MEDICAL SCIENCES

DIGITAL TECHNOLOGIES IN PROSTHODONTICS

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Abstract

The development of new materials and additive technologies represents a cutting-edge scientific direction in dentistry. The demand for these technologies is driven by the high quality of dental prostheses and restorations, including: aesthetic appeal, precise control over thickness and spatial dimensions, and geometric accuracy of critical design and technological elements of the prosthetic structure.

Additive digital technologies reduce material consumption, decrease the need for personnel, and significantly shorten the time required to transfer information from the patient to the dental technician, as well as the overall fabrication time of prostheses.

Dentists need to be aware of the full range of possibilities offered by digital technologies to provide a personalized approach to each clinical situation. Timely training of specialists fully proficient in digital workflows is a key condition for ensuring high-quality prosthodontic care.

Keywords: additive digital systems and technologies; prosthodontics.

Rapid Development of Digital Technologies in Dentistry

The global dental industry is advancing at a pace far exceeding other areas of medicine. A major breakthrough in dentistry has been driven by digital technologies, which are now widely used at all stages of prosthodontic treatment. Among these, CAD/CAM systems (Computer Aided Design / Computer Aided Manufacturing) are the most prevalent [1–6].

Thanks to the rapid development of computer technologies, new opportunities for applying automated systems in dentistry emerge every year. Today, almost all leading global manufacturers of dental equipment offer their own CAD/CAM systems [7–10].

The use of dental CAD/CAM systems is not limited to the fabrication of prostheses. Several CAD/CAM systems have been developed for surgical applications. For example:

- SURGI GUIDE (MATERIALISE, Belgium) is used to produce individual surgical templates that facilitate accurate placement of dental implants during surgery.
- NOBELGUIDESOFTWARE (NOBELBIOCARE, Sweden) enables the fabrication of a restoration immediately after implant placement.

Both systems utilize data from computed tomography (CT), specialized CAD software to determine optimal restoration placement, and CAM technologies for manufacturing templates or working models [11–14].

Open vs. Closed CAD/CAM Systems

CAD/CAM systems are categorized as open or closed. An open system allows replacement of any of its modules with a compatible module from another manufacturer, and integration with other systems is relatively seamless. Openness can be considered at various levels of the software and hardware hierarchy of the system or its components. In some cases, system openness refers to compliance with modern industry standards, enabling integration with other open systems.

CAD/CAM systems can also be classified according to the method of optical scanning into clinical (intraoral) systems and dental laboratory systems. In clinical systems, intraoral scanning is performed directly in the patient’s mouth, and the data is transmitted as a digital file. In dental laboratory systems, scanning is performed on gypsum models [15].

Subtractive vs. Additive Methods

CAD/CAM technologies are divided based on the manufacturing method into:

1. Subtractive methods – involve material removal processes such as milling and grinding to achieve the desired prosthetic shape. This method is called the subtractive method because the material is “taken away” (English: subtractive).
2. Additive methods – involve material addition processes, including stereolithography, 3D printing, selective laser sintering, and direct injection printing [16]. These methods are alternatives to subtractive techniques and are referred to as additive methods (English: additive).

Additive manufacturing, also known as 3D printing or fabber technologies, is sometimes called rapid prototyping (RP). It is based on converting CAD models into solid physical objects using specialized digital fabrication devices called fabbers.

Currently, 3D printing is especially effective for creating metallic components of removable prostheses [17]. It is also suitable for producing larger or more complex structures such as facial prostheses or skeletal models, which are difficult to fabricate using traditional CAD/CAM methods that are better suited for smaller components. Additive manufacturing allows the use of materials with varying properties and consistencies [18].

In Russia, there is no unified classification of additive technologies. Methods are typically categorized based on materials used, the presence or absence of a laser, layer formation techniques, energy delivery, etc.

Two main additive manufacturing technologies are used:

Laser-based technologies:

- Laser polymerization – a UV laser gradually hardens a liquid photopolymer, either directly or through a photomask, layer by layer, forming a durable plastic object.
- Laser sintering – a laser selectively fuses powder (e.g., from light-alloy plastics) layer by layer to form the contour of the desired part.

Inkjet-based (jetting) technologies will likely follow in the next section.

Additive Manufacturing: Jetting Technologies and Laser History in Dentistry

Laminating (Laser-Based Additive Method)

- The part is built from multiple layers of material, which are gradually stacked and fused together. A laser traces the contour of each cross-section of the future object. After processing, excess powder is removed from the finished part.

Jetting (Inkjet-Based) Technologies:

1. Material solidification upon cooling – a dispensing head deposits droplets of heated thermoplastic onto a cooled base platform. The droplets quickly solidify and bond together, forming layers of the object.
2. Powder bonding or sintering – similar to laser sintering, but here the powder is bonded with a liquid adhesive from a jetting head. This method can also reproduce colors by using binders of different shades [19].

History of Lasers in Dentistry:

- The first laser was invented in 1960 by Theodore Maiman, using a ruby crystal to produce an intense red light, with no medical application initially.
- In 1964, Goldman proposed using lasers in dentistry, specifically for caries treatment. For safety in the oral cavity, pulsed lasers were later introduced. With growing experience, the anesthetic effect of lasers was discovered.
- In 1968, CO_2 lasers were first used for soft tissue surgery.

Modern dental lasers are increasingly used in endodontics, periodontology, surgery, orthodontics, and implantology, gradually replacing scalpels, electrosurgical tools, and some medicinal approaches due to their high clinical efficacy and ease of use. Lasers allow for minimally invasive, virtually painless procedures that meet high clinical standards.

Fused Deposition Modeling (FDM) and 3D Printing:

- FDM, invented by S. Scott Crump and patented in 1988, creates 3D forms by extruding heated thermoplastic layer by layer, without using a laser.
- In 2000, PolyJet photopolymer jetting technology was developed, where a printer head deposits photopolymer layers that are cured with UV light.
- The term “3D printing” was coined in 1995 by Jim Bredt and Tim Anderson, who modified a flatbed inkjet printer to produce three-dimensional objects instead of images on paper [20].
- One of the rapid prototyping methods used in dentistry is laser stereolithography (SLA). The term “stereolithography” was introduced in 1986 by Charles W. Hull, who patented the method and device for producing solid physical objects by sequentially layering a photopolymer material. The method is based on the photo-initiated polymerization of a light-sensitive photopolymer composition (PPC) using laser radiation.
- Using this technology, a computer-designed 3D object is synthesized from liquid PPC in consecutive thin layers (0.05–0.2 mm) formed by laser exposure on a movable platform [21, 22]. Typically, the processor for generating horizontal cross-sections first converts the 3D model description in STL format into a series of layer cross-sections with the required layer thickness. This array is saved in an SLI file, which contains 2D vector data to sequentially control the laser beam orientation via mirrors, laser activation commands, platform movement, and other operations [23–25].
- Next, the laser is activated to cure the polymer in areas corresponding to the object walls. After this, the platform is lowered by the thickness of one layer. At this stage, a special brush wets any areas that might remain dry due to surface tension. Upon completion of the object’s construction, it is immersed in a bath with special solutions to remove excess material and clean the part. Finally, it undergoes intense UV exposure for complete curing. Like many other 3D prototyping methods, SLA requires support structures, which must be manually removed after fabrication [26].
- The 3D printing process saves considerable costs and significantly improves the quality of surgical procedures, such as dental implantation. In addition to producing prostheses, crowns, and bridges, 3D printing allows for the fabrication of orthodontic aligners. Teeth are scanned, a 3D model is created based on the scan, and the aligners are subsequently printed [27, 28].
- Laser stereolithography enables rapid transition—from a design or engineering idea to a finished model—in just a few hours to a few days. Selective laser sintering (SLS) is another technology used to manufacture ceramic or metal dental restorations. Examples include the Medifacturing system (BegoMedical AG, Germany) and DigiDent (Hint-ELs, Germany). In this method, the computer calculates the tool path, similar to other CAD/CAM systems, but instead of milling, the laser sintering fuses the material layer by layer.

риала, двигаясь по заданной траектории внутри ем-кости, заполняемой послойно керамическим или ме-таллическим порошком. Каждый последующий слой спаивается с предыдущим [31]. В стоматологии сте-реолитография нашла своё применение в ортопедии, ортодонтии, имплантологии и челюстно-лицевой хи-рургии [30–35].Таким образом, цифровые технологии в настоящее время развиваются и совершенствуются, обеспечи-вая врачей-стоматологов новыми более эффективными возможностями для лечения пациентов. Востребо-ван-ность технологий обусловлена высоким качеством из-готовления зубных протезов и реставраций: эстетич-ностью, полным контролем толщины и пространства, геометрической точностью размеров ответственных конструкторско-технологических элементов и формы изделия. Кроме того, аддитивные цифровые технологии снижают расход материалов, уменьшают количество не-обходимого персонала и существенно сокращают сроки передачи информации от пациента зубному технику и сроки изготовления протезов. Сохранение данных в цифровом формате позволяет повторно воспроизвести протез в случае поломки. Разработка новых материалов и аддитивных технологий является новым научным на-правлением в стоматологии. Врачи-стоматологи долж-ны быть осведомлены о спектре возможностей, предо-ставляемых цифровыми технологиями. Своевременная подготовка специалистов, в полной мере владеющих цифровыми технологиями, программным обеспечени-ем, является важным условием обеспечения качества стоматологической помощи

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