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Artificial intelligence in prosthodontics

A project submitted to the council of the College of Dentistry/ University of Baghdad in partial fulfillment of the requirement for the degree of BDS in dentistry.

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SUPERVISOR CERTIFICATION

This is to certify that this project **(Artificial intelligence in prosthodontics)** was organized and prepared by the undergraduate student **Ghada Hashim Abbas** under my supervision in the Department of Prosthodontic, College of Dentistry/ University of Baghdad, as partial fulfillment of the requirements for the degree of BDS in Dentistry.

Supervisor

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DECLARATION

I declare that this project was prepared, written, and entirely the result of my own work and I have faithfully and properly cited all sources used in the dissertation.

Signature

Ghada Hashim Abbas

DEDECATION

I am honored to dedicate this project ,Which I had poured my humbled effort ,To my sweet Father and Mother, They instilled in me desire to learn and made sacrifices, Whose effection ,Love and encouragement was enough to fuel my desire to finish this work ,For pushing me to shine and for their endless love ,Which I believe in a step into the world of Dentistry.

I also would like to dedicate this to my brothers(Haider and Abbas),and my beloved sister(Raghad).Whose support was equal of importance in motivating me.

To my family for their presence ,Love ,Warmth and being my backbone.

To my best friends who were my second family, For their support , Believe,

motivating words ,love and kindness.

And of course my friends ,Who shared with my every single step in this journey ,to the memories we had together and to the support and love we give it to each other.

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List of abbreviations

Abbreviation	Mean
AI	Artificial Intelligence
CD	Complete Denture
AR	Augmented reality
ANNs	Artificial Neural Networks
ML	Machine Learning
DL	Deep Learning
CDSS	Clinical decision support systems
CAD/CAM	Computer-aided design and computer aided manufacturing
OCT	Optical Coherence Tomography
AMD	Anatomic Measuring Device
ATI	Advanced Try-In
AIRD	AvaDent Implant Record Device

INTRODUCTION

INTRODUCTION

Artificial intelligence (AI) is playing an increasingly important role in digital dentistry. AI-based algorithms are being used to analyze health data, research findings, and treatment techniques to offer diagnostic and therapeutic recommendations for individual patients. AI-based algorithms can be used to analyze health data, research findings, and treatment techniques to offer diagnostic and therapeutic recommendations for individual patients. (Buchanan, 2004)

Artificial intelligence is being used to create virtual patients in dentistry. Virtual patients can provide an excellent method for learning and honing patient interviewing skills, medical history taking, recordkeeping, and patient treatment planning. (Cook, Erwin and Triola, 2010)

Artificial intelligence -based devices can also be used to let patients oversee their health and easily share data with their dental practitioners. They are also being used to let patients oversee their health and easily share data with their dental practitioners. Additionally, AI is being used to create more accurate and aesthetically pleasing restorations using CAD/CAM technology. (Mirghani et al., 2016)

Augmented reality (AR) technology is being used in dentistry to provide virtual information in addition to that of the real environment. It is being used in oral and maxillofacial surgery to help with dental implant placement and orthognathic surgery. It is also being used in restorative dentistry, orthodontics, and endodontics to help patients visualize what they will look like after the treatment. Augmented reality can also be used in combination with additional software to enhance education and practice, allow for quicker and more precise individualized diagnoses, and enable discussions of dental treatment planning options with patients. (Joda et al., 2019)

Reactive machines are a type of AI that can be used in prosthodontics. They are designed to respond to specific stimuli and can be used to automate certain processes, such as the fabrication of dental prostheses. Reactive machines can also be used to detect and diagnose oral diseases, such as caries and periodontal disease, as well as to plan and execute prosthodontic treatments. Reactive machines can also be used to create 3D models of teeth and jaws, which can be used to create prostheses and other dental appliances. (Bidra, Taylor and Agar, 2013)

Digital technologies have been used in prosthodontics to create more accurate and aesthetically pleasing restorations. CAD/CAM technology is used to create inlays, onlays, veneers, crowns, fixed partial dentures, implant abutments, and even full-mouth reconstructions. Intraoral cameras are used to capture high-resolution images of the teeth and mouth, which can then be used to create a digital 3D model of the intraoral cavity (Ting-shu and Jian, 2014).

Computer-aided design (CAD) and 3D printing are being used in dentistry to create more accurate and aesthetically pleasing restorations. CAD/CAM technology is being used to create digital models of the patient's mouth, which can then be used to plan and practice complex dental procedures. AI-based algorithms can be used to analyze health data, research findings, and treatment techniques to offer diagnostic and therapeutic recommendations for individual patients. 3D printing can also be used to create custom-made dental prostheses, such as crowns, bridges, and dentures. (Shick et al., 2019)

Aims of the review

- The aim of this project is to explore the use of artificial intelligence (AI) in prosthodontics and its potential role in:
  - Improving diagnostic accuracy.
  - Creating more accurate restorations.
  - Creating aesthetically pleasing restorations.
  - Analyzing health data.
  - Analyzing research findings.
  - Explore treatment techniques to offer diagnostic and therapeutic recommendations for individual patients.
- Additionally, the project discusses the use of CAD/CAM technology, intraoral cameras, and 3D printing in dentistry, and delves into the future of digital techniques in dentistry.

CHAPTER 1

REVIEW OF LITERATURE

1. Review of literature.

1.1 Introduction to artificial intelligence (AI) in prosthodontics

AI is modern technology based on replicating human intelligence and activities with the help of computer algorithms. It is a form of a data-driven mathematical model. The model is trained on the previously available data, which enables the capabilities of predictions. The digitalized data is increasing day by day in the present time and helps in the training of AI models to generate more accurate results. AI model is similar to the neural network of the human body. Also, the model is referred as ANN, which stands for an artificial neural network. (Rong et al., 2020)

With the advent of implantology, various limitations of the fixed and removable prosthesis can be solved. Acceptance of implant prosthesis has been increased in recent years due to better aesthetics and stability. The cementation of implants prosthesis in the mouth may result in several problems when conventional CAD-CAM systems are used. Errors can be due to many reasons such as positional errors, cementation errors and occlusal or interproximal adjustment with an abutment. Henriette Lerner et al proposed an AI model to minimize these errors. (Shick et al., 2019)

This AI model was to help in the fabrication of fixed implant prosthesis using monolithic zirconia crowns. The deployment of the AI model to assist in the detection of subgingival margins of the abutment. Also, this model helped in increasing the dentist's focus on tooth preparation and maintaining interproximal and occlusal contacts (Chen, Stanley and Att, 2020).

1.2 Overview of AI and its applications in healthcare

It is seen that the use of AI in prosthodontics is increasing at an exponential rate. The results of the implementation are similar and sometimes better than humans. AI can be seen as a potential tool in every aspect like classifying denture fixtures, extracting marginal lines and minimizing human error involved in cementation of implants. Every study found a higher accuracy in the prediction results compared with humans. (Shan, Tay and Gu, 2021)

In health care systems, there is a large amount of data which gives ideal learning inputs of machine learning enabled decision support systems. Clinical decision support can improve the diagnostic accuracy and it helps the healthcare workers to sort out the complexities in clinical variabilities. It has potential application in the field of orthodontics, periodontics and oral surgery for analyzing the condition and treatment planning. It is also used for reducing the feudal claims in the field of dental insurance; it checks the accuracy of the details provided by the patients(Shan, Tay and Gu, 2021).

In future, the dental clinics might establish an AI comprehensive care system replacing the dental assistant. Before every appointment, the patient analyser will dictate the planning of patient's treatment with regard to his age, gender, vital signs, medical history, health conditions and drug usage (Shan, Tay and Gu, 2021).

1.3 Benefits of AI in prosthodontics

Artificial intelligence (AI) has been widely utilized in the field of medicine since its conception over 60 years ago. Although the maturity of AI in the field of dentistry has lagged in several subfields such as periodontology, endodontics, orthodontics, restorative dentistry, and oral pathology, there has been a large interest in the past few years as artificial intelligence has become increasingly accessible to researchers. (Carrillo-Perez et al., 2021)

AI has made substantial progress in the diverse disciplines of dentistry including dental disease diagnosis ,localization, classification ,estimation, and assessment of dental disease .On a broader level, AI enables the creation of intelligent machines that can achieve tasks without requiring human intervention (Revilla-León et al., 2021).

Machine learning (ML) is a subset of AI that utilizes computational algorithms to analyze datasets to make predictions without the need for explicit instructions. Towards a more sophisticated and increasingly independent approach for diagnosis, treatment planning, and risk assessment, there has been increased interest in deep learning (DL) applications .To provide expert support to healthcare practitioners, artificial neural networks (ANNs) can be utilized as clinical decision support systems (CDSS) .Moreover, such systems aid dental clinicians in producing improved dental health outcomes. (Schwendicke, Samek and Krois, 2020)

1.4 Machine learning techniques for prosthodontic applications

ML is the scientific study of algorithms and statistical models used for a vast array of processing tasks without requiring prior knowledge or hand-crafted rules. Recent years have witnessed the widespread of ML due to its superior performance for various healthcare applications such as dentistry. (Ossowska, Kusiak and Świetlik, 2022)

ML algorithms fall into two learning types: supervised and unsupervised. The amount of data generated by healthcare service providers is huge, making the data analysis process cumbersome. ML helps in effectively analyzing the data and gaining actionable insights (Tekkeşin, 2019).

Additionally, different dentistry applications can benefit from ML techniques, including disease diagnosis, prognosis, treatment, and automating the clinical workflow. Moreover, ML for clinical applications has great potential to transform traditional healthcare service delivery (Joda et al., 2020).

With machine learning, computers are able to infer their own rules by using advanced algorithms. Machine learning is used in e commerce, automobile, internet search, sensor, robotics, speech recognition, image recognition etc.

Machine learning is subdivided into four categories of learning :

- Supervised learning: The computer has a tracing data set which is correctly labeled by a human expert.
- Unsupervised learning: The computer does not use a tracing data set, but it tries to take up the data without the human guidance separating the data into clusters or groups.
- Semi supervised learning: It is not easy to supervise every dataset so when a large amount of unlabeled data is combined with a small amount of labeled data the accuracy of machine learning can be improved.
- Reinforced learning: According to Hal Varian, it is a form of sequential experimentation of a computer in an attempt to achieve a goal while interacting with a dynamic external environment (Grischke et al., 2020).

1.5 Deep learning techniques for prosthodontics applications

It is a type of machine learning that utilizes the network with different computational layers to analyse the input data. (Esteva et al., 2017)

Recent years have seen a surge of interest in the DL field, a subfield of ML, as it allows machines to mimic human intelligence in increasingly independent and sophisticated ways. DL uses multiple layers of non-linear units to analyze and extract useful knowledge from huge amounts of data. (Thompson, Jammal and Medeiros, 2020)

The extracted knowledge is then used to produce state-of-the-art prediction results. The neural network architectures used in DL provide the capability to perform automatic and accurate detection in healthcare. Based on the study, DL has enormous potential to bring genuinely impactful applications to the field of dentistry (Pethani, 2021).

1.6 Computer vision for prosthodontics applications

Methods that help computers gain understanding from digital Image. (Feature detection, image warping).The application of computer vision method is Automation of tooth restoration designs (Ahmed et al., 2021).

Three applications for reconstruction of surface information introduced:

- First aimed at building database of normalized depth images of posterior teeth and then extracting characteristic features from these images.

Results: Database created. To judge quality of automatic detection of cusp tips, 20 range images evaluated manually by dentist, twice. Average distance between automatic and human evaluation approx. 0.17 mm, with 70% patients having <0.1 mm distance between marked tip positions.

- Second digitally reconstructed given occlusal surface of posterior tooth with prepared cavity from intact model tooth from database. This could then be used for automatic milling of dental prosthesis.

Results: Dentist manually blackened 10 images to simulate cavities of 3 different sizes. Software program used to reconstruct damaged areas. Afterward, areas compared with original occlusal surfaces. Mean height difference between original and computed surfaces in range of 0.2 to 1.0 mm.

- Third, laser scanner scanned and 3Dcopied hand-made interim wax inlay or crown into different material (such as, ceramic). Results converted to format required by computerintegrated manufacturing for automatic milling.

Results: System tested with several objects in addition to teeth. Usually, 10 images used for construction of complete 3D models (Ahmed et al., 2021).

1.7 Robotics in prosthodontics and its relationship to AI

Similar to other fields, dentistry is also moving forward toward a new era of data-driven medicine assisted by robots. Robotic dental assistance has the potential to be applied to different fields including orthodontics, implant dentistry, and prosthodontics (Bolding and Reebye, 2021).

To improve the applicability of AI in dentistry, more flexible systems are needed to reach human-level performance and further improve the reliability of AI-based models in clinical practice (Chen et al., 2021).

1.8 The Virtual Patient:

A virtual patient is a digital simulation of a real human being, created from collected patient data. It can be used for educational, research, treatment planning, and patient enlightenment purposes (Rekow, 2020).

It is created by combining 3D computer-based reconstructions of human body parts, such as the head and neck, with patient-related information, such as dental findings, functional findings, and digital data such as 3D radiographs, facial 3D scans, and 3D tooth scanning. Virtual patients can be used to improve the education of future health-care professionals by optimizing their cognitive and practical skills, as well as to simulate patient-related issues (Kwon, Park and Han, 2018).

1.8.1. Idea behind the Virtual Patient

The idea behind a virtual patient is to create a database containing patient-related information to get an overview of the patient's medical and dental history. This information can then be used to create digital case scenarios for training purposes and to represent a useful source for research (Beuer, Schweiger and Edelhoff, 2008).

Additionally, 3D visualizations of the head, especially the orofacial region, can be used to create a digital portrayal of the patient. This can be used to improve the accuracy of diagnosis and treatment planning, as well as to simulate patient-related issues (Beuer, Schweiger and Edelhoff, 2008).

1.8.2. Types of virtual patient

There are several types of virtual patients, including virtual reality simulators, 3D computer-based reconstructions, and digital study models. Virtual reality simulators are used to train students and practitioners on periodontal procedures, while 3D computer-based reconstructions are used to simulate patient's intraoral soft and hard tissues for prospective 3D implant planning (Oberoi et al., 2018).

Digital study models are used to fuse different datasets of a human being, including facial surface scan and CBCT data, to generate digital study models based on CBCT data (Oberoi et al., 2018).

1.8.3. Applications of Virtual patients in medical education

Virtual patients can be used in medical education to improve the cognitive and practical skills of future health-care professionals. They can be used to simulate patient-related issues, such as diagnostics, treatment planning, and execution.

Additionally, they can be used to create digital case scenarios for training purposes and to represent a useful source for research. Virtual patients can also be used to improve the accuracy of diagnosis and treatment planning, as well as to simulate patient-related issues (Kononowicz et al., 2019).

1.8.4 Role of Virtual patients in diagnostics, treatment planning, and execution

Virtual patients can be used to improve the accuracy of diagnosis and treatment planning, as well as to simulate patient-related issues. They can be used to create digital case scenarios for training purposes and to represent a useful source for research.

Additionally, 3D visualizations of the head, especially the orofacial region, can be used to create a digital portrayal of the patient. This can be used to improve the accuracy of diagnosis and treatment planning, as well as to simulate patient-related issues (Huang, Liaw and Lai, 2013).

1.8.5. Role of Virtual patients in dental education

Virtual patients can be used in dental education to improve the cognitive and practical skills of future dental professionals. They can be used to simulate patient-related issues, such as diagnostics, treatment planning, and execution.

Additionally, they can be used to create digital case scenarios for training purposes and to represent a useful source for research. Virtual patients can also be used to improve the accuracy of diagnosis and treatment planning, as well as to simulate patient-related issues (Aimar, Palermo and Innocenti, 2019).

1.8.6. Future role of virtual patients

In the future, virtual patients may be used to create more realistic simulations of patient-related issues, such as diagnostics, treatment planning, and execution. Additionally, they may be used to create more interactive and immersive virtual reality simulations, such as manikin-based and virtual reality simulations.as shown in (Figure1.1)

Furthermore, virtual patients may be used to create more realistic and life-like avatars for use in film-making and other media (Ayoub and Pulijala, 2019).

Figure1.1: Illustration of augmented reality. On the screen a radiological image is superimposed to a real-time capturing of a person(Ayoub and Pulijala, 2019).

1.9. Meanings of Digital Impressions

Digital impressions are a type of dental impression that is taken using digital technology, such as intraoral scanners, digital cast scanners, and cone beam computed tomography.Digital impressions are becoming increasingly popular in the dental profession due to their accuracy and convenience. They are also more cost-effective than traditional impressions, as they require less time and materials (Xia et al., 2001).

1.9.1 Advantages and disadvantages of Digital Impressions

The main advantages of digital impressions are accuracy, convenience, and cost-effectiveness. Digital impressions are more accurate than traditional impressions, as they provide a high-resolution image of the prepared tooth. They also require less time and materials, making them more cost-effective. Additionally, digital impressions are more comfortable for patients, as they eliminate the need for traditional impression materials. (Patzelt et al., 2013b).

The main disadvantage of digital impressions is that they are not suitable for all clinical scenarios. For example, digital impressions are not able to capture an image through tissue, saliva, and blood, so they are not suitable for capturing subgingival preparation margins. Additionally, digital impressions require a significant initial investment, which may not be feasible for some dental practices (Patzelt et al., 2013b).

1.9.2. Indications of Digital Impressions

Digital impressions are most commonly used for fixed restorations, such as crowns, inlays, onlays, veneers, and fixed partial dentures. They can also be used to fabricate and mill provisional restorations in one appointment, and to design and mill restorations that can be sent to a dental laboratory via the internet. Digital impressions can also be used to create 3D printed or milled casts based on the data from the digital impression (Ahrberg et al., 2015).

1.9.3 Contraindications of Digital Impressions

The main contraindication for digital impressions is the inability to access the area with the digital camera. This can occur if the camera head is too large or the patient does not have the ability to open wide enough to accommodate the camera head.

Additionally, digital impressions require patient cooperation, so lack of patient cooperation can also be a contraindication. (Amin et al., 2016)

1.9.4 Conventional impression versus digital impression making

Conventional impression making involves taking an impression of the prepared tooth using a custom tray and impression material .Digital impression making involves taking an impression of the prepared tooth using digital technology, such as intraoral scanners, digital cast scanners, and cone beam computed tomography. (Imburgia et al., 2017)

Digital impressions are more accurate than conventional impressions, as they provide a high-resolution image of the prepared tooth.Additionally,digital impressions are more cost-effective than conventional impressions, as they require less time and materials (Brawek et al., 2013).

1.9.5 Economic roles of computer-aided impression making

The economic roles of computer-aided impression making include improved efficiency and profitability of the dental practice, reduced remakes, reduced seating time of restorations, and lower or eliminated laboratory bills (Alghazzawi, 2016).

Digital impressions are also less costly than conventional impressions, as they require less time and materials .Additionally, digital impressions can be sent to the dental laboratory via the internet, which reduces the cost of shipping and handling (Lee and Gallucci, 2012).

1.9.6. Digital impression technique in prosthodontics

Digital impression techniques are increasingly being used in prosthodontics for the treatment planning of implant placement and the design and milling of implant abutments and restorations. Digital impressions are more accurate than conventional impressions and can be used to fabricate and mill restorations in one appointment chairside (Galhano, Pellizzer and Mazaro, 2012).

Additionally, digital impressions can be sent via the internet to a laboratory for design and fabrication of physical casts and/or prostheses. Digital impressions are also less costly and easier to store, as they do not take up any physical space (Galhano, Pellizzer and Mazaro, 2012).

1.9.7. Future innovations of digital impressions

Future innovations in the area of digital impressions can only be limited by the imagination. Research is now being done with the use of SONAR technology in capturing images, and radiation-free Optical Coherence Tomography (OCT) has been used in optometry for a while, but now, applications in dentistry are evolving. (Anadioti et al., 2014)

OCT produces real time images as deep as 3 mm into the tissue structure, which would make imaging systems even more user-friendly by eliminating the interference of blood and soft tissue in making impression (Della Bona et al., 2021).

Additionally, companies are developing dental imaging systems with the elimination of the need for powdering during imaging, and the cameras are steadily improving. It is predicted that by the year 2015, a majority of dental impressions sent to dental laboratories will be digital. (Della Bona et al., 2021).

1.10. Components of Digital acquisition units

Digital acquisition units typically consist of a digital camera, a computer, and software. The digital camera is used to capture the image of the prepared tooth, the computer is used to process the image, and the software is used to design and mill the restoration. Additionally, some digital acquisition units may also include a milling machine, which can be used to fabricate the restoration chairside. (Wismeijer et al., 2013)

Intraoral cameras and scanners are being used in prosthodontics to create digital models of the patient's mouth. These digital models can then be used to plan and practice complex dental procedures, such as crowns, bridges, and dentures. Intraoral cameras and scanners can also be used to capture high-resolution images of the teeth and mouth, which can then be used to create custom-made prostheses.

Additionally, intraoral cameras and scanners can be used to detect hidden and overlooked defects in teeth and other parts of the cavity. (Yuzbasioglu et al., 2014)

1.10.1 Sole impression systems

Sole impression systems are digital acquisition systems that use a digital camera, computer, and software to capture a digital impression of the prepared tooth. These systems are used to fabricate crowns, bridges, inlays, onlays, and veneers in one appointment (Renne et al., 2017).

They are more accurate and efficient than conventional impressions, and can be used to send the digital impression to a qualified dental laboratory for processing and fabrication of the restoration. Additionally, some sole impression systems may also include a milling machine, which can be used to fabricate the restoration chairside (Renne et al., 2017).

1.10.2 Prosthetic role of CAD/CAM impression systems

CAD/CAM impression systems are used to fabricate crowns, bridges, inlays, onlays, and veneers in one appointment. They are more accurate and efficient than conventional impressions, and can be used to design and mill the restoration chairside in the dental office. Additionally, these systems can be used to send digital impressions via the internet to a dental laboratory for design and fabrication of physical casts and/or prostheses (MIYAZAKI et al., 2009).

1.10.3 Prosthodontic applications of iTero

The iTero scanner is an open platform system that offers the ability to connect to a certified design software and chairside milling machine as shown in (Figure1.2). It can be used to fabricate crowns, bridges, inlays, onlays, and veneers in one appointment. Additionally, it can be used to send digital impressions via the internet to a dental laboratory for design and fabrication of physical casts and/or prostheses (Dawood et al., 2015).

Figure1.2: Captured screenshots of a partial arch digital impression done with the iTero. (Dawood et al., 2015)

1.10.4 3M true definition scanner

The 3M True Definition Scanner is a digital scanning system that uses a blue LED light and an active wavefront sampling video imaging system to capture a virtual cast as shown in (Figure1.3). It is an open platform system that can be connected to a certified design software and chairside milling machine, allowing for the fabrication of crowns, bridges, inlays, onlays, and veneers in one appointment (Vandewegheet al., 2016).

(A)

(B)

Figure1.3:A.3M True Definition intraoral scanning system,**B.** the 3M True Definition Scanner (Vandeweghe et al., 2016).

1.10.5 CEREC systems

CEREC systems are CAD/CAM technology systems that have been in existence for close to three decades. The CEREC AC digital impression system with BlueCam, released in 2009, has a number of improved technologies over the older RedCam system, including an image-capturing system that automatically determines the focus of the subject and instantly saves the image.

The CEREC software is robust enough to design and mill single-unit inlays, onlays, veneers, crowns, and fixed partial dentures, both provisional and permanent, as well as implants abutments (Gildo Coelho Santos et al., 2013).

1.10.6 PlanScan in prosthodontics

The PlanScan system, driven by E4D Technologies. It uses blue laser light with real-time video-streaming technology to capture the dental data, and it is powder-free. It can be used to design inlays, onlays, crowns, bridges, and veneers, and the scans can be sent to the laboratory for processing, designing, and manufacturing of the restorations or the restorations can be milled chairside using the PlanMill 40 milling machine as shown in (Figure 1.4).(Mangano et al., 2017).

The PlanScan system is increasingly being used in prosthodontics for the treatment planning of implant placement and the design and milling of implant abutments and restorations (Kim, Park and Shim, 2018).

Figure1.4: PlanScan intraoral scanning system with PlanMill milling machine and laptop (Mangano et al., 2017).

1.10.7 CS3500 intraoral digital impression scanner in prosthodontics

The CS 3500 intraoral scanner is one of the latest available powder-free intraoral scanners that enables dental professionals to scan patients' teeth to create color 3D images. It can be used to design a single crown, bridge, inlay, onlay, and veneer through the CS Restore software and milled with the optional care stream milling machine (CS 3000) or the data can be sent to a laboratory for design and milling (Abduo and Elseyoufi, 2018).

Additionally, the colored 3D image are supposed to help drawing margin lines easily and identifying the differences between natural tooth structure and existing restorations. The CS3500 intraoral digital impression scanner is increasingly being used in prosthodontics for the treatment planning of implant placement and the design and milling of implant abutments and restorations (Abduo and Elseyoufi, 2018).

1.11. Digital Design and Manufacture of Implant Abutments

1.11.1. Implant abutments

Implant abutments are generally classified into two types: prefabricated implant abutments and custom-made implant abutments.Prefabricated abutments are manufactured using subtractive manufacturing technology and are readily available (Khalifeh et al., 2013).

Custom abutments are designed digitally and fabricated using milling technology. CAD/CAM abutments are economical to fabricate and provide optimum contours for the restoration resulting in better esthetics and function (Joda and Brägger, 2015).

Digital design and manufacture of implant abutments is becoming increasingly popular due to its accuracy and cost-effectiveness. CAD/CAM abutments are designed digitally and fabricated using milling technology for each individual patient. Prefabricated abutments are also widely used and can be easily modified. (Flügge et al., 2015)

Custom abutments, which were traditionally waxed and cast, can now be designed digitally and fabricated using milling technology. ATLANTIS abutments are individually designed to fabricate cement- or screw-retained abutments (Schubert et al., 2019).

1.11.2 Prefabricated abutments

Prefabricated abutments are manufactured using subtractive manufacturing technology and the seating surface of these abutments is precision milled to passively fit the head of the implant with very low machining tolerance. They are biocompatible and can be easily modified, but their contours are rarely anatomic and do not support the surrounding soft tissues. . An example of a prefabricated abutment is shown in (Figure 1.5) (Joda, Zarone and Ferrari, 2017).

Figure1.5 :A titanium prefabricated abutment designed for an implant with an external connection. Note the gold abutment screw that is used to retain the abutment and the impression coping used to make an impression from the head of the implant (Joda, Zarone and Ferrari, 2017).

1.11.3 Custom abutments

Custom abutments were first described in 1988 and traditionally consisted of a plastic sleeve or a gold cylinder that could be waxed to specification and cast in metal alloy to fabricate an abutment as shown in (Figure1.6). With the continued evolution of dental technology, abutments can now be designed digitally and fabricated using milling technology for each individual patient. CAD/CAM abutments are economical to fabricate and provide optimum contours for the restoration resulting in better esthetics and function (Elgezawi et al., 2017).

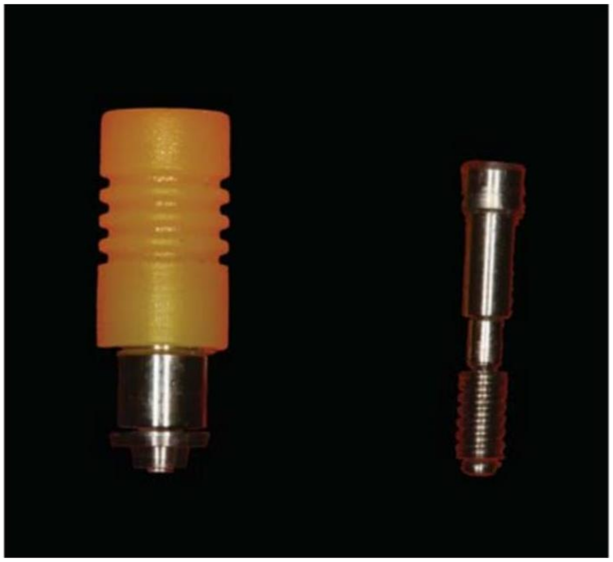


Figure1.6: A Gold Adapt (NobelBiocare) custom abutment and retaining screw, before fabrication (Elgezawi et al., 2017).

1.11.4. CAD/CAM abutment design principles

CAD/CAM abutment design principles involve two digital workflows. In the first workflow, a conventional impression is made of the head of the implant to fabricate a master cast in which implant position and angulation relative to other structures in the dental arch is registered. This master cast is then verified for accuracy and scanned using a desktop scanner to fabricate a digital master cast (D’haese et al., 2016).

Custom abutments can be digitally created and designed with optimum anatomical contours to provide adequate resistance and retention form, esthetic emergence profile, and optimum hygiene (Patzelt et al., 2013).

In the second workflow, a digital impression is made using impression copings specifically designed for digital impressions, and they are referred to as scan bodies.

As shown in (figure1.7) (Lee et al., 2005).

A scan body is used to index the implant position and used to obtain a digital master cast. The digital master cast can then be used to virtually design a custom abutment, which can be later milled and sent to the clinician (Lee et al., 2005).

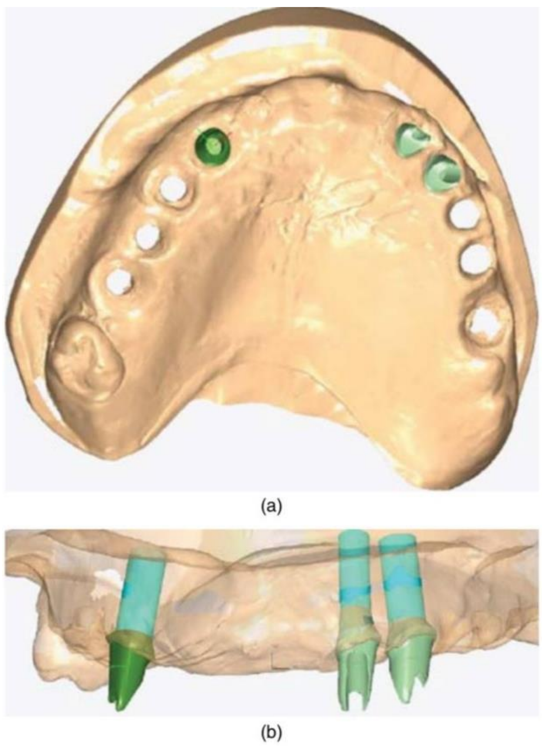


Figure1.7: a) Occlusal view of scanned master cast and the design of CAD/CAM custom abutments. White color represents the location of implants and abutments are in green**.(b)** Frontal view of scanned master cast and abutments design (Lee et al., 2005).

1.11.5. ATLANTIS abutments

ATLANTIS abutments are individually designed to fabricate cement- or screw-retained abutments. The master cast is scanned (by DENTSPLY Implants) to fabricate a digital master cast with accurate representation of soft tissues, remaining teeth, and implant.The opposing cast is also scanned along with the occlusal registration and the provisional restoration or (waxup) to digitally articulate the casts and design the custom abutments. Once the abutments are designed, a link is sent to the dentist or laboratory technicians to review the abutment design and edit it using ATLANTIS 3D Editor software (Zeller et al., 2019).

ATLANTIS 3D Editor software is an online, easy to use, graphic supported communication tool for the dental laboratories and dentists. Using this software, the dentist/laboratory technician can evaluate articulated casts and edit the abutment design.

A superimposed view of the provisional restoration can be used to investigate the available restorative space, margin type, width, and location relative to soft tissues and emergence profile of the designed custom abutment.

The occlusal and frontal views can also be used to evaluate the path of insertion of the restoration. Once the design of custom abutments is finalized and approved, the abutments are fabricated (by DENTSPLY Implants) and returned to the dentist to try in the mouth.As shown in (Figure 1.8) (Zeller et al., 2019).

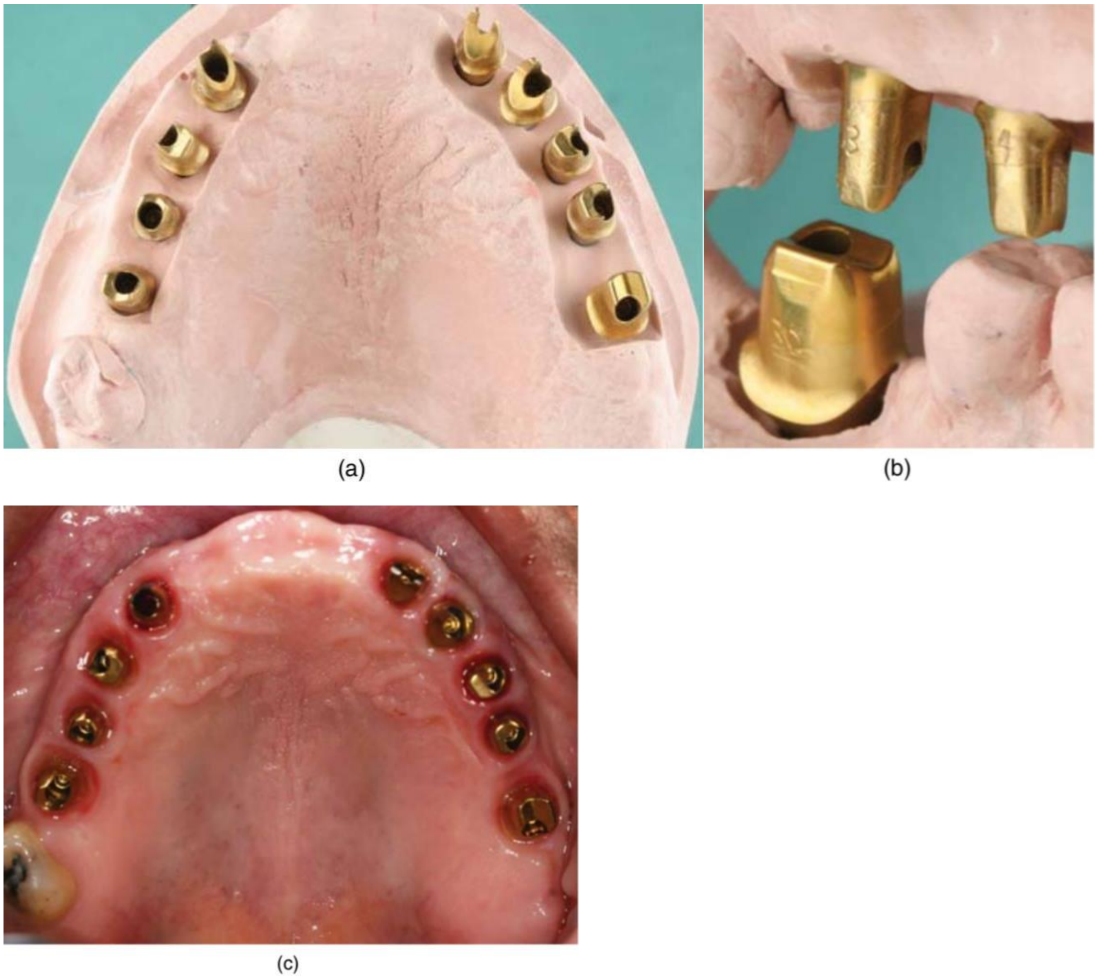


Figure1.8: a) Occlusal view of milled ATLANTIS abutments.The abutments are coated with TiN to give gold shading. **(b)** Lateral view of ATLANTIS custom abutments. **(c)** Try-in of abutments in the mouth.(Zeller et al., 2019).

1.11.6. NobelProcera abutments

NobelProcera abutments are compatible with 3D Shape intraoral scanners and can be designed directly from an intraoral digital impression without the need to obtain and scan a master cast. The finalized design can be sent online to order milled abutments. It can be fabricated from Ti-6Al-4V, zirconia, alumina, base metal alloy (cobalt chromium), IPS e.max, and acrylic (Telio CAD) for the fabrication of provisional restorations (Sailer et al., 2007).

NobelProcera software can also be used to fabricate milled bars, screw-retained attachments, and clips. In addition, the software can be used to design virtual bars by installing digital abutments on the digital master cast and allowing the software to connect these abutments with a bar, using preset bar designs programmed into the software. As shown in (Figure 1.9).Bar dimensions, location, distance from soft tissue can be intuitively and easily edited according to the specifications provided by the dentist (Sailer et al., 2007).

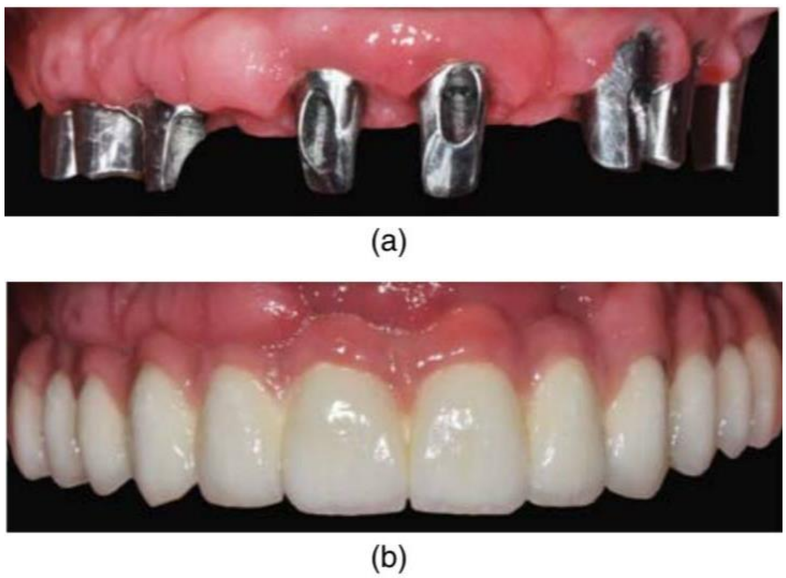


Figure1.9: (a) Custom abutments designed using NobelProcera system. **(b)** Final prosthesis cemented on NobelProcera abutments (Sailer et al., 2007).

1.12. BellaTek encode system

The BellaTek Encode system uses a custom-designed coded healing abutment (Encode abutment) to convey implant position in the dental arch.

The abutment is engraved with specific occlusal surface coding and can be used instead of an impression coping or a scan body.

The digital master cast can be made either directly using an intraoral digital impression system of the coded healing abutment or indirectly by scanning a cast made from a conventional impression.However, the accuracy of this system is not fully characterized and more studies are needed to evaluate the accuracy and the potential of this system(Batak et al., 2020).

1.13. Relation of complete dentures and the CAD/CAM technology

CAD/CAM stands for computer-aided design and computer-aided manufacturing. It is a technology that uses computer software to design and manufacture products. CAD/CAM is used in a variety of industries, including dentistry, to create products such as complete dentures (Steinmassl et al., 2018).

CAD/CAM technology is used to create complete dentures by designing and manufacturing them using computer software. This technology allows for the fabrication of complete dentures in two appointments, with the first appointment consisting of data gathering and the second appointment consisting of denture placement and adjustments. Additionally, CAD/CAM technology can be used to fabricate trial dentures and conversion dentures (Jokstad, 2004).

1.14. Advantages and disadvantages of CAD/CAM dentures

1.14.1. Advantages of CAD/CAM dentures

The advantages of CAD/CAM dentures include a superior fit and strength compared to conventionally processed acrylic resin, less residual monomer, and more hydrophobic properties.Additionally, CAD/CAM dentures require less clinical chair time, can be produced in two appointments, and can be used to produce a spare denture or a replacement denture if the patient loses their denture(s).(Ceyhan et al., 2003).

1.14.2. Disadvantages of CAD/CAM dentures

The disadvantages of CAD/CAM dentures include a learning curve for the inexperienced clinician initially that could lead to unsatisfactory results, the need to use a dimensionally stable and temperature resistant impression material to resist distortion during shipping, and the lack of trial placement appointment which could create an increased chance for less than an ideal outcome and missed opportunity for minor adjustments (Baba et al., 2020).

1.15. Commercially available CAD/CAM complete dentures

Currently, two commercial manufacturers are available for the fabrication of CAD/CAM dentures. AvaDent Digital Dentures (Global Dental Science LLC., Scottsdale, AZ) uses subtractive manufacturing for the fabrication of their dentures, while Dentca (Dentca Inc., Los Angeles, CA) uses additive manufacturing (such as RP or 3D printing) to fabricate trial dentures and then the definitive denture(s) is/are processed conventionally using 3D printed flasks (van Noort, 2012).

1.16. Step-by-step procedures for the fabrication of complete dentures using the AvaDent system:

The AvaDent system allows for the fabrication of complete dentures using three methods: (Arakawa et al., 2021).

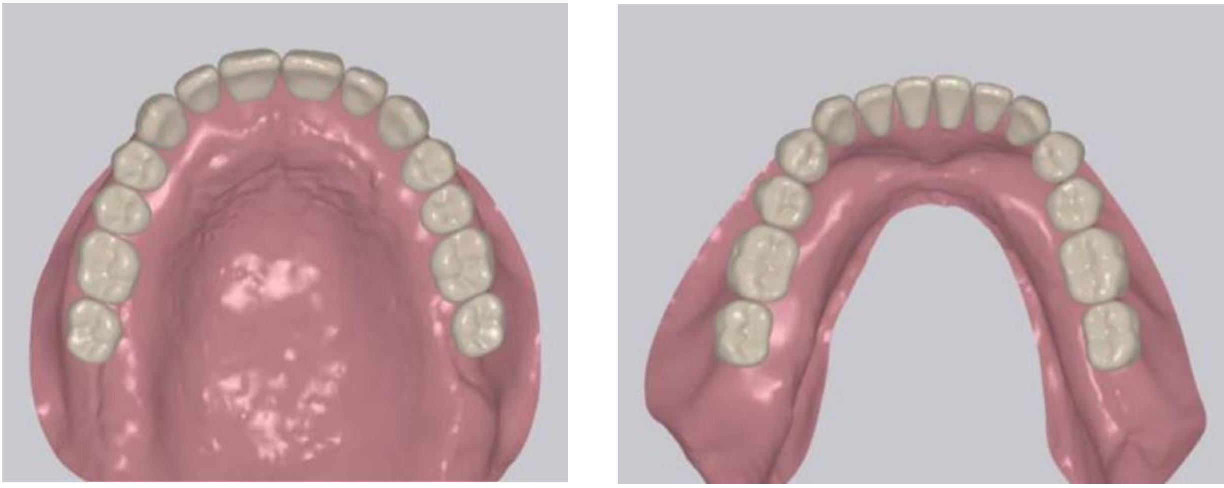
1) Duplicate a patient's existing denture for use in making a reline impression and interocclusal record.
2) Use of Good Fit denture trays for impressions and records.
3) Use of anatomic measuring device (AMD) as shown in (Figure1.10) (Arakawa et al., 2021).

Figure1.10: Mandibular and maxillary Anatomical Measuring Devices (Arakawa et al., 2021).

After the impressions and records are taken, a digital preview of the prostheses is emailed to the clinician for approval. The denture bases are then milled from different choices of base material with recesses into which the requested denture teeth are bonded. Prior to the fabrication of the final digital denture, the clinician can request an optional advanced try-in denture (ATI) to allow for evaluation of esthetics, phonetics and functional components of the denture in the patient’s mouth. Adjustments can be made to the trial denture by repositioning the teeth in the wax to meet the needs of the patient (Arakawa et al., 2021).

1.16.1 Laboratory procedures

The laboratory procedures for the fabrication of CAD/CAM dentures involve the disinfection of the complete arch impressions and the connected maxillary and mandibular AMDs, which are then laser scanned. A computer software program is then used to build the occlusal relationship of the maxillary and mandibular arches from the morphologic data obtained by scanning. The digital preview of the prostheses is then emailed to the clinician for approval as shown in (Figure 1.11). The denture bases are then milled from different choices of base material with recesses into which the requested denture teeth are bonded (Kattadiyil, Goodacre and Baba, 2013).



(a) (b)

Figure1.11: (a) Maxillary full arch view of the digital preview of the prostheses. **(b)**Mandibular full arch view of the digital preview of the prostheses.
(Kattadiyil, Goodacre and Baba, 2013)

1.16.2. Denture placement and adjustments

The placement and post-placement adjustments of CAD/CAM complete dentures are similar to the placement of conventional dentures using pressure indicating paste and making adjustments to the base as necessary to optimize the base-to-mucosa contact. Intraoral occlusal adjustments are made as required. In the case of significant occlusal discrepancies, a clinical remount procedure can be performed (Joachim Tinschert et al., 2004).

1.17. Step-by-step procedures for the fabrication of complete dentures using the Dentca system;

The Dentca system allows for the fabrication of complete dentures in two appointments. The first appointment consists of data gathering (impressions, jaw relations, occlusal plane orientation, tooth mold, and shade selection) and the second appointment consists of denture placement and adjustments.

The Dentca system provides the clinician with a starter kit that contains stock trays of different sizes (S, M, L, and XL), a Dentca™ Lip ruler, a Dentca™ Jaw Gauge, and an EZ-Tracer™ as shown in (Figure1.12). The appropriate maxillary and mandibular trays are selected based on the patient's arch size and adhesive is applied to the selected stock trays.

Figure1.12: Maxillary and mandibular Dentca stock trays and lip ruler. (Han et al., 2017)

The definitive impressions are then made in the same manner used to make the definitive impressions for the AvaDent system. After the impressions are taken, a digital preview of the prostheses is emailed to the clinician for approval. The denture bases are then 3D printed and the denture teeth are bonded to the base. The final denture is then polished and delivered to the patient (Han et al., 2017).

1.17.1 Laboratory procedures for the fabrication of complete dentures using the Dentca system

The laboratory procedures for the fabrication of complete dentures using the Dentca system involve the selection of the appropriate maxillary and mandibular trays based on the patient’s arch size and the application of adhesive to the selected stock trays. The definitive impressions are then made in the same manner used to make the definitive impressions for the AvaDent system. After the impressions are taken, a digital preview of the prostheses is emailed to the clinician for approval. The denture bases are then 3D printed and the denture teeth are bonded to the base. The final denture is then polished and delivered to the patient (Anadioti et al., 2020).

1.18. Technique description for the fabrication of a digital definitive fixed complete denture

The technique description for the fabrication of a digital definitive fixed complete denture involves taking final impressions and records, using the AvaDent implant record device and verification jig to simplify the impression making process, reseating and attaching the denture with screws, making an interocclusal record between the AIRD (which is a duplicate of the complete denture but has an occlusal opening that fits over the verification jig,It functions as an impression tray)and the opposing provisional denture as shown in (Figure1.13), sending the final impression and interocclusal record to Global Dental Science, and using the digital data to create a definitive maxillary CD and a mandibular fixed CD (Nedelcu et al., 2018).

(a)

Figure1.13: (a) AvaDent implant record device(Nedelcu et al., 2018).

(b)

Figure1.13(b): AvaDent verification jig. (Nedelcu et al., 2018).

The maxillary denture can have commercially available denture teeth placed into the milled recesses on the denture base or custom milled teeth. Finally, the definitive maxillary denture is placed and the occlusion is finalized (Ahlholm et al., 2016).

1.19. Future application of digital techniques in dentistry:

Smart teeth are being used in prosthodontics to monitor various factors, such as saliva's pH, food intake, and the quantity of bacteria present in the mouth. Smart teeth can also be used to detect hidden and overlooked defects in teeth and other parts of the cavity. Additionally, smart teeth can be used to create custom-made prostheses, such as crowns, bridges, and dentures (Jones, 2021).

Regenerative dentistry is being used in prosthodontics to promote and improve the healing of tissues and organs of the human body, to restore the physiological architecture and the main functions lost. Regenerative dentistry can be used to create custom-made prostheses, such as crowns, bridges, and dentures, as well as to detect hidden and overlooked defects in teeth and other parts of the cavity. Additionally, regenerative dentistry can be used to create self-healing teeth and biological therapy for damaged teeth. Additionally, regenerative dentistry and nanodentistry are being used to develop materials with novel properties and to create more efficient treatment (Salinas and Vallet-Regí, 2013).

CRISPR technology is being used in prosthodontics to correct genetic errors and turn on/off genes in cells and organisms. CRISPR can be used to detect hidden and overlooked defects in teeth and other parts of the cavity, as well as to create custom-made prostheses, such as crowns, bridges, and dentures. (Belizário and Napolitano, 2015).

Additionally, CRISPR can be used to develop new therapies to combat systemic diseases, such as genetic disorders (Belizário and Napolitano, 2015).

Robotics in navigational surgery is being used in prosthodontics to place dental implants. Robotics in navigational surgery can also be used to detect hidden and overlooked defects in teeth and other parts of the cavity, as well as to create custom-made prostheses, such as crowns, bridges, and dentures.Additionally, robotics in navigational surgery can be used to execute surgical tasks directly on patients without any apparent control by a surgeon (Khalifeh et al., 2013).

Nanodentistry is being used in prosthodontics to diagnose, treat, and prevent oral and dental disease. Nanodentistry can be used to detect hidden and overlooked defects in teeth and other parts of the cavity, as well as to create custom-made prostheses, such as crowns, bridges, and dentures.Additionally, Nanodentistry can be used to create sophisticated methods for diagnosis, therapy, and prevention (Abiodun Solanke, Ajayi and Arigbede, 2014).

2. Conclusions

- The conclusions of this project illuminate that AI has the potential to improve diagnostic accuracy, create more accurate and aesthetically pleasing restorations, and contribute to the overall improvement of dental care quality and accessibility.
- The project also discusses the future of digital techniques in dentistry, which will continue to evolve and enhance the field of prosthodontics.
- Overall, the project emphasizes the importance of incorporating technology and AI into dental practice to provide the best possible outcomes for patients.

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