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New Assessment Model of Financing Treatment of Patients with Complete Tooth Loss

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Abstract

According to the World Health Organization, the global prevalence of complete tooth loss is estimated to be 7% among individuals aged 20 years and older, while for those aged 60 and over, this rate significantly increases to 23%. This study is relevant due to the psychological trauma, social challenges, and functional limitations caused by tooth loss, as well as the uneven availability of dental care worldwide. The goal of this research is to develop and implement a new model to assess the socioeconomic feasibility of investing in digital technologies for diagnosing and treating patients with complete tooth loss using removable polymer prostheses produced through additive 3D printing. The study employs scenario analysis, the clustered rankings coordination method, statistical methods, expert opinion assessment using Kendall's coefficient of rank concordance, system analysis and design, questionnaires, sociometry, and functional modeling. The practical significance of this research lies in providing a quantitative assessment of economic opportunities for effectively using RPDs in three groups: RPDs without additional fixation means; those with special adhesive agents for improved fixation; and implant-supported prosthetics with conditionally removable dentures similar to RPDs. The scientific novelty of this study is the development of a new evaluation model that justifies the choice of prosthetic treatment technology for patients with complete tooth loss, enabling the most rational use of resources.

Keywords:

Denture;
Dental Implant;
Expert Assessment; Patient;
Clustered Ranking;
Scenario Analysis.

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1- Introduction

Dental diseases negatively affect the health and quality of life of the population and are a global public health problem because of their increasing prevalence in many low- and middle-income countries and their significant socioeconomic transformation [1-4]. In countries with a high level of income and life, the need for removable plate dentures (RPD) is quite low; in particular, in the USA by 2012, it was 4.9% of the total population, which is equivalent to 15 million people [5]. The prosthetic treatment of patients with complete tooth loss using traditional analog technology is a labor-intensive

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process that involves dentists, dental laboratory employees, and other dental clinic services. The continuity and stages of interaction between these factors do not always occur smoothly, which affects the effectiveness of this dental organization. As a result of medical errors in diagnosis and planning and technological errors in the performance of work [6, 7], the effectiveness of treatment is low, patients refuse to use complete removable dentures, and their quality of life suffers [8, 9].

Bersanov et al. [10] analyzed the quality of traditional removable partial denture construction provided to the population of the Chechen Republic. The author considers these outdated prostheses, highlights their low quality, which, in his opinion, leads to inevitable bone atrophy under the prosthesis, and notes the insufficient strength of the dental materials from which the construction is made. Porfiryev et al. [11] recommend a 3-year warranty period for removable plate dentures, with subsequent necessary replacement due to the aging of the polymer material and the inevitable destruction of the surface of the prosthetic construction, even if it remains fully functional. According to many authors [12-14], the aging of dental materials creates favorable conditions for the increased adhesion of microorganisms and the formation of microbial biofilms, particularly in individuals with a genetic predisposition.

Healthcare reflects the level of a country's socioeconomic development [15], as national health is one of the most important goals of socioeconomic development in any state. Healthcare in Russia is financed primarily at state expense since it uses budgetary and insurance financing mechanisms, which, along with other problems of legal regulation, affect the investment attractiveness of Russian medicine [16, 17]. This study examined digital technologies for diagnosing and treating patients with complete tooth loss using removable polymer dentures based on additive three-dimensional printing technology, the pricing of which is based on the tariffs of the Russian Federation's compulsory medical insurance.

Assessing investment effectiveness in healthcare is a key task for those making management decisions in introducing innovative technologies in medical practices for treating socially significant and widespread diseases; complete loss of teeth could be included in this list [18], In particular, digital technologies for diagnosing and treating patients with complete tooth loss using removable polymer dentures based on additive three-dimensional printing technology. The number of innovation projects in socially significant healthcare areas is increasing [19]. In particular, the treatment of patients using removable plate dentures (RPD) appears to be the most common technology in the denture treatment of patients with complete tooth loss [17, 18]. Complete loss of teeth, especially in geriatric patients, becomes an invalidation that seriously affects the quality of life of people in this category. Along with dental problems, this contingent is mostly susceptible to socially significant comorbid diseases; therefore, there is no sense in talking about healthy aging in this case [17, 20, 21]. Despite research in this area, the problem of assessing the socioeconomic feasibility of such investments remains.

It was established that geriatric patients with complete loss of teeth had difficulty adapting to RPD [22, 23]. It is caused by psychological characteristics, an acute reaction to dental treatment [24], poor denture fixation due to difficult prosthetic conditions, and the traumatic effect of the design on the denture bed. Overall, this leads to a refusal to use RPD [25, 26]. In most cases, special adhesives improve RPD fixation with a properly manufactured design [27]. However, their use is a financial burden on pensioners and other socially vulnerable groups. Therefore, the advantages and disadvantages of RPDs were analyzed in economic terms, including cost-effectiveness and potential financial benefits.

Dentistry, like many other areas of medicine, is striving not only to achieve optimal treatment results but also to ensure cost effectiveness in healthcare [28]. Implanting denture treatment in patients with complete loss of teeth has acquired significant recognition as an innovative and effective approach for improving their quality of life and increasing the effective period of using orthopedic devices [29, 30]. However, the risk of complications remains owing to errors in selecting a denture treatment device [31, 32], dental material [33-36] and their production technology [37]. The study examined socio-economic aspects of mass use of the RPDs that are dentures recommended for preferential denture treatment [17, 22].

Medical and social models of preferential denture treatment do not allow repeated or multiple visits to healthcare institutions because of ineffective denture treatment results. Patients receive dentures that do not meet the requirements of functionality, aesthetics, and long-term use ($\geq$ 5 years), which significantly reduces their quality of life and social functioning. In addition, these problems place a heavy economic burden on the state, as the number of citizens' requests for preferential dentures increases significantly and the quality of services decreases, which does not contribute to the rational and efficient use of budget funds [20].

The results of this study could serve as the basis for a systematic analysis to justify the selection of treatment technology and optimize costs in maintaining the functional state of the denture structure and the patient's quality of life. Based on the above, the study becomes relevant in theoretical and practical planes with regard to the formation of a methodology for a comprehensive economic assessment of the massive use of RPDs in denture treatment of patients with complete loss of teeth and the modern working conditions of dentists. This study also provides a comparative

analysis of the economic feasibility with and without special adhesives that improve fixation and implantation denture treatment using a conditionally removable structure, which is perceived by a patient as a fixed denture.

Based on the inclusion, non-inclusion, and exclusion criteria, three groups of patients were selected. The RPDs were manufactured using traditional analog technology from acrylic plastic, and the dentures were fixed to the jaw in different ways.

- Group-1 (RPD-1): patients used the RPD without additional means of fixing the structure;
- Group-2 (RPD-2): patients used special adhesive agents to improve RDP fixation;
- Group-3 (RPD-3): patients received implantation denture treatment including a conditionally removable denture similar to the RPD design.

This study aimed to determine the optimal distribution of healthcare resources in terms of socioeconomic efficiency and their effective use by developing recommendations for choosing a technology for prosthetic treatment of patients with complete tooth loss and denture design and an economic calculation of the feasibility of the choice. The subjects of this study included patients who needed an RPD and were not using (Group-1) or using special adhesives to improve RPD fixation (Group-2), as well as those who underwent implantation denture treatment (Group-3).

Research hypothesis: The socioeconomic feasibility of choosing a technology for denture treatment in patients with complete loss of teeth and denture design significantly depends on the RPD type used and the social status of the patients. For decision-making management, it becomes a quantitative assessment of the economic opportunities for the effective use of removable dentures, considering the socioeconomic status of patients and state support measures in the form of preferential prosthetics using dental implants as well as an additional source of information in choosing the treatment regimen.

2- Material and Methods

Three types of methodological interactions are used in medical practice: economic, social, and medical.

The economic efficiency of using the RPD should be assessed using the following indicators [38-42]: net present value, profitability index, internal rate of return, discounted payback period, and ordinary payback period. In addition, the acquisition of different types (designs) of RPDs by patients with complete loss of teeth should be considered an investment process for the entire period of denture use.

Ensuring high rates of economic development in implantation denture treatment and its sustainable competitive position in healthcare largely depend on the efficiency of using the economic resources allocated for preferential denture treatment and the patient's financial capabilities [43]. Therefore, the estimated characteristics of the financial flow of funds characterizing receipt of financial resources from its implementation and spent on development, production, and use of dentures during the warranty period should be understood as the *economic feasibility of investing* in financing the treatment of patients with complete loss of teeth using RPDs [44-47].

Economic feasibility analysis and assessment in making a management decision to invest in the development and practical implementation of various promising technologies and equipment for patients in dental medical organizations are additional sources of information in decision-making regarding the treatment method. In addition, determining the investment attractiveness of a doctor is helpful for choosing the optimal treatment method for a patient [48]. The possibility of paying for a denture through credit, insurance, or charitable foundations also influences a patient's choice of denture type.

Social effect assessment of removable dentures is an important task, making it possible to evaluate the impact of this technology on the quality of life of patients and their social well-being.

Social effects include a wide variety of factors, such as improved physical comfort and aesthetics, the ability of ultimate nutrition, restoration of speech and communication, increased self-esteem, and social integration. Social effect calculation makes it possible to assess the impact of removable dentures on the quality of life of patients, their opportunities to participate in social and professional activities, and their social position and status. In addition, a social effect assessment helps determine the economic viability of using this technology. Improving a patient's quality of life could lead to a decrease in the costs of additional treatment and medical care, as well as an increase in the patient's productivity and ability to work. Thus, assessing the social effects of removable dentures is an integral part of justifying the effectiveness of this technology and making informed decisions from the perspective of healthcare and social policy. Within the framework of this study, three key groups of patients with complete loss of teeth were considered to assess the social effectiveness of the RPD: 1) working citizens with an average salary, 2) working citizens with a minimum salary, and 3) pensioners with an average pension.

The amount of money for each group in which a patient in the *n*-th category (*n* = 1, 2, 3) was able to save was calculated according to the following formula:

$$S_n = D_n - \max\{LW; 0{,}6 \cdot D_n\}, \quad (1)$$

where D_n is the amount of cash received by the *n*-th category of citizens per month, RUB, LW is the living wage in Russia as of 2023, and RUB, $max\{\text{LW};0.6{\cdot}D_n\}$ is the maximum of two values, that is, the living wage amount and 60% of the monthly cash received. This condition does not exceed the debt burden indicator established by the Central Bank of the Russian Federation [49]. Thus, according to Federal Law No. 601-FZ dated December 29, 2022, "On Amendments to the Federal Law "On Consumer Credit (Loan)" [50] credit and microfinance organizations are obliged to calculate the borrower's debt burden and notify the borrower in writing about existing risks if the calculated value of the borrower's debt burden exceeds 50%. Simultaneously, a debt burden indicator of 35-40% is considered comfortable, and a value of 30% is optimal.

Next, the period is required for the *n*-th category of citizens to accumulate a sufficient amount of money to pay for treatment using the RPD *j*-th type (*j* = 1, 2, 3):

$$T_{nj} = \frac{IC_j + C_j}{D_n}, \quad (2)$$

where IC_j is the initial cost of purchasing the RPD *j*-th type, RUB, C_j is the additional patient costs associated with using the RPD *j*-th type RUB.

The share of cash received by the *n*-th category of citizens, which could be used to purchase RPD, is determined by the following formula:

$$k_n = \frac{S_n}{D_n}, \quad (3)$$

In the ***socio-economic feasibility*** of financing the treatment of patients with complete loss of teeth, expert assessments will be used along with the clustered ranking coordination method [51-54].

Considering the above, the research algorithm flowchart is presented in Figure 1. Figure 1 presents a flowchart of the comprehensive system of socioeconomic feasibility of financing treatment for patients with complete tooth loss. It details the main aspects and criteria for making key management decisions related to the optimal combination of factors and parameters that directly affect social, economic, and socioeconomic efficiency indicators when selecting the RPD type for a specific category of patients, taking into account their social status.

Innovative technology algorithm for socio-economic feasibility of financing treatment of the patients with the complete loss of teeth:

Step 1. Initial data input. At this stage, the main RPD parameters are entered into the model. They include useful life, installation cost, and additional annual costs associated with using the RPD, such as adhesive application and periodic examinations by a dentist, as well as the patient's social status and income level.

Step 2. Social, economic and socio-economic efficiency assessment: If necessary, the initial parameters for socioeconomic feasibility were clarified and adjusted at this stage, and the efficiency type to be assessed was selected as social, economic, or socioeconomic. Social efficiency is assessed by the period required to accumulate the required amount of denture and the share of funds in the patient's total income, which should be saved to accumulate the required amount within the given model parameters. Economic efficiency considers the quantitative parameters of the economic assessment of investing in RPD acquisition, such as net present value (NPV), profitability index (PI), internal rate of return (IRR), investment payback period (PP), and discounted payback period (DPP). Socioeconomic efficiency is based on expert assessment using the clustered ranking coordination method and considers the patient's income level, RPD price affordability, comprehensive assessment of the patient's capacity and quality of life restoration, period of useful RPD use, additional annual costs associated with its operation, and other factors and quantitative parameters.

Step 3. Management decision making: in socially and economically feasible selection of the RPD type for a specific category of citizens to optimize the total costs of using the RPD, taking into account the RPD and its installation cost, as well as ensuring restoration of the patient's capacity and quality of life. This allows for the assessment of the need and scope of state and government support measures for citizens of the Russian Federation with complete loss of teeth.

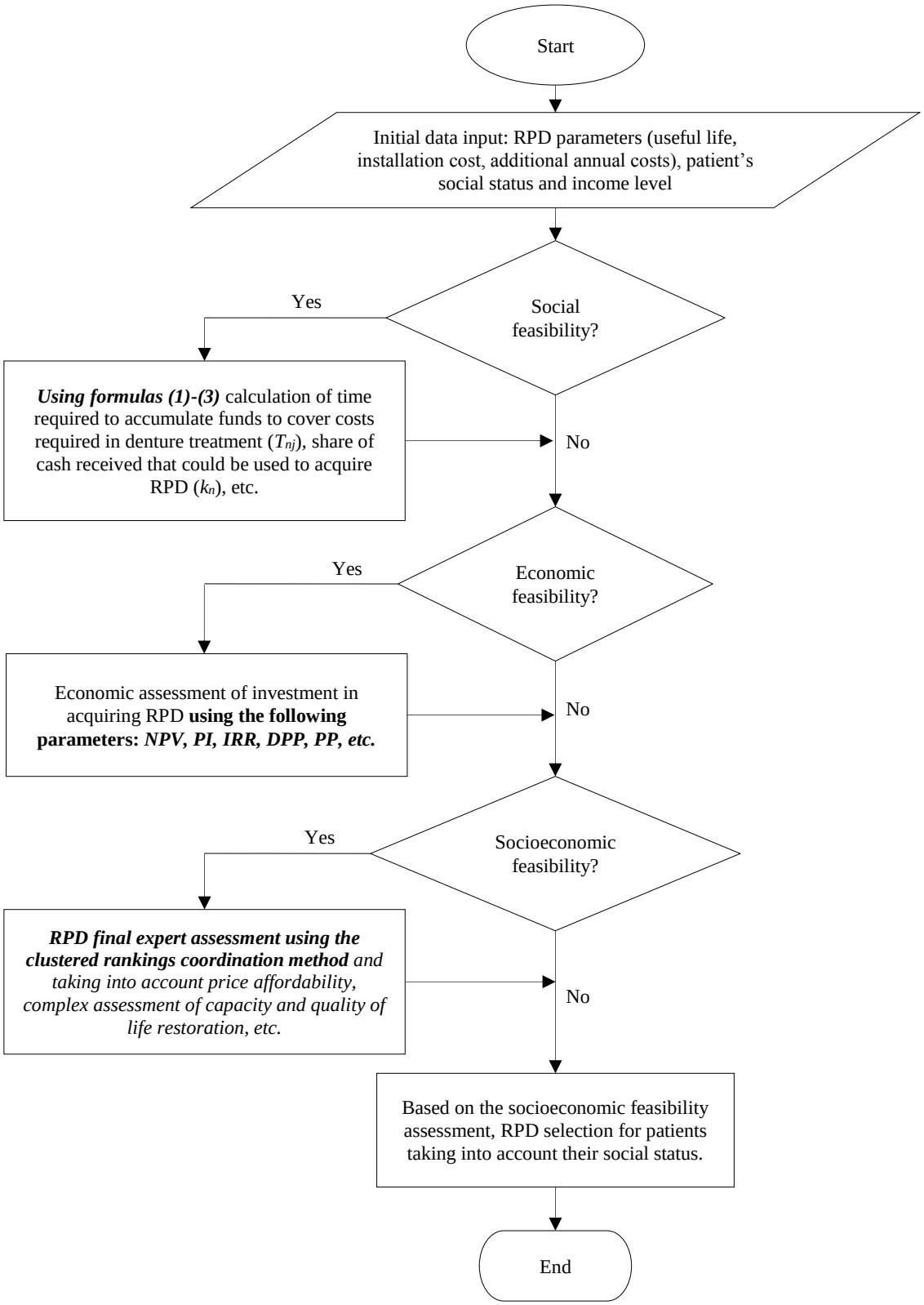

Figure 1. Research algorithm flowchart

3- Results

The initial data on the socioeconomic feasibility of financing the treatment of patients with complete loss of teeth are presented in Table 1. Figure 2 schematically presents a scenario analysis of patient costs based on the RPD type.

As the diagnostics and adjustment stages are the same for all three RPD types, they can be neglected in this study. To simplify the socioeconomic model without losing its meaning, we used a variable, that is, the average statistical RPD, with the same economic, operational, and technological parameters in each scenario. Key characteristics were compared at different stages of matching.

Table 1. Initial data for the socio-economic feasibility of financing treatment of the patients with complete loss of teeth

RPD group	Denture cost, RUB	Costs at stages, RUB		Useful life, years	Additional annual costs, RUB	Comprehensive assessment of the patient's capacity and quality of life restoration
		Clinical	Operational			
RPD-1	X	-	-	1	-	40%
RPD-2		-	Adhesives use – 9,432	1	9,432	50%
RPD-3		Implants installation – 192,500	-	5	38,500	80%

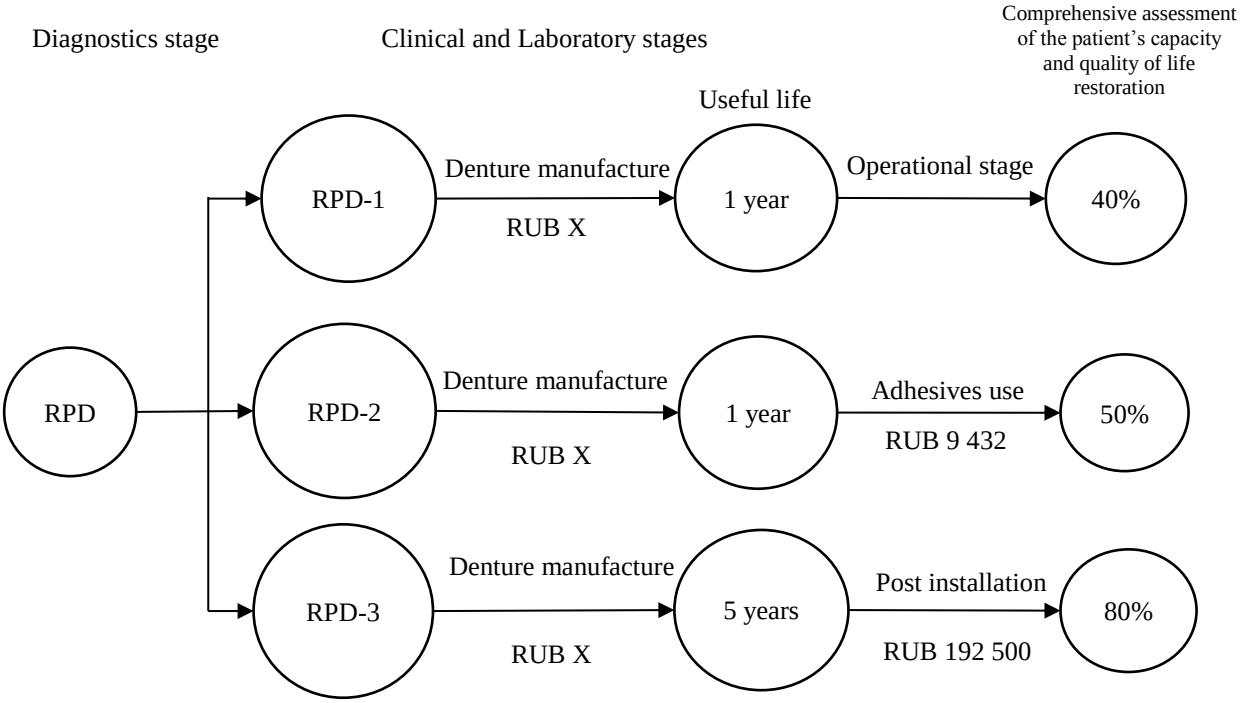

Figure 2. Scenario analysis of the patient's costs depending on the RPD type

1-1- Social Feasibility for Financing Treatment of the Patients with Complete Loss of Teeth

According to the Federal State Statistics Service (Rosstat) [55], as of 2023 in the Russian Federation, the population below working age was estimated to be 27,160 thousand, the working age population was 83,440 thousand, and the population over working age was 35,847 thousand, with a total population of 146,980,061 people [55]. Thus, the number of working-age citizens was 56.77% of the total population of the Russian Federation. According to Rosstat, the average monthly nominal accrued employee salary in organizations in the Russian Federation was equal to RUB 70,922 as of September 2023 [55]. Working citizens who received their minimum salaries in Russia constitute Group-2. This category of citizens belongs to the first 10% group (decile groups) in terms of salaries; therefore, its number is 83,440,000 people and 0.1 = 8,344,000 people, which makes up 5.68% of the total population of the Russian Federation. Group-3 consists of pensioners; their number in Russia reaches 35,847 thousand people, 24.39% of the total population of the Russian Federation, with an average pension of RUB 21,864 [56-58]. Table 2 presents the results of the assessment of the social effects of the considered groups of citizens.

Table 2. Social feasibility for financing treatment of the patients with complete loss of teeth

No.	Name of the Group	Average monthly amount of cash received, RUB	Minimum average monthly amount of cash that a patient is able to save to acquire RPD, RUB	Share of average monthly cash received that could be used to acquire RPD	Term of saving cash to cover costs associated with denture treatment, RPD-1	Term of saving cash to cover costs associated with denture treatment, RPD-2	Term of saving cash to cover costs associated with denture treatment, RPD-3
1	2	3	4	5	6	7	8
1	Group-1 (working citizens with average salary)	62,470	24,988	40%	$\frac{X}{24\,988}$	$\frac{X}{24\,988} + 1\ month$	$\frac{X}{24\,988} + 4\ months$
2	Group-2 (working citizens with minimum salary	16,242	1,867	11.5%	$\frac{X}{1\,867}$	$\frac{X}{1\,867} + 25\ months$	$\frac{X}{1\,867} + 104\ months$
3	Group-3 (pensioners with average salary)	21,864	7,489	34.3%	$\frac{X}{7\,489}$	$\frac{X}{7\,489} + 7\ months$	$\frac{X}{7\,489} + 26\ months$

The calculation of the S_n cash amount received (column 4), which the citizens included in each category would be able to save, was performed using formula (1). As of 2023, the living wage is RUB 14,375 [59], the minimum salary is RUB 16,242 [60], and the average pension is RUB 21,864 [52]. Therefore, S_1=62,470-max{14,375;0.6·62,470}= RUB 24,988, as indicated in the first line of column 4 in Table 2. This is similar to the remaining lines in column 4 of Table 2.

The share of average monthly cash received and allocated to acquire the RPD is presented in Column 5 of Table 2. This is determined using (3). The term required for the *n*-th category of citizens to accumulate a sufficient amount of cash to pay for treatment using the RPD *j*-th type is calculated using formula (2) and is presented in columns 6-8 of Table 2: column 6 – RPD-1, column 7 – RPD-2, and column 8 – RPD-3. In addition, it is necessary to calculate using Equation (2), during which patients are able to accumulate the amount necessary to cover the costs associated with each RPD type. For example, for RPD-1 (see the first line of Column 6 in Table 2), the specified period is calculated as follows: $T_{11} = \frac{X}{S_1} = \frac{X}{24\,988}$, where X is the RPD cost and S_1 is the cash amount that a patient in the first category would be able to save in RUB. This was similar for the other groups of patients and types of dentures (see columns 6-8 in Table 2).

Figure 3 presents the dynamics of accumulating the required amount of cash relative to the prosthetic cost for patients in each group.

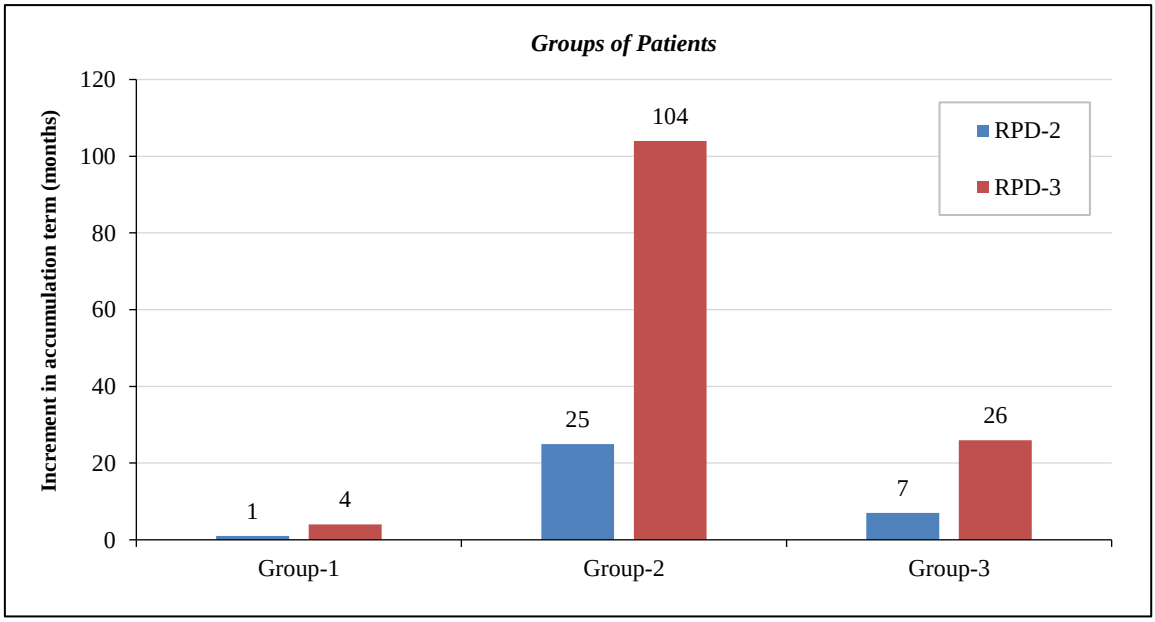

Figure 3. Distribution of the accumulation term increment of the required cash amount for RPD-2 and RPD-3 relative to the RPD-1 cost by patients of each Group

It follows from Figure 3 that patients from Group-2 (working citizens with minimum salary) would not be able to accumulate the required amount to install RPD, since the period of accumulating the required amount of cash would be more than 104 months or slightly less than 9 years, exceeding the RPD-3 useful life.

Economic feasibility of financing treatment of the patients with complete loss of teeth is presented in Table 3. Economic justification for the financing of treatment for patients with complete tooth loss requires determination of the discount rate. The cumulative method best considers all types of investment risks associated with both industry and economic factors, and the specifics of the assessed socioeconomic effect [61]. The rate was calculated using the following formula:

$$Y = R + r \tag{4}$$

where Y is the discount rate (%), R is the risk-free rate of return (%), r is the total premium for individual risks related specifically to the specific features of the functioning of a given medical institution, and the risks are premiums for other risks. When determining the risk-free rate (R) in the Russian market, one can use the rate of investments characterized by the lowest level of risk: the refinancing rate of the Central Bank of the Russian Federation, deposits of Sberbank of the Russian Federation and other reliable Russian banks, and RF government bonds [62].

According to information presented on the official website of the Central Bank of the Russian Federation [63], the key rate from December 18, 2023, was 16.00%. Leaving the expert assessment procedure, which is described in detail in [54], outside the scope of our study, we note that the risk premium for the socioeconomic justification of financing prosthetic treatment for patients with complete tooth loss was 4.00%.

Thus, the discount rate obtained using the cumulative construction method [64] is $Y = R + r$ = 16.00% +4.00% = 20.00%, as indicated in the last line of Table 3.

Table 3. Economic feasibility of financing treatment of the patients with complete loss of teeth

No.	Indicator name	RPD type		
		Standard RPD (RPD-1)	RPD with adhesives (RPD-2)	RPD based on dental implants (RPD-3)
1	2	3	4	5
1	Annual cash received, RUB	224,050	270,630	409,600
2	Net present value (NPV), RUB	670,047 – 3X	809,349 – 3X	1,224,955 – X
3	Profitability index (PI), un. fractions	670,047 / X	809,349 / X	1,224,955 / X
4	Discounted cash flow, RUB	1,120,250 – 3X	1,353,150 – 3X	2,048,000 – X
5	Internal rate of return (IRR)	$0 = \sum_{t=1}^{5} \frac{224\,050}{(1+IRR_{RPD-1})^5} - \sum_{t=1}^{5} \frac{X}{(1+0,2)^t}$	$0 = \sum_{t=1}^{5} \frac{270\,630}{(1+IRR_{RPD-2})^5} - \sum_{t=1}^{5} \frac{X}{(1+0,2)^t}$	$0 = \sum_{t=1}^{5} \frac{409\,600}{(1+IRR_{RPD-3})^t} - X$
6	Discounted payback period (DPP), years	$DPP = \min n, where \sum_{t=1}^{n} \frac{224\,050}{(1+0,2)^t} \geq 3X$	$DPP = \min n, where \sum_{t=1}^{n} \frac{270\,630}{(1+0,2)^t} \geq 3X$	$DPP = \min n, where \sum_{t=1}^{n} \frac{409\,600}{(1+0,2)^t} \geq X$
7	Payback period (PP), years	3X / 1,120,250	3X / 1,353,150	X / 2,048,000
8	Weighted average cost of capital (WACC)		20%	

The annual cash inflow for each RPD type is determined by the increase in the patient's quality of life and salary amount, which is directly proportional to his comprehensive assessment of the capacity and level of quality-of-life restoration:

$$CF_{nj} = Sal_n \cdot K_j, \tag{5}$$

where CF_{nj} is the annual cash inflow of the n-th category of citizens (n = 1, 2, 3) using the RPD j-th type (j = 1, 2, 3), RUB; Sal_n is the average annual salary of the n-th category of citizens, RUB; and K_j is the comprehensive assessment of the patient's capacity and quality of life restoration after installing the RPD j-th type unit fractions (see last column in Table 1). For example, the amount of RUB 224,050 indicated in the first line of column 3 in the table for the working elderly and senile citizens was calculated as follows: RUB 560,124 (average annual salary of the working elderly and senile citizens according to [59]) · 0.4 (comprehensive assessment of the patients' capacity and quality of life restoration (see Table 1) = RUB 224,050.

The values presented in lines 2-8 in Table 3 were calculated using dynamic methods in assessing the investment efficiency; they were described in detail, for example, in works [33-37]. In particular, the net present value indicated in the second line of Column 3 of Table 3 is identified as follows:

$$\begin{aligned} \text{NPV} &= \sum_{t=1}^{5} \frac{224\,050}{(1+0.2)^t} - \sum_{t=1}^{5} \frac{X}{(1+0.2)^t} \\ &= \text{RUB } 670{,}047 - \text{RUB } 0.83X - \text{RUB } 0.7X - \text{RUB } 0.58X - \text{RUB } 0.48X - \text{RUB } 0.4X \\ &= \text{RUB } 670{,}047 - \text{RUB } 3X. \end{aligned} \tag{6}$$

The calculations used a planning horizon of five years and a weighted average cost of capital (discount rate) of 20% (see the last line in Table 3). The values in the other columns of the second line of Table 3 were calculated in a similar manner.

The return on investment shown in line 3 of Column 3 in Table 3 is calculated as follows:

$$PI = \frac{670{,}047 - 3X + \sum_{t=1}^{5} \frac{X}{(1+0.2)^t}}{X} = \frac{670{,}047}{X} \tag{7}$$

Calculations were similar for other columns of line 3 in Table 3.

Discounted cash flow shown in line 4 in Table 3 were calculated as follows:

$$\sum_{t=1}^{5} 224{,}050 - \sum_{t=1}^{5} \frac{X}{(1+0.2)^t} = 1{,}120{,}250 - 3X\ RUB. \tag{8}$$

Calculations were similar for the remaining columns of line 4 in Table 3.

An analysis of the data presented in lines 1-4 and 7 in Table 3 shows that the highest indicator values were observed for RPD-3. In other words, RPD based on dental implants are economically efficient. To understand this, it is sufficient to compare the values in lines 1-4 and 7 in columns 3-5 of Table 3.

Let us compare the expressions presented in the corresponding columns of line 5 in Table 3 to understand the type of denture leads. For example, equating the expressions in columns 3 and 4 of Table 3.

$$\sum_{t=0}^{5} \frac{224\,050}{(1+IRR_{RPD-_1})^5} - \sum_{0}^{5} \frac{X}{(1+0.2)^t} = \sum_{t=0}^{5} \frac{270\,630}{(1+IRR_{RPD-2})^5} - \sum_{0}^{5} \frac{X}{(1+0,2)^t} \quad (9)$$

It can be concluded that the larger the numerator, the larger the denominator should be for equality to hold.

Therefore,

$$IRR_{RPD-_1} < IRR_{RPD-_2}$$

Similarly, comparison of data in columns 4 and 5 leads to a conclusion that

$$IRR_{RPD-1} < IRR_{RPD-2} < IRR_{RPD-3}.$$

Therefore, according to this indicator, RPD using dental implants (RPD-3) is the leader.

The same reasons can be applied to the expressions in line 6 of Table 3, leading to the conclusion that the RPD-3 discounted payback period is the shortest among the compared RPDs. This indicates that RPDs based on dental implants are the leader of this indicator.

Thus, the use of RPDs based on dental implants appears economically feasible according to dynamic methods of assessing investment efficiency for the RPD-3 values that is, accepting a planning horizon of five years. Based on expert assessment using the clustered rankings coordination method [51-54], socio-economic feasibility was prepared for financing the treatment of patients with complete loss of teeth, as presented in Table 4.

The method of matching clustered rankings, described in detail by Orlov [54], for example, is one of the most common and easy-to-use decision-making methods for multi-criteria problems. This approach was based on an expert assessment method. The main requirement for expert assessment is the reliability of information. By definition [65], information is reliable if it is representative, accurate, or valid. These properties, characterizing the degree of information quality, are achieved, among other things, by qualitative and quantitative optimization of the composition of the group of experts [66].

Generalized expert assessments are expressions of the consistent opinions of experts and compromise collective judgment considering the subjectivity of the experts' viewpoints. Careful elaboration of possible scenarios for the development of events is a key step in this examination, allowing control over uncertainty issues. In this regard, for high-quality expert assessment, it is necessary to select qualified experts in the field of methods and approaches to financing primary health care who are interested in an objective assessment of the feasibility and prospects of social, economic, and socioeconomic indicators as promising and scientifically substantiated from the viewpoint of the socioeconomic justification for financing prosthetic treatment of patients with complete tooth loss. An extremely significant condition for achieving a compromise is that each party in the examination must be represented by an equal number of participants. The procedure for selecting experts can be conducted objectively when experts are selected using special selection methods; for example, by checking the documentation created by experts earlier by analyzing their sociodemographic data and subjectively, that is, by voting, mutual assessment of future experts, or self-assessment. Special requirements are imposed on the experts themselves, and these requirements are widely covered in specialized literature [67].

An expert assessment can be face-to-face when the participants of the examination have the opportunity to exchange opinions, or in absentia when each expert answers the questions posed, for example, in the form of a questionnaire. Brainstorming can be used to conduct expert assessment. Based on the above, an expert group was formed, consisting of the following representatives: employees of the financial services of medical organizations, practicing doctors, employees of administrative and managerial personnel of dental medical organizations, full-time students, working citizens, and pensioners. Each expert independently answered the questions posed; that is, the expert survey procedure was conducted in absentia. The total number of respondents was six, with one person per group.

In assessment theory, there are several methods for matching the assessment results. Two main approaches can be distinguished [66].

1) An approach based on mathematical weighing (mathematical approach). The sum of the weights assigned to the different results should be equal to unity (or 100%).

2) An approach based on subjective weighing (subjective approach). The formal requirement for the sum of the weights is not satisfied. The final assessment of the enterprise value is supported by a verbal description of the factors that, in the appraiser's opinion, influence it.

Let us take a closer look at the method of matching clustered rankings.

Suppose there is a finite number of objects that will be represented by natural numbers 1, 2, 3, …, *k*, and their set is called a carrier. We assume that the clustered ranking defined for a given carrier is the following mathematical objective: Let the objects be divided into groups called *clusters*. Clusters do not have common elements and their union (as sets) is the entire set of objects under consideration (the entire carrier).

In accordance with this definition, to coordinate clustered rankings, experts were offered a questionnaire, the structure of which is presented in Table 4.

For each indicator, Table 4 shows its value and score, making it possible to rank the RPDs to increase their quality and usefulness for patients according to the assessed quantitative criterion. For example, the term cash accumulation to cover costs associated with denture treatment was minimum for RPD-1 and maximum for RPD-3. Therefore, RPD-1 was assigned three points, RPD-2 received two points, and RPD-3 was assigned one point (see lines 1-4 in Table 4). This appears to be similar for all other indicators in Table 4.

In Table 4, experts were asked to enter numbers corresponding to the rank that the expert gives to a given criterion according to its degree of importance for assessing the feasibility and prospects of social, economic, and socioeconomic indicators as promising and scientifically substantiated from the viewpoint of socioeconomic justification of financing prosthetic treatment for patients with complete tooth loss. If experts consider several criteria to be equivalent for an examination (Table 4), they must indicate the same number of criteria that are equivalent in their opinions. This group of combined criteria, in accordance with the above definition from the textbook [54], was considered a *cluster*. Thus, Table 4 may have numbers from 1 to 3 if there are no clusters, and from 1 to 2 if there is one cluster with two criteria included in it, up to the situation when the expert considers that all three criteria are equivalent and ranked first; that is, there is a unit in all corresponding lines in Table 4.

For clusters, the entire group of elements is assigned the same score, equal to the arithmetic mean of the scores of the elements included in it.

After collecting the questionnaires completed by the experts (see Table 4) and processing the obtained results, namely assigning a weighting coefficient to each criterion by normalizing the obtained scores so that the sum of the weighting coefficients is equal to 1 (100%), and multiplying the sum of the scores for each source of financing by the obtained weighting coefficient, it is possible to obtain the distribution of expert opinions as a percentage characterizing the degree of preference of the corresponding RPD and social, economic, and socioeconomic indicators as promising and scientifically substantiated from the viewpoint of socioeconomic justification for financing prosthetic treatment of patients with complete tooth loss. The expert group questionnaire survey using the method of matching clustered rankings showed the following results (in percentages characterizing the degree of preference of the corresponding RPD): RPD-1, 32.00%; RPD-2, 31.58%; and RPD-3, 36.42%, as indicated in the last line of Table 4.

The final denture-type assessment, which determined the priority of each RPD type, was calculated using the clustered-ranking coordination method.

Let us analyze Table 4, which defines indicators according to various categories of consideration of financing treatment of patients with complete loss of teeth, to select the most efficient RPD from a socioeconomic perspective. From the perspective of social factors, it is important to consider indicators for comprehensive assessment of the patient's capacity restoration and quality of life improvement (10% weight). RPD-1 is leading (line 4, Table 4) in terms of this indicator, since this type of denture treatment has been able to ensure the optimal vitality of patients for many years due to its technical characteristics. Let us consider the most important economic indicators when choosing denture treatment financing: the return on investment (line 7) and payback period (line 11). Regarding return on investment, the RPD-3 option leads in terms of this indicator. The return on invested funds was the highest. Moreover, RPD-3 was the best option with regard to the payback period, as this particular type of denture treatment had the best ratio between the invested funds and payback period.

When considering socioeconomic characteristics, it is important to note the useful life period (line 13). RPD-3 has a large margin compared with other denture treatment options. If the object is assessed according to the price–quality parameters, it is important to analyze the useful life of the investment object. Therefore, RPD-3 was the best treatment option for patients with complete tooth loss.

The final assessment of all RPD types (last line, Table 4) determined that the RPD-3 option was the most optimal for patient treatment. The ratio of the quality and price indicators determines the competitiveness of this option.

Table 4. Socioeconomic feasibility for financing treatment of the patients with complete loss of teeth

No.	Group of indicators	Indicator name		Indicator weight	RPD-1	RPD-2	RPD-3
1	2	3		4	5	6	7
1	Social	Term of accumulating cash amount to cover costs associated with denture treatment for Group-1 (T1)	Value	6%	$\frac{X}{24,988}$	$\frac{X}{24,988} + 1\ month$	$\frac{X}{24,988} + 4\ months$
			Score		3	2	1
2		Term of accumulating cash amount to cover costs associated with denture treatment for Group-2 (T2)	Value	6%	$\frac{X}{1,867}$	$\frac{X}{1,867} + 25\ months$	$\frac{X}{1,867} + 104\ months$
			Score		3	2	1
3		Term of accumulating cash amount to cover costs associated with denture treatment for Group-1 (T3)	Value	6%	$\frac{X}{7,489}$	$\frac{X}{7,489} + 7\ months$	$\frac{X}{7,489} + 26\ months$
			Score		3	2	1
4		Comprehensive assessment of capacity and quality of life restoration (K)	Value	10%	40%	50%	80%
			Score		1	2	3
Denture type assessment according to the social indicators group				***28%***	***38.10%***	***33.33%***	***28.57%***
5	Economic	Net present value (NPV), RUB	Value	10%	$670,047 - 3X$	$809,349 - 3X$	$1,224,955 - X$
			Score		1	2	3
6		Weighted average cost of capital (WACC), RUB	Value	5%	0.2	0.2	0.2
			Score		2	2	2
7		Profitability index (PI)	Value	6%	670,047 / X	809,349 / X	1,224,955 / X
			Score		1	2	3
8		Discounted cash flow, RUB	Value	5%	$1,120,250 - 3X$	$1,353,150 - 3X$	$2,048,000 - X$
			Score		1	2	3
9		Internal rate of return (IRR)	Value	2%	$0 = \sum_{t=1}^{5} \frac{224,050}{(1+IRR_{RPD-1})^5} - \sum_{t=1}^{5} \frac{X}{(1+0,2)^t}$	$0 = \sum_{t=1}^{5} \frac{270,630}{(1+IRR_{RPD-2})^5} - \sum_{t=1}^{5} \frac{X}{(1+0,2)^t}$	$0 = \sum_{t=1}^{5} \frac{409,600}{(1+IRR_{RPD-3})^t} - X$
			Score		1	2	3
10		Discounted payback period (DPP)	Value	3%	$\sum_{t=1}^{n} \frac{224,050}{(1+0,2)^t} \geq 3X$	$\sum_{t=1}^{n} \frac{270,630}{(1+0,2)^t} \geq 3X$	$\sum_{t=1}^{n} \frac{409,600}{(1+0,2)^t} \geq X$
			Score		1	2	3
11		Payback period (PP)	Value	6%	3X / 1,120,250	3X / 1,353,150	X / 2,048,000
			Score		1	2	3
Denture type assessment according to the economic indicators group				***37%***	***22.06%***	***30.39%***	***47.55%***
12	Socio-economic	Additional costs, RUB	Value	5%	0	9 432	192 500
			Score		3	2	1
13		Useful life period, years	Value	8%	1	1	5
			Score		1.5	1.5	3
14		Share of additional costs	Value	4%	0%	5%	20%
			Score		3	2	1
15		Costs management efficiency	Value	5%	100%	95%	80%
			Score		3	2	1
16		RPD type assessment characteristic	Value	7%	40%	48%	64%
			Score		1	2	3
17		Price affordability (PA), RUB	Value	6%	X	X + 9,432	X + 192,500
			Score		3	2	1
Denture type assessment according to the socio-economic indicators group				***35%***	***37.62%***	***31.43%***	***30.95%***
Final denture types of assessment					32.00%	31.58%	36.42%
Deviation of the object rank sum from their average sum for all objects					-1.333	-1.753	3.087
Squared deviations of the object rank sum from their average sum for all objects					1.778	3.074	9.528
Sum of squared deviations of the object rank sum from their average sum for all objects						14.379	
Kendall's coefficient of rank concordance (consistency)						0.200	
Significance level of Kendall's coefficient of rank concordance						2.397	
Tabular value of value of Pearson criterion $\chi^2_{0,95;2}$						0.10	
Conclusion on the significance of Kendall's coefficient of rank concordance (consistency) at the 5% level						*Significant*	

4- Discussion

- In the present article, authors propose an interpretation of the economic feasibility of investments in financing the treatment of patients with complete tooth loss using the financial flow of funds, characterizing the receipt of financial resources from its sale and spent on the development, production, and use of the prosthesis during the warranty period. In addition, the methodology for the evaluation of this model is developed on the basis of economic efficiency, social effects, and expert assessments, using the method of matching clustered ranks and assessing the consistency of the results obtained by Kendall's coefficient of rank concordance.
- An algorithm and software for innovative technology of socio-economic justification for financing the treatment of patients with complete tooth loss, as well as a flowchart of the research algorithm, were developed. These reflect in detail the main aspects and criteria for making key management decisions related to the optimal combination of factors and parameters that have a direct impact on the indicators of social, economic, and socioeconomic efficiency of the choice of the RPD type for a particular category of patients, taking into account their social status. The developed algorithms provide balanced management decision-making on the socially and economically justified choice of the RPD type for a particular category of citizens to optimize the total costs (taking into account the cost of the RPD itself and its installation). It helps ensure the patients' ability to recover and improve their quality of life, which makes it possible to assess the need for and the amount of state and governmental support measures for Russian citizens with complete tooth loss.
- Based on results of assessing the social effect of using each RPD type, it becomes evident that citizens of the working category, actually 83,440 thousand people in number, which constitutes 56.77% of the total population of the Russian Federation, with an average salary of RUB 62,470 per month (Group-1) would be able to save RUB 24,988 per month (see Table 2). That is, 40% of the money earned corresponds to the comfort level in terms of debt burden. Working citizens receiving the minimum salary (Group-2) would be able to save only RUB 1,867 per month (see Table 2) and would not be able to save cash to pay for RPD with dental implants. This group comprises 8,344 thousand people, constituting 5.68% of the total population of the Russian Federation. Pensioners receiving an average pension would save RUB 7,489 (see Table 2), amounting to 34.3% of their pensions. This group comprised 35,847 thousand people, or 24.39% of the total Russian Federation population.
- Analysis of the socio-economic parameters showed that RPD-1 is leading in terms of price affordability, since additional costs for the RPD with implants amount to RUB 192,500 (considering a useful life of five years). Additional costs for RPD with adhesives would cost RUB 9,432 (Table 4). However, the RPD-3 useful life is five years, while that of RPD-1 and RPD-2 is one year (see Table 1).
- Prices for dental implants, calculated using the tariffs of Russian compulsory medical insurance, are not socially affordable for working citizens with minimum salaries and pensioners in Russia. They would have to save funds for at least 104 months and 26 months, respectively (see Table 3). Thus, only RPD-1 and RPD-2 are affordable to them, while RPD-3 creates a significant financial burden on these patients and requires social adaptation as well as government support measures.
- Regarding the economic feasibility assessment, the results show that using RPD-3 in the implantation denture treatment structure for patients with complete loss of teeth is the most cost-effective and efficient for patients of those professions and professional responsibilities, where aesthetics and appearance of the oral cavity, as well as the excellent condition of the teeth, are of utmost importance. Such professions include musicians, artists, TV presenters, reporters, trainers, teachers, and top managers. Poor dental health and insufficient oral cavity quality can lead to job loss. This is proven by the results of calculating key economic indicators, such as net present value, profitability index, interim rate of return, discounted payback period, ordinary payback period, and discounted cash flow (see Table 3).
- The overall assessment of each type of denture (see Table 4) confirms the socioeconomic feasibility of selecting implant denture treatment by calculating key indicators of socioeconomic efficiency for patients whose professional responsibilities are related to the oral cavity quality functioning and excellent condition of the teeth. According to the last line in Table 4, the final score for conventional RPD was 32.00%, RPD with adhesives – was 31.58%, and RPD with dental implants – was 36.42%. Thus, the final RPD assessment made it possible to determine the priority of dental prostheses over dentures with adhesives and usual types of RPDs. This allowed us to conclude that the RPD-3 design is the most attractive option for treating patients with complete loss of teeth, whose professional responsibilities are associated with quality functioning of the dentofacial apparatus.
- Analysis of the data presented in Table 4 shows that according to the social indicator assessment results, conventional RPD is leading (38.10%), followed by RPD using adhesives (33.33%), while dental implants occupy the last place in the social indicator group (28, 57%).
- Based on the results of assessing the economic indicators (see lines 5-11 in Table 4), the situation is fundamentally different from that observed for the social indicators group: RPD with dental implants leads (47.55%), followed by RPD with adhesives (30.39%), and conventional RPD (22.06%).
- Regarding the socioeconomic indicators group (lines 12-17 in Table 4), the usual RPD again occupied the first place (37.62%), followed by RPD with adhesives (31.43%), and finally dental implants (30.95%).

- The results of assessing the level of expert opinion consistency using Kendall's rank concordance criterion make it possible to conclude that expert opinions are fairly consistent because the significance level of Kendall's coefficient of rank concordance (consistency) (2.397, see Table 4) exceeds the tabular value of the Pearson criterion (0.10) at the 5% significance level for a number of degrees of freedom equal to two ($k = 2$).

5- Conclusions

To support the research hypothesis proposed above, we noted that dental implants are economically unaffordable for working citizens with minimum salaries and pensioners in Russia. They would have to raise funds for at least 104 and 26 months. Thus, only RPD-1 and RPD-2 were affordable. The RPD-3 type creates a significant financial burden on these population segments and requires social adaptation and government support. At the same time, for the conventional RPD (RPD-1), the final assessment using the clustered rankings coordination method was 32.00%, for RPD with adhesives (RPD-2), the estimate was 31.58%, and for RPD with dental implants (RPD-3), the final assessment resulted in 36.42%. Thus, the final RPD assessment ensures the priority of dental prostheses over dentures with adhesives and the usual type of RPD. Thus, it can be concluded that the RPD-3 design appears to be the most attractive option for treating patients with complete loss of teeth, whose professional responsibilities are associated with the quality of their dentofacial apparatus.

The scientific novelty of this research lies in the fact that, using socioeconomic instruments, the study shows how it is possible and necessary to redistribute the healthcare resources of the Russian Federation for the optimal choice of prosthetic treatment technology for patients with complete loss of teeth and dental prosthesis design according to the criterion of socioeconomic efficiency.

5-1- Strengths and Limitations of the Study

The comprehensive innovative technology developed by the authors combines social, economic, and socioeconomic efficiency assessments with the expert evaluation method and provides patients, dentists, healthcare functionaries, and healthcare managers with the following opportunities:

- Make optimal management decisions regarding RPD selection according to the criterion of minimizing total costs for its installation and subsequent operation, taking into account the patient's social status and RPD parameters, such as useful life, functional characteristics, level of the patient's capacity and quality of life restoration, aesthetics, and other important characteristics.
- We obtained a final assessment of expert opinions based on a combined analysis of medical (professional), social, economic, and socioeconomic factors influencing RPD perception by different categories of citizens to determine the most attractive types of dentures for treating patients with complete loss of teeth, and the sources for financing such treatment.
- The model developed in this study can be easily replicated in other countries with different health systems and economic conditions, considering the specifics of these systems. This model is universal and does not depend on a specific region of application.

5-2- Comparison with Previous Research Results and Scientific Advancement of Knowledge

The proposed in this study new assessment model of socioeconomic feasibility of financing treatment of the patients with complete loss of teeth in health care differs from other well-known models that unlike the existing works of specialists in dentistry, organization, and financing healthcare, for example [68-73], this study proposes a comprehensive system to support management decision-making in selecting the RPD types for various categories of citizens based on socio-economic analysis. This analysis included a set of widely used parameters for the economic assessment of investments in RPD acquisition (NPV, PI, IRR, PP, and DPP). It is supplemented by social criteria (period of accumulating necessary funds for RPD acquisition, share of monthly income with patients sent to acquire RPD, etc.), parameters ensuring an increase in the capacity and quality of life of patients, providing an efficient tool for selecting the treatment regimens for patients with complete loss of teeth, as well as quantitative assessment of the state and government measures to support citizens needing dentures.

5-3- Model Limitations

- To increase the accuracy in solving the problem of optimal combination of factors influencing the socio-economic feasibility of financing treatment of patients with complete loss of teeth, this study recommends including anatomical, physiological, and other features that limit the use of certain RPD types in the management decision-making model, as well as factors that require priority consideration when choosing them and assessing the total cost of treatment.
- Consideration of the socio-economic feasibility of financing the treatment of patients with complete loss of teeth is significantly influenced by RPD manufacturing technology (digital or analog). This study examines average statistical RPDs with the same economic, operational, and technological parameters. This greatly simplifies the study, but simultaneously allows for a comparative analysis of three groups of RPDs and three categories of

citizens without losing accuracy and meaning. The three categories of citizens were working citizens with a minimum salary, working citizens with an average salary, and pensioners with an average pension. Thus, the conditional simplification model makes it possible to comprehensively and systematically point of view to consider the issue of optimal selection of the RDP; that is, the matter is a 3 × 3 matrix, where categories of citizens are considered along one axis (dimension) and RPD types on the other.

- This study uses subjective expert opinions as the final assessment, and the processing results are based on the clustered ranking coordination method, which significantly reduces the number of potential customers in innovative technology and makes it difficult to verify the results using real data and real operating conditions. To increase the reliability of the results obtained, it is necessary to improve the objectivity of the assessment; for example, through the development of special questionnaires balanced with respect to the possibilities of subjectivizing the answers and introducing other methods in processing the expert assessment results. Hierarchy analysis methods [74-76] with the ability to assess consistency [77-81] could be of interest, as well as methods of grouping expert opinion indexes and other popular and practical methods [82-85].

5-4- Conclusion, Recommendations and Areas for Future Research

Theoretical significance lies in the development of a new model for assessing the socioeconomic feasibility of financing the treatment of patients with complete tooth loss in the healthcare system. Moreover, it involves determining the socioeconomic feasibility of investing in digital technologies for the diagnosis and treatment of patients with complete tooth loss using removable polymer prostheses made using additive 3D printing technology to address socially significant and widespread oral pathology with a new model for the treatment of patients with complete tooth loss.

Practical relevance consists of the development of the evaluation model, algorithm flowchart, and software, which makes it possible:

1) For Patients: to assess the socioeconomic feasibility of the choice of prosthetic treatment technology for patients with complete tooth loss and prosthesis design depending on the type of RPD used, taking into account the socioeconomic status of the patients.
2) For Decision Makers: to perform a quantitative assessment of economic opportunities for the effective use of removable prostheses, taking into account the socioeconomic status of patients and state support measures.
3) For Dentists: to use additional sources of information when choosing a treatment scheme.

Policy Recommendations: The complex innovative technology developed by the authors for the socio-economic feasibility of financing treatment of patients with complete loss of teeth could be introduced to improve the accuracy, efficiency, and validity of management decisions to expand the arsenal of means to restore the capacity, working ability, and quality of life of citizens and a set of tools for financing dental services, which is important for healthcare managers and functionaries.

Managerial Implications: The present scientific work provides management decision makers with effective tools for determining the optimal types of RPDs for various categories of citizens, taking into account their social status and income level.

Further research on the study subject should include the following:

- Supplement socio-economic feasibility of financing treatment of patients with complete loss of teeth with medical (professional) efficiency, and also include technology of denture manufacture, anatomical and physiological characteristics of patients in the study, and, if possible, predicting the industry technological development directions for several years in advance. Thus, further research should focus on promising technologies in denture treatment and not evaluate outdated technologies and methods of compensating for the absence of dentition or complete tooth loss.
- Extension of the RPD types introduced in this study to other categories of citizens, for example, using more detailed income levels and professional and/or social status to make such a study more complete and account for the specifics, preferences, and wishes of separate categories of citizens.
- Taking into account the possibility of scaling the RPD types in the existing manufacturing and technological realities and capabilities, the existing and projected costs of manufacturing, and the realization of various types of RPDs.
- Adapting the complex innovative socioeconomic feasibility technology developed in this study to other RPD types, for example, considers a wider range of dental implants.
- Research and analysis of alternative financing strategies, not only citizens' own funds, such as insurance schemes (e.g., use of medical savings accounts [86, 87], voluntary health insurance, etc.) or payments that could allow dental implants (RPD-3) and related treatment schemes more affordable for Russian citizens.
- Inclusion of the developed complex tools in the unified information and analytical system for managing dental services with prospects for their interaction with the widely used application software products in dental medical organizations.

6- Declarations

6-1- Author Contributions

Conceptualization, D.I.G., A.V.M., and S.N.P.; methodology, D.I.G. and E.V.K.; validation, E.V.K., M.Sh.M., and K.G.A.; formal analysis, S.N.P. and E.V.K.; investigation, A.V.D. and D.G.R.; data curation, N.L.K., S.N.K., and S.A.A.; writing—original draft preparation, D.I.G., A.V.M., S.N.P., E.V.K., and M.Sh.M.; writing—review and editing, D.I.G., E.V.K., M.Sh.M., A.V.D., S.N.K., and S.A.A. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

The data presented in this study are available in this article.

6-3- Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Not applicable.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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