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DESIGNING AND MANUFACTURING DENTAL PRODUCTS WITH COMPUTER-AIDED TECHNOLOGIES

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Abstract: Information and communication technologies, including the frameworks of contemporary dentistry, have found use in the healthcare industry. The technique of fine-milling ready ceramic blocks to create a completed dental restoration is known as CAD/CAM application in dentistry. The terms Computer-Aided-Design (CAD) and Computer-Aided-Manufacture (CAM) refer to the computer-aided design and manufacturing of inlays, onlays, crowns, and bridges in dentistry, respectively. In essence, CAD/CAM technology enables the creation of two- and three-dimensional models, as well as the numerical control of machines to materialise them. Many dental offices worldwide are concentrating on integrating contemporary IT solutions into daily operations in order to improve productivity, save expenses, boost patient and user happiness, and eventually turn a profit. Apart from specialised software for clinic administration, inventory control, etc., or hardware like intraoral scanning or lasers for cosmetic dentistry, the use of CAD/CAM technology in the prosthetic area has gained prominence lately. A restoration that closely resembles the anatomy of a normal tooth must be achieved after pathologically altered tooth structure has been removed. By using CAD/CAM technology on suitable ceramic blocks, restorations like as inlays, onlays, bridges, and crowns may be created quickly and accurately.

The benefits of this technology are discussed in the article, along with the pleasure of patients and dentists who use systems like Cercon, Celay, Cerec, Lava, and Everest, which are essential to contemporary dentistry when producing permanent dental restorations.

1. Introduction

Modern dental practice implies an increased application of information and communication technologies. There are numerous advantages to facilitate the work of the dentist, but also users of dental services that are becoming more demanding in terms of aesthetics, with the clearly expressed desire for the minimum of staying and delaying in the dental office. The computer, as a means of interactive communication, have a greater role in prosthodontics in terms of practice in dental office, but also in dental technical laboratories. Namely, when it is necessary to substitute the removed pathologically-altered tissue, and producing a fixed prosthetic inlays, onlays, crowns and veneers are indicated, or when it is necessary to make up missing teeth, and therefore bridges are produced, it comes to the fore the application of CAD / CAM technology.

In the early 90s, over 70% of private dental practices in the United States used PCs [1]. Undoubtedly the advantage of such a work organization is to increase the speed of work, communication with patients and reducing the space for data storage [2]. An important role is also to reduce the possibilities of entering wrong, illogical or incomplete data [3]. This computer application today represents far the most common form of using in our profession. The use of computers in therapy is a challenge for enthusiast and visionaries who developed a whole new field: computerized dentistry. CAD / CAM systems represent the pinnacle of computer technology with lots of realized and potential applications in dentistry. CAD / CAM systems in dentistry consist, basically, of three components [4]:

- The first component is a device that reflects the preparation of teeth and other supporting tissues and is responsible for spatial data digitalization (CAI - Computer Aided Inspection);
- The second component consists of computer which plans and calculate body form of

restoration, equivalent to the area of CAD-s;

- The third component represents a numerically controlled milling machine which from the basic shape produces dental restoration, corresponding CAM area. As a rule, there are recommended additional processing such as polishing or individual preference by a dental technician or doctor [5].

2. CAD/CAM technology in dentistry

Year 1985 is the key to the introduction of CAD / CAM technology in dentistry. In fact, this year, with the help of triangular cameras it is executed multidimensional measurement, enabling the transfer of information on the measurement to the computer screen. With the help of a PC, software for image processing and connections with CNC milling machine, it is obtained the first silicate inlay restoration at the University of Zurich. Then it was almost unimaginable technology and practical creation of a new concept in dentistry. In Germany, the CAD / CAM technology is introduced in the dental practice in 1988 [6]. Modern software provides such a possibility where the minimum thickness of the restoration is less than the recommended, it alerts the dentist to the existing problem. Also, on the virtual model is marked and clearly identifiable critical areas that can be corrected with the offered tools. (Www.sirona.com)

The development of technology went from the machine copy milling through to fully computer-controlled system, with a large base form of the tooth, which allowed the automatic production of crowns and bridges. Today, there is several of these systems (Cerec, Cercon Celaya, Lava, Everest) and they are considered to be the ones in the future to have a much greater use in producing fixed restoration. Figure 1 shows the fixed restoration produced by means of computer-controlled system.



Figure 1. Producing fixed restorations with the aid of computer-controlled system

Thanks to the CAD-CAM technology and numerous studies, it resulted in formula for making extremely faithful restoration, which not only possess outstanding aesthetic characteristics, but also extremely biocompatible. It is a non-metal ceramics. Depending on the defect in the teeth, these materials may be used for making crowns and bridges, dental veneers, but also for special fillings.

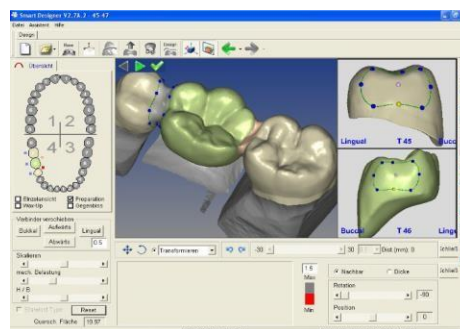


Figure 2. Innovative CAD/CAM technology

All of these restorations are produced in laboratories for dental technology, equipped with CAD-CAM technology (computer), what guarantee outstanding precision and aesthetics, as shown in Figure 2.

By forming a 3D image of teeth and gums on the screen, it allows the dentist that by cursor form a very precise and appropriate anatomical design of missing tooth substance. The resulting 3D models provide an ideal basis for restoration design. When designing it is in a very simple manner taken into account the relationship with adjacent teeth, the teeth in the opposite jaw that establish appropriate contacts, but also the relationship between restorations and the soft tissue and gums.

CAD/CAM machine through further milling process of finished ceramic blocks produces restoration of teeth which is the exact replica of the 3D drawings, ie. design of restoration, which is done by dentist via the CAD / CAM software, as shown in Figure 3. Factory ceramic blocks which are processed by milling process, are made in a number of different shades, so that the color corresponding to the requirements of patients, as well to the parameters that determine the high level of aesthetics.

By applying modern machines type MC XL for grinding of finished ceramic and zirconia blocks, fixed prosthetic restoration can be today made for only 2-3 hours in the office. The advantages of this machine are multiple, as shown in Figure 4. Precision of milling is moving in the range of +/- 25 microns, while the time required for grinding circular bridge does not exceed 6 minutes. Thanks to a grinding resolution of 7.5 microns, prosthetic restoration surfaces that are produced this way are certainly adhere better, compared to conventionally made works (www.kalmar.hr/usluge/cadcam).



Figure 3. CAD/CAM technology for manufacturing dental crowns and bridges



Figure 4. CAD/CAM allows us to quickly restore damaged teeth with natural-colored ceramic fillings

3. Proces od producing metal-free restorations by CAD/CAM technology

The process of producing ceramic restorations by CAD-CAM technology is more precise than the conventional process of producing metal-ceramic crowns and bridges. Figure 5 provides an overview of the CAD / CAM system in the process of producing crown bridges.

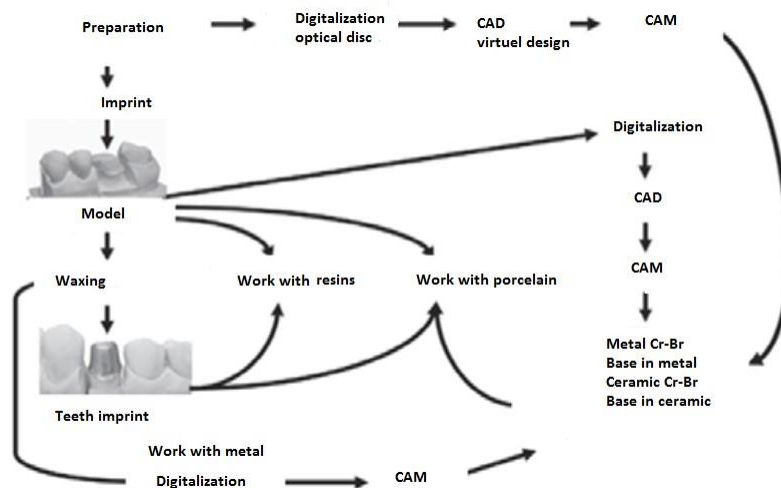


Figure 5. Display of dental CAD / CAM system in the process of producing crown-bridges [7]

Prosthetic restoration are made in several phases, which are allocated by the following order [8]:

1. *Overview and history*- Based on the indications and the status of the tooth, as shown in Figure 6, the dentist diagnoses and recommends several options, explaining the pros and cons, depending on the indication.



Figure 6. Overview and history

2. *Preparation of teeth for placing prosthetic restorations.* Process begins by grinding of teeth and its suppression, which is carried out by dentist depending on the type of the ceramics to be used for the certain clinical case, i.e. to create prosthetic restoration.

3. *Taking the tooth imprint.* The dentist performs the tooth imprint (one or more, depending on which prosthetic restorations works), on which it will carry out further construction and casting of prosthetic restoration.

4. *Casting of the model.* Based on the tooth imprint plaster model is casted, on which is carried out further work, on the basis of tooth imprint.

5. *3D scan of the model.* 3D oral camera captures teeth, after which the image is transferred to a computer and processed using the software. These cameras allow a high degree of accuracy and efficiency, and are particularly suitable for the restoration of individual crown.

6. *Modeling.* CAD / CAM software modeling the teeth based on the entered requirements.

7. *3D teeth printing.* Before you start teeth printing, you need to install ceramic blocks in the milling. The ceramic block is fixed on the wheel that allows block to be inserted. Bridge is produced by milling process on the basis of the 3D model from the block set in the CAD-CAM device. Milling machine develops the desired shape in accordance with the instructions of a computer. The ceramic block is processed by turning on its axis, a diamond disk rotates, moves up and down around the ceramic block and processes it. The movement of the diamond disc is enabled via electric rail.

8. *Cementation.* Prosthetic restorations are cemented with special aesthetic cement for metal-free ceramics, as presented in Figure 7. There are two types of cementing - temporarily and definitively. Temporary cementing of restoration is done in the period of adaptation of prosthetic restoration to the jaw, while definitive cementing is done after ensuring that the prosthetic restorations is accepted.

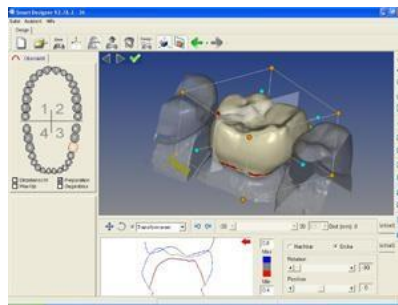


Figure 7. Display of the metal-free restoration by CAD / CAM technique

The advantages of metal-free ceramic compared to metal-ceramic works:

- Complete biocompatibility of materials,
- The absence of allergy to this material (a large number of patients with metal-bridges suffer from allergic reactions because of the large amount of nickel in the metal alloy),
- Absence of bimetallicism at metal-free works (creating low-voltage levels between the two metals, eg. between metal-ceramic crowns),
- Firmness of works is 4 times higher than the metal used for metal-ceramic works,
- Persistence and not changing its physical and chemical properties even after long years spent in the mouth,
- The aesthetic superiority compared to metal-ceramic works,
- Beneficial effects on the gums, ie. „gingiva“ with which it comes into contact,
- The absence of dark discoloration of the “gingiva” at the junction of crown and gums.

The disadvantages of metal-free ceramic compared to metal-ceramic works:

- Price. Due to the expensive and long-term development of this technology, expensive CAD-CAM machines and expensive process for manufacturing, metal free crowns are more expensive than metal-ceramic works. However, taking into account the relationship between price and quality, it can be said that the ratio is on the side of metal-free ceramics.

4. Types of metal-free works

4.1. Metal

Metal-free crowns are aesthetic restorations that are made in the dental laboratory of special blocks by using CAD-CAM techniques. Blocks have characteristics very similar to natural teeth, depth and transparency, so that the final product represents a faithful copy of natural teeth. Cemented by a special cement, which further contribute to the aesthetic characteristics of the crown.

4.2. Inlay – Onlay

These are dental restorations which represent transition between crown and filling. They are used when there is no much remaining tooth structure, and avoiding producing crowns. In the cases when dental caries too much devastated the tooth structure, and when after the removal of caries, the resulting cavity can't be adequately compensated by classical fillings (either of amalgam or composite), then it is produced inlays.

Inlays are usually made of ceramic or metal (although now days rarely made of metal). The main difference between the inlay and the fillings is, in addition to the material from which it is made, that the inlay is made outside of the mouth. Therefore, for the manufacturing of inlays it is needed at least two visits to the dentist. In the first visit to remove the carious mass and preparing the tooth for an inlay. Then making tooth imprints. Based on tooth imprints technician in the lab creating an inlay, which is then in the second visit cemented in the mouth of patient.

Depending on the size of the inlay, ie. the extent of the cavity that is formed after the removal of caries, we distinguish two forms of this restoration, as presented in Figure 8, including:

- inlays (inlay) - which affects maximum of two surfaces of the tooth (for example making inlays can be seen in the Dental SPA center).
- onlays (onlay) - that affect three or more surfaces of the tooth.



Figure 8. Inlay-Onlay bridges

4.3. Inlay Bridges

Inlay bridge is minimal invasive method for metal-free dental restorations, excluding implants. In this type of bridges adjacent teeth are grounded to a minimum in the form of fillings, as presented in Figures 9a and 9b. For all other types of bridges adjacent tooth is grinded and onto it is set crown in order to carry the missing tooth.

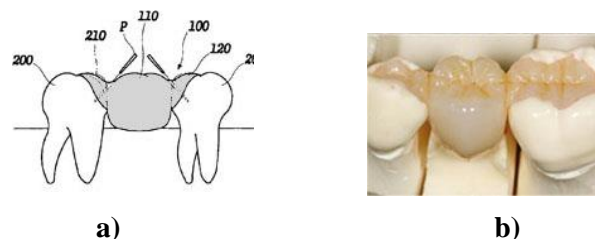


Figure 9a and 9b : Inlay bridges

5. Optical methods of spatial digitalisation

Optical methods of spatial digitalisation, like mechanical, based on the criteria of space where the scan is performed, are divided as:

- intraoral and,
- extraoral methods.

In relation to the size of the scanning area, they are classified on the dotted and striped (surfaced).

Intraoral scanning means work in a dental office, while the *extraoral methods*, mainly related to laboratory work. Both methods have been developed side by side, but today in the practical application is present only a single intraoral (two are in announcement) and the great number of extraoral systems. The requirements set for them are different. For ergonomic reasons, intraoral scanner should not be fixed to the remaining teeth. This affects the request of its shape, size, weight and ability to maintain hygiene, but above all the speed of scanning. Empirically it is proven that trained user can keep the scanner head immovable and still versus the scanned tooth, mostly for 0.5 seconds. The data on the speed of data measurements acquisition, in addition to the resolution, is one of the most important in the choice of the system and its broad applicability. Size of the scanning field is minimally 14x14mm, and optimally 25x14mm. The range of scanning depth should be at least 10 mm, but should not be greater than 14 mm. Scanner resolution should be at least $\pm 25\mu\text{m}$ [9]. The most famous representative of intraoral optical method is Cerec system, as shown in Figure 10 (Sirona Dental Systems GmbH, www. Sirona.de) [10].



Figure 10. Sirona, 3M Dental CAD/CAM System

This technique is using more light rays, in the form of lines, projected on the preparation (line hatched area). The rays in rapid oscillations move across the object, so that in a short period of time is obtained three-dimensional shape of preparation. Similarly to conventional photography, the camera at the time of recording should be kept as still as possible. Fixing the camera opposite to the object at this system is not necessary because the time required for data processing from all the 340,000 pixels is less than 0.5 sec. – as illustrated in Figure 11. During the year 2005 are shown two more intraoral scanners Evolution 4D and HintEls.

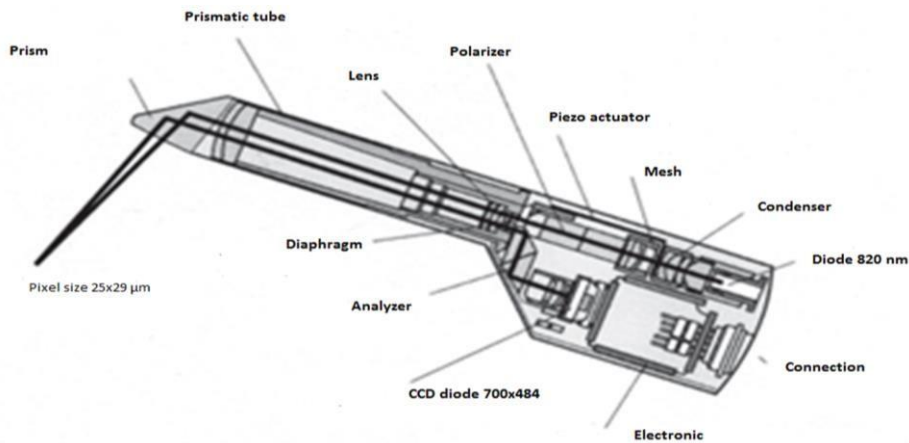


Figure 11. Scheme of Cerec 2 scanner head section

Extraoral systems scan is carried out on the model, and for this reason there is a need for dental technical laboratory. In these systems it is not critical high speed data collection, because the head of the scanner and the object that is scanned are immovable, but the width of the scanning and precision measurements.

A different solution, to achieve the third dimension by using the CCD chips, gives the *laser triangulation procedure*, after Lelandais and Clainchard-in (1984). If you focus laser dot air with oscillating mirror for CCD camera there will be a clear limited laser line. The great advantage of this system is the possibility of scanning undermined surfaces. This mode is for now only possible as extraoral methods.

Representative of extraoral dot scanner is Cerec Scan, illustrated in Figure 12, and Cerec inLab, illustrated in Figure 13. The scanner is fixed to one of the motors of the milling machine and object of scanning is movable. Scanner resolution is similar to the intraoral scanner, but the scan time of one tooth is much longer. For the “four-member” bridge it takes 2-3 minutes. This year, the factory has developed a new high-resolution scanner, in which this time is reduced to about 40 seconds (Cerec INEOS) [11].



Figure 12. Cerec Scan – integrated laser scanner, dot scanner in the left engine



Fig. 13. Cerec inLab system – from left to right: inEos ekstraoral Cerec in Lab with inbuilt dot scanner, PC computer with 3D softver

6. Advantages of using CAD / CAM technology in dentistry

In dental practice, CAD / CAM technology is primarily used to provide patients with one or multiply-restorations in the mouth or on the teeth themselves. Application of this technology provides a simplified procedure compare to the current way of producing. Restorations made this way are long-term, as the first studies saying. Figure 14 shows restorative dentistry with CEREC® 3D computerized. Sirona study shows

that in five years 95-97% of CEREC's crowns are still intact, while the degree of preserved inlays and onlays is 90-95% after ten years.



Figure 14. Restorative dentistry with CEREC® 3D computerized

The patient is provided with comfort and complete treatment is performed in one session in the context of dental practice, of course with condition that a dentist has so called *Chairsaide* CAD / CAM. This actually means that the entire equipment can be placed in the area of dental office. This is a remarkable advantage, because it eliminates the need to continue work in dental technical laboratories, as well eliminates additional costs. However, if the CAD / CAM technology is located in the dental laboratory and is applied by dental technician, it requires two visits to the dentist. By using this technology very precise restorations are produced, which so far is certainly not the case, whether it is about complicated multi-member bridges, crowns, inlays, onlays or veneers.

Advantages of using CAD / CAM technology for dentists are:

- The patient spends less time in the office;
- A simplified procedure;
- Significantly reduced costs for dental technical laboratories;
- Reduced consumption of materials;
- Increased productivity;
- Easier way of producing;
- Precisely produced restorations;
- Increased productivity.

Advantages of using CAD / CAM technology in dental-technical laboratory:

- Easier way of producing;
- More precisely made restorations;
- Lower consumption of materials;
- Higher productivity.

Advantages of using CAD / CAM technology to produce onlays:

- Very often saves the tooth structure compared to traditional crowns.

Advantages of using CAD / CAM technology to produce inlays:

- Much better restoration than traditional fillings.

7. Survey of patient satisfaction using CAD / CAM technology in Bosnia and Herzegovina

In general, bearing in mind that for providing the services patients are essential, because who would provide services if there would be no demand, and crucial is continuously conducting research and analysis of feedback from patients. When analyzing opinions, feelings and experiences of patients, it is necessary to take all factors into account that in any way touch the patient. These are above all: speed of service delivery, the pain that is (not) felt when providing services, aesthetic effects, and the price of services as one of the most important elements, keeping in mind the economic crisis and the turbulent market developments in our and as well regional areas.

Accordingly, it is formulated ten questions, formed into the questionnaire for assessing the level of satisfaction of patients after making dental implants using CAD / CAM technology. After treating the patient, while still in the dentist's chair, ask the patient to set aside a few minutes to fill out the questionnaire, expressing their opinions and feelings about the experience with dental restorations. Also, in addition to the above questions, to which the patient responds, indicating the level of agreement with the above findings, the patient has the ability to verbally and in writing to state its suggestions that would contribute to the further improvement and advancement of providing these services.

Table 1. Structure of questions for patients with five suggested answers on the issue (Author 2016)

Questions	Disagree	Partially agree	Agree	Mostly agree	Strongly agree	Total:
1. The process of preparations for the prosthetic restoration is pleasant and does not last long.	0	10	13	28	49	100
2. It is not necessary repeatedly to come to the dentist, in order to complete the preparation process.	0	0	38	42	20	100
3. Producing restorations takes surprisingly short.	0	0	4	22	74	100
4. During producing restoration , it is involved surprisingly professional staff	10	16	12	18	44	100
5. Installing restoration is completely painless.	0	11	32	24	33	100
6. Restorations do not differ entiate from natural teeth, look completely natural.	0	0	10	19	71	100
7. Once the restoration is set up, it is needed a certain period of adaptation.	0	2	30	22	46	100
8. Dental restorations give completely natural feelings, no need for restrictions of certain foods.	0	0	0	0	100	100
9. Recommend the proces tom its frineds.	0	1	50	25	24	100
10. Price is afrodable.	0	0	9	12	79	100
Total:	10	40	198	212	540	1000
Participations in %.	1	4	19,80	21,20	54	-

In order to investigate the satisfaction level of patients, 100 patients are examined and asked 10 questions per patient, in the past 6 months. The results showed that patients exceptionally satisfied with making dentures by CAD / CAM technology. Since the questions are formulated mainly that the first column (I disagree) reflects the lowest level of satisfaction of the patient (1%), while the last two columns reflect the highest level of patient satisfaction (75.20%).

The research results and responses participation depending on the customer satisfaction, is shown in the following Figure 15.

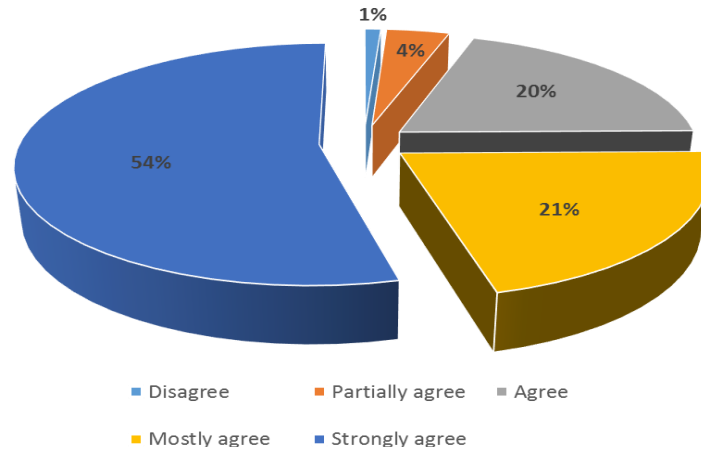


Figure 15. Structure of the responses to the questionnaire on patient satisfaction (Author 2016)

From Figure 15 can be noted that the most significant participation in the structure of responses take final answers to the set of 10 questions: most agree and strongly agree, that is the highest level of patient satisfaction in the amount of 75.20%. A minimum participation to the set of 10 questions take answers: do not agree, that is the lowest level of patient satisfaction of 1%. **The introduction of new technologies in Bosnia and Herzegovina leads to the improvement of services in the field of dental medicine, as confirmed by patient satisfaction (95%).** Accessibility prices to patients is very satisfactory (91%). On the issue of “producing restorations is short”, patient satisfaction was 96%. Asked whether dental restorations giving a natural feeling?, patient satisfaction is 100%.

Broken down by one question from the questionnaire, structure response is as follows - Figure 16:

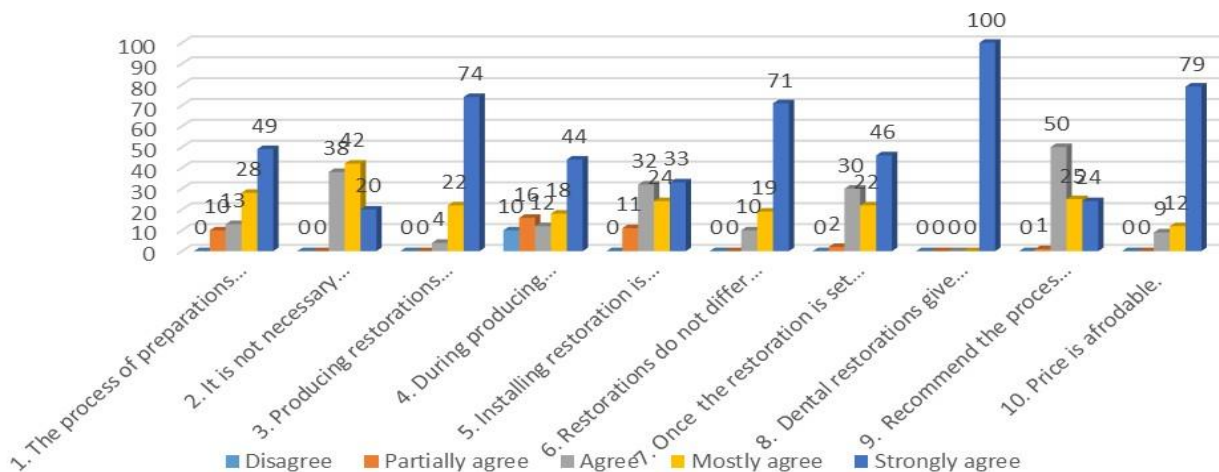


Figure 16. The structure of the questionnaire responses on the issues of patient satisfaction (Author 2016)

8. Conclusions

The dentist must use CAD/CAM technology in aesthetic fixed restorations if they want to be considered as pioneers in the creation of inlays, onlays, crowns, and bridges. In addition to providing excellent quality, expertise, and profit, the employment of this technology results in a continual growth in "new" and happy patients.

Every advancement in information and communication technology is also used in a variety of medical specialties, including dentistry. This investigation provides further proof why using IT in dentistry is

essential. In the future, as information and communication technologies advance, they will have a greater influence on prompt diagnosis, prompt and appropriate treatment, monitoring of therapeutic effect, and, when required, achieving a high standard of aesthetics across all medical and dental specialties.

Many researchers have dreamed of "the ideal CAD / CAM system" for many years. Given that all individual errors in procedures and equipment are caused by the precision of restorations made by CAD / CAM technology, and that scanning is the first place where errors may arise, a higher resolution scanner will most definitely improve the overall quality of the system.

Patient satisfaction (95%) attests to the fact that the adoption of new technology improves dental medical services. Patients' satisfaction with accessibility pricing is quite high (91%). 96% of patients expressed satisfaction with the fast turnaround time for restorations. When asked whether dental restorations seem natural, patients respond positively (100%) to these questions. The advancement of dental medical services via new technology has an aesthetic quality. The creation of prosthetics is completed more faster when CAD/CAM technology is used, and these systems are user-friendly.

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