REVIEWS

ANALYSIS OF TECHNOLOGIES FOR RAPID PROTOTYPING OF DENTAL CONSTRUCTIONS

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ABSTRACT

In the following article new technologies for the production of dental implants are presented. Using the best achievements of mechanical engineering, such as CAD/CAM and additive technologies, entirely new opportunities for increasing complexity, geometric accuracy, speed, and production efficiency of dental products are discovered.

Keywords: *new technologies, rapid prototyping, Inkjet, SLM, NC CAM*

INTRODUCTION

In recent years there has been a rapid development of technologies in the dental field. This is due to the use of specialized CAD/CAM dental software systems, which are aiding the design and manufacturing processes of dental restorations, placed on a functionally new level, unmatched compared to the current methods.

Technologies are improving and often the introduction of new, superior methods, techniques, coming from other fields of science and economy is observed, as it happened with the digital cameras, created by computer companies. And thus in the last years, the dentistry field is experiencing an increasing influence of systems, that are coming and/or adapted from the high-tech segment of engineering.

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Even during the 80s in the Western world, mainly in the USA, Canada and France, dental specialists and technicians started researching the opportunities of using the newly arrived in the industry CAD/CAM systems and scanning devices for the purposes of dentistry. Pioneers in this field are J. Duncan, Emeritus, F. Duret, D. Rekow, J. Nasedkin, R. Caudil.

Their achievements became the foundations for implementation of engineering technologies in dentistry and prostheses manufacturing – laser scanning techniques, usage of CAD/CAM software systems, rapid prototyping technologies, milling and above all, adapting all these technological processes for the purposes, needs and specifics of the dentistry.

CAD/CAM are software-based, high performance technologies with old traditions in the industrial sector. In the dental practice, these technologies are aiming to replace the casting technologies with high-speed automatic machining of dental constructions (crowns, veneers, bridges…) or directly metal building (3D printing) by means of computerization of the main operations of preparation and manufacturing of the physical models. The total cycle of operation starts with an identical to the classic method first step – physical taking of an impression of the jaw and the surrounding teeth (performed in the dentist's office). Then it is necessary for the recorded information to be further improved on and subsequently transformed into a digital form. The process of digitalization starts with the scanning of a plaster model, or with an intraoral scanner directly into the oral cavity (1,2). After scanning has finished, reconstruction of the scanned surfaces is performed with specialized software (the software provided from the manufacturer of the 3D scanner is the most frequently used one). These software systems are managing the stages of scanning, and the entire subsequent process (known as re-engineering) to the creation of a precise virtual three-dimensional image of the scanned physical model. The process continues in a 3D CAD system for three-dimensional morphological and anatomical modeling for dental constructions and restorations and finishes with the use of a CAM system that creates control programs for the manufacturing of the constructions on CNC machines, or for post-processing during direct metal building (3D printing). CAD dental restorations are as good as handmade ones and in most cases even better (3).

In Bulgaria, the so-called "classical" way of working is still the leading method. It is based on outdated technologies, which generally consist of the following processes:

- physical taking of an impression of the jaw and adjacent teeth – fig 1.a (performed in the dental office, used materials: alginates, silicones, etc.);
- subsequent sending of the impression to the dental laboratory;
- using the taken impression to manually form the corresponding element (crown, bridge, abutments, etc.) from technical wax;
- the manually created model is used to cast the construction (like a disposable melting wax model)
- after the cast is made, manual cleaning and finishing follow, then the prosthesis is sent back to the dental office to be received by the patient

These technologies do not allow the use of a lot of the new, advanced materials for dental constructions like zirconium oxide and others. In addition to being slow, this technology is highly dependent on the skill, experience and current condition of the technician. Often the model is not accurate enough and it is necessary to be sent back to the laboratory for corrections, and/or to be manually corrected on site by the dentist, if possible. It creates inconvenience for the patient as well as requires his repeated visits to the dentist's office.

New manufacturing methods for dental constructions

Methods, techniques and materials, used in dentistry have experienced serious development in the past years. The use of dental restorations (like: crowns, bridges, abutments, onlay and inlay etc.) is becoming even more relevant.

There are a number of specific requirements for dental constructions implants and in particular for the crowns. They should be durable, made from safe for human health materials, (for example – not causing allergies), built from inert or chemically neutral materials, because of the acidity of the consumed foods and the microflora in the human mouth; should not be damaging to the teeth, gums and jaw.

Among the used materials there are different metals (stainless steel, titanium etc.) and alloys (for example cobalt, tungsten and chromium, cobalt + chromium + molybdenum, or manganese + silicon + carbon + nitrogen; copper + zing + nickel alloys etc.), including precious metals (gold, silver – palladium), and metal-ceramic materials (consisting of 60-75% feldspar, 15-32% quartz and the increasingly more used zirconium oxide). The accuracy of their manufacturing contributes to the main factors responsible for the longevity of the constructions (4). Special requirements are needed in these cases unlike when using the conventional methods for manufacturing.

Recently in Bulgaria, a new type of manufacturing has started being used. It is based on a new technology for dental constructions, in particular milling – made inside dental laboratories. However, in most cases it's achieved using small desktop milling machines, with comparatively low quality, and low productivity. These mills have a relatively small number of working axes and do not support high-speed milling.

Generally, this technology is used by all dentistry companies for the purposes of creating metal and ceramic dental implants. This leads to a series of problems, mainly unfamiliarity with the CAD/CAM technologies, which are new and extrinsic for them – 3D scanning, 3D modeling, CNC programing, post-processing of the manufacturing program, so that the 3D model could be manufactured with the constraints that come from milling. These are technologies that are just now making an appearance in the dental field.

The next few steps differ from the standard dental applications and are implemented through the use of the most modern computer technologies:

Automatic form and shape capture using a stationary 3D scanner allows the fabrication of dental crowns and bridges with very high precision (5). The scanner is located at the dental office or at the manufacturing company (which only requires the dental impression from the dentist) (Fig.1b). It must be noted that mobile scanners can also be used, operated by the dentist. When working with them, a dental impression is not required, instead the scan is taken directly from the patient.

The utilization of 3D CAD software, for a process known as Reverse Engineering, allows the processing of the scan data which then turns the scan information into a working 3D model – at this point the model is digitized and ready to be sent for manufacturing.

Using 3D CAD software enables the use of an alternative way for modeling bridges, crowns, dental inserts, etc., compared to the standard approach of hand-formed dental wax. The process is further simplified by using standard components, found in libraries inside the software, which are modified to fit the patient's requirements (Fig. 1c).

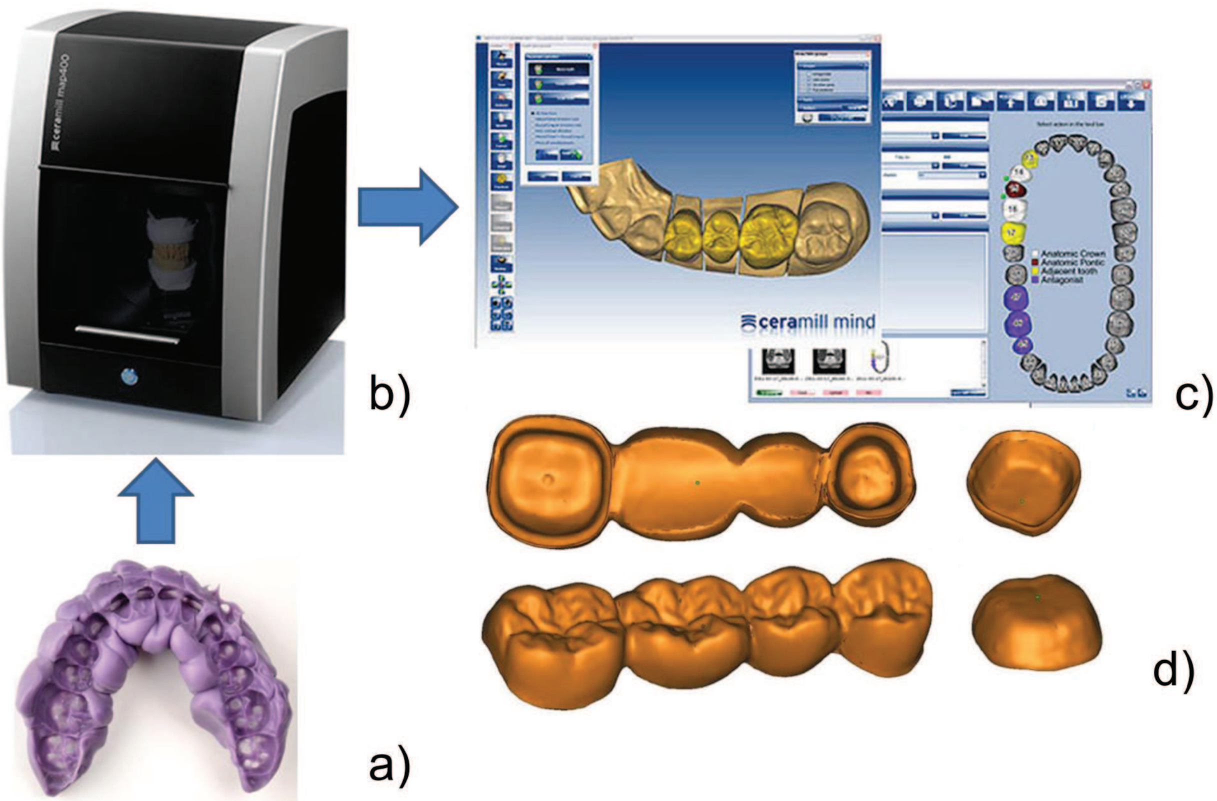

Fig. 1. CAD modeling process

MANUFACTURING METHODS

The next step is transforming the digitized 3D model into a physical one. In theory, many of the material-additive manufacturing technologies are suitable to be used for the creation of dental constructions, some of which are listed below (6):

- Stereo Lithography – SLA

- 3D printing
- Polyjet technology
- Laminated Object Manufacturing – LOM
- Solid Ground Curing
- Inkjet technology
- Fused Deposition Modeling – FDM
- Selective Laser Sintering – SLS
- Selective Laser Melting – SLM, Direct Metal Laser Sintering – DMLS
- Laser Engineered Net Shaping – L.E.N.S.

In reality, only a few of the additive technologies are suitable for the dental field, since high precision and specific material characteristics are required to achieve the complex morphological shape of the implant.

- 3D prototyping with inkjet technology and subsequent precision investment casting (7).
- 3D metal printing using the selective laser melting technology (SLM) (8).
- Material subtracting technologies – NC CAM manufacturing (9).

Prototyping Using the "Inkjet Technology"

The "Inkjet technology" allows the manufacturing of high-precision models from a polymer material with characteristics similar to technical wax. The 3D scan data acquired from the first step shown on Fig.1 is used as an input data for the process.

The approach is as follows: The prepared CAD model of the constructions (prepared or scanned), sometimes with additions needed for molding such as casting feeders, etc., is scaled (in correspondence with the coefficient of thermal shrinkage in casting) and exported to an STL file, which is then sent to the operating system of the rapid prototyping machine (Fig. 2a, b). The model goes through a feasibility check and is sent for production.

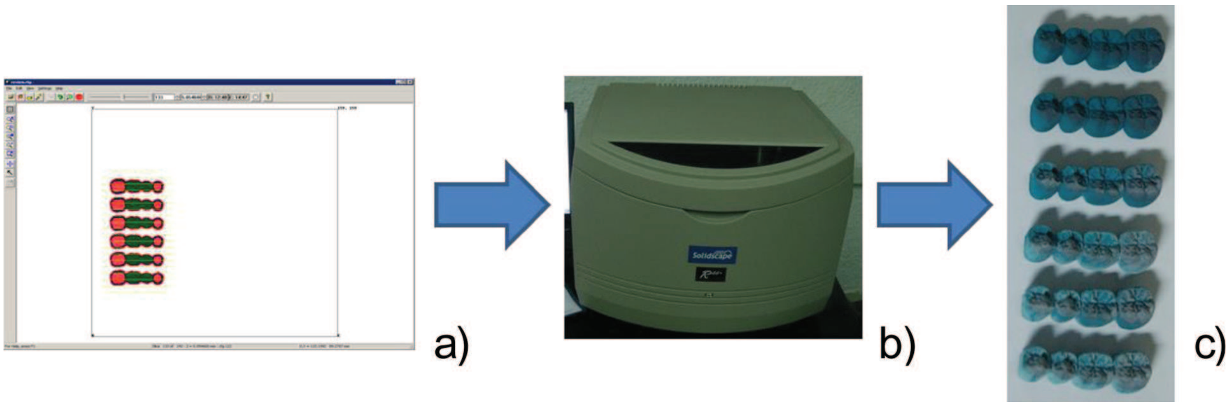

Fig. 2. Rapid Prototyping for investment casting

The rapid prototyping model, Fig. 2c, serves as a physical representation of the real model and it is subsequently used as a base for precision molding.

The process of precision molding is done in the conventional way: The prepared model is placed in the casting and serves as a "core". After casting, the model is melted. This leaves a cavity with the same shape. Afterwards, metal is used to cast the mold and the part takes the required final shape.

The process takes longer in comparison with conventional methods, however the resulting model is of significantly higher quality (10). The method is generally used for complex shapes with high requirements of accuracy.

Direct Production of Dental Constructions (Sellective Laser Melting – SLM)

This is one of the newest technologies and it's also the first method of rapid prototyping, where metallic powder, sized between 10 and 45 μm, is used as raw material, which is then converted to solid material through the production process. An important advantage of this method is the lack of organic components.

Again the STL file of the dental construction should be imported (Fig. 3a). Then the part is built layer by layer in the SLM machine (Fig. 3b), where normal layer thickness is usually around 30 μm. This process allows for completely automated manufacturing of complex design scenarios, using CAD geometry in the matter of only a few hours, without using any tools. The final product (Fig. 3c) is of high geometric accuracy, acceptable finish and adequate mechanical properties.

The CAM software (Fig. 4a), using the geometry of the 3D model, calculates a stock piece (automatically or manually) and the following properties are inputted:

- Material type;
- Tool/tools, cutting parameters;

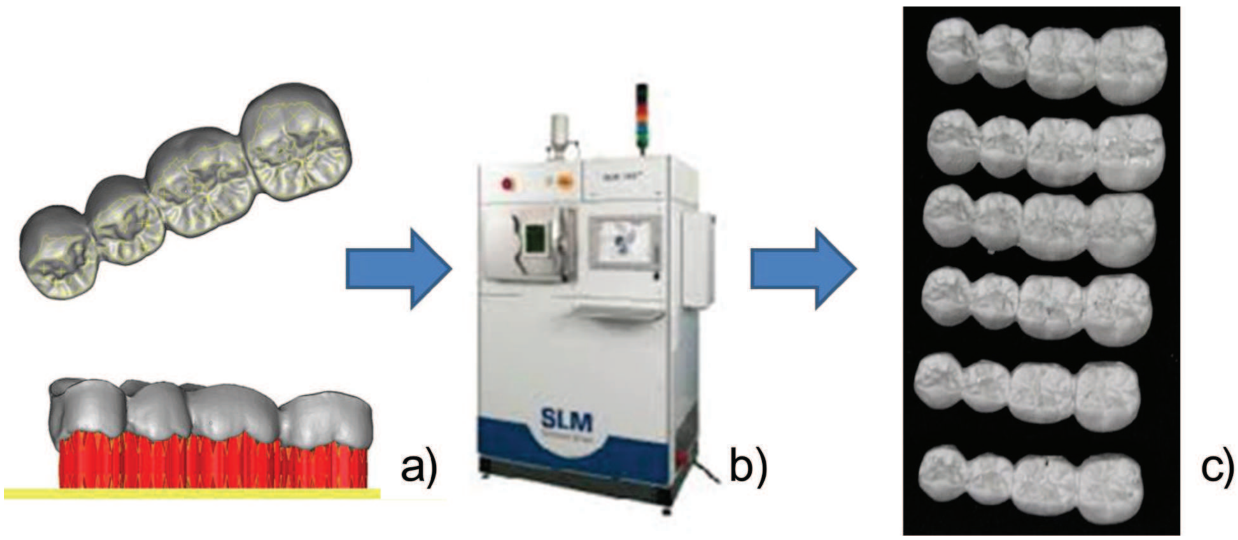

Fig. 3. Direct metal production of dental constructions

In general, SLM technology excels the traditional methods of manufacturing due to the following advantages: it doesn't require any tooling; the overall manufacturing speed is higher than the one of conventional techniques; the achieved geometry quality is acceptable for the needs of dental medicine; many different alloys can be used as raw materials, such as alloyed steel, cobalt-chromium alloys, Inconel 624 and 718, and titanium alloys Ti6AlV4, Ti6Al7Nb; the final metallic part is the final product, ready for use; allows for extremely precise inner transitions to be built into the models, which are usually not possible with other manufacturing methods, like casting, for example.

Due to the properties mentioned above, this technology appears to be a progressive choice for dental construction production (11).

NC CAM Manufacturing

The completely finished design of the part, developed within the CAD system (crown, bridge, jaw, bezel, etc.) is physically manufactured, after which the physical model is implanted into the patient.

- Stock mounting;
- Type of machining, according to the technological capabilities of the software and the CNC machine, varying between 3+2 and 5 working axes;
- Machining strategies are chosen, according to the available software options and the geometrical conditions of the part;
- Cutting tool paths and the appropriate feeds are inputted;
- Precise, virtual analysis of the cutting process is conducted, in order to avoid mistakes, due to incorrect cut offs, incisions or bad machining. Collision analysis is conducted.

After all inexactness and programming errors are fixed (i.e. the program analysis shows no more problems) post-processing is conducted, which translates the source code into the machines program code (5 axes machining center - Fig. 4b).

Once the program is processed by the CAM system, it is uploaded to the machine's CPU, via a serial interface device, flash stick, USB port, optical cable, etc. The required cutting tools are set up by the machine operator into the correct positions, then the stock piece/pieces are mounted and the cutting process is started.

Milling machines can be used with a wide variety of materials. Lately, the most widely used materials are chromium-cobalt alloys (Fig. 4c), zirconium oxide (Fig. 4d), as well as different types of polymers (Fig. 4e), some of which are appropriate to be used as fuse models.

technological point of view. Physical models can be produced with complex shapes that would be much more expensive, not to say impossible to produce, using conventional manufacturing. Some methods of material-adding manufacturing are used to produce finished parts with complex shapes, such as human endoprosthesis or aerospace components.

Capabilities of the material removal manufacturing technology are presented (HSM- High Speed

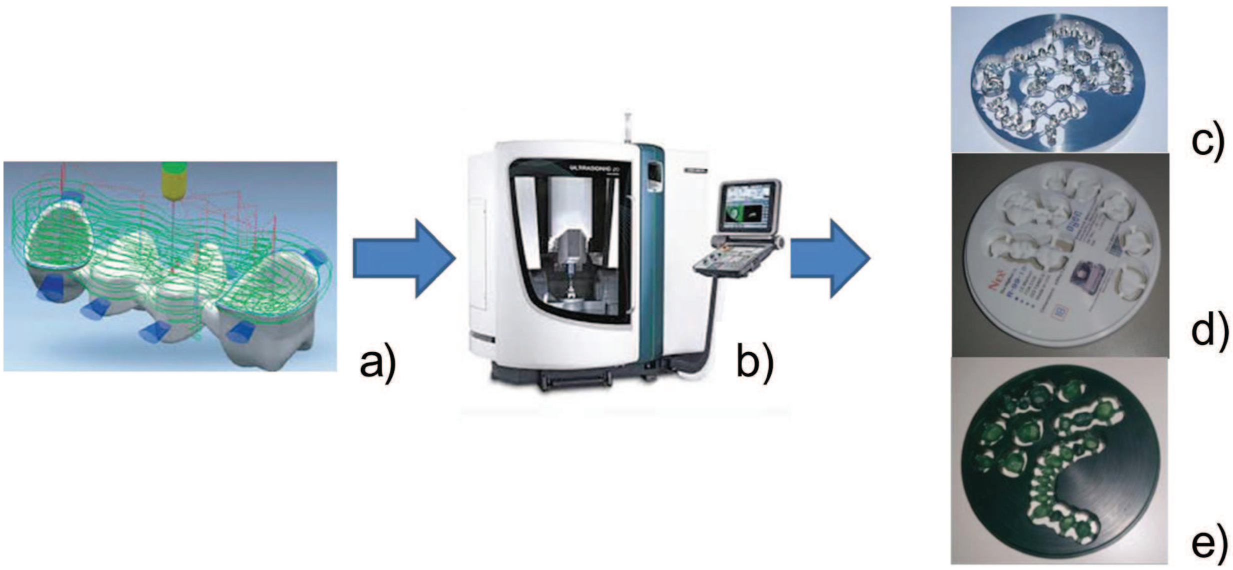

Fig. 4. NC CAM subtraction manufacturing process (High Speed Milling)

Milling), which allow for different dental materials to be machined, such as zirconium, chromium-cobalt and technical wax with high level of automation and geometrical accuracy.

5-axis milling allows for better surface finish, respectively lower roughness, because the disadvantage of 3-axis machining- the impossibility to dynamically maintain the angle between the tool and the normal surface at the point of contact - is avoided. This feature is particularly significant when it comes to the complex shapes of the implant.

The technological methods for dental constructions manufacturing, reviewed above, are new and exclusively progressive, accurate, and highly effective when it comes to production of dental components.

In practice, the dental manufacturing concept is set at an entirely new platform that has no analogue and can't be compared with the conventional

Thanks to the facts mentioned above, these new technologies, heavily influenced by the world of engineering, are becoming more and more popular with dental production, allowing for higher quality, saved time and satisfied patients.

CONCLUSION

One clear advantage of the latest CAD/CAM technology to traditional methods is the ability to make restoration with practically one visit by the patient.

The rapid manufacturing technologies, also known as "Material-Addition Manufacturing", work in a way that is the exact opposite of the conventional manufacturing methods. Instead of being "dug" from the stock, the part is "printed" layer by layer via material addition.

Another important advantage of rapid prototyping over the conventional methods is that the construction doesn't need to be optimized from a techniques, available now, when it comes to quality, manufacturing time and cost.

Also, the comfort for the patient must be noted as well, because with these methods he is only required to visit the dentist twice (for measurement and for application) in order to be fitted with dental constructions of high quality, made just for him.

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