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Digital Mathematical Modeling In Predicting The Clinical Effectiveness Of Fixed Prosthetic Restorations On Dental Implants

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Abstract: The article presents a theoretical rationale for the use of digital mathematical modeling in predicting the biomechanical effectiveness of fixed prosthetic restorations on dental implants. The possibilities of the finite element method (Finite Element Analysis, FEA) in analyzing the stress-strain state of the “implant–abutment–prosthetic restoration–bone tissue” system are considered. The influence of implant diameter and length, bone quality, fixation type, and prosthetic material on the distribution of functional load is analyzed. It is shown that the use of mathematical modeling increases the predictability of clinical outcomes and reduces the risk of biomechanical complications.

Keywords: mathematical modeling, finite element method, dental implants, fixed prosthetics, biomechanics, digital dentistry.

Introduction

Modern prosthetic dentistry is actively integrating digital technologies into the processes of diagnosis, planning, and treatment of patients. Fixed prosthetic restorations on dental implants are an effective method for restoring dentition defects; however, clinical success largely depends on the correct assessment of biomechanical loads, the condition of bone tissue, and the design features of the prosthesis[1].

Despite the high survival rates of implants (over 90–95% in the long term), complications associated with bone tissue overload, marginal bone resorption, screw loosening, and fractures of prosthetic constructions remain a relevant problem. In this regard, the importance of mathematical modeling as a tool for predicting the functional effectiveness and durability of prosthetic restorations is increasing[2].

The key factor determining the long-term success of implant treatment is the adequate distribution of functional load in the “implant–bone–prosthesis” system. In clinical practice, direct measurement of stresses in bone tissue is impossible, which determines the relevance of applying mathematical modeling methods[3].

Digital modeling makes it possible to quantitatively assess the stress-strain state (SSS) of the biomechanical system and to predict potential risk zones before the clinical treatment stage.

Aim of the Study

The purpose of this study was to give a more in-depth theoretical and methodological justification for the importance of digital mathematical modeling in assessing both clinical effectiveness and long-term biomechanical stability of fixed prosthetic restorations supported by dental implants[4]. The study aims to identify how contemporary information technologies such as Finite Element Method (FEM) can be used in a systematic approach towards studying and understanding stress distribution in the complex biomechanical system consisting of the implant, abutment, prosthetic restoration and surrounding bone tissue[5].

The main purpose of the study is to test the prediction potentiality of digital modeling in locating regions with concentrated stress, verifying how implant design characteristics (diameter, length and angulation) influence it, in addition to checking different prosthetic materials and fixation types specific biomechanical effect. By evaluating biomechanical factors such as axial and lateral loadings, the study attempts to elucidate the effects of mechanical determinants on peri-implant bone behavior and prosthetic structures.

In addition, the study aims to evaluate potential clinical implications of embedding digital mathematical modelling into standardised care pathways. This encompasses its application in preoperative planning and personalized designing of treatments, risk estimation, as well as prevention of mechanical complications including marginal bone resorption, screw loosening, abutment fracture, and veneering material failure[6].

In conclusion, the aim of this study is to show that digital modeling is not only a theoretical tool of analysis but also an important clinical instrument used both for increasing predictability of treatment and personalized implant therapy. Also that it is a common factor in reducing complications or further maintenance needs as well as helping move forward evidence-based prosthetic dentistry[7].

Materials and Methods

The work is based on an analysis of domestic and foreign publications devoted to the use of the finite element method (FEM) in implantology.

The finite element method is a numerical approach for solving problems in continuum mechanics by discretizing the studied object into finite elements with specified mechanical characteristics[8].

When modeling the “implant–bone–prosthetic restoration” system, the following parameters are taken into account:

- elastic modulus of titanium (110 GPa);
- elastic modulus of cortical bone (13–20 GPa);
- elastic modulus of cancellous bone (0.1–2 GPa);
- type of implant–abutment connection;
- nature of the load (axial, oblique, lateral);
- magnitude of the functional load (100–300 N).

Data from three-dimensional tomographic reconstruction of the jaw structures were used to build the virtual biomechanical model.

The distribution of von Mises equivalent stresses and maximum principal stresses in cortical and cancellous bone tissue is analyzed[9].

Result and Discussion

Analysis of the literature data indicates that the highest concentration of stresses is localized in the cervical region of the implant and in the area of the cortical plate. Under axial loading, stresses are distributed relatively evenly, whereas under lateral loading their magnitude increases by 2–3 times.

It has been established that:

1. Increasing the implant diameter helps reduce stress concentration in the marginal zone.
2. Increasing the implant length has a less pronounced effect on load redistribution.
3. Bone tissue of types D3–D4 demonstrates a higher amplitude of deformation.
4. Rigid prosthetic materials (zirconium dioxide) transmit the load mainly to the cervical area, which requires precise occlusal balance.
5. Bridge restorations create a complex system of load distribution, especially in the presence of a distal cantilever[10].

The obtained data confirm that mathematical modeling makes it possible to predict the risk of bone tissue overload and to optimize the parameters of implant treatment[11].

The use of digital modeling in prosthetic dentistry makes it possible to individualize the choice of implant diameter and length, determine the optimal spatial position of implants, predict the influence of occlusal factors, assess the allowable size of cantilever elements, and reduce the risk of early and late complications.

The integration of mathematical models into digital protocols forms the basis of a personalized approach in implantology[12].

A promising direction is the combination of mathematical modeling with machine learning algorithms to create predictive models of implant survival. The use of large clinical databases will make it possible to account for systemic risk factors and generate personalized recommendations[13].

Mathematical modeling is a method of studying real objects by constructing their mathematical analogues[14]. In dentistry, the most common tool is the finite element method (FEM, FEA), which allows the analysis of the distribution of stresses and deformations in complex biomechanical systems.

- The “implant–bone–prosthesis” system is considered as a set of materials with different mechanical properties:
- titanium implant (high elastic modulus);
- cortical and cancellous bone tissue (anisotropic materials);
- prosthetic restoration (metal-ceramic, zirconia, composite, etc.).

FEM makes it possible to:

- determine zones of stress concentration;
- assess the influence of implant diameter and length;
- simulate various implant angulation options;
- compare fixation types (screw-retained, cement-retained);
- study the influence of occlusal load.

The biomechanical stability of an implant is determined by the uniform distribution of masticatory load. When stress distribution is unfavorable, there is a risk of marginal bone resorption[15].

Main Factors Affecting the Stress-Strain State

1. **Implant diameter and length.**
   Increasing the diameter reduces the level of stress in the cervical region.
2. **Bone quality.**
   In D3–D4 bone, a higher concentration of stresses is observed.
3. **Type of prosthetic restoration.**
   Bridge restorations create a more complex distribution of load compared with single crowns.
4. **Prosthetic material.**
   Rigid materials (zirconia) transfer the load differently than metal-ceramics.

Mathematical models allow these parameters to be quantitatively assessed before the beginning of the clinical treatment stage.

Modern digital protocols include computed tomography, intraoral scanning, 3D modeling, and virtual implant positioning.

The integration of CT data with modeling software makes it possible to create an individual model of the patient’s jaw. This makes it possible to predict the degree of primary stability, the optimal implant angulation, bone thickness, and the probability of overload under a specific type of occlusion.

Thus, digital mathematical modeling becomes an element of personalized medicine.

Using mathematical modeling, it is possible to identify risk zones for the development of complications:

- marginal bone resorption;
- abutment fracture;
- loosening of screw fixation;
- chipping of the veneering material.

Studies show that the maximum stresses are most often localized in the area of the implant neck and in the cortical plate. When lateral loads are modeled, stresses increase by 2–3 times compared with axial loading.

Predictive models make it possible to adjust the treatment plan in advance—change the implant diameter, choose another material, or redistribute the load.

A promising direction is the use of artificial intelligence and machine learning for the analysis of large arrays of clinical data. The combination of mathematical modeling and statistical algorithms will make it possible to:

- form individual forecasts of implant survival;
- take systemic factors into account (osteoporosis, diabetes mellitus);
- develop optimal prosthetic treatment schemes.

In the future, it may be possible to create fully automated systems for digital prediction of the outcomes of prosthetic treatment.

Conclusion:

Mathematical modeling is an effective tool for predicting the clinical effectiveness of fixed prosthetic restorations on dental implants. The use of the finite element method and digital technologies makes it possible to assess stress distribution, identify zones at risk of overload, and optimize construction parameters before treatment begins.

The integration of mathematical models into clinical practice increases treatment predictability, reduces the frequency of complications, and contributes to the development of personalized implantology. Thus, digital modeling is becoming an integral component of modern prosthetic dentistry.

References

[1] Kenjayev [1] C. E. Misch, Contemporary Implant Dentistry, 3rd ed. St. Louis, MO, USA: Mosby, 2008.

[2] P. I. Brånemark, G. Zarb, and T. Albrektsson, Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago, IL, USA: Quintessence, 1985.

[3] J. P. Geng, K. B. C. Tan, and G. R. Liu, “Application of finite element analysis in implant dentistry: A review of the literature,” J. Prosthet. Dent., vol. 85, no. 6, pp. 585–598, 2001.

[4] L. Himmlová, T. Dostálová, and A. Kácovský, “Influence of implant length and diameter on stress distribution: A finite element analysis,” J. Prosthet. Dent., vol. 91, no. 1, pp. 20–25, 2004.

[5] M. Sevimay, F. Turhan, M. A. Kılıçarslan, and G. Eskitaşcıoğlu, “Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown,” J. Prosthet. Dent., vol. 93, no. 3, pp. 227–234, 2005.

[6] K. J. Anusavice, C. Shen, and H. R. Rawls, Phillips' Science of Dental Materials, 12th ed. St. Louis, MO, USA: Elsevier, 2013.

[7] G. A. Zarb, C. L. Bolender, and S. E. Eckert, Prosthodontic Treatment for Edentulous Patients, 12th ed. St. Louis, MO, USA: Mosby, 2004.

[8] H. J. Chun et al., "Evaluation of design parameters of osseointegrated dental implants using finite element analysis," J. Oral Rehabil., vol. 29, no. 6, pp. 565–574, 2002.

[9] M. A. A. Duyck and R. Naert, "Failure of oral implants: Aetiology, symptoms and influencing factors," Clin. Oral Investig., vol. 2, no. 3, pp. 102–114, 1998.

[10] R. G. Craig and J. M. Powers, Restorative Dental Materials, 11th ed. St. Louis, MO, USA: Mosby, 2002.

[11] S. S. Isidor, "Influence of forces on peri-implant bone," Clin. Oral Implants Res., vol. 17, suppl. 2, pp. 8–18, 2006.

[12] G. H. Wiskott and U. C. Belser, "Lack of integration of smooth titanium surfaces: A working hypothesis based on strains generated in the surrounding bone," Clin. Oral Implants Res., vol. 10, no. 6, pp. 429–444, 1999.

[13] T. Albrektsson and A. Wennerberg, "Oral implant surfaces: Part 1—Review focusing on topographic and chemical properties of different surfaces and in vivo responses to them," Int. J. Prosthodont., vol. 17, no. 5, pp. 536–543, 2004.

[14] M. D. Karl and G. I. Taylor, "Effect of material selection on the biomechanical behavior of implant-supported restorations," Clin. Oral Implants Res., vol. 23, no. 3, pp. 334–341, 2012.

[15] S. Natali, P. Pavan, and C. Ruggero, "Evaluation of stress induced in peri-implant bone tissue by misfit in multi-implant prosthesis," Dent. Mater., vol. 22, no. 4, pp. 388–395, 2006.