of this book.

Ethics Approval We have worked upon the standard publicly available dataset "Labial Teeth and Gingival Image Database" and "AEGIS Dental Network Database". Hence, there is no requirement of an ethical clearance certificate.

Contents

About the Authors

Soma Datta received the M.Sc. and M.Tech. degrees from the University of Calcutta, India, in 2005 and 2007, respectively. She completed her Ph.D. in 2022 from the same University of Calcutta. At the beginning of her professional career, she had been with the Research and Development section of Tata Consultancy Service (TCS) Limited as a system engineer. After that, she joined the University of Calcutta, Kolkata, as a Ph.D. Research when she was selected for fellowship under the prestigious Visvesvaraya Ph.D. Scheme funded by the Government of India. She has good publications in the image processing domain. Her research interests include medical imaging and pattern recognition. Currently, Soma is an assistant professor in the Department of Engineering, at Sister Nivedita University.

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Nabendu Chaki is a Professor in the Department Computer Science & Engineering, University of Calcutta, Kolkata, India. He is sharing 7 international patents including 4 US patents. Besides editing more than 40 conference proceedings with Springer, Dr. Chaki has authored 8 text and research books and over 250 Scopus Indexed research papers in Journals and International conferences. He has served as a Visiting Professor in different places including Naval Postgraduate School, USA; Ca Foscari

University, Italy and AGH University in Poland. He is the founder Chair of ACM Professional Chapter in Kolkata and served in that capacity for 3 years since January 2014. He had been active during 2009–2015 toward developing several international standards in Software Engineering and Service Science as a Global (GD) member for ISO-IEC.

Acronyms

ADA	Adaptive Dragonfly Algorithm
AI	Artificial Intelligence
BL	Band Limited
CAD	Computer Aided Design
CBCT	Cone Beam Computer Tomography
CCD	Charge Coupled Device
CNN	Convolution Neural Network
DASM	Directed Active Shape Model
DCT	Discrete Cosine Transformation
DEJ	Dentino Enamel Junction
DFT	Discrete Fourier Transform
DIFOTI	Digital Imaging Fiber Optic Trans-illumination
DSR	Digital Subtraction Radiography
DT	Decision Tree
ECM	Electronic Caries Monitoring
FCNN	Fully Deep Convolution Neural Network
FN	False Negative
FOTI	Fiber Optic Trans-illumination
FP	False Positive
GAC	Geodesic Active Contour
HIP	Horizontal Integral Projection
HSI	Hue, Saturation, Intensity
HR	High Resolution
ICDAS	International Caries Detection and Assessment System
IOC	Intraoral Camera
LBP	Local Binary Pattern
LLE	Locally Linear Embedding
LR	Low Resolution
LSTM	Long Short-Term Mode
LTG-IDB	Labial Teeth and Gingival Image Database
LVQ	Learning Vector Quantization

MAP	Maximum a Posteriori Probability
MPCA	Multi-linear Principle Component Analysis
MRF	Markov Random Field
NS	Neutrosophic
OCT	Optical Coherence Tomography
PCA	Principle Component Analysis
PSO	Particle Swarm Optimization
QLF	Quantitative light induced fluoresce
RGB	Red, Green, and Blue
ROI	Region of Interest
RT	Radon Transformation
SAR	Simultaneous Auto Regressive
SR	Super Resolution
TN	True Negative
TP	True Positive
VIP	Vertical Integral Projection
WHO	World Health Organization

Part I
Identification of the Problem Domain and the Area of Contributions

The healthcare sector is a top priority, with end-users demanding the highest standards of patient care, service, and monitoring, regardless of cost. Despite its significant share of both international and national budgets, the sector often falls short of societal expectations. Medical professionals rely on various imaging techniques to diagnose diseases, but patient variability and differences in imaging modalities complicate this process. Additionally, heavy workloads can lead to expert fatigue, increasing the risk of errors and inconsistent diagnoses. To address these challenges, an automated solution is needed. Such a system could diagnose diseases, measure predictive targets, monitor lesions, and provide realistic predictive models, aiding medical experts in developing efficient treatment plans. Most diagnostic methods rely on sound or image analysis, with sound-based diagnostics offering preliminary insights and detailed examinations predominantly relying on visual observations. Dental caries, with a long and complex history, saw relatively low incidence during the Bronze and Iron Ages. However, its rate increased during the Neolithic period with the cultivation of carbohydrate-rich plant foods. Ancient civilizations such as the Egyptians, Israelites, Indians, Mesopotamians, Chinese, Incas, Greeks, and Romans documented dental and oral problems and their treatments. A Sumerian text from 5000 BC described a 'tooth worm' believed to cause caries by boring holes in teeth and causing pain through its movement. Modern dentistry attributes caries to oral microorganisms in the presence of fermentable sugars, enamel and dentine layers, organic acids, and dietary foods. Caries can affect individuals of any age, leading to the demineralization and destruction of hard tissues, making it the most common disease globally. The study of dental caries, known as Cariology, remains a significant field in medical education. In the chapters of this book, the authors will discuss various techniques for detecting dental caries in both dental radiographic and color images.

Chapter 1
Introduction

1.1 Background

There is no ambient environment where human beings can stay for a long time with full mental satisfaction. The reason behind such a phenomenon is the high cognitive ability of human beings. The famous psychologist Lewin [11, 23] described this as Brownian motion [8] type trend of the human mind from different points of view. Even so, these characteristics of the mind can be expressed by a simple mathematical formula. It could be defined as

$$\frac{dy}{dx} \neq 0 \tag{1.1}$$

This represents the rate of change of human satisfaction with respect to time. In equation (1.1), x is the time and y is a function of satisfaction with respect to time. Basically, $\frac{dy}{dx} \neq 0$ is the driving force that changes the wild human to become a civilized one. Negative value of $\frac{dy}{dx}$ means there is a sign of destruction or upcoming renaissance. On the other hand, positive value of $\frac{dy}{dx}$ represents the sign of improvement. Value of $\frac{dy}{dx} > 0$, for a group of people, indicates that the group of people are improving a lot. This indirectly indicates the societal improvements. We have to focus on a lot of matters to improve our society. Among these, the solution of "health-related issues" is quite vital because the wastage of man-hours due to health-related issues is one of the hindrances of societal improvement. Now, if we focus on health-related issues, it could be categorized into two broad categories as follows [18]:

1. **Life-threatening diseases:** These are the diseases for which mortality rate is very high. Examples: stroke, cancer, cardiovascular diseases, etc.
2. **Non-life-threatening diseases:** These are the diseases for which mortality rate is low. These create discomfort to our body. Examples: cold and cough, dental caries, crack of bones, etc.

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It is observed that many research works have been done to initially detect the life-threatening diseases that assist physicians [3]. Not only that, many image processing-based research works have also been conducted to detect the initial stage of the disease using different modalities of images like computer tomography (CT), magnetic resonance imaging (MRI) , positron emission tomography (PET), etc. [12, 26]. On the other hand, less life-threatening diseases cause a huge amount of man-hour loss. It mainly creates discomfort and pain in our body. The healthcare domain is a high prioritized research area than the other domains. Here, end-users expect the highest level of comfortable patient care, services, monitoring, etc. regardless of cost. So far, the healthcare domain does not fulfill the societal expectation even though it consumes a high percentage of international and national budgets. Generally, medical experts analyze different modalities of medical images and detect the diseases. Immense variations occur from patient to patient for the disease detection from the same modalities of images. These cause the total system to be very complex.

Due to heavy workload, medical experts become fatigued. Hence, automatic pre-processing techniques would help them to reduce their workload. The different modalities of data are collected from different image acquisition systems. This data collection from different sources is often incompatible, high in dimension, rich in variables, and sometimes having poor resolution. These different variations of medical images require a hectic and tedious effort from medical practitioners. As humans make mistakes, the system sometimes is prone to error. Final decision for the disease diagnosis varies from expert to expert. Hence, an automatic solution is required to resolve this complex problem. The automatic system would be able to diagnose a disease, measure the predictive targets, provide monitoring lesion, and also provide a realistic predictive model that could assist the medical expert to emerge a proper treatment plan in less amount of time. Most of the disease diagnosis methods are either based on sound or images. Sound-based diagnosis gives a rough idea about the disease. However, detailed examinations are mostly based on visual observations.

1.2 Importance of Medical Image Analysis

Eyes are the most sophisticated transducers of the human body. The minute difference could be detected through eyes. Most of the diagnostic methods are image-based due to this reason. Even in USG, reflected sound information is converted to an image for better understanding. Hence, medical image analysis is important for disease diagnosis. Medical image analysis provides visual information of the whole human body. The aim of medical image analysis is to assist radiologists and physicians in making the diagnosis and treatment process more accurate. Radiologists depend on different modalities of data to detect the diseases [13]. These different imaging modalities have an important role in detecting abnormalities and mal-functionality from various body organs. Hence, different modalities of medical image analysis are very essential in the modern healthcare system. Figure 1.1 shows what type of

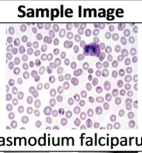
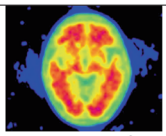
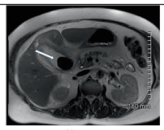
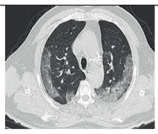
Sl No	Type of Image	Sample Image	Mainly used for
1.	Histopathology	 Plasmodium falciparum	Epithelium, Endothelium, Germ Cells, Placenta, Blood cells
1.	X-ray	 Broken knee	Mammography, Dental, Dexa scan, Orthography
2.	Ultrasound	 Normal Pancreas	Breast, Doppler, Whole abdomen, Cranial, Gall Bladder, Thyroid
3.	PET	 PET image of Alzheimer'sPatient	Cardiology, Infected tissues, Neuro Imaging, Pharmacokinetics
4.	MRI	 Gall Stone	Liver, Oncology, Neuro Imaging, Cardiovascular diseases
5.	CT	 COVID 19 Lungs image	Abdomen, Appendix, Chest, Brain, Kidney, Breast

Fig. 1.1 Different modalities of images for different organs

diseases are detected from what kind of image modalities. These are the recent trends in medical image analysis for different modalities of medical data [28–30].

It is clear from Fig. 1.1 that lots of research works have been carried out on different human organs like the brain, heart, liver, abdomen, etc. It is further observed that as oral diseases are not life-threatening, patients are prone to self-medicate and use some homemade remedies. A patient goes to a dentist once the pain goes beyond their tolerance capacity. But, at that time it is too late for the patient. Hence, people should be warned about it so that dentists also could help them to get rid of unnecessary pain, that occurs due to deadly oral diseases.

1.2.1 Oral Health Issues Due to Dental Caries

Dental caries is a bacterial infection caused by Streptococcus mutats in the presence of carbohydrates and saliva in our mouth [1, 24]. A World Health Organization (WHO) report disclosed that 90% of adults and more than 60% [17] of children are affected by dental caries. Figure 1.2a shows the worldwide caries affection severity rate, and Fig. 1.2b shows the age-wise caries affection rate. According to Fig. 1.2a, 11% of the whole world population are in high risk zone and 9% of the whole population are in low risk zone. According to Fig. 1.2b, caries affection rate at the age of 12–15 is a high 40.6% and at the age of 40–49 it is 8.6% [5, 20].

1.2.2 Types of Dental Caries

Dental caries are of four types. These are enamel caries, dentine caries, pulp caries, root caries, and inter-proximal caries [2, 7, 9, 25].

1. **Enamel caries:** If the bacterial infection occurs at the upper calcium layer of the teeth, then it is called enamel caries.
2. **Dentine caries:** After decaying the enamel layer, if the infection goes inside of the dentine layer then it is called dentine caries. Enamel and dentine caries are also called early caries.
3. **Pulp Caries:** Pulp caries occurs when the infection touches the pulp region that is the nerve region of the teeth; then it is called pulp caries. It is very painful.
4. **Root caries:** When pulp caries remains untreated for a long period of time, then root caries occurs. In that case, solutions are either extraction of the affected tooth or going for root canal.
5. **Inter-proximal caries:** This caries occurs in between two consecutive teeth.

Figure 1.3 shows different types of dental caries.

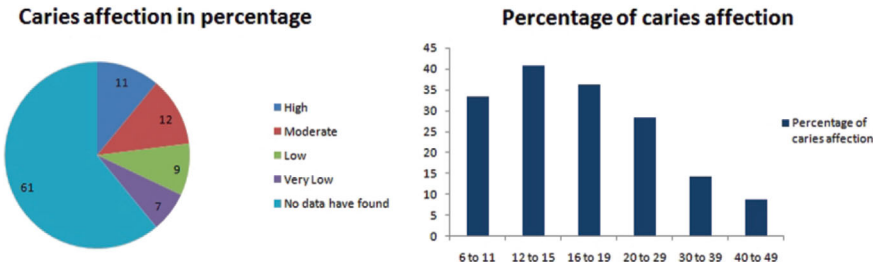


Fig. 1.2 **a** Worldwide caries affection rate. **b** Age-wise caries affection rate

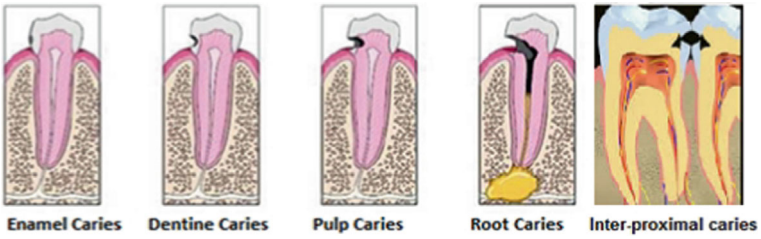


Fig. 1.3 Different types of dental caries

1.2.3 Imaging Type Used to Detect Caries Lesion

There are three types of imaging techniques that are generally used to detect dental caries. These are colored imaging technique, X-ray imaging technique, and cone bean computer tomography [16, 21].

1. **Colored imaging technique:** This imaging technique is also called RGB images. Here images are captured using an intraoral camera that is very handy, non-invasive in nature and has a LED lighting system to capture tooth decay. It is used to detect early caries and amalgam restoration. This imaging technique is also used to monitor the progress of caries lesion.
2. **X-ray imaging technique:** This imaging technique is used to detect hidden caries, inter-proximal caries, etc. These techniques are of four types. These are listed as follows:

    a. Periapical dental X-ray: It contains the image of a specific tooth from its top to bottom.
    b. Panoramic dental X-ray: It shows the whole image of upper and lower jaws.
    c. Bitewing dental X-ray: It highlights the specific region of a tooth or gum.
    d. Occlusal dental X-ray: It is used for children.

3. **Cone bean computer tomography (CBCT):** CBCT is used to get the tooth structure along with the other facial bonny structures like nasal cavity, sinus, etc. It is quite expensive. This imaging technique needs unnecessary radiation. Hence, dentists suggest for CBCT only for a certain critical situation.

Figure 1.4 shows four different types of dental X-ray images. In this research work, we have worked upon dental RGB images, periapical, and bitewing radiographic images.

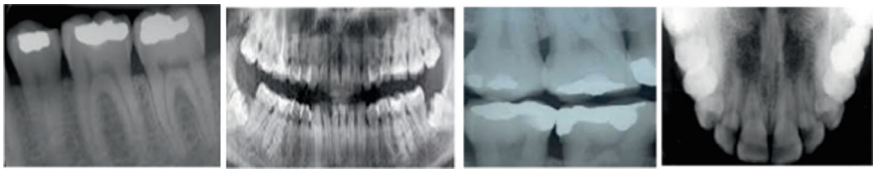


Fig. 1.4 **a** Periapical X-ray. **b** Panoramic X-ray. **c** Bitewing X-ray. **d** Occlusal dental X-ray

1.2.4 Symptoms of Dental Caries

Symptoms [4, 19] of dental caries vary from person to person. It depends on its size and location. When caries lesion is in its early stage, it may not have any symptoms at all. When the erosion of teeth gets larger, the following symptoms are observed:

1. Mild to sharp pain at affected tooth during eating and drinking something sweet, hot, or cold. It is also known as called tooth sensitivity.
2. Visible holes in teeth.
3. Bad breath.
4. Brownish, blackish marks may appear on any surface of an affected tooth.
5. Fever, chills, and abscess in the case of acute caries.

Complications may arise during caries as follows:

1. Cavernous sinus thrombosis can be life-threatening.
2. Heavy tooth pain, tooth loss, and discoloration.

1.2.5 Factors that Increase the Risk of Tooth Caries

Due to maintain good teeth condition people should know the following factors that increase the probability of dental caries [15].

1. Poor oral hygiene.
2. Diet with those rich in sugar and carbohydrates.
3. Alcohol consumption.
4. Tobacco uses, etc.

1.2.6 Importance of Dental Caries Detection at Its Early Stage

It is clear that very few research works have been done in detecting oral diseases. As per the report provided by [14], University of Central Lancashire, Medical School

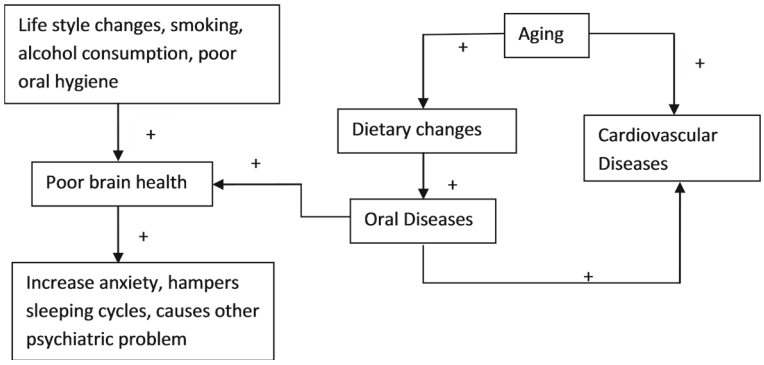


Fig. 1.5 Relation between oral disease and other complex life-threatening diseases

and Dentistry, dental caries, gum infection, and poor oral hygiene could be directly linked with Alzheimer's, cardiovascular diseases, etc. Hence, dental treatment is quite important to make our body fit. Early caries detection also plays an important role in decreasing the probability of these harmful diseases. Figure 1.5 shows how other diseases are related to oral infection.

Dietary changes and poor oral hygiene degrade our tooth condition. It is clear that periodontal disease increases the probability of cardiovascular diseases. Aging is another factor for it. Oral bacterial infection causes poor brain health condition that also increases anxiety, disorder in sleeping cycle, and many other psychiatric diseases. On the other hand, our daily life style, smoking, and alcohol consumption also affect the brain condition [10]. Therefore, we need to focus on the oral hygiene. Not only that, we need to be very cautious in getting diagnosis of the oral diseases at its early stage. Unfortunately, oral disease detection is overlooked in the modern research domain. In this thesis, I have focused on the early dental caries detection from colored and X-ray images to assist dentists.

1.3 Motivation

It is clear that dental caries is not an ordinary oral health issue. It is not confined within the oral boundary. Dental caries can cause cardiovascular disorder and may affect other body organs. Early detection of caries lesion and monitoring of the caries lesion at periodic intervals are important like the follow-up of a tumor lesion. Limited amount of research works have been carried out in this domain from an engineering perspective. Due to this reason, effective software tools are not available to detect and monitor caries lesion with minimum manual intervention. As a consequence, dentists have to do this diagnosis and follow-up process by manual observation with