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A Fully Integrated System for Digital Dentistry Workflow and Manufacturing Management

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ABSTRACT

To improve interoperability between various digital components and maximize workflow effectiveness in a collaborative setting, a novel platform for the field of digital dentistry was developed. This platform facilitates interoperability and collaboration management by implementing the DICOM standard, thereby enhancing integration and coordination among various stakeholders. This platform has some limitations, and it is not enough to cover most of digital dentistry in dental practice. So, this study aims to cover this gap and the limitations of this platform and process of production in digital dentistry practice. This paper reviews peer-reviewed literature to analyze elements that impact the process of digital dentistry and critically examines an array of technologies and practices to unveil the underlying technologies in the digital dentistry workflow. The study found the absence of many workstations and one modality in the previous platform, as well as the absence of the integration of all dental workflow phases and the absence of the application layer. So, we proposed a novel system that covers most of the digital dentistry in dental practice with the process of production. The new novel platform added one modality, which is the facial scanner, and three workstations, including orthodontic alignment, Digital Design Smile (DSD), and guided endodontic planning. Also, the new system takes into account the integration of all dental workflow phases and the application layer, which was not part of the old platform, as well as the integration of different intelligently guided software to diagnose and suggest treatment.

1. Introduction

The progression of digital health is imminent to enhance the quality of healthcare services, while simultaneously optimizing healthcare management [1-4]. This innovation has been important in minimizing prescription errors and adverse drug responses, as well as enhancing compliance with practice guidelines within the healthcare profession [5]. Digital dentistry is a field of dentistry that utilizes advanced digital technologies for diagnosis, treatment planning and various dental procedures. It involves the use of digital tools, modalities, and workstations such as CBCT, CAD/CAM,

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intraoral and extraoral scanners, implant planning guides, CNC machining, 3D digital printer, among others [6,7].

The importance of learning about digital dentistry in both theoretical and practical aspects was proposed in a digital dentistry module for Bachelor Dentistry (BDS) students that aims to introduce and educate them on digital dentistry. The digital dentistry module was developed, which can be implemented in various dental institutions depending on the available resources and infrastructure. Integrating the course with digital technology and clinical workflows is expected to provide graduates with the essential knowledge, skills and experiences necessary to competently deliver patient care [8].

This study ultimately projects an improved ability to offer high-quality healthcare services to patients. As such, this study will be useful to many stakeholders in the healthcare sector. First, the study outcomes may serve as a guide for the healthcare sector to increase the adoption of digital dentistry in all dental care practices. May revise the existing policy of installing digital dentistry in all healthcare facilities based on the outcomes. Given that dental practitioners are the main users of digital dentistry, this study contributes to the expansion of their knowledge base pertaining to a more effective, safer and high-quality treatment delivery. Besides, policymakers and managers in the healthcare sector may acquire insights into the various issues raised by end-users that may influence their adoption of digital dentistry. This study aims to enhance the automation of digital dentistry workflows, which is crucial to improving interoperability between various digital components and maximizing workflow effectiveness in a collaborative setting.

An alternate digital workflow that interrupts data integration and transmission is frequently created using a partial manual entry process. This has negative effects on productivity, increases the likelihood of data entry errors and raises the possibility of privacy protections being breached. Additionally, non-integrated data transfer techniques might not be sufficient to handle the volume of users, data storage requirements, and the transmission of patient data. To ensure optimal useability, the information technology (IT) infrastructure must be evaluated for high-volume users or institutions. To ensure that the IT is of the appropriate size and capacity for the institution's current and anticipated future needs, capacity management is used [9].

The three main file formats used to store data after the acquisition of an intraoral scan must be able to be recognized, accessed, and used by software programs. Standard Triangle Language (STL), Object (OBJ), and Polygon (PLY) are the names of these three file types. These file types are utilized to simply encode the 3D geometry of a model or object. By tracing and filling the shape of an object with neighboring triangles (facets) that meet at butt joints, an "approximate mesh" created from STL files encodes the 2D surface. The most popular file type for 3D printing is STL, but this results in a less accurate model because STL files don't include any information about surface texture or shade [10,11].

By building a model of the object with adjacent polygonal facets, OBJ and PLY files are converted into a precise mesh. The latter two formats also contain data on surface texture, color and original mesh. By using 3D printers, one can fabricate 3D objects such as dental restorations (crowns, dentures, etc.) using both approximate mesh and precise mesh models. Even though an integrated workflow is preferred, a review of other workflow possibilities is necessary. Integrated workflows exist for digital dentistry, as shown in Figure 1 [12].

The introduction of new materials for prosthetic construction and new computerized solutions improves dental treatment and workflow for patients and dental participants, including dentists, dental surgeons, laboratories, and production facilities. Digital tools like scanners, design software, production planning software, CNC milling machines, and more recently 3D printers make it easier to produce various prosthetics and surgical guide tools while improving the quality and cutting down on treatment time.

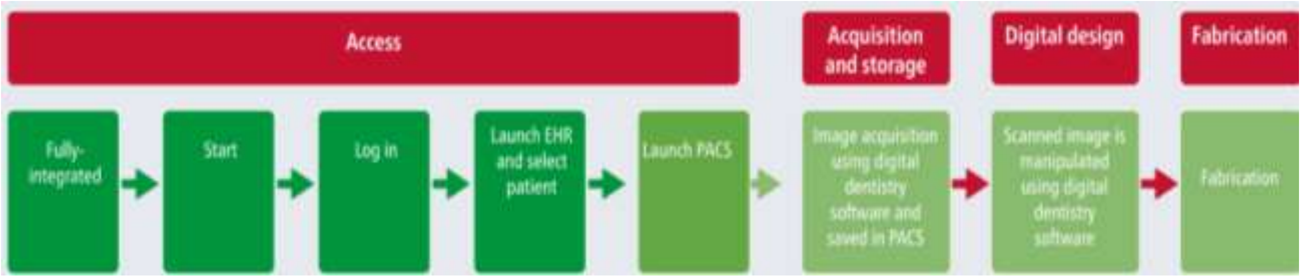

Fig. 1. Integrated workflows for digital dentistry [12]

For digital planning in endodontics, cone-beam computed tomography (CBCT) serves as the foundation. Endodontic planning is based on data obtained from careful exploration of CBCT images, which reveal specifics of the internal anatomy of the teeth and surrounding structures. On the other hand, intraoral scanner images that capture the external surface of teeth and surrounding periodontal tissues are the primary foundation for digital planning used in oral rehabilitation. Endodontists have a hard time finding root ramifications, fractures and perforations, as well as different levels of obliteration and root canal wall thickness because the structures they are looking for are so small. High-resolution imaging tests are necessary to visualize the endodontic microanatomy in this complex condition [13].

The dental industry is using CNC machines, which opens up the possibility of producing prosthetics for dentistry. Current resin-based 3D printers can create a variety of surgical guides and dental prosthetics. 3D imaging and modeling, as well as CAD technologies, are significantly influencing the entire field of dentistry. This digital data can be used to precisely create unique and complex geometrical forms in a variety of materials, either locally or in manufacturing centers. Even though a 3D printer can currently create almost everything we make for our patients, no one technology can meet all of their needs. Similar technology is being used to print models for restorative dentistry and patterns for the lost wax process, which is becoming more and more crucial with the development of intraoral scanning systems. The technology is already widely used in orthodontics, where high-resolution printing in resin is already an entirely practical proposition. It is becoming standard practice and a requirement in maxillofacial and implant surgery to use anatomical models created using a variety of different 3D printing techniques to aid in the planning of complex treatments. It is widely accepted that using surgical guides printed in resin or autoclavable nylon may make surgery less invasive and more predictable [14].

According to recent studies, using 3D-printed guides in the field of endodontics has potential. 3D-printed guides with endodontic clinical applications can be made using computer-aided design and manufacturing technologies. The term "guided endodontics," which includes 3D planning, 3D models, and 3D printed guides, is increasing in popularity. Studies demonstrate that, particularly in highly complex cases, the use of 3D printing in endodontics opens up the possibility of promising techniques with highly predictable outcomes and a low risk of iatrogenic damage [15].

In light of the rapid advancement of information technology, society is currently undergoing a transformative shift towards the digital age, where the majority of tasks and processes are increasingly reliant on computer systems and the internet. Within the dental industry, there has been a notable adoption of sophisticated software applications that enable the modification and creation of smiles, resulting in a significant transformation of esthetic dentistry practices. The concept and software known as digital smile design (DSD) have emerged relatively recently, aiming to analyze an individual's smile using a combination of input scanners and photographs. A wide range of solutions and predictions are offered regarding the design of the smile, to the extent that it can accurately identify and address minor adjustments [16].

Based on the needs of the customer or patient, it is crucial to take customized details into account during the design and production of the final product. This calls for a manufacturing system that is pull-oriented. One of the primary obstacles in the field of digital dentistry is the insufficient understanding of engineering principles among the majority of participants involved in dental workflows. While these individuals possess expertise in dentistry, there is a pressing need for them to enhance their knowledge and skills in utilizing digital devices [17,18]. This is one pressing need for highly automated digital dental solutions, allowing users to perform routine tasks with ease and without needing extensive engineering knowledge.

A digital image analysis program, for example, can only handle images of a standard size and resolution, including images in which the patient is positioned in a standard manner. The new capabilities of digital technology, utilizing 3D facial scans, have acceptable levels of reliability for soft tissue analysis. However, additional investigations are required to validate these findings. The development of radiation-free techniques has the potential to become a more reliable approach, aiming to minimize the exposure of orthodontic patients to radiation. The lack of standardization for comparison and diagnosis hinders the adoption of 3D images. Therefore, conventional radiological methods, such as CBCT, are still utilized even in non-elective cases due to their defined requirements. The study suggests that the integration of intraoral scanning with 3D facial scans has the potential to emerge as the preferred diagnostic method in the field of orthodontics [19].

2. Digital Process in Digital Dentistry Platform

Prosthetics are typically created in four steps: scanning, design, process planning and production [20]. Digitalization, which can be thought of as reverse engineering, is the first step [21]. Using a digital scanner, the patient's gum and tooth health must be recorded in this step. After preparing a patient's teeth, dentists customarily take an impression of their mouth and send it to a dental laboratory. The technician creates a stone cast from the impression, which a lab or extraoral scanner then converts into a digital cast. Intraoral scanners have enhanced this step-in dentistry. Most scanners offer this type of output, and scan file formats are typically in STL (STereoLithography/standard tessellation language). To enable interoperability with other participants who have different software or device data structures, all companies recently supported STL format as an option among their formats.

At the design level, the utilization of these networks and cutting-edge technologies is expected to enhance the time-frame efficiency of current digital workflows and has the potential to establish itself as a clinical standard in the near future for workflows that rely on the integration of 3D images for treatment planning and evaluation of outcomes [22] (Figure 2). The software package involves a tooth database that assists users in selecting the optimal treatment or prosthetics based on their morphology and dimensions. The typical output format of design software is commonly in STL format, which can be readily imported into various computer-aided manufacturing (CAM) software packages [23].

The third stage involves the completion of production planning. During this particular stage, the Dental CAM software displays a notable level of automation, allowing users to obtain G-code by simply specifying the type and material of the prosthetic being designed, as well as the shape of the material stock. The typical format for G-code is a text file in the majority of software packages. The final stage involves the transfer and compilation of the acquired G-code by the controller of a CNC machine in order to fabricate the prosthetic. In the dental market, there is a wide range of CNC machines manufactured by various CNC machine manufacturers. These machines are distinguished based on the type of prosthetics they produce and the specific materials they are designed to work with.

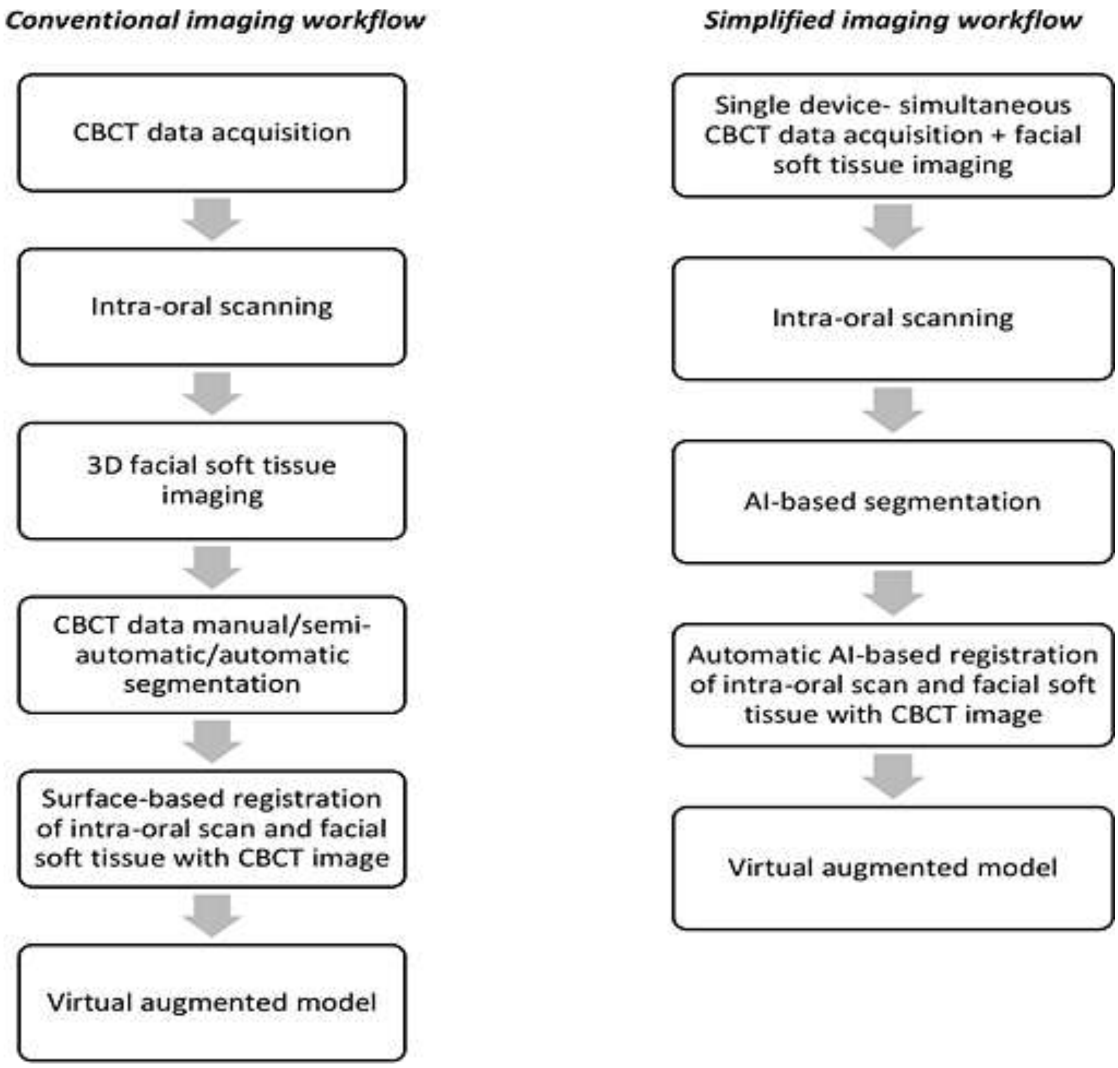

Fig. 2. Imaging workflow [22]

3. Results and Discussion

Ideally, an integrated digital workflow optimizes the efficiency of data transfer among various stages, including acquisition, storage, planning and fabrication. The successful integration of components necessitates compatibility as well as the presence of an intermediary that facilitates the interaction between these applications. This is commonly referred to as an application programming interface (API). Moreover, the implementation of an integrated system facilitates convenient accessibility across various platforms. As an illustration, an image captured within a specific clinic or operating room has the capability to be promptly accessed from an alternate site, such as a laboratory, via a centralized server. The essential elements of a cohesive workflow are: The practice's electronic health record (EHR) system is accessed through a login that is specific to the provider. Firstly, the provider selects the patient and proceeds to initiate the practice's picture archiving and communication system (PACS).

Acquisition: The PACS is responsible for receiving the digital data that has been acquired. Digital design: In the context of dentistry, suitable and standardized software for digital dentistry is utilized for treatment planning or design. It is important to realize that integrating digital dentistry into the normal workflow of large dental institutions is a complicated process that requires careful attention to detail and a well-organized infrastructure. In our increasingly digital world, it is very important to protect against cyberattacks and data breaches by maintaining the integrity of patient data when it is being collected, sent, and stored. Also, new digital technologies require dental staff to have advanced training in technology and IT systems that can handle large amounts of data. For dental institutions with a lot of patients, a smooth transition to a digital workflow requires careful planning, organization, and infrastructure [12].

A novel platform has been developed for the field of digital dentistry, aiming to enhance interoperability between various digital components and optimize workflow efficiency within a collaborative environment [24]. The platform facilitates interoperability and collaboration management by implementing the DICOM standard, thereby enhancing integration and coordination among various stakeholders. The platform has some limitations, and it is not enough to cover most of digital dentistry in dental practice. The platform is depicted in the Figure 3, and the manufacturing process is depicted in the Figure 4.

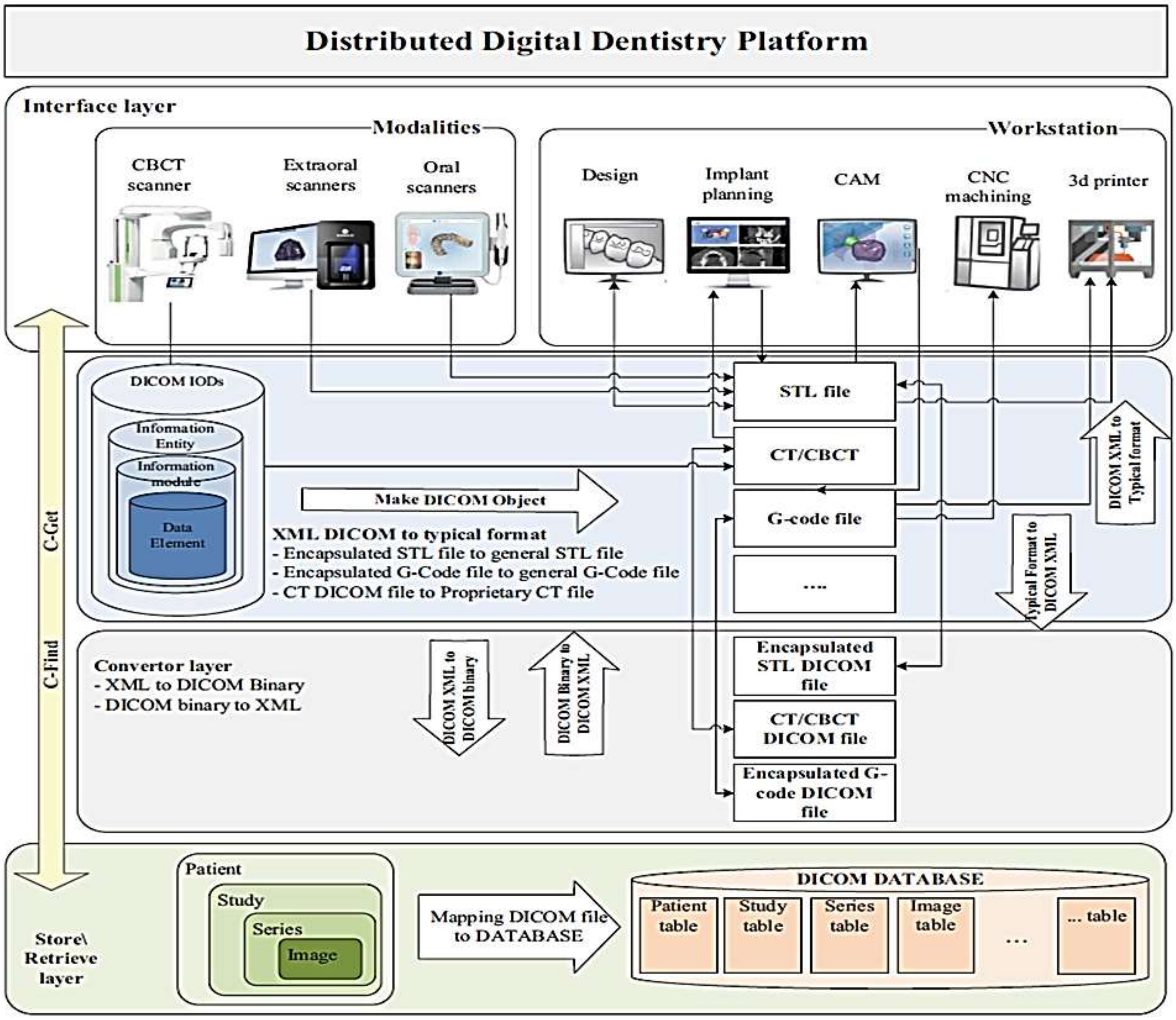

Fig. 3. A novel distributed digital dentistry platform [24]

This study aims to cover this gap and the limitations of this platform and process of production in digital dentistry practice. So, we proposed a novel platform that covers most of the digital dentistry in dental practice with the process of production. The novel platform added one modality, which is the facial scanner, and added three workstations, including orthodontic alignment, DSD, and guided endodontic planning. Figure 5 shows how the new modalities and workflows have the advantage of enhancing the digital dentistry workflow and optimizing the resources in dental practice.

The imaging center is a critical process that ensures all required input has been added to the system. In designing, the software and technology utilize the inputs, and based on the inputs and the requirements based on the treatment plan by clinicians, the final model of treatment will be created. In the production phase, the devices and the final product for clinicians with the treatment tool. Also, the new platform takes into account the integration of all dental workflow phases on the application layer, which was not included in the previous platform. In the imaging center, all digital devices are included in one standard and send their files to the design center, which can handle all these imaging inputs by using intelligent software that processes all the required treatments based on the treatment plan. The comprehensive vision in diagnosis and treatment is better for all stakeholders in dental practice. This will improve patient experience and clinical outcomes as well. So, integrated IT solutions that deal with different modalities and treatment plans increase the chance of improving dental workflow.

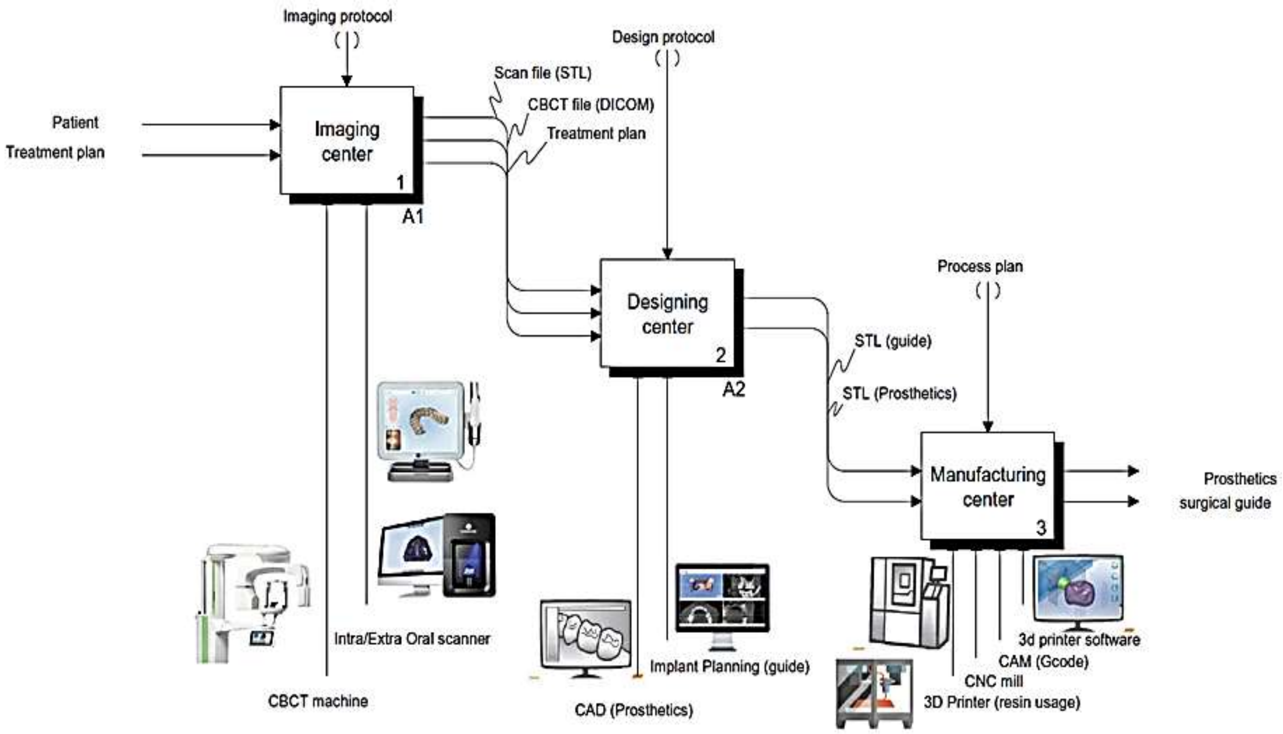

Fig. 4. Production process of surgical guides and prosthetic parts [24]

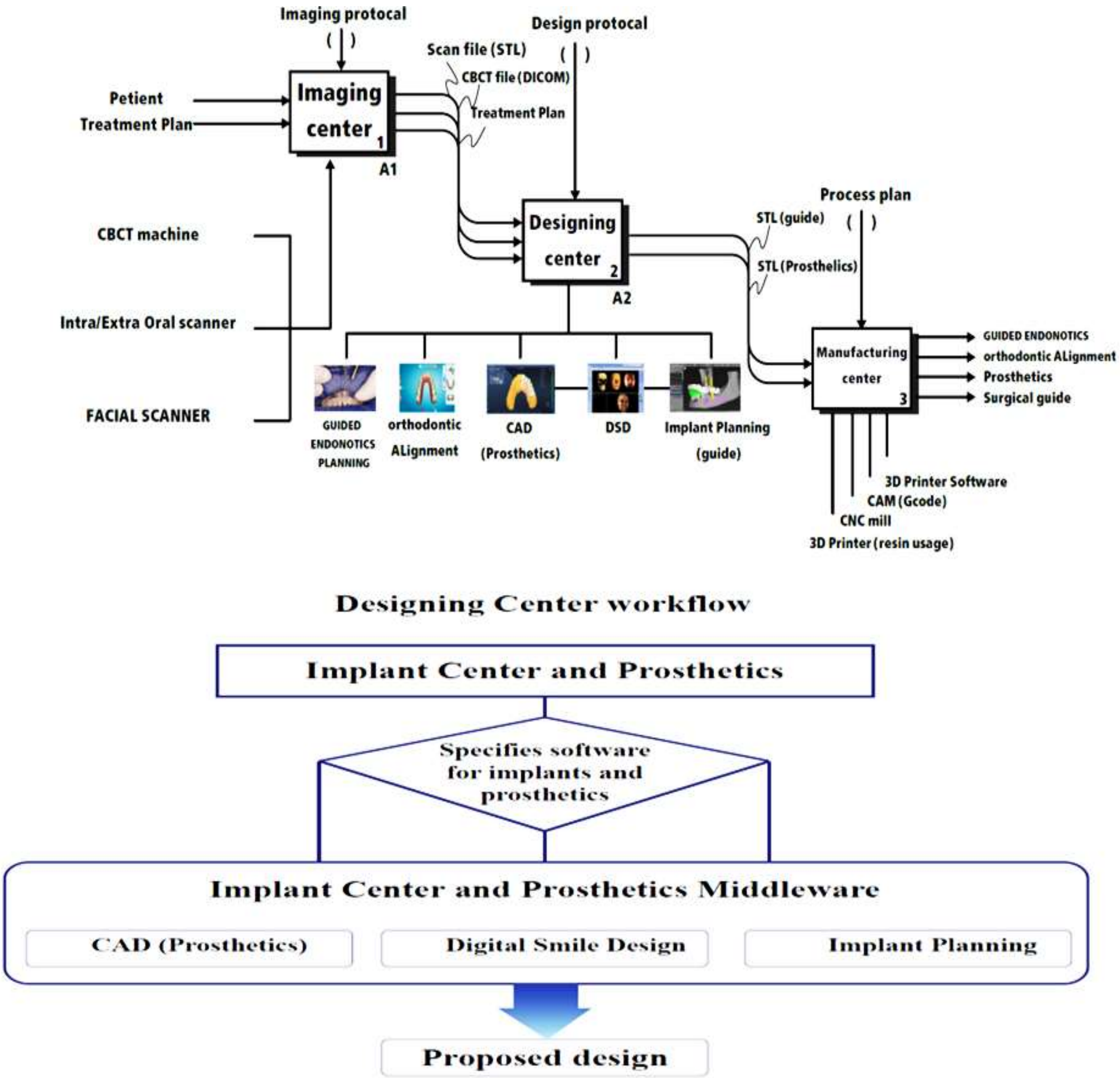

Fig. 5. The new production process of digital dentistry parts

The integration of DSD and CAD/CAM enables enhanced accuracy and adherence to the initial design. The patient underwent a rehabilitation procedure involving the utilization of veneers made from leucite-reinforced feldspathic ceramics. This process was facilitated by the CAD/CAM system, along with a digital wax-up obtained through the DSD technique. This workflow streamlines the design and fabrication process, resulting in enhanced precision and reliability for the rehabilitation procedure. The utilization of digital planning and development in the creation of mockups enhances the predictability of clinical conditions. The successful fabrication of ceramic veneers through the employment of the CAD/CAM technique necessitates the careful application of adhesive cementation, as well as a comprehensive understanding of both the practical and theoretical aspects of the procedure by the practitioner [25].

Digital dental technology is constantly evolving, opening up new opportunities for building full virtual environments. The method described incorporates 3D face scans with cone beam computed tomography and intraoral scans to add a facial perspective to the standard digital workflow. With the help of this workflow, clinicians can acquire a full digital image of the patient for use in facially generated diagnostic wax-ups as well as plan and carry out a predictable implant placement and interim prosthesis. Using this method, a temporary complete-arch fixed implant-supported prosthesis can be printed in 3D, guided surgery can be performed, and the entire process is fully digital [26].

Figure 6 shows an extended set of modalities and workstations for a novel digital dentistry platform in the dental practice and application layer. This new model identified all the required modalities and technologies for digital dentistry and applications. The use of the DICOM standard will be an advantage to our model and enhance knowledge and integration. The digital dentistry workflow is taken into account in this study. All digital files are exchanged between participants in a fully digital workflow, as was previously mentioned.

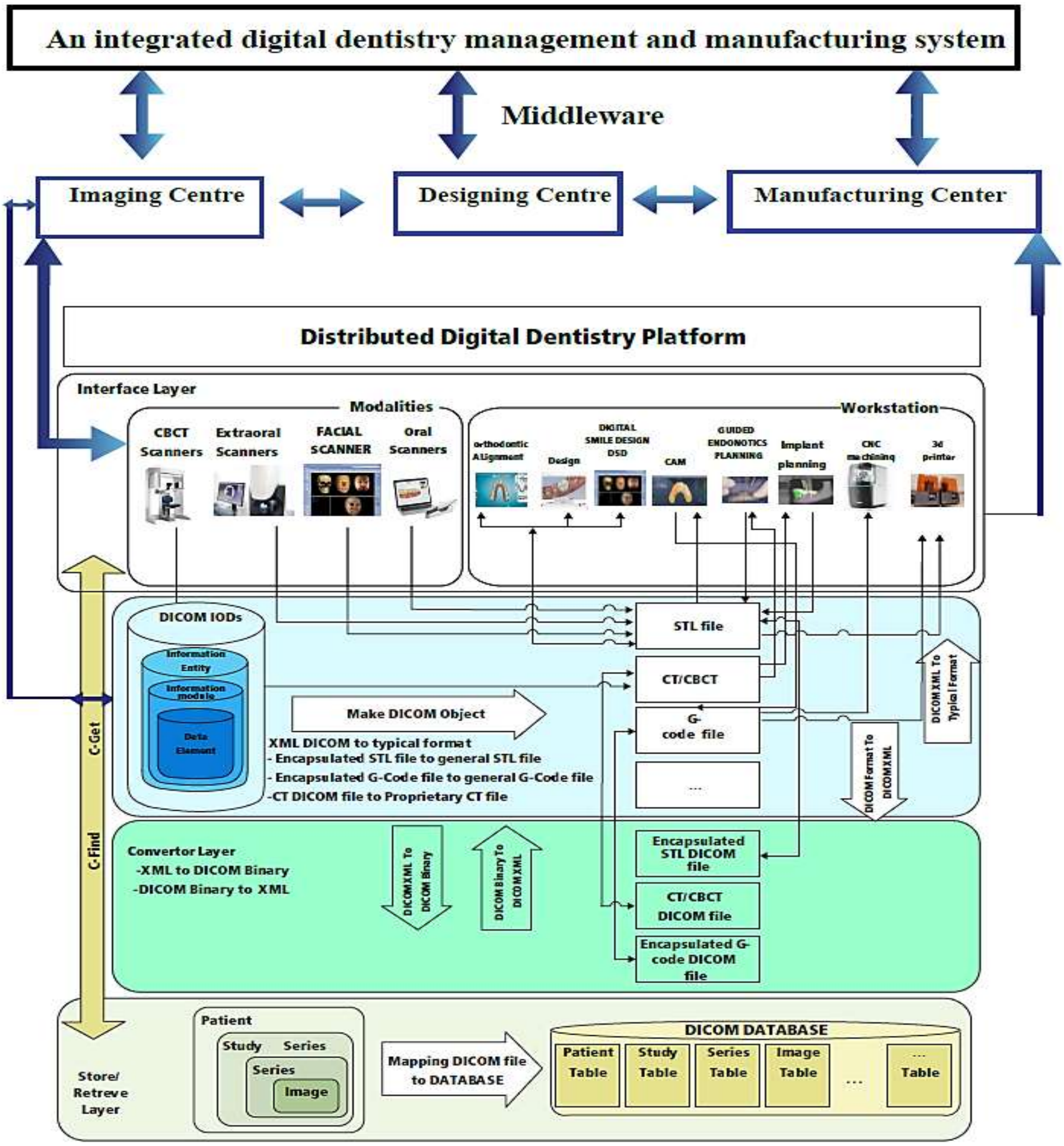

Fig. 6. An integrated digital dentistry management and manufacturing system

However, treatment plans are included in the scan stage's input, the designing stage's output, and the production stage's output. This research employs concepts to manage orders, providers, and services due to the integration of digital data into a manufacturing process. This demonstrates how the cloud manufacturing paradigm can best be studied in the context of digital dentistry. Digital dentistry service providers may be thought of as supporting all orders, depending on the digital workflow, processes, and resources required. It is typical for service providers to include CNC machines and 3D printers. Consequently, the three stages of scan, design, and production can be taken into consideration to process all orders based on the actual workflow in digital dentistry.

4. Conclusions

The automation of digital dentistry workflows is crucial to improving interoperability between various digital components and maximizing workflow effectiveness in a collaborative setting. The famous platform developed by Valizadeh *et al.,* [24] is a novel platform for the field of digital dentistry. This platform facilitates interoperability and collaboration management by implementing the DICOM standard, thereby enhancing integration and coordination among various stakeholders. However, this platform has some limitations, and it is not enough to cover most of the digital dentistry in dental practice. So, this study covered this gap and the limitations of this platform and process of production in digital dentistry practice. This paper reviewed peer-reviewed literature, analyzed elements that impact the process of digital dentistry, and critically examined an array of technologies and practices to unveil the underlying technologies in the digital dentistry workflow. So, we proposed a novel system that covers most of the digital dentistry in dental practice with the process of production. The new novel platform added one modality, which is the facial scanner, and three workstations, including orthodontic alignment, Digital Design Smile (DSD), and guided endodontic planning. Also, the new system takes into account the integration of all dental workflow phases and the application layer, which was not part of the old platform, as well as the integration of different intelligently guided software to diagnose and suggest treatment.

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