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The Role of CAD/CAM Technologies in Enhancing Dental Procedures

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Abstract:

This study explores the transformative impact of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) technologies on dental practice, highlighting their role in enhancing precision, efficiency, and patient outcomes. CAD/CAM systems have revolutionized traditional dental workflows, allowing for the digital design and fabrication of dental restorations, prosthetics, and orthodontic appliances with unprecedented accuracy. By integrating advanced software and automated manufacturing processes, dental professionals can streamline treatment planning, reduce turnaround times, and improve the fit and aesthetics of dental appliances. This research examines various applications of CAD/CAM technologies in dentistry, including digital impressions, 3D modeling, and milling processes, alongside their benefits, such as enhanced customization and reduced material waste. Furthermore, the study addresses the challenges associated with the adoption of these technologies, including the need for specialized training and investment in equipment. Ultimately, the findings underscore the significance of CAD/CAM in modern dentistry, providing valuable insights for dental practitioners seeking to enhance their clinical practices and deliver superior patient care. The integration of these technologies not only represents a significant advancement in dental work but also aligns with the broader trend towards digitalization in healthcare.

The paper presents the advantages of using this technology as well as satisfaction of the patients and dentists by using systems as: Cercon, Celay, Cerec, Lava, Everest, which represent imperative of modern dentistry in creating fixed dental restorations.

1. Introduction

The integration of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) technologies in dentistry has marked a significant evolution in the field, enabling practitioners to enhance the precision and efficiency of their work. Traditional dental processes often relied on manual techniques, which, while effective, could be time-consuming and prone to human error. The introduction of CAD/CAM systems has transformed this landscape, allowing for the digital design and rapid production of dental restorations, such as crowns, bridges, and dentures, with remarkable accuracy.

CAD involves the use of specialized software to create detailed 3D models of dental structures, allowing practitioners to visualize and customize treatment plans based on individual patient needs. This digital approach not only improves the accuracy of designs but also facilitates better communication between dental professionals and patients. CAM technology complements CAD by automating the manufacturing process, utilizing milling machines or 3D printers to produce dental appliances directly from digital files. This synergy between CAD and CAM streamlines workflows, reduces production times, and minimizes material waste, ultimately leading to improved patient satisfaction.

Moreover, the adoption of CAD/CAM technologies enhances the quality of dental work, enabling the creation of restorations that fit better and have superior aesthetics compared to traditional methods. Despite the numerous advantages, the transition to digital technologies is not without challenges, including the need for significant investment in equipment, software, and training. As dental professionals navigate this technological shift, understanding the applications, benefits, and potential hurdles associated with CAD/CAM technologies is essential for maximizing their impact in clinical practice.

This study aims to provide a comprehensive overview of the role of CAD and CAM technologies in modern dentistry, examining their applications, advantages, and challenges. By exploring the transformative effects of these technologies, this research seeks to inform dental practitioners about the potential for improved outcomes in

their practices and contribute to the ongoing evolution of dental care.

• The first component is a device that reflects the preparation of teeth and other supporting tissuesandisresponsibleforspatialdatadigitalization (CAI - ComputerAidedInspection);

• Thesecondcomponentconsistsofcomputerwhichplansandcalculatebodyformofrestoration, equivalenttotheareaofCAD-s;

• The third component represents a numerically controlled milling machine which from the basicshape produces dental restoration, corresponding CAM area. As a rule, there are recommended additionalprocessingsuchaspolishingorindividualpreferencebyadentaltechnicianordoctor[5].

2. CAD/CAMtehnologyindentistry

Year 1985 is the key to the introduction of CAD / CAM technology in dentistry. In fact, this year, with thehelpoftriangularcamerasitisexecutedmultidimensionalmeasurement,enablingthetransferofinformation on the measurement to the computer screen. With the help of a PC, software for imageprocessing and connections with CNC milling machine, it is obtained the first silicate inlay restoration atthe University of Zurich. Then it was almost unimaginable technology and practical creation of a newconcept 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 lessthan the recommended, it alerts the dentist to the existing problem. Also, on the virtual model is markedandclearly identifiablecriticalareasthatcanbecorrectedwiththeofferedtools.(Www.sirona.com)

The development of technology went from the machine copy millingthrough to fully computer-controlled system, with a large base form of the tooth, which allowed the automatic production of crownsand bridges. Today, there is several of these systems (Cerec, Cercon Celaya, Lava, Everest) andthey areconsidered to be the ones in the future to have a much greater use in producing fixed restoration. Figure 1showsthefixed restoration produced bymeansofcomputer-controlledsystem.

Figure1.Producingfixedrestorationswiththeaidofcomputer-controlledsystem

ThankstotheCAD-CAMtechnologyandnumerousstudies,itresultedinformulaformakingextremelyfaithfullrestoration,whichnotonlypossessoutstandingaestheticcharacteristics,butalsoextremelybiocompatible.Itisanon-metalceramics.Dependingonthedefectintheteeth,thesematerialsmay beusedfor making crownsand bridges,dentalveneers,but alsoforspecialfillings.

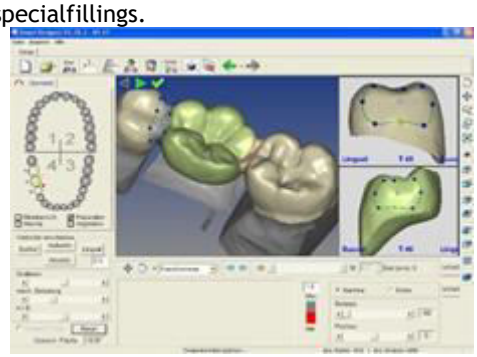


Figure2.InnovativeCAD/CAMtechnology

All of these restorations are produced in laboratories for dental technology, equipped with CAD-CAMtechnology(computer), whatguaranteeoutstandingprecisionand aesthetics,asshowninFigure2.

By forming a 3D image of teeth and gums on the screen, it allows the dentist that by cursor form a veryprecise and appropriate anatomical design of missing tooth substance. The resulting 3D models provide anideal basis for restoration design. When designing it is in a very simple manner taken into account therelationship with adjacent teeth, the teeth in the opposite jaw that establish appropriate contacts, but alsotherelationship betweenrestorationsandthesoft tissueandgums.

CAD/CAM machine through further milling process of finished ceramic blocks produces restoration ofteeth which is the exact replica of the 3D drawings, ie. design of restoration, which

is done by dentist viathe CAD / CAM software, as shown in Figure 3. Factory ceramic blocks which are processed by millingprocess, are made in a number of different shades, so that the color corresponding to the requirements ofpatients,aswellto theparametersthatdeterminethe high levelofaesthetics.

By applying modern machines type MC XL for grinding of finished ceramic and zirconia blocks, fixedprosthetic restoration can be today made for only 2-3 hours in the office. The advantages of this machineare multiple, as shown in Figure 4. Precision of milling is moving in the range of +/- 25 microns, while thetimerequiredforgrindingcircularbridgedoesnotexceed6minutes.Thankstoagrindingresolutionof 7.5microns,prostheticrestorationsurfacesthatarereproducedthiswayarecertainlyadherebetter,comparedto conventionallymadeworks(www.kalmar.hr/usluge/cadcam).

Figure 3. CAD/CAM technology formanufacturingdentalcrownsandbridges

Figure4.CAD/CAMallowsustoquicklyrestoredamagedteethwithnatural-coloredceramicillings

3. Procesodproducingmetal-freerestorationsbyCAD/CAMtehnology

TheprocessofproducingceramicrestorationsbyCAD-CAMtechnologyismoreprecisethantheconventional process of producing metal-ceramic crowns and bridges. Figure 5 provides an overview oftheCAD/CAMsysteminthepro cessof producingcrownbridges.

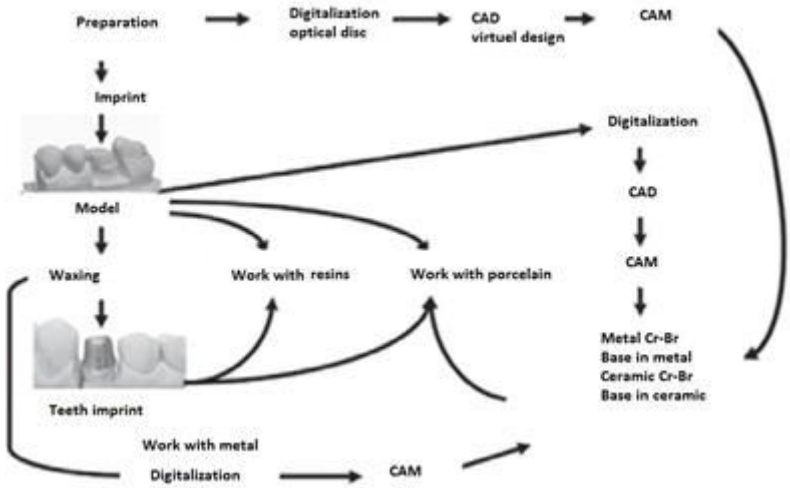


Figure 5. Display of dental CAD / CAM system in the process of producing crown-bridges

[7]Prostheticrestorationaremadeinseveralphases,whichareallocatedbythefollowingorder[8]:

1. *Overviewandhistory*-Basedontheindicationsandthestatusofthetooth,asshowninFigure6, the dentist diagnoses and recommends several options, explaining the pros and cons, depending on theindication.

Figure6. Overviewandhistory

2. *Preparation of teeth for placing prosthetic restorations.* Process begins by grinding of teeth andits suppression, which is carried out by dentist depending on the type of the ceramics to be used for thecertain clinicalcase, i.e. to createprostheticrestoration.

3. *Taking the tooth imprint*. The dentist performs the tooth imprint (one or more, depending onwhichprostheticrestorationsworks),onwhichit willcarryoutfurtherconstructionandcastingofprostheticrestoration.

4. *Casting of the model*. Based on the tooth imprint plaster model is casted, on which is carried outfurtherwork,onthebasisof tooth imprint.

5. *3D scan of the model*. 3D oral camera captures teeth, after which the image is transferred to acomputerandprocessedusingthesoftware.Thesecamerasallowahighdegreeofaccuracyandefficiency,andarepartic ularly suitablefor therestoration of individualcrown.

6. *Modeling*.CAD/CAMsoftware modelingtheteethbasedontheenteredrequirements.

7. *3D teeth printing*. Before you start teeth printing, you need to install ceramic blocks in themilling. The ceramic block is fixed on the wheel that allows block to be inserted. Bridge is produced bymilling process on the basis ofthe 3D model from the block set in the CAD-CAM device. Millingmachine develops the desired shape in accordance with the instructions of a computer. The ceramic blockis processed by turning on its axis, a diamond disk rotates, moves up and down around the ceramic blockandprocesses it.Themovement ofthediamond disc isenabled via electricrail.

8. *Cementation*. Prosthetic restorations are cemented with special aesthetic cement for metal-freeceramics, 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,whiledefinitivecementingisdoneafterensuringthattheprostheticrestorationsis accepted.

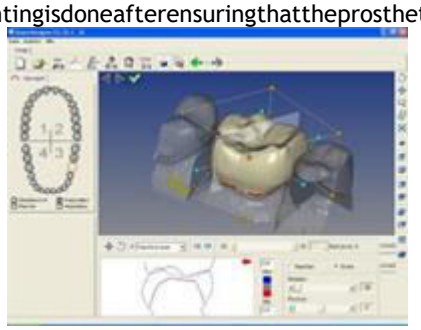


Figure7. DisplayofthemetaI-freerestorationbyCAD/CAMtechniqueTheadvantagesof metal-freeceramiccomparedtometal-ceramic works:

- Completebiocompatibilityofmaterials,
- The absence of allergy to this material (a large number of patients with metal-bridges suffer fromallergicreactionsbecauseof thelargeamount ofnickelin themetalalloy),
- Absence of bimetallism at metal-free works (creating low-voltage levels between the two metals, eg.betweenmetal-ceramiccrowns),
- Firmnessof worksis4timeshigherthanthemetalusedformetal-ceramicworks,
- Persistenceandnotchangingitsphysicalandchemicalpropertiesevenafterlongyearsspentinthemouth,
- Theaestheticsuperiority comparedtometal-ceramicworks,
- Beneficialeffectsonthe gums,ie.„gingiva“withwhichitcomesintocontact,
- The absence of dark discoloration of the “gingiva” at the junction of crown and gums.Thedisadvantagesofmetal-freeceramiccompared tometal-ceramicworks:
- Price. Due to the expensive and long-term development of this technology, expensive CAD-CAMmachines and expensive process for manufacturing, metal free crowns are more expensive thanmetal-ceramic works. However, taking into account the relationship between price and quality, it canbesaid thatthe

ratio ison thesideofmetal-freeceramics.

4. Typesofmetal-freeworks

4.1. Metal

Metal-free crowns are aesthetic restorations that are made in the dental laboratory of special blocks byusingCAD-CAMtechniques.Blockshavecharacteristicsverysimilartonaturalteeth,depthandtransparency, so that the final product represents a faithful copy of natural teeth. Cemented by a specialcement,which furthercontributetotheaestheticcharacteristicsofthecrown.

4.2. Inlay-Onlay

These are dental restorations which represent transition between crown and filling. They are used whenthereisnomuchremainingtoothstructure,andavoidingproducingcrowns.Inthecaseswhendentalcaries too much devastated the tooth structure, and when after the removal of caries, the resulting cavitycan'tbeadequatelycompensatedbyclassicalfillings(eitherofamalgamorcomposite),thenitisproduced inlays.

Inlays are usually made of ceramic or metal (although now daysrarely made of metal). The maindifference between the inlay and the fillings is, in addition to the material from which it is made, that theinlay is made outside of the mouth. Therefore, for the manufacturing of inlays it is needed at least twovisits to the dentist. In the first visit to remove the carious mass and preparing the tooth for an inlay. Thenmaking tooth imprints. Based on tooth imprints technician in the lab creating an inlay, which is then in thesecondvisitcemented in the mouthofpatient.

Depending on the size of the inlay, ie. the extent of the cavity that is formed after the removal of caries,wedistinguish twoforms ofthisrestoration, aspresentedinFigure8,including:

- inlays (inlay) - which affects maximum of two surfaces of the tooth (for example making inlayscanbeseen in theDentalSPA center).
- onlays(onlay)-thataffectthreeormoresurfacesofthetooth.

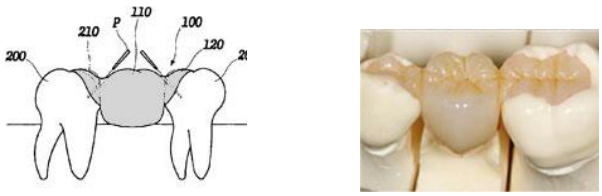
Figure8. Inlay-Onlaybridges

4.3. InlayBridges

Inlay bridge is minimal invasive method for metal-free dental restorations, excluding implants. In this typeof bridges adjacent teeth are grounded to a minimum in the form of fillings, as presented in Figures 9a and9b. For all other types of bridges adjacent tooth is grinded and onto it is set crown in order to carry themissingtooth.

a) **b)**

Figure9aand**9b**:Inlay bridges



5. Opticalmethodsofspatialdigitalisation

Opticalmethodsofspatialdigitalisation,likemechanical,basedonthecriteriaofspacewherethescanisperformed, aredivided as:

- intraoraland,
- extraoralmethods.

Inrelationtothesizeofthescanningarea,they areclassifiedonthedottedandstriped(surfaced).

*Intraoralscanning*meansworkinadentaloffice,whilethe*extraoralmethods*,mainlyrelatedtolaboratory work. Both methods have been developed side by side, but today in the practical application ispresent only a single intraoral (two are in announcement) and the great number of extraoral systems. Therequirements set for them are different. For ergonomic reasons, intraoral scanner should not be fixed to theremaining teeth. This affects the request of its shape, size, weight and ability to maintain hygiene, butabove all the speed of scanning. Empirically it is proven that trained user can keep the scanner headimmovable and still versus the scanned tooth, mostly for 0.5 seconds. The data on the speed of datameasurements acquisition, in addition to the resolution, is one of the most important in the choice of thesystem and its broad applicability. Size ofthe scanning field is minimally 14x14mm, and optimally25x14mm. 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 ± 25µm [9]. The most famous representative of intraoral opticalmethodisCerecsystem,asshown inFigure10 (SironaDentalSystemsGmbH,www.Sirona.de) [10].

Figure10.Sirona,3MDentalCAD/CAMSystem

This technique is using more light rays, in the form of lines, projected on the preparation (line hatchedarea). The rays in rapid oscillations move across the object, so that in a short period of time is obtainedthree-dimensional shape of preparation. Similarly to conventional photography, the camera at the time ofrecording should be kept as still as possible. Fixing the camera opposite to the object at this system is notnecessary 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 andHintEls.

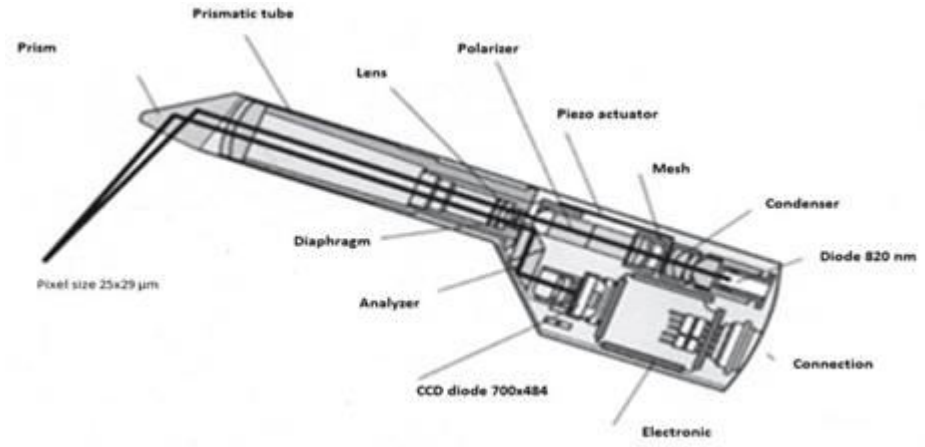


Figure11.SchemeofCerec2scannerheadsection

Extraoral systems scan is carried out on the model, and for this reason there is a need for dentaltechnical laboratory. In these systems it is not critical high speed data collection, because the head of thescanner and the object that is scanned are immovable, but the widthof the scanning and precisionmeasurements.

A different solution, to achieve the third dimension by using the CCD chips, gives the *laser trianguprocedure*, after Lelandais and Clainchard-in (1984). If you focus laser dot air with oscillating mirror forCCD camera there will be a clear limited laser line. The great advantage of this system is the possibility ofscaning underminedsurfaces.This modeisfornowonly possibleasextraoral 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 ofscanning is movable. Scanner resolution is similar to the intraoraoral scanner, but the scan time of onetooth is much longer. For the "four-member" bridge it takes 2-3 minutes. This year, the factory hasdevelopedanewhigh-resolutionscanner,inwhichthistimeisreducedtoabout40seconds(CerecINEOS)[11].

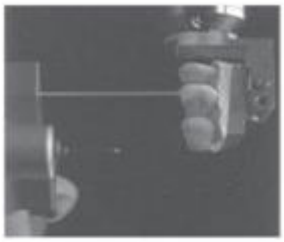


Figure12. CerecScan–*integrated laser scannerr, dotscannerintheleftengine*

Fig. 13. Cerec inLab system – *from left to right:inEos ekstraoralCerec in Lab with inbuilt dotscanner,PCcomputerwith 3Dsoftver*

6. AdvantagesofusingCAD/CAMtechnologyindentistry

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 simplifiedprocedure compare to the current way of producing. Restorations made this way are long-term, as the firststudiessaying. Figure14showsrestorativedentistrywithCEREC®3Dcomputerized.Sironastudy showsthat in five years 95-97% of CEREC's crowns are still intact, while the degree of preserved inlays andonlaysis 90-95%aftertenyears.

Figure14. RestorativedentistrywithCEREC®3Dcomputerized

The patient is provided with comfort and complete treatment is performed in one session in the contextof dental practice, of course with condition that a dentist has so called *Chairsaide* CAD / CAM. Thisactually means that the entire equipment can be placed in the area of dental office. This is a remarkableadvantage, because iteliminates theneedtocontinueworkindental technicallaboratories, as welleliminatesadditionalcosts.However,iftheCAD/CAMtechnologyislocatedinthedentallaboratoryand is applied by dental technician, it requires two visits to the dentist. By using this technology veryprecise restorations are produced, which so far is certainly not the case, whether it is about complicatedmulti-memberbridges, crowns, inlays,onlaysorveneers.

AdvantagesofusingCAD/CAMtechnology fordentistsare:

- Thepatient spendslesstimeintheoffice;
- Asimplifiedprocedure;
- Significantlyreducedcosts fordentaltechnicallaboratories;
- Reducedconsumptionofmaterials;
- Increasedproductivity;
- Easierwayofproducing;
- Preciselyproducedrestorations;
- Increasedproductivity.

AdvantagesofusingCAD/CAMtechnologyindental-technicallaboratory:

- Easierwayof producing;
- Morepreciselymaderestorations;
- Lowerconsumptionofmaterials;
- Higherproductivity.

AdvantagesofusingCAD/CAMtechnologytoproduceonlays:

- Veryoftensavesthetoothstructurecomparedtotraditionalcrowns.

AdvantagesofusingCAD/CAMtechnology toproduceinlays:

- Muchbetterrestorationthantraditionalfillings.

7. SurveyofpatientsatisfactionusingCAD/CAMtechnologyinBosniaandHerzegovina

In general, bearing in mind that for providing the services patients are essential, because who wouldprovideservicesiftherewouldbenodemand,andcrucialiscontinuouslyconductingresearchandanalysis of feedback from patients. When analyzing opinions, feelings and experiences of patients, it isnecessary to take all factors into account that in any way touch the patient. These are above all: speed ofservice delivery, the pain that is (not) felt when providing services, aesthetic effects, and the price ofservices as one of the most important elements, kepping in mind the economic crisis and the turbulentmarketdevelopmentsin ourand aswellregional areas.

Accordingly, it is formulated ten questions, formed into the questionnaire for assessing the level ofsatisfaction of patients after making dental implants using CAD / CAM technology. After treating thepatient,whilestillinthedentist'schair,askthepatienttosetasideafewminutestofilloutthequestionnaire,expressing theiropinionsandfeelingsabouttheexperiencewithdentalrestorations.Also,inadditiontotheabovequestions,towhichthepatientresponds,indicatingthelevelofagreementwiththe above findings, the patient has the ability to verbally and in writing to state its suggestions that wouldcontributetothefurtherimprovementand advancementofprovidingtheseservices.

Table1. Structureofquestionsforpatientswithfivesuggestedanswersontheissue(Author2016)certainperiod ofadaptation.

Questions	Disagree	Partially agree	Agree	Mostly agree	Strongly agree	Total:
1. The process of preparations for the prosthetic	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	0	0	4	22	74	100
4. During producing restoration , it is involved	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	0	0	10	19	71	100
7. Once the restoration is set up, it is needed a	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 10questions

per patient, in the past 6 months. The results showed that patients exceptionally satisfied withmaking dentures by CAD / CAM technology. Since the questions are formulated mainly that the firstcolumn (I disagree) reflects the lowest level of satisfaction of the patient (1%), while the last two columnsreflectthehighestlevelofpatientsatisfaction(75.20%).

The research results and responses participation depending on the customer satisfaction, isshown inthefollowingFigure 15.

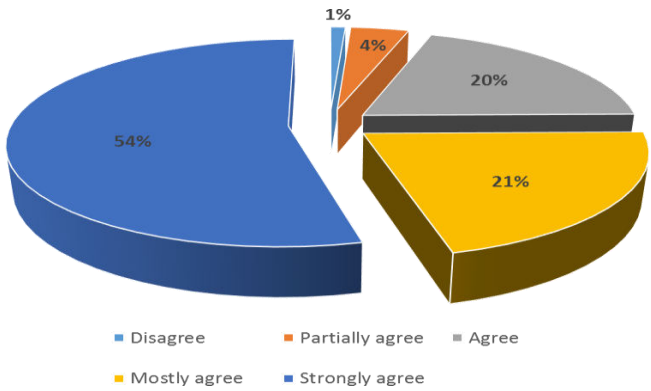


Figure15. Structureoftheresponsestothequestionnaireonpatientsatisfaction(Author2016)

From Figure 15 can be noted that the most significant participation in the structure of responses takefinal answers to the set of 10 questions: most agree and strongly agree, that is the highest level of patientsatisfaction in the amount of 75.20%. A minimum participation to the set of 10 questions take answers: donot agree, that is the lowest level of patient satisfaction of 1%. **The introduction of new technologies inBosnia and Herzegovina leads to the improvement of services in the field of dental medicine, asconfirmed by patient satisfaction (95%).** Accessibility prices to patients is very satisfactory (91%). Ontheissueof"producingrestorationsisshort",patientsatisfactionwas96%.Askedwhetherdentalrestorations giving anaturalfeeling?,patientsatisfaction is100%.

Brokendownby onequestionfromthequestionnaire,structureresponseisasfollows -Figure16:

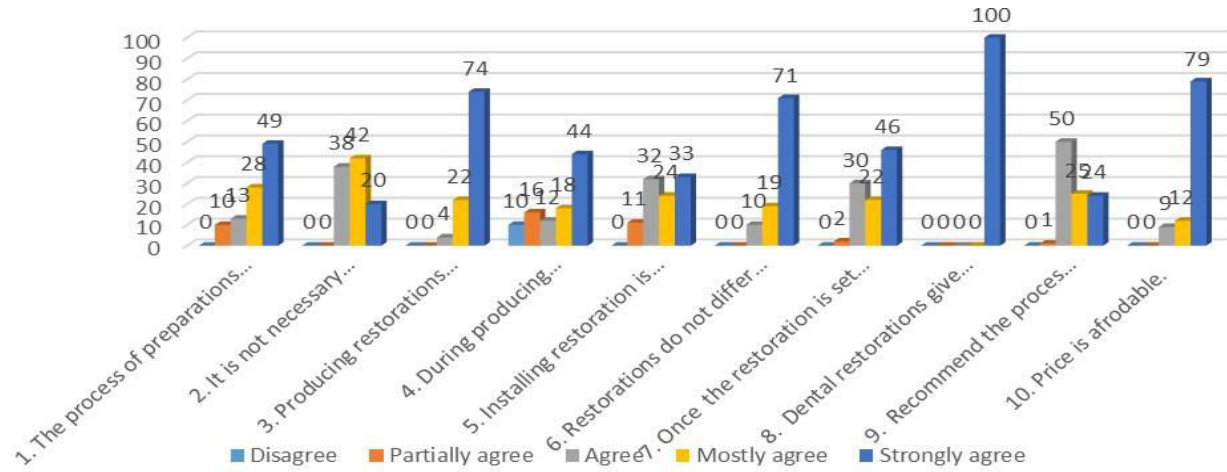


Figure16. Thestructureofthequestionnaireresponsesontheissuesofpatientsatisfaction(Author2016)

8. Conclusions

In conclusion, the integration of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) technologies has profoundly impacted modern dentistry, offering significant advancements in precision, efficiency, and patient care. This study underscores the transformative potential of CAD/CAM systems in enhancing the quality of dental restorations and streamlining clinical workflows. By enabling digital design and automated production, these technologies not only reduce the time required for treatment but also improve the accuracy and aesthetic outcomes of dental appliances. Furthermore, the ability to customize designs based on individual patient needs fosters enhanced communication between practitioners and patients, ultimately leading to higher satisfaction rates. However, the transition to CAD/CAM technologies is accompanied by challenges, including the necessity for substantial investments in training and equipment, which may pose barriers to adoption for some dental practices. Addressing these challenges is crucial for maximizing the benefits of CAD/CAM integration. Future research should continue to explore innovative

applications of these technologies, as well as strategies to overcome barriers to implementation. Overall, CAD and CAM technologies represent a significant leap forward in dentistry, promising to enhance the efficacy of dental treatments and improve the overall quality of patient care.

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