Reviews

Acrylic resins in the CAD/CAM technology: A systematic literature review

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Abstract

At present, new acrylic plastic technologies are being developed in dentistry. Although this kind of material has been used for dental prostheses for over 80 years, it has been produced in the form of disks with the computer-aided design/computer-aided manufacturing (CAD/CAM) technology for over 15 years.

The purpose of the article was to collect information from the literature on acrylic materials processed through the milling technology (CAD/CAM). The publicly available databases PubMed, Google Scholar and Scopus were searched using the key word "acrylic resins, CAD/CAM". All articles describing the application and testing of CAD/CAM disks were selected. Duplicate articles were removed. More than 100 articles that described the use of materials machined using the milling equipment were found. These included works comparing the mechanical properties, biocompatibility and clinical use of the materials. After the initial selection, 36 papers on this subject were included in this review.

The number of studies on the processing of acrylic materials with the use of the CAD/CAM technology has been increasing worldwide. Since such materials have better mechanical properties, no polymerization shrinkage occurs during processing, the amount of residual monomer material is very low and they have better color stability than self-curing materials.

Key words: acrylic resin, surface, flexural strength, residual monomer, CAD/CAM

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Introduction

Traditional acrylic materials consist of a powder and a monomer mixed together to form dough. In the case of thermally polymerized materials, it is necessary to supply heat energy to start the reaction. Self-curing materials polymerize at room temperature or in warm water of a temperature below 65°C. So far, the polymerization process have been carried out in a dental technician's workshop, or in special cases – in a dentist's office.[1–5]

This type of process leads to the contraction of the material, and in some cases, it can lead to the formation of porous structures inside the material after polymerization.[6] In the computer-aided design/computer-aided manufacturing (CAD/CAM) technology using acrylic disks, the curing process is carried out directly at the manufacturer's. Although the details of the production process are a trade secret, some stages remain unchanged. These include mixing the powder and the liquid in appropriate proportions, and storing the dough at a low temperature (−18°C) for about 24 h. In the next step, the dough is placed into molds, pressed, and gradually polymerized at gradually increasing temperatures. The whole task is to increase the degree of polymerization without creating voids (pores inside the material). The result is a product with very long polymer chains, low residual monomer content and high hardness.[7,8]

Currently, disks in tooth colors A1–C4 in the Vita® classical system are monochromatic or in 3–5 layers (from the lightest – A1 to A4). Thus, from one block it is possible to make crowns and bridges smaller in the cervical layer and lighter on the incisal edge.[9,10]

Apart form that, there are acrylic blocks in pink for making denture bases and transparent ones for making surgical guides in implantology.[10]

There are also hybrid materials on the market, which are a combination of ceramic and acrylic disks, so-called polymer-infiltrated ceramic (Vita Enamic®; Vita Zahnfabrik, Bad Säckingen, Germany). According to Patel, this kind of material has a very high fracture strength of about 180 MPa.[9]

In some systems for making dentures, the denture plate itself is milled and the teeth, produced with the traditional technology, are glued into the prepared holes with a self-curing material and a bonding agent (e.g., from Ivoclar Vivadent, Schaan, Liechtenstein). Other manufacturers recommend cutting teeth from one block and denture plates from another (AvaDent, Omaha, USA).[10]

A comparison of commercially available systems for the production of dentures based on the CAD/CAM system is comprehensively presented in an article by Baba (Ceramill® Full Denture System; Amann Girrbach, Pforzheim, Germany; Dentca™; Dentca Inc., Torrance USA; Avadent™; Global Dental Science, Scottsdale, USA; Wieland®; Wieland Dental + Technik, Pforzheim, Germany) and by other researchers.[1,10]

Material and methods

The publicly available PubMed, Google Scholar and Scopus databases were searched with the key word "acrylic resins, CAD/CAM" for articles from 2010 through 2020. The 1st screening of the literature databases returned 106 articles. The availability of articles in English or Polish (with an English abstract) was used as the 1st criterion. The selection was then checked and duplicate articles were rejected. Articles describing the application and testing of CAD/CAM acrylic disks were used. The total number of studies and the methods applied for screening for the review as well as the summary of the screening results are presented in Fig. 1. All the excluded articles together with the reasons for exclusion are shown in Table 1.

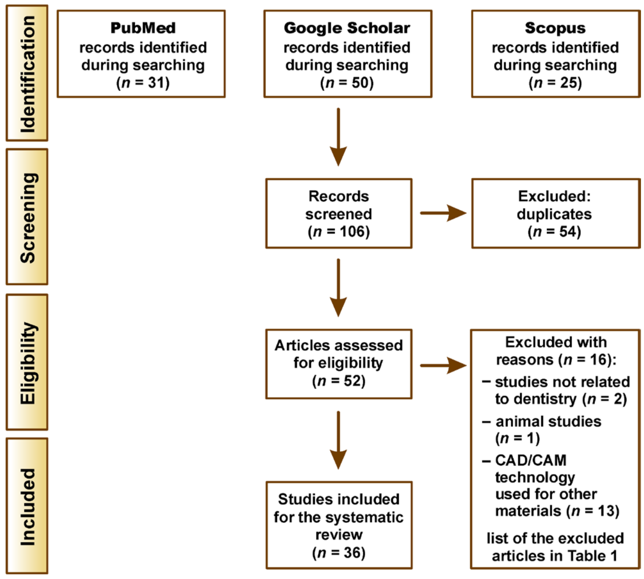

Fig. 1. Flow chart of the criteria for selecting articles

CAD/CAM – computer-aided design/computer-aided manufacturing.

Results

After the exclusion criteria were applied, 36 source articles were identified. Four of them appeared in more than 1 database, so they were used only once. The remaining articles were divided into 3 groups depending on what they referred to: mechanical properties; biocompatibility; and clinical use.

Mechanical properties

Andreescu et al. compared the mechanical properties of various acrylic materials available in the form of disks and intended for making denture plates.[10] The following were used in the research: Avadent, Baltic Denture System™ (Merz Dental, Lütjenburg, Germany), Ceramill Full Denture System, Dentca/Whole You™ (Dentca Inc.), and Wieland Digital Denture™ (Wieland Dental + Technik).[10] The flexural strength of the prefabricated materials is up to 146 MPa. The residual monomer content is also very low (less than 1%).

Table 1. Selection of publications

No.	Publication	Reason for exclusion
1	Wimmer T, Huffmann AMS, Eichberger M, Schmidlin PR, Stawarczyk B. Two-body wear rate of PEEK, CAD/CAM resin composite and PMMA: Effect of specimen geometries, antagonist materials and test set-up configuration. *Dent Mater*. 2016;32(6):e127–e136.	PMMA used for testing; it is not a CAD/CAM sample
2	Papaspyridakos P, Lal K. Immediate loading of the maxilla with prefabricated interim prosthesis using interactive planning software, and CAD/CAM rehabilitation with definitive zirconia prosthesis: 2-year clinical follow-up. *J Esthet Restor Dent*. 2010;22(4):223–234.	zirconium dioxide used as the main construction component, not an acrylic resin
3	Drago C, Saldarriaga RL, Domagala D, Almasri R. Volumetric determination of the amount of misfit in CAD/CAM and cast implant frameworks: A multicenter laboratory study. *Int J Oral Maxillofac Implants*. 2010;25(5):920–929.	the implant made with the use of the CAD/CAM and lost-wax technologies, the prosthesis made from a heat-curing resin, not CAD/CAM
4	Proussaefs P. Immediate provisionalization with a CAD/CAM interim abutment and crown: A guided soft tissue healing technique. *J Prosthet Dent*. 2015;113(2):91–95.	the final crown made from a ceramic material
5	Albero A, Pascual A, Camps I, Grau-Benitez M. Comparative characterization of a novel cad-cam polymer-infiltrated-ceramic-network. *J Clin Exp Dent*. 2015;7(4):e495–e500.	ceramic CAD/CAM materials tested
6	Cho Y, Raigrodski AJ. The rehabilitation of an edentulous mandible with a CAD/CAM zirconia framework and heat-pressed lithium disilicate ceramic crowns: A clinical report. *J Prosthet Dent*. 2014;111(6):443–447.	a ceramic CAD/CAM material used for rehabilitation
7	Bonfante EA, Suzuki M, Lorenzoni FC, et al. Probability of survival of implant-supported metal ceramic and CAD/CAM resin nanoceramic crowns. *Dent Mater*. 2015;31(8):e168–e177.	a ceramic CAD/CAM material tested
8	Dehurtevent M, Robberecht L, Béhin P. Influence of dentist experience with scan spray systems used in direct CAD/CAM impressions. *J Prosthet Dent*. 2015;113(1):17–21.	a heat-curing acrylic resin used for testing
9	Başaran EG, Ayna E, Vallittu PK, Lassila LVJ. Load bearing capacity of fiber-reinforced and unreinforced composite resin CAD/CAM-fabricated fixed dental prostheses. *J Prosthet Dent*. 2013;109(2):88–94.	a composite resin used for testing
10	Ji MK, Park JH, Park SW, Yun KD, Oh GJ, Lim HP. Evaluation of marginal fit of 2 CAD-CAM anatomic contour zirconia crown systems and lithium disilicate glass-ceramic crown. *J Adv Prosthodont*. 2015;7(4):271–277.	a ceramic CAD/CAM material tested
11	Lin WS, Metz MJ, Pollini A, Ntounis A, Morton D. Digital data acquisition for a CAD/CAM-fabricated titanium framework and zirconium oxide restorations for an implant-supported fixed complete dental prosthesis. *J Prosthet Dent*. 2014;112(6):1324–1329.	a ceramic CAD/CAM material tested
12	Tsitrou EA, Helvatjoglu-Antoniades M, van Noort R. A preliminary evaluation of the structural integrity and fracture mode of minimally prepared resin bonded CAD/CAM crowns. *J Dent*. 2010;38(1):16–22.	composite and ceramic materials used for testing
13	Spyropoulou PE, Razzoog ME, Duff RE, Chronaios D, Saglik B, Tarazzi DE. Maxillary implant-supported bar overdenture and mandibular implant-retained fixed denture using CAD/CAM technology and 3-D design software: A clinical report. *J Prosthet Dent*. 2011;105(6):356–362.	titanium used in the CAD/CAM technology
14	Bentz RM, Balshi SF. Complete oral rehabilitation with implants using CAD/CAM technology, stereolithography, and conoscopic holography. *Implant Dent*. 2012;21(1):8–12.	a composite material used for CAD/CAM
15	Maunula H, Hjerppe J, Lassila LLV, Närhi TO. Optical properties and failure load of thin CAD/CAM ceramic veneers. *Eur J Prosthodont Restor Dent*. 2017;25(2):86–92.	a ceramic material used for testing
16	Ciocca L, Mingucci R, Gassino G, Scotti R. CAD/CAM ear model and virtual construction of the mold. *J Prosthet Dent*. 2007;98(5):339–343.	non-dental use (ear making)

PMMA – polymethyl methacrylate.

Similar work was performed by Saad et al., who tested flexural strength, impact resistance, surface roughness, and residual monomer concentration.[11] Comparison tests were conducted for the heat-curing materials Acrostone® (Acrostone, Cairo, Egypt) and Momentive Performance Materials (MP-M) (Merz Dental). Acrylic resins were polymerized in long cycles – for 7 h at 70°C and for 30 min at 100°C. The results from this study show that the MP-M samples have better mechanical properties than the conventional acrylic resin. For example, the flexural strength for the CAD/CAM samples was 116.79 ±24.95 MPa, and for the heat-curing resin it was 94.58 ±5.75 MPa.[11]

The higher resistance to swapping and greater flexibility module of acrylic disks have also been confirmed by other authors (Yilmaz et al.[12] and Neves Pascutti et al.[13]). They tested 8 different brands of acrylic CAD/CAM disks and compared them with the values provided by the producers. In some cases, the fracture toughness value was up to 10–15% lower. Buduru et al. stated that some disk had 0.16% unpolymerized methyl methacrylate (MMA) inside the material.[14]

Steinmassl et al. performed an investigation of the residual monomer releasing from a conventional denture made with the CAD/CAM technology after 7-day storage in water.[15] Four systems were investigated: Baltic Denture System, Vita VIONIC® (Vita Zahnfabrik), Wieland Digital Denture, and Whole You Nexteeth™ (Whole You Inc., San Jose, USA). In addition, the authors examined the density of the milled dentures and their surface area. Baltic Denture System and Whole You Nexteeth had a significantly higher density as compared to the conventional acrylic resin; Baltic Denture System had a significantly smaller surface area. The concentration of residual monomer varied from 0.6 to 6 ppm, depending on the manufacturer.[15]

One of the important mechanical parameters, even one that is required by the standard ISO 20795-1:2013,[16] is the stability of the bars of the material from which the medical device is made. This topic was raised in a study by Dayan et al., who compared the color change of self-curing (Weropress®; Merz Dental), heat-curing (Paladent®; Heraeus Kulzer, Hanau, Germany), light-curing (Eclipse®; Dentsply Sirona, York, USA) resins, and samples milled from CAD/CAM disks (M-PM).[17] Standard solutions were used for the tests – coffee, cola, red wine, and distilled water (control group). The results were measured with a spectrophotometer before and after storage (after 7 and 30 days), and any color changes (ΔE) were calculated. The smallest color changes were recorded for the samples made from a CAD/CAM disk. The greatest color changes were seen in the case of the materials which were treated with red wine.[17] Similar observations about color changing were reported by Al-Qarni et al.[18]

Rayyan et al. tested differences in color, water sorption and solubility, and dye penetration between various materials for interim restorations, which are used to protect the pulp against thermal, mechanical, physical, and bacterial contamination.[19] One representative was chosen for each group: CAD/CAM (Cercon® PMMA; DeguDent, Rosbach vor der Höhe, Germany), self-curing powder/liquid (Alike™; GC Corporation, Tokyo, Japan), bis-acrylic (Acrytemp™, Zhermack, Badia Polesine, Italy), and DuraCetal® (Myerson, Chicago, USA). Under a microscopic examination, the samples prepared from the polymethyl methacrylate (PMMA) block showed no dye penetration through zinc oxide-based interim cement (RelyX Temp NE®; 3M ESPE, Seefeld, Germany) when placed in a polyester mold. A comparison between the sorption of individual materials interestingly showed that in the case of the samples milled from PMMA, it was 8.7 ±0.7 μg/mm^3, while for the traditional acrylic resin it was 28.5 ±2.0 μg/mm^3. Similar observations were presented for abrasion – the samples made from a CAD/CAM disk had values which were half that of the other materials.[19]

Materials used for dentures have to demonstrate proper light translucency and fluorescence to imitate soft tissues and the teeth in the patient's mouth. This issue has been presented by Güth et al. for 5 manual and 11 CAD/CAM polymer materials, using a spectrophotometer.[20]

Marginal adaptation, wear resistance and fracture resistance were compared between heat-curing and CAD/CAM acrylic resins by Elagra at al.[21] Marginal adaptation was tested using a stereomicroscope; afterward, the images were analyzed by means of software to measure the marginal gap between the model and the crown. CAD-Temp® (Vita Zahnfabrik) had an average space of 15.026 ±4.340 μm, while the value for the self-curing resin TempSpan® (Kerr Corporation, Orange, USA) was ten-fold higher: 145.418 ±25.365 μm.[21]

Modern prosthetics very often requires very different materials to be joined together – acrylic, composite, metal, and others. It can be particularly difficult in the case of the acrylic ones made with the CAD/CAM technology, where the material is polymerized under high pressure and at temperatures exceeding 100°C. This issue was discussed in more detail by Stawarczyk et al., who tested the connection between the Gradia® composite (GC Corporation) and 3 different PMMA blocks – CAD-Temp, artBloc® Temp (Merz Dental) and Telio CAD® (Ivoclar Vivadent) – after 7-days storage in distilled water.[22] Such joints are crucial, for example, when it is necessary to customize teeth milled from a PMMA block by using composite dyes, which are available in a larger range of colors. The authors prepared the acrylic surface in the following ways: no treatment; air abrasion (50 μm Al_2O_3); air abrasion with a silanating agent (50 μm Al_2O_3 + 3-methacryloxypropyltrimethoxysilane (MPS) (Monobond S®; Ivoclar Vivadent)) and an adhesive resin (StickRESIN®; Everstick, Turku, Finland) for Gradia/MMA application; and silica coating and silanization (CoJet-System™; 3M ESPE). The conclusion reported in this study was that CAD/CAM polymers could be veneered only with a PMMA-based veneer, with and without air abrasion. Adhesion between the acrylic block and the composite after water storage was very weak; mainly cohesive delamination was observed.[22]

During use, dentures should be cleaned to maintain hygiene; some patients use toothbrushes and pastes for this purpose. The resulting increase in surface roughness and weight loss has been tested by Shinawi.[23] For this purpose, Polident disks (Polident, Volčja Draga, Slovenia) were used, being subjected to abrasion tests with 40,000 and 60,000 brush strokes, which corresponds to approx. 3 years of brushing. Increased surface roughness leads to faster biofilm accumulation and colonization of various microorganisms, which can lead to mucosal inflammation and halitosis. As a result, surface roughness increased by 0.06 and 0.08 μm, and the simultaneous weight loss was 0.22 and 0.4 mg after 40,000 and 60,000 brushing cycles, respectively.[23]

Studies on the smoothness of the surface of acrylic plastics in the form of CAD/CAM disks were presented by Alammari.[24] The samples were polished by mechanical (pumice slurry and a polishing paste with Al_2O_3 (Universal Polishing Paste®; Ivoclar Vivadent)) and chemical means, and their surface roughness was measured. Chemical polishing was performed in a preheated jar containing MMA monomer at 75 ±1°C for 10 s. The author considered mechanical polishing as the most effective polishing technique and concluded that a better surface was obtained for the samples of CAD/CAM resins as compared to the heat-curing material.[24]

Biological compatibility

One of the first screening tests to determine whether a material is biocompatible is cytotoxicity testing on different cell cultures. In the data provided by manufacturers, it is sometimes possible to find such information. For example, inno/Blanc CORiTEC® (imes-icore, Eiterfeld, Germany) has a cell survival rate of 96–98% under 24-hour exposure.[14]

The adhesion of *Candida albicans* to the surfaces of denture plates made with the CAD/CAM technology was tested in relation to the traditional resins by Al-Fouzan et al.[25] After a 24-hour incubation period, the number of colonies present on the surface of the acrylic sample was calculated. In the case of CAD/CAM disks, this value was 1.1×10^3, while for the traditional heat-polymerized resin it was 2.3×10^3.[25]

Souza et al. tested a very important property of acrylic materials, i.e., cytotoxicity.[26] The samples of materials for manufacturing crowns and bridges were in contact with a cell culture for 24 h. One of the tested materials was VIPI BLOCK TRILUX® (VIPI, Pirassununga, Brasil) – an acrylic resin material used in the CAD/CAM technology, which was analyzed for the viability of oral keratinocytes (NOK-SI (RRID:CVCL-BW57)) from human oral mucosa. Alamar blue was used for detection. Cell survival for this material was not disturbed, in contrast to the self-curing type of acrylic materials. In addition, the authors compared surface smoothness and the adhesion of cells to the selected materials. The lowest roughness value was reported for the material in the form of milling disks.[26]

Clinical use

Buduru et al. made a comparison of 2 new methods used to make splints with the CAD/CAM and three-dimensional (3D) printing technologies.[14] Such devices allow the etiology of pain to be diagnosed, muscle or temporomandibular joint pain to be treated, or new occlusal positions to be tested. In both methods, instead of the traditional impression, an intraoral scanner (3Shape Trios®; 3Shape, Copenhagen, Denmark) was used. During the next step, a digital splint, 3-millimeter-thick, was made using the 3Shape Appliance Designer™ (3Shape). The 1st splint was fabricated from a disk (imes-icore), using the Zenotec Select™ milling machine (Wieland Dental + Technik). The 2nd device was prepared with Dental LT Clear Resin® (Formlabs Inc., Somerville, USA) and the printer used was Form 2 (Formlabs Inc.) with the stereolithography technique. The benefits of digital splints were appreciated in terms of working time, because the traditional technique required more than 5 h in the dental laboratory. Computer processing takes 1 h, a CAD/CAM device can be milled in 75 min and using the 3D printing technology takes 90 min. The 2nd parameter – the fit of the digital splint (both milled and printed) – was significantly better than that of the conventional splint. The best occlusion was obtained from the printed splint, and with the same benefits for the cost, since the cost of printing an occlusal splint is lower than the cost of milling one. In addition, there is not as much material waste as in the case of CAD/CAM.[14]

Infante et al. gave a detailed description on using the AvaDent system to produce removable dentures.[27] Firstly, impressions are taken using individual trays with silicones; then, the contacts between the jaw and the mandible are established using special maxillary and mandibular anatomic measuring devices (AMDs). After all of the impressions are sent back to AvaDent, the company prepares the denture with the CAD/CAM technology. The teeth are fixed into the denture base with a self-curing material. There is also an option of milling a model of the denture in wax with embedded teeth, which goes to the dentist to test the position and color of the teeth.[27] Other systems for milling CAD/CAM dentures used in clinical practice were described in a study by Han et al.[28]

Clinicians will be very interested in the accuracy and matching of prostheses made from an injection-molded material under pressure (Ivocap®; Ivoclar Vivadent) and restorations milled from acrylic disks (VIPI BLOCK TRILUX; VIPI). According to Lee et al., the accuracy measured in 2 points of the mid-palatal suture was significantly lower for than for the other method; however, the degree of fine reproducibility was higher in the case of the injection-molding technique.[29]

A clinical examination was carried out by Ali and Al-Harbi on 2 upper dentures for 1 patient, one made from the traditional heat-polymerized acrylic resin and the other milled from an acrylic block.[30] Then, they tested the force required to dislodge the maxillary prosthesis. Their results indicated that a force of over 2,000 gf was needed to remove the restoration from the oral cavity, whereas the traditional one had a lower adhesion of about 1,400 gf.[30]

Other authors compared the accuracy of dentures produced with the CAD/CAM technology to traditional supplements.[31–35] Everyone is of the opinion that milled dentures have a slightly better fit in comparison with traditional dentures. This is due to the shrinkage of the material during polymerization, the lower surface roughness coefficient and the more homogeneous surface of the polymerized material in industrial conditions, among other things.

Conclusions

The literature review clearly indicates that acrylic materials used in the CAD/CAM technology have better mechanical and biological properties than traditional acrylic materials. The only disadvantage of these materials is the waste of the remaining material after milling the restoration, which can no longer be used. At present, a new 3D printing technology is becoming more and more important. However, it still has some limitations, e.g., the inability to print multicolor teeth with an appropriate degree of translucency.[12,13,15,28,35,36]

Yet, CAD/CAM materials have a lower adhesion between the acrylic teeth and the denture plate. This is due to the fact that in the case of heat-curing materials, the teeth are polymerized along with the denture plate. In most CAD/CAM systems, however, the teeth are glued using a self-curing resin. In addition, CAD/CAM blocks are harder and more cross-linked. There are fewer double bonds to which the self-curing resin can be attached. Some authors have concluded that polymer beads may not dissolve completely into monomer prior to polymerization, and the fast drying of bonding agents after contact with CAD/CAM blocks and acrylic teeth gives poor mechanical retention.[35,36]

Prosthetic processes in the CAD/CAM technology should be used when higher mechanical resistance, better surface smoothness and better color stability are required as well as when semi-permanent crowns and bridges and removable dentures are needed.

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