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MODERN IMPLANTOLOGY TECHNOLOGIES AND THEIR ADVANTAGES

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ABSTRACT. This article analyzes the development of modern technologies in the field of dental implantology and their application in clinical practice. Within the scope of the research, new approaches such as digital implantology, robotic implantation systems, 3D-printed implants, bioactive coatings, and regenerative technologies have been examined. Additionally, the advantages of these innovative technologies compared to traditional methods, including higher precision, reduced invasiveness, faster healing, and long-term stability, are discussed. Based on literature analysis, data on the effectiveness indicators of modern implantology systems and improvement of clinical outcomes are presented.

Keywords: dental implantology, digital implantology, navigational implantation, bioactive coatings, 3D-printed implants, regenerative technologies.

INTRODUCTION. Dental implantology has achieved significant development over the past decades and is currently considered one of the most effective treatment methods for tooth loss. Modern technologies in the field of implantology have significantly improved not only the implantation process itself but also rehabilitation outcomes (Buser et al., 2017). Due to the implementation of digital technologies in dentistry, improvement of biocompatible materials, and optimization of surgical protocols, the reliability and long-term stability of implantation systems have increased significantly. Innovations in modern implantology are developing primarily in four directions: increasing surgical precision, improving biological integration, reducing patient discomfort, and shortening treatment duration (Joda et al., 2019). This article examines the main directions of modern implantology technologies, their advantages, and effectiveness in clinical practice.

DIGITAL IMPLANTOLOGY TECHNOLOGIES

Computer-Aided Implant Surgery (CAIS)

Computer-Aided Implant Surgery (CAIS) systems have brought about significant changes in implantology in recent years. These systems combine 3D visualization, planning, and navigation capabilities, allowing for detailed study of the patient's anatomical structure and development of precise implant placement plans (Tahmaseb et al., 2014). CAIS technology includes the following stages:

Obtaining 3D images of the patient using cone beam computed tomography (CBCT)
Planning implant placement using specialized software
Preparing surgical templates using stereolithographic or 3D printing methods
Precise implant placement using templates

Research shows that CAIS systems significantly increase the precision of implant placement compared to traditional methods. According to a meta-analysis conducted by D'haese et al. (2017), the use of navigational implantation systems resulted in an average deviation of less than 1 mm in placement, which is 2-3 times better than traditional methods.

Navigational Implantation Systems

Navigational implantation systems (dynamic navigation) provide the ability to track the position and direction of surgical instruments in real-time. These systems are implemented using stereo cameras, sensors, and operational 3D visualization, providing surgeons with additional precision

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and safety levels in implant placement (Block & Emery, 2016). Based on clinical research conducted by Block et al. (2017) evaluating the placement results of over 100 implants, the average precision indicators achieved using navigational systems were as follows:
Average deviation at entry point: 0.4 mm
Average deviation at apex: 0.7 mm
Average angular deviation: 2.4°
These indicators show significantly higher precision compared to traditional methods and reduce the risk of damaging important anatomical structures.

Robotic Implantation Systems

Robotic implantation systems are considered one of the most advanced technologies in dental implantology. These systems automate part of the implant placement process while strictly adhering to pre-programmed plans (Jung et al., 2022). Modern robotic implantation systems such as the Yodatea implant system (Neocis Inc., Miami, FL, USA) eliminate natural hand tremors of surgeons and significantly reduce placement errors. In research conducted by Mandelaris et al. (2018), the precision indicators achieved using robotic systems were as follows:
Average deviation at entry point: 0.3 mm
Average deviation at apex: 0.5 mm
Average angular deviation: 1.8°

MODERN IMPLANT DESIGN AND MATERIALS

Nanostructured Implant Surfaces

Methods for modifying implant surfaces to improve osseointegration of implants are continuously being refined. Currently, nanostructured implant surfaces have been developed that modify surface topography not only at the micro level but also at the nano level (Wennerberg & Albrektsson, 2009). Nanostructured implant surfaces such as SLA (Sand-blasted, Large-grit, Acid-etched) and SLActive (Straumann AG, Basel, Switzerland) significantly increase the speed and quality of osseointegration. This allows for shortening implant loading periods and increasing treatment effectiveness. Research conducted by Wennerberg and Albrektsson (2009) showed that osseointegration indicators of implants with nanostructured surfaces are 20-30% higher than conventional implants.

Bioactive Coatings

Coating implant surfaces with bioactive substances further activates the osseointegration process. Currently, the following bioactive coatings are widely used:
Hydroxyapatite (HA) coatings
Calcium phosphate coatings
Bioactive glass coatings
Coatings containing growth factors (BMP-2, PDGF)
Collagen and peptide coatings
In a systematic review conducted by Jenny et al. (2016), it was found that early osseointegration of implants with bioactive coatings is 40-60% higher compared to plain implants, and bone formation around implants is significantly accelerated.

3D-Printed Implants

3D printing technologies (additive manufacturing) have opened new prospects in implantology. Using this technology, it is possible to create implants customized to each patient's individual anatomical structure (Chahine et al., 2018). The most important advantages of 3D-printed implants include:
Ability to create implants with complex geometries
Optimization of implant internal structure porosity
Enhancement of integration with bone tissue
Reduction of stress-shielding effect
Ability to incorporate bioactive substances into implant structure

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In in vivo studies conducted by Chahine et al. (2018), 3D-printed titanium implants showed 30-40% higher bone-implant contact levels compared to conventional implants.

MINIMALLY INVASIVE IMPLANTATION TECHNOLOGIES

Flapless Implantation

Flapless implantation allows for significantly reducing the level of surgical intervention. This method enables implant placement using special instruments without cutting and opening the gingiva (Chrcanovic et al., 2014).

Main advantages of flapless implantation:

Reduction in surgical procedure duration

Decreased pain and discomfort for patients

Accelerated healing period

Better preservation of soft tissue aesthetics

Reduced level of bone resorption

According to meta-analysis results by Lin et al. (2014), the average survival period of implants placed using the flapless implantation method does not differ from implants placed using conventional methods ($p>0.05$), but patient discomfort and healing time are significantly reduced.

Mini-Implants

Mini-implants (implants with diameter less than 3 mm) are one of the less invasive implantation methods, used in cases with insufficient bone width or in patients with thin alveolar ridges due to genotype (Shatkin et al., 2020).

Advantages of mini-implants:

Reduces the need for bone grafting

Simplifies surgical procedure

Shortens rehabilitation period for patients

Less expensive than conventional implants

In long-term research conducted by Shatkin et al. (2020), over 2500 mini-implants were observed, and 94.3% successful function over 7 years was recorded, which is nearly identical to standard diameter implants.

REGENERATIVE TECHNOLOGIES AND IMPLANTOLOGY

Hard Tissue Regeneration

In cases with insufficient bone volume, modern regenerative technologies are used to increase the effectiveness of implant placement. These technologies include:

Autogenous bone transplants

Allogenic and xenogenic bone substitutes

Synthetic bone substitutes (β-tricalcium phosphate, bioglass)

Guided bone regeneration membranes (GBR)

Growth factors and plasma concentrates (PRF, PRGF)

Bone tissue engineering methods

In research conducted by Urban et al. (2019), the use of xenogenic bone substitutes in combination with GBR technique achieved an average increase of 5.6 mm in bone volume in the horizontal direction, which is sufficient for successful implant placement.

PRF and PRGF Technologies

Platelet-rich fibrin (PRF) and platelet-rich growth factors (PRGF) are autogenous biomaterials extracted from the patient's own blood that accelerate tissue regeneration and improve implantation outcomes (Miron et al., 2017).

The following positive results are observed when using PRF and PRGF:

Accelerated soft tissue healing process

Activated bone regeneration

Reduced inflammatory process

Decreased pain syndrome

Reduced infection risk

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According to research by Miron et al. (2017), bone regeneration around implants is accelerated by an average of 40-50% when PRF is used, and soft tissue integration is significantly improved.

Stem Cell Technologies

Stem cells and tissue engineering technologies are opening new prospects in implantology. Research is being conducted on the use of mesenchymal stem cells (MSCs) and exosomes derived from them to accelerate bone tissue regeneration (Khojasteh et al., 2018). In research conducted by Khojasteh et al. (2018), it was shown that bone regeneration process using stem cells proceeded 70% faster compared to the control group.

MODERN PROSTHETIC SOLUTIONS

Digital Prosthodontics

Digital prosthodontics (CAD/CAM technologies) has significantly improved the prosthetic process over implants. Using these technologies, the following advantages can be achieved:

Production of high-precision prosthetics

Reduction of manufacturing time

Improvement of prosthetic aestheticsReduction in the number of visits for patients

Research conducted by Joda et al. (2017) showed that prosthetics produced using digital technologies have 2-3 times higher precision compared to prosthetics produced using traditional methods.

Immediate Loading Protocols

Immediate loading protocols allow for the installation of temporary or permanent prosthetics within a few hours or days after implant placement (Gallucci et al., 2018).

Advantages of this technology:

Reduced treatment duration

Increased patient comfort

Better preservation of soft tissue profile

Improved aesthetic results

According to systematic analysis results conducted by Gallucci et al. (2018), the success rate of immediate loading protocols in properly selected patients was found to be identical to traditional protocols (above 95%).

CLINICAL EFFECTIVENESS OF MODERN IMPLANTOLOGY TECHNOLOGIES

Implant Survival Rate Indicators

One of the main goals of modern implantology technologies is to ensure long-term stability of implants. Recent research confirms high survival rate indicators of modern implants. According to meta-analysis results conducted by Howe et al. (2019), the 10-year survival rate indicator of modern implant systems is 94.6%, which is significantly higher than traditional tooth prosthetic methods.

Aesthetic Results

Aesthetic results are considered one of the important criteria for implantation success. Modern implantology technologies allow for significant improvement in aesthetic results. According to systematic analysis results conducted by Cosyn et al. (2018), when using digital planning and navigational implantation systems, aesthetic results averaged 8.7 points (out of maximum 10 points) according to the Pink Esthetic Score (PES), which is 20% higher compared to traditional methods.

Patient Satisfaction Level

Patient satisfaction with implantation results is considered one of the most important indicators. Modern implantology technologies significantly increase patient satisfaction levels. In research conducted by Ravidà et al. (2019), when using minimally invasive implantation methods, patient satisfaction level averaged 9.2 points (out of maximum 10 points) according to the Visual Analog Scale (VAS), which is a statistically significantly higher indicator compared to traditional methods ($p<0.001$).

CONCLUSION

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Modern implantology technologies have elevated the effectiveness of dental implantation to a new level. Digital planning, navigational and robotic implantation systems, advanced implant design and materials, minimally invasive implantation methods, and regenerative technologies have improved all stages of implantation and enhanced results.

The main advantages of these innovative technologies include:

High precision and reliability in implant placement

Minimally invasive intervention and reduced discomfort for patients

Shortened treatment duration

Improved aesthetic and functional results

Long-term stability of implants

Clinical research data confirms the superiority of modern implantology technologies compared to traditional methods, while treatment effectiveness, reliability, and patient satisfaction indicators remain high. The development of these technologies makes a significant contribution to the future progress of the implantology field.

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