Physical and methodological approach to the modern methods of the investigation of dental materials properties

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Abstract. Each medical doctor should be able to complete professional tasks using their knowledge of physics, especially when providing a comprehensive care to a patient. This article reveals how to use knowledge of the course of physics specially developed of a Medical University to help trainee medical doctors to develop skills to complete professional tasks. Content of physics and its tasks for a Medical University must be professionally oriented. This article provides a classification of professionally oriented questions of physics specially made to be taught at a Medical University. It also gives content a sample of a professionally oriented task in physics for a Medical University. All these above mentioned tasks are closely correlating with each other. As an example, the article explains specific of teaching Biophysics at a Medical University. Professionally oriented content of Biomechanics – modern methods of study properties of materials used for dental care. Methods of physics for destructive inspection testing: tensile strength, compressive strength, hardness of materials, Poisson’s ratio, fluctuating stress and dynamic testing etc. Methods of physics for non-destructive inspection testing: thermal, acoustic, optical, radio-wave, radiative, capillary, magnetic and electric testing.

1. Introduction

Medicine has being using the results of theoretical and experimental advances in physics for a long time. Physiological processes in the human body proceed according to the laws of physics. A lot of diagnostic and therapeutic methods are based on physical phenomena. Most medical apparatus are physical devices by design. Hence, physics is very important for modern medicine [1,2,3].

The analysis of research on the study of physics by future medical specialists is carried out. Conclusions of the analysis: 1) the problem of teaching physics to future medical specialists is an urgent topic of research in recent years; 2) these studies reflect the following issues: selection of physics content at the Medical University (S. V. Babin, T. N. Shamaeva) [4], implementation of interdisciplinary connections of physics with other disciplines in a Medical University (A.F. Zubov, N.A. Ladnich, E.M. Starikova) [5,6], forms, methods, technologies of teaching physics to future doctors (N.P. Pupyrev, E.A. Semenyuk) [7], the value aspect of physics course at the Medical University (O. E. Akulich) [8]; the implementation of the principle of professional orientation in the process of teaching physics to medical students (L. E. Ryazanova, A.V. Tarasova) [9,10], the formation of experimental skills in future doctors (N. G. Arzumanyan) [11], and polytechnic competencies (Yu. I. Nikitina) [12], the problem of preparing medical students for solving professional problems in teaching physics at a Medical University in the
context of integrating physics with biomedical disciplines within the framework of our dissertation research (Biryukova A.N. (Kobzar A.N.)) [3,13]; 3) there are few studies that consider the pedagogical methodology of teaching modern methods of studying the physical properties of dental materials to the future dentists. Therefore, the topic of our article is relevant.

2. Discussion

Presently at the Medical Universities students study the main general physics sections, elements of biophysics [13]. Questions of general physics are the basis for studying the professionally-oriented questions – questions that need to be studied and solved for the future professional activity of a doctor [3]. For example, at the Medical University (FGBOU VO "SCHEMNIK" of the Ministry of Health of Russia), students study the basic discipline " Physics, mathematics". Its objective is "to form a systematic knowledge of the physical processes and properties in biological objects (in the human body). This is necessary for the development of other academic disciplines and the formation of professional medical qualities». Physical sections of the discipline: "Mechanics of liquids and gases. Acoustics", "Electrical and magnetic properties of tissues and the environment", "Fundamentals of medical electronics", "Optics", "Elements of quantum biophysics, ionizing radiation". In addition, future dentists at the same Medical University study the multiple choice discipline "biophysics". It includes the following sections: "Biomechanics", "Transfer processes in biological systems. Bioelectrogenesis", "Introscopic diagnostic methods", "Physical foundations of medical ecology", "Physical Foundations of electrography", "Quantum-physical foundations of diagnostic and treatment methods", "Ionizing radiation".

Each section of these disciplines includes professionally-oriented questions. In the framework of our educational research the general structure of professionally-oriented physics content at the Medical University (classification of professionally-oriented physics questions) has passed the expert assessment of medical specialists and has been successfully implemented in the educational process at the Medical University (Figure 1) [3].

![Figure 1. Structure of professionally oriented Physics content in the Medical University.](image)

As an example, let's consider the particular features of the section "Biomechanics" study by future dentists. This section studies the following professionally-oriented questions of Physics-modern methods of the physical properties of dental materials study (Mechanical pressure and deformation of materials. Laws of elastic deformation. Basic elastic and plastic characteristics of materials. Diagrams
of forces, pressure, and bending moments (on the example of dental structures). Physical aspects of strength and fracture of materials. Quantitative characteristics of deformation: mechanical pressure (σ), absolute elongation (Δl), relative elongation (ε).

To evaluate the mechanical properties of dental materials, it is necessary to study the characteristics of materials under the influence of loads. For example, we can consider the dependence of the mechanical pressure (σ) on the relative elongation of the beam (ε) in the diagram.

Depending on the behavior of the material during the load test, there are two main types of materials: brittle (have no residual deformations and are destroyed when the stress in the material reaches the ultimate strength) and plastic (small ultimate strength, significant residual deformations, do not break). The dental seal in the oral cavity is affected by longitudinal and transverse forces (not only compression deformation, but also shear deformation).

At the Medical University, future dentists consider the physical aspects of the strength and destruction of the material: the influence of temperature, loading speed, humidity, time on the strength of the material, the theoretical strength (for example, dental materials) [3,13].

Studying this material, future dentists can solve professionally-oriented physical tasks (subject matter: deformation characteristics, Hooke’s law, Poisson’s ratio in dentistry). The physical tasks at the Medical University should be professionally oriented. We have developed a model of the content of a professionally oriented physical task in a Medical University (Figure 2). This model is interrelated to the general structure of the professionally oriented physics content in the Medical University (Figure 1) [3,13,14].

Here are examples of these tasks for dentists.

**Task 1.** Evaluate the compliance of the strength properties of the dental seal. It is known that the maximum working pressure is $4 \times 10^7$ Pa, the minimum pressure is $10^7$ Pa, the tensile strength of the sealing material (amalgam) is 50 MPa, the ultimate strength under compression deformation is 400 MPa.

**Task 2.** When chewing food, relative deformations occur on the molars. The Poisson’s ratio of the teeth is 0.4. Determine the relative volume change of the molars. The relative strain is $4.8 \times 10^{-4}$.

**Task 3.** The temperature in the oral cavity can range from 0 °C to 70 °C. Evaluate the mechanical pressure that occur in the cavity. Select the appropriate structural material (dental filling material) for the strength requirements under these conditions. The temperature coefficient of linear expansion of tooth tissues is $(10-15) \times 10^{-6}$ K$^{-1}$, the Young’s modulus for tooth enamel is 83,000 MPa, for dentin-18,600 MPa.

We have developed a classification of professionally oriented physical tasks at the Medical University. It is interrelated to the classification of professionally oriented questions of physics course at a Medical University (Figure 1), with the content model of a professionally oriented physical task at a Medical University.
The classification of professionally oriented physical tasks in a Medical University:

➢ physical tasks concerning the specifics of studying the human body as a physical object, the manifestations of physical phenomena, processes in the human body, disease prevention;
➢ physical tasks concerning the specifics of the application of physical phenomena, processes, devices in diagnostics for studying the human body;
➢ physical tasks concerning the specifics of the application of physical phenomena, processes, devices for the treatment of the human body [3].

According to this classification, a complex of professionally-oriented physical tasks has been developed and adapted for all the main sections of physics course at the Medical University [15].

In addition to the basic concepts in the section "Biomechanics", methods for evaluating the physical and mechanical properties of materials should be considered. This is very important for the future professional activity of a dentist. Determination of the physical and mechanical properties of dental materials is necessary to control the quality of products made. Physical methods of destructive testing include tensile strength test method, compressive strength method, material hardness method, Poisson's ratio method, test method under variable loads, dynamic test method and others. Non-destructive testing methods are based on thermal, acoustic, optical, radio wave, radiation, capillary, magnetic, electric phenomena. Many methods are of interest in dental practice. In dental materials science, the most important methods are flaw detection, designed to detect cracks and methods for control of geometric characteristics: linear and volumetric dimensions, crown thicknesses, degree of abrasion, shrinkage coefficient.

Good accuracy in the assessment of strength characteristics is provided by destructive tests [16-27]. Methods of destructive testing are mainly used at the stage of preclinical testing of new dental materials and in the experimental justification of new types of prostheses.

We describe briefly the basic methods for evaluating the physical and chemical properties of materials that are also used in dentistry.

Mechanical methods include:

• The tensile strength test method. The result of the tests is the receiving of the tension diagram. From this diagram, the main mechanical characteristics of the material can be determined including the ultimate strength, the ultimate ductility, the yield strength, the relative elongation, the relative narrowing, the Young's modulus, the work spent on the destruction of dental materials.
• The method of determining the compressive strength. This is a test for brittle materials. For plastic materials, the compression test is not used. When compressed, such materials are strongly deformed. The main mechanical characteristics of the material, namely, the ultimate strength, relative shortening and relative broadening, are determined from the compression diagram.
• The method for determining of the materials hardness. The material hardness is the ability of the material to resist the mechanical penetration of other bodies into it. Hardness is one of the main indicators of dental materials.
• Currently, the most widely used method is indentation. For plastic materials, there is a relationship between the hardness and the ultimate strength. This allows the strength tests to be replaced by simpler hardness tests. There are three methods for determining the hardness of materials during indentation: the Brinell method (indentation of a steel ball and determination of the area of its imprint); The Rockwell method (indentation of a diamond cone and determination of depth); the Vickers method (indentation of a diamond pyramid with an angle at the top of 136° and determination of the footprint area). Each method has its own advantages and disadvantages and a certain degree of use in dentistry.
• Currently, a method for microhardness determining by indenting a diamond pyramid is generally applicable. This method is extensively used in dentistry. It allows to determine the hardness of the tooth enamel (healthy and affected by caries), the hardness of various filling compositions. This method includes the determining the Vickers hardness at low loads by measuring the area of the resulting print using a measuring microscope. The method of microhardness determining makes it possible to identify inhomogeneities of hardness (material structure).
• **The method for determining the Poisson's coefficients.** The Poisson's ratio is most often determined by uniaxial compression of a sample (as an example of a tooth, a filling), by measuring the longitudinal and transverse deformations.

• **The variable load test method.** Such tests are used for brittle and ductile materials under conditions of repeated variable loads. These types of loads are experienced by all elements of the human maxillofacial apparatus. Externally, the destruction of the material under variable loads occurs instantly. Through the microscope, you can see two areas. The first section has a smooth surface (fatigue fracture area). The second one more often has a crystalline structure and is similar to a fracture in static tests. The destruction of the material occurs due to the growth of the crack.

• **The dynamic test method.** The method is used for plastic materials. Dynamic tests are model tests for shock loads, deformation of materials at high speed, and for materials with cracks. Dynamic tests consist in determining the impact strength (the ratio of the work of the impact failure of the sample to the area of its cross-section at the site of failure).

**Thermal methods** for testing materials include methods for measuring temperatures. The method of differential thermal analysis is used to determine the temperatures in a material when a certain amount of heat is released or absorbed. This method is used to study the crystallization process. The method uses simultaneous heating and cooling of the test and reference sample. At the moment of the phase transition, there is a temperature difference between the sample and the reference. The method of dilatometric analysis consists in recording changes in the linear or volumetric dimensions of samples under isothermal conditions, or during heating or cooling. In the absence of phase transformations in the material, its dimensions change smoothly without jumps. The phase transition is accompanied by an abrupt change in the length or volume of the sample. One of the advantages of dilatometric analysis is the weak dependence of its results on the rate of change in the sample temperature. Measurements are carried out on special devices, dilatometers. The design of the devices differs in the method of registering the deformation of the sample: mechanical, electrical, or optical.

Let’s consider acoustic methods of non-destructive testing of materials. The main recorded parameters in these methods are the wave amplitude, intensity, and impedance of the material. The elastic modulus and shear modulus determine the propagation velocities of sound waves in the material. Acoustic control methods are divided into two types: 1) methods of receiving and emitting ultrasonic waves; 2) methods of registering acoustic waves in materials due to any external influences. In medical diagnostics, the following methods are commonly used: echo method, shadow method, impedance method, noise vibration method.

With the help of optical methods, it is possible to detect voids, cracks, and internal pressure. Many optical research methods are studied at the Medical University, including microscopy and its special techniques, photometry, colometry, nephelometry, spectral analysis, luminescence analysis, polarography. The application of these methods in dentistry involve control of the structure of metals, alloys, plastics, colorimetric and nephelometric control of liquid compositions, control of the color of artificial teeth, inserts and inlays, granulometric analysis of solid compositions, control of abrasive wear of bores, control of stresses in the most dangerous sections of models of complex prostheses, etc. For scientific research, the surface control of artificial teeth or prostheses is carried out using microinterferometers.

Radio-wave research methods in the ultrahigh frequency range are used to control the quality of products made of dielectric materials. Internal defects can be detected by changing the signal characteristics through the product. Radio-wave inspection methods allow to detect various types of local and distributed defects: air and foreign inclusions, cracks, polymer layer delaminations, density inhomogeneities, and the presence of mechanical pressure.

Radiation methods record ionizing radiation after passing through the test material. In the presence of internal defects, the intensity of the transmitted radiation changes dramatically. It gives the possibility to determine the location of defects. The radiographic method is based on obtaining a visible image of the internal structure of the product using special detectors. Depending on the ionizing radiation used, there are several methods including X-ray radiography, mammography, accelerator and neutron
radiography. The *radioscopic method* consists in observing the image of the internal structure of the product on the screen. The *radiometric method* involves the registration of electrical signals when the product is illuminated by ionizing radiation. The method is used for the process of product control automation.

*Cupillary methods* are based on the diffusion of special flaw detection substances into various materials. The essence of the method is as follows: open cracks (welding, thermal, grinding, deformation, fatigue), pores and scratches are filled with a special flaw detection composition using various methods of impregnation (capillary, vacuum, compression, ultrasonic, vibration).

*Magnetic methods* for measuring magnetic properties are used to evaluate the composition of a metal alloy. These methods are widely used in orthopedic dentistry. Saturation magnetization and coercive force are measured experimentally. When studying this material, dental students can fill in a comparative table 1.

It is advisable for students to discuss the theoretical material in the form of a discussion based on a problem-reserve analysis (SWOT- analysis) (table 2) [3].

**Table 1.** Morden methods of studying properties of dental materials in the aspect of physics.

| Method of physics name | Method of physics description |
|------------------------|------------------------------|
| History of the method, the field of its research | Description of the method, the scheme |
| Basic physical quantities, parameters | Advantages and disadvantages of the method |
| Application in dentistry | Other medical applications |

| Methods of physics for destructive testing |
| Methods of physics for non-destructive inspection testing |

**Table 2.** SWOT- analysis of the physical aspects of the strength of dental materials

| Analysis objective features | Strengths | Weaknesses |
|----------------------------|-----------|------------|
| What physical characteristics of the strength of the materials allow them to be used in dental materials? | What physical characteristics of the strength of the materials limit their use as dental materials? |
| What are the current prospects for the use of dental materials in medicine, taking into account their strength characteristics? | What prevents the use of dental materials in medicine, taking into account their strength characteristics? |

| Analysis subjective features | Opportunities | Threats |
|-----------------------------|---------------|---------|
| What benefit can be achieved for the patient as a result of taking into account the physical characteristics of the strength of dental materials? | What negative consequences for the patient can cause the medical use of dental materials? What can be the reason for these negative consequences, taking into account the strength characteristics of dental materials? |
| What are the advantages of modern methods of using dental materials in medicine for the patient, taking into account their strength characteristics? | |
3. Conclusions

As shown by many years of teaching experience at the Medical University, the study of modern methods for assessing the physical properties of dental materials allows future dentists to form knowledge about the dependence of the strength characteristics of various dental structures on physical factors; develop the ability to evaluate the dental structure in terms of the strength characteristics of the materials used; the ability to choose the proper dental material depending on its physical and mechanical properties and the specific dental situation.

In general, this makes a significant contribution to the formation of future dentists' ability to solve professional tasks of a doctor, including on the basis of physical knowledge and skills. This allows you to increase the motivation of students to study physics at the Medical University, to facilitate their activity. The use of appropriate professionally oriented physical tasks promotes the development of the student's creative personality.

These conclusions were confirmed in the course of our study on the basis of adapted methods. As an example, we will describe one of them. The adapted questionnaire of A. S. Markov included 25 statements about the learning motives of students (on a 5-point scale) [28].

The analysis of the results of the survey allowed us to assess the professional (1), cognitive (2), social motives (3), pragmatic (4), the motives of personal prestige (5) of future doctors in the process of studying at the Medical University (Figure 3). The diagram shows the results of students’ survey at the beginning and at the end of the experiment.

![Figure 3. According to AS Markov.](image)

In the course of the study (Figure 3), the level of the main learning motives of students has increased, that could be explained, among other things, by the effectiveness of highlighting, structuring and studying professionally-oriented physics content in a medical university (for example, the described issues of dentistry) and the use of professionally-oriented physical tasks in the educational process.

So, the results obtained allow us to draw a general conclusion about the effectiveness of the methodological approach to modern methods of studying the physical properties of dental materials described in this article.

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