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THE DIGITAL PROTOCOL DEVELOPMENT AND EFFECTIVENESS EVALUATION FOR COMPLEX DENTAL TREATMENT

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Abstract

The work is devoted to the development of a protocol for digital planning of dental treatment with the use of high-precision instruments and confirmation of its clinical effectiveness.

A detailed analysis of the diagnostic and planning resources of dental treatment was carried out at the first stage of this study to optimize and structure them into a single digital complex. The analysis of cone-beam computed tomography results was provided with the artificial intelligence technology called Diagnocat. We compared the automated software report with the description of the radiographic scans of the same patients for the validation of artificial intelligence compiled by dental experts, who have continuous record of service in the specialty for more than 10 years in the specialization.

To confirm the clinical effectiveness of the developed digital dental planning, 109 patients were examined who demanded aesthetic porcelain restorations in the maxillary arch. The study included 48 patients, randomly divided into a study group and a control group of 24 patients. At the end of the prototype, all patients were surveyed to assess the quality of life and satisfied dental treatment using OHIP-14 (Oral Health Impact Profile) questionnaire.

In total, according to the results of the report analysis compiled by an expert group and a software based on artificial intelligence, 439 pathologies were identified in 638 teeth. The obtained results of the CBCT (cone-beam computed tomography) analysis give grounds to draw conclusions about the obvious superiority of artificial intelligence technology in terms of the time spent on diagnostics and the quality of dental patient radiological description. Summarizing the results of the questionnaire survey based on the OHIP-14 questionnaire, we can conclude that the quality of life of patients has doubled according to the results of the digital dental treatment planning complex.

Keywords: *digital dentistry, digital planning, smile design, artificial intelligence, prototyping.*

Introduction

Treatment planning is the main stage in the comprehensive rehabilitation of dental patients [*Zimmermann M., Mehl A, 2015*]. Over the years, dentists have used various analog technologies to obtain predictable results [*Ryakhovsky A, 2014*]. Though two-dimensional images were previously used in planning, it is not always possible to obtain a guaranteed treatment result, which was approved by the doctor with the patient at the first consultation [*Apresyan S et al., 2020*].

Dentists use silicone impressions, wax-up, mock-up and other instruments with traditional analog planning technologies [*Ryakhovsky A, 2019*]. But when a dental technician begins to make porcelain restorations according to only a 2D design of the future teeth, it is almost impossible to identically reproduce the result that was agreed upon by the doctor and the patient [*Coachman C et al., 2017; Apresyan S et al., 2020*].

At the moment, the use of digital capabilities at the diagnosis and treatment planning stages is not innovation, but rather is considered as an already

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reasoned enough approach to the dental patient rehabilitation [*Stelzle F, 2010*].

The key point at the stages of digital treatment planning is obtaining digital impressions [*Ryakhovsky A, 2014*]. Direct teeth copies and adjacent anatomical structures are visualized immediately during the scanning procedure, and the high resolution of the images obtained allows to assess the state of existing restorations, defects in teeth and dentition, their size and shape, the occlusal contacts type and even reproduce the articulation movements of the patient's mandible [*Ryakhovsky A, 2019*].

A lot of dentists already actively use intraoral scanners, facial scanners, treatment planning software in 2D and 3D modes in their practice [*Apresyan S et al., 2020*].

The fundamentals of smile design are directly related to the general aesthetic principles that determine facial beauty. Despite the subjectivity of this concept, many of the features of a harmonious face are recognized by most people in the same way, the dentists are guided by these ideas during treatment [*Ryakhovsky A, 2019*]. The patient is left with a relatively large number of decisions even with the most detailed description of his or her wishes that specialists must make during the work. If a smile planning is carried out using special software, certain principles should be incorporated into the software to create harmonious view [*Apresyan S et al., 2020*].

The software allows to create individual prosthetic constructions with high precision, thus achieving the best functional parameters and at the same time improving the results of aesthetic restorations [*Ryakhovsky A, 2009; Holyoak M, 2013*]. Preliminary computer planning allows not only to find the optimal way of restoration, but also to bring its aesthetic result as close as possible to the patient's expectations [*Ahrberg D et al., 2016*]. These technologies help to accurately reproduce digital denture models, the characteristics of which have been worked out and approved by the dentist together with the patient at the stage of digital planning [*Coachman C et al., 2012*].

However, this procedure does not allow assessing the state of bone tissue and intraosseous structures, for that computed tomography is used. The combination of radiographic data with volumetric images of the dentition and jaws obtained during scanning allows not only to determine the state of visible and invisible dentition structures, but also to plan high-quality dental treatment [*Ryakhovsky A, 2014*].

In addition to software for modeling dentures, new computer technologies appear, including those operating on the artificial intelligence principle (neural networks), which allow both diagnosing dental pathologies and schematically visualizing them for patient understanding [*Apresyan S et al., 2020*].

Machine production methods of removable and fixed dentures, such as computer milling and additive technologies, are being actively introduced along with diagnostic digital methods in modern dentistry, [*Almodalal A, Abou N, 2020*].

New opportunities in medicine are opened by the achievements of applied mathematics and information technologies [*Olesova V et al., 2011*]. The main necessary parameters to build a mathematical model of the dentoalveolar system are the physical, mechanical and geometric characteristics of the objects involved in this system, which can be obtained by combining the scan results and computed tomography data into a single volumetric image [*Abbas A, 2012*]. The possibility of introducing mathematical modeling into dental practice already makes it possible to provide a personalized approach to the specialized patient treatment and to assess the long-term prognosis of dental prosthetics [*Naumovich S, Naumovich S, 2011*].

However, to date, there is no step-by-step protocol for digital planning of complex dental treatment, which will be confirmed by research and clinical studies.

The study aimed to improve the efficiency of prosthodontic dental rehabilitation through the development of a step-by-step protocol for integrated digital dental treatment planning.

Material and methods

The search for the analysis of the known resources of dental treatment diagnostics and planning for their optimization and integration into a single digital complex was carried out in the scientific databases eLIBRARY, PubMed and

To overcome it is possible, due to the uniting the knowledge and will of all doctors in the world

Scopus for the last 11 years from 2008 to 2019. For the analysis, publications were selected that describe algorithms for computer dental treatment modeling, describe the software and the necessary equipment, as well as the immediate and long-term results of treatment using these methods.

Each patient underwent a Vatech "PaX-i3D Smart" Cone Beam Computed Tomography (Vatech, Korea) scanning for the diagnostic stage of complex digital dental treatment planning.

Diagnocat technology was used for Cone Beam Computed Tomography (CBCT) analysis. The neural network analyzes the 3D image of the head on CBCT and recognizes the state of the patient's dentition, makes a detailed graphical report, in which it automatically marks the pathologies found.

Validation of artificial intelligence technology consisted in comparing the analysis results of the "Radiographic status" of 24 patients, specifically 638 teeth and periodontal tissues. The Diagnocat report was compared with the conclusions received by the expert group of dentists. The function of the Diagnocat technology - "Radiographic report" was taken as a basis. The experts were 5 dentists with extended education in the specialty "Radiology". Mandatory conditions for attracting experts were continuous record of service in the specialty for at least 10 years. We compared the number and accuracy of diagnosed dental problems, the presence of caries, periodontitis, pathological destructions in the bone, as well as the time spent on the description of CBCT scans by the expert group and the Diagnocat program. A total of 24 CBCT scans were analyzed.

The complex of digital dental treatment planning for patient motivation for complex treatment and familiarize themselves with the clinical view in an accessible form, included an additional stage of 2D imaging. This stage was divided into 2 substages: 2D-visualization of existing dental problems and 2D-smile design. A standard photo protocol was used for 2D imaging, including portrait and intraoral photographs. Portrait photographs were taken with a Canon EOS 80D with a Canon Zoom Lens EF 50 *mm* in the following settings - "M" mode on the camera and on the flash, shutter speed on the camera - 1/125, on the flash - 1/64, aperture: F10, ISO: 200. Intraoral photographs in the framework of the study were obtained using the same camera, a Macro Ring Lite MR14EX II and a Macro Lens EF 100 *mm*. We used auxiliary equipment for shooting: black labial retractors, black contrast, occlusal speculum, lateral speculum, frontal labial retractor. We used the following settings - "M" mode on the camera and on the flash, shutter speed on the camera - 1/200, on the flash - ETTL, aperture: F22, ISO: 200.

The Bellus3D FaceApp program was used to scan the face. 3D images can be used to demonstrate dental status to patients, and the 3D models generated by the application can be exported to file formats compatible with other dental programs for further denture modeling.

Intraoral scanners were used to scan the dentition: CEREC Omnicam (Dentsply Sirona, Germany) and 3Shape Trios (3Shape, Denmark).

The 2D and 3D data generated the 3D scene, which is the most important element in comprehensive digital dental treatment planning. For three-dimensional planning of dental treatment, the Russian 3D program was used. An important feature of the Avantis 3D program is the ability to visualize not only the coronal parts of the teeth, but also the roots. Visualization of the root position is important information for predicting occlusal loads and planning prosthetics.

The final stage of the digital protocol for complex digital dental treatment planning of patients was the production of prototype prostheses for future functional and aesthetic restorations. Prototype prostheses using the Next Dent 5100 3D 3D printer (SYSTEMS, USA) can be manufactured using direct and indirect methods. The indirect method is more costly and requires the use of an impression material, the direct method is simpler and more comfortable for the patient. The resulting image was converted into a printing module of a dental 3D printer, then polymer veneers-prototypes were made using 3D printing. The coincidence of the size and shape of the teeth and dentition was assessed by comparing the STL files used to create the model with the results of scanning the manufactured polymer prostheses-prototypes in the Avantis 3D program.

We examined 109 patients who demanded aesthetic porcelain restorations for the maxillary teeth to confirm the clinical effectiveness of the developed complex for digital planning of dental treatment and within the framework of a software for

virtual prototyping of a smile. In accordance with the inclusion, non-inclusion and exclusion criteria, 48 people (17 men and 31 women, aged 25 to 38 years) were selected from the study and randomly divided into 2 equal groups - the study and control groups, 24 patients in each group.

Patients of the main group underwent dental treatment diagnostics and planning according to a digital protocol, including the use of a 2D planning program, with the final stage of prototyping a smile with restorations using computer technology 3D printing.

The control group consisted of patients, diagnostics, planning and prototyping of their smile was carried out by the analog method with obtaining physical impressions, wax modeling, intraoral production of prototype prostheses by a direct method through a silicone index. The Digital Smile Design 2D software was used at the initial stage of visual 2D virtual image of a smile coordination.

Evaluation of the functionality of the manufactured polymer prototypes of future restorations was assessed using the T-Scan 3 device using the "Multi-Bite" scanning technique.

All patients of the study and control groups at the end of prototyping - making a polymer model of future restorations - were surveyed to assess the quality of life using the OHIP-14 questionnaire and to assess the satisfaction with the dental treatment provided. We took a questionnaire for assessing the quality of conditions for the provision of services by medical organizations in an outpatient setting recommended by the Ministry of Health of the Russian Federation published on the portal for an independent assessment of the quality of conditions for the provision of services by medical organizations in the city of Moscow on the website of the Ministry. The questionnaire, optimized in accordance with the tasks of the study and the passport of the specialty of dental specialists, required a monosyllabic answer and contained the following questions:

1) Did the doctor see you at the time specified by appointment?
2) Are you satisfied with the doctor's attitude towards you (friendliness, politeness)?
3) Before contacting a medical organization, did you refer to the information published on the official website of the medical organization?
4) When contacting a medical organization, were you assigned a radiographic diagnostic?
5) Are you satisfied with the comfortable conditions for the provision of services in a medical organization?
6) Did you have enough time to decide on the shape, color and position of your teeth at the stage of agreeing on the layout of your future smile?
7) Have you experienced any discomfort when performing manipulations in the oral cavity?
8) Did the shape and position of the teeth in the dentition, agreed at the initial stage of visualization of the smile design, coincide with those after fixation of the prototype prosthesis?
9) Did you meet your expectations with the results obtained?
10) Did the provision of diagnostic and dental treatment planning services require a one-time visit to the clinic?
11) In general, are you satisfied with the conditions for the provision of services in this medical organization?

When analyzing the results obtained, we analyzed the reasons for their decline, as well as the comments and suggestions of the respondents.

Patients were questioned at two stages: before prototyping and 7 days after fixation of polymer prototypes of future restorations.

RESULTS

Totally 235 articles were analyzed in total, 41 articles were identified in the eLIBRARY system database, the rest in the PubMed and Scopus databases. There were 76 articles that met inclusion criteria for a refined request and related directly to dental treatment planning. The articles were arranged as follows in the annual order: 2 articles in 2008; 1 in 2009; 4 in 2010; 5 articles - 2011; 4 in 2012, 4 in 2013; 8 in 2014; 12 in 2015; 14 in 2016; 2 in 2017; 17 articles in 2018 and 34 articles in 2019; - that points to the constant growth of interest in solving this issue.

As a result of the analysis of information sources, we proposed the following methodology for creating a complex for digital dental treatment planning:

1. Methodology for the rehabilitation stage planning.
2. Technique of 2D-virtual dental planning in the smile zone.
3. Technique of 3D virtual dental planning (prototyping) in an aesthetically significant region.

4. Technique for the computer production of prototype prostheses, according to the 3D virtual functional and aesthetic model.

When planning the rehabilitation stage of the complex dental treatment, we consider the first priority to be consistent with the full scope of dental diagnostic procedures, including using modern digital techniques.

Each patient underwent maximum resolution cone-beam computed tomography.

CBCT report requires professional skills and takes a considerable amount of time. When analyzing the diagnostic programs available on the dental market, our attention was attracted by the domestic dental diagnostic technology based on artificial intelligence - Diagnocat. Diagnocat technology works from the manufacturer's server. The neural network analyzes the 3D image of the skull on CBCT and recognizes the state of the patient's dentition, makes a detailed graphical report, where it automatically marks the pathologies found.

In order to include the Diagnocat technology in the complex of digital dental treatment planning, we considered it necessary to validate this software.

The coefficient of expert agreement in this study was 0.89, which corresponds to a high level.

In total, according to the results of the report analysis compiled by an expert group and artificial intelligence technology, 439 pathologies were identified from 638 teeth.

The expert group detected 428 pathologies and did not diagnose 11, while the software detected 441 problems, that is, 2 more than it actually presents, taht is explained by the lack of analysis of image distortion when the radiographic metal density elements "emitting". Two more of these diagnosed problems were misdiagnosed, according to the expert group. Thus, the total error of the program was 4 absolute units of error as diagnostics, which is 2.75 times less than the error made by the expert group.

The time spent on the analysis of the radiographic situation of the oral cavity by experts, including the description, was 1020 minutes (17 hours), which on average corresponds to 42.5 minutes for one CBCT study and exceeds the time spent by the computer program by 9.4 times. The time for computer analysis, including the time for registering the results with a description of the radiographic situation, was 108 minutes (1.8 hours), which on average corresponds to 4.5 minutes for examining one CBCT scan.

Evaluation of the effectiveness of the developed protocol for complex digital dental treatment planning and the virtual smile prototyping method a was carried out by analyzing the results of a questionnaire survey of 48 patients requiring prosthetics of aesthetic defects of the anterior teeth at the stage of prototyping.

The patient occlusion balance was assessed before and after the mock-up using the "Multi-Bite", "Right/Left Excursion", "Protrusive Excursion" scanning techniques. Before the mock-up, the average value of the distribution of the relative occlusal load between the right and left sides in patients corresponded to 51.8 ± 1.20%, no imbalance in the process of mouth closing and opening, as well as areas of excessive loads, was found. The average time for closing the dentition was 0.18 ± 0.04 s, the time for opening was 0.19 ± 0.02 s.

The differences in the parameter "opening time" of left and right excursions were in average 0.04 ± 0.02 s when evaluating laterotrusion.

The opening time during protrusion did not exceed 0.4 s (0.19 ± 0.04). There were no mandibular deviations and excursions.

As a result of repeated digital measurement of the occlusion balance after the mock-up, the following average parameters were determined: the distribution of the relative occlusal load between the right and left sides was 50.7 ± 0.90%; the closing time was 0.17 ± 0.04 s; opening time was 0.19 ± 0.03 s. The time difference between the opening of the left and right laterotrusion was 0.03 ± 0.03. The opening time during protrusion did not exceed 0.4 s (0.17 ± 0.04). The values of each parameter obtained before and after the mock-up were statistically processed using the nonparametric Wilcoxon test - there were no significant differences ($p \geq 0.05$).

At the second stage, the patient's satisfaction with the quality of the provided medical service for planning dental treatment was compared according to the proposed digital and traditional analog protocol.

Answering the question about satisfaction with the comfort of the conditions for the provision of services in a medical organization, 5 pa-

tients of the control group answered negatively, while the patients of the study group in their entirety gave a positive answer. Considering that this person contingent, answering the question about the compliance of expectations with the obtained results, also answered negatively, it can be assumed that this is a part of patients who were not satisfied with the result of the prototyping and could not share this dissatisfaction with the general understanding of the comfort of the conditions for the provision of services.

As well, 13 respondents of the control group, answering the question of the questionnaire, indicated that they experienced discomfort during the diagnostic procedures, versus 24 patients of the study group who did not experience any discomfort during the same procedure. In personal communication, it turned out that this discomfort was associated with repeated removal of physical impressions, which caused the urge to vomit and fear of damage to the teeth during the extraction of the impression after structuring. Nine people noted discomfort associated with the unpleasant odor of plastic and the removal of its remains from the oral cavity after fixing the mock-up and during its grinding and polishing in the oral cavity.

The next discrepancy in the opinions of the respondents of the studied groups can be considered 12 negative answers from the patients of the control group versus 24 positive answers from the patients of the study group in the question of the expectation conformity and prototyping results. During a personal conversation with these patients, it turned out that the shape and position of the teeth, agreed with the dentist at the stage of wax-up, did not correspond to their ideas of the shape and position of the dentition in the oral cavity according to the results of intraoral prototyping (Table 1).

The key question confirming the effectiveness of the 2D planning stage was the question of sufficient time to make a decision at the mock-up approval stage. All patients of the study group re-

Table 1.

Results of the questionnaire to assess the effectiveness of the developed digital planning dental treatment complex.

Question	The total number of responses from patients in the study groups			
	Study Group (n=24)		Control group (n=24)	
	Yes	No	Yes	No
Did the doctor see you at the time specified by appointment?	24	0	24	0
Are you satisfied with the doctor's attitude towards you (friendliness, politeness)?	24	0	24	0
Before contacting a medical organization, did you refer to the information published on the official website of the medical organization?	24	0	24	0
When contacting a medical organization, were you assigned a radiographic diagnostic?	24	0	15	9
Are you satisfied with the comfortable conditions for the provision of services in a medical organization?	24	0	19	5
Did you have enough time to decide on the shape, color and position of your teeth at the stage of agreeing on the layout of your future smile?	24	0	12	12
Have you experienced any discomfort when performing manipulations in the oral cavity?	24	0	13	11
Did the shape and position of the teeth in the dentition, agreed at the initial stage of visualization of the smile design, coincide with those after fixation of the prototype prosthesis? 9. Did you meet your expectations with the results obtained?	24	0	12	12
Did you meet your expectations with the results obtained?	24	0	19	5
Did the provision of diagnostic and dental treatment planning services require a one-time visit to the clinic?	24	0	0	24
In general, are you satisfied with the conditions for the provision of services in this medical organization?	24	0	20	4

sponded positively and noted the possibility of independent remote planning of their own smile, not limited in time. They also noted the possibility of consulting with the relatives about coordinating the shape, size, position and color of teeth. And, in our opinion, this parameter can be considered as a key in a positive assessment of the proposed complex digital protocol for planning prosthodontic treatment at the stage of patient motivation.

Diametrically opposite in absolute value answers were received to the question about the frequency of visits to the office to provide the desired service - planning dental prosthodontic treatment. The study group patients required a single visit.

At the third stage of assessing the clinical effectiveness of the developed digital treatment planning complex questionnaire was carried out to determine the quality of life indicators. The results of the patient questionnaire before and after the restoration prototyping according to the OHIP-14 questionnaire were evaluated in points in accordance with the answers; never - 1; almost never - 2; usually 3; rarely - 4; very often - 5: - in terms of the quality of everyday life, chewing food, the ability to communicate. The results are shown in table 2.

Analyzing the data obtained, we can conclude that the initial situation in terms of the quality of life of the respondents in two groups was similar and indicated dissatisfaction in the social aspect of communication in daily life, while dissatisfaction with the chewing function was not noted. That is

Table 2.

Results of patient survey according to the OHIP-14 questionnaire before and after the restoration prototyping (average score)

OHIP-14 Questionnaire Questions before		Study group		Control group	
		before	after	before	after
Daily life	Have you had trouble pronouncing any words because of problem with your teeth, mouth or dentures?	1.8±0.25	2.1±0.18	2.1±0.1	1.9±0.18
	Have you had painful aching in your mouth?	1.1±0.25	1.1±0.2	2.4±0.001	2.3±0.35
	Have you found it uncomfortable to eat any foods because of problems with your teeth, mouth or dentures?	1.2±0.15	2.6±0.36	1.9±0.5	2.1±0.3
	Have you found it difficult to relax because of problems with teeth, mouth or dentures?	1.1±0.15	3.2±0.35	1.2±0.1	3.6±0.05
	Have you felt that life in general was less satisfying because of problems with teeth, mouth or dentures?	1.1±0,23	2.1±0,25	1.1±0.01	2.4±0.05
	Have you been totally unable to function because of problems with teeth, mouth or dentures?	1.4±0.01	2.1±0.05	1.2±0.13	2.3±0.5
Chewing food	Have you felt that your sense of taste has worsened because of problems with your teeth, mouth or dentures?	1.3±0.3	1.4±0.35	2.1±0.1	2.3±0.1
	Do you find it difficult to eat due to problems with your teeth, oral mucosa or dentures?	1.3±0.01	1.2±0.25	1.5±0.13	1.3±0.4
	Has your diet been unsatisfactory because of problems with teeth, mouth or dentures?	1.1±0,30	1.3±0.25	1.4±0.10	1.4±0.03
	Have you had to interrupt meals because of problems with teeth, mouth or dentures?	1.1±0.5	1.1±0.1	1.1±0.18	1.1±0.2
Ability to communicate	Have you been a bit embarrassed because of problems with teeth, mouth or dentures?	1.2±0.15	3.2±0.3	1.3±0.1	3.3±0.1
	Do problems with teeth, oral mucosa or dentures make you uncomfortable?	1.1±0.5	3.4±0.05	1.3±0.1	3.3±0.2
	Have you been a bit irritable with other people because of problems with teeth, mouth or dentures?	1.2±0.05	2.9±0.2	1.1±0.01	3.1±0.25
	Have you had difficulty doing you usual jobs because of problems with teeth, mouth or dentures?	1.1±0.01	2.9±0.05	1.4±0.1	3.8±0.3

associated with aesthetic smile disorders, namely the criteria for inclusion in the study - diagnoses - fluorosis and hypoplasia of the enamel of the anterior teeth. According to the results of the prototyping after 7 days, there were also no significant differences in the answers of the respondents in the study and control groups. However, the results showed a general trend towards improved quality of life. The criterion of inconvenience due to dental problems decreased twice and corresponded to the answer "never". Position of respondents in the question "Do problems with teeth, oral mucosa or dentures make you uncomfortable?" improved from 3.4 ± 0.05 to 1.1 ± 0.5 in the main group and from 3.3 ± 0.2 to 1.3 ± 0.1 in the control group. A similar positive trend was noted in the responses to the questions "Have you had difficulty doing you usual jobs because of problems with teeth, mouth or dentures?" and "Have you been a bit embarrassed because of problems with teeth, mouth or dentures?" The quality of life indicators in these questions increased 2.4 and 2.6 times, respectively, and generally corresponded to the answers - never.

Summarizing the results of the questionnaire survey using the OHIP-14 questionnaire, we can conclude that the quality of patient life has been increased twice based on the results of the digital dental treatment planning complex.

Discussion

The main aim of the study was to increase the efficiency of dental prosthetic rehabilitation of patients by developing and implementing a complex of digital planning on the initial stages of treatment, including diagnostic techniques, modeling and manufacturing of dental prostheses prototypes using modern computer technologies. Another purpose of the study was achieved by solving a number of problems according to information sources, analyzing the modern digital technologies used at the stages of integrated planning of dental treatment, and substantiating the need for their optimization and implementation as a medical service. The analysis showed an annual growth in the need for systematization of a large arsenal of digital technologies in dentistry aimed at planning and conducting treatment of specialized patients. It was proposed to divide the planning of diagnostics and treatment of a dental patient using modern digital technologies into stages. The first stage is the rehabilitation stage planning, which includes diagnostics of the patient's dental status and preparation for prosthodontic treatment. When studying modern information sources, digital tools and programs were identified that provide an objective diagnosis of the main dental pathologies. Particular attention was drawn to computer technology operating on the artificial intelligence principle in the process of diagnosing a dental patient according to radiographic examination data - Diagnocat. The relevance and necessity of including this program was confirmed by the results of its validation. The main conclusion was made about the obvious superiority of the computer program over the expert assessment in terms of the time spent on the diagnosis and report of the dental patient radiographic scans.

The second stage, 2D virtual planning of the dentition in the smile zone, includes 2D visualization in the mandatory form of dental digital photography protocols and 2D creation of a virtual smile using digital 2D planning programs.

The third stage, 3D virtual planning (prototyping) of teeth in an aesthetically significant area, included digitalization of clinical patient data, CBCT scanning of the dentition with and without occlesuin, and face scanning. Based on the analysis of information sources, the expediency of using CBCT of the patient's head as a whole was established; the use of an intraoral scanner that has the function of determining the teeth color, visualizing occlusal contacts of teeth, recognizing hidden carious cavities; use of facial scanning with a mobile phone with installed Bellus 3D AppFace software. 3D planning and modeling of a prototype smile - includes the use of CAD programs that ensure the use of the maximum clinical and functional digital data of the patient for the modeling of prototype dentures. As part of the study, the programs most often used for planning and modeling in dentistry were identified and analyzed: Exocad (Germany), DSD 3D (Brazil) and the domestic program Avantis 3D. The analysis revealed the superiority of the functionality of the Avantis 3D software, which allows not only to include occlusal contacts of the dentition in the process of modeling prostheses, but also to reproduce the individual articulatory movements of the patient, which is due to the full use of his clinical data.

The fourth stage is the computer production of prototype prostheses, according to a 3D virtual functional and aesthetic model, including the production of prototypes of dental prostheses using the additive 3D printing method. At this stage, recommendations are given for the manufacture of denture prototypes using the 3D printing method directly, in a direct way, and by means of a silicone key, in an indirect way, obtained from a printed model of a prototype patient's dentition. A complex for digital planning of dental prosthetic treatment was formed based on the results obtained in solving the above problems, including:

1. Rehabilitation stage planning: involvement of the software based on the artificial intelligence Diagnocat as a diagnostic tool.
2. 2D virtual planning in the smile zone: dental photography and digital 2D smile planning software.
3. 3D-virtual planning (prototyping) of teeth in an aesthetically significant area: computed tomography with visualization of the TMJ anatomical elements; scanning of the dentition using a scanner that has the function of determining the teeth color and hidden carious cavities; face scanning with a mobile tactile computer device with Bellus 3D AppFace installed; planning of prosthetic treatment in the Avantis 3D program with the possible integration of an algorithm for correcting the occlusal surface using mathematical modeling, if necessary.
4. Computer production of prototype prostheses, according to 3D virtual functional and aesthetic model: production of functional and aesthetic prototypes of dentures using the additive 3D printing method with harmonization of occlusion using a digital T-scan device.

The final studies confirming the developed complex effectiveness were: study of patient satisfaction with the provision of this dental service; development of a universal methodology for assessing its economic efficiency and the actual assessment of the clinical and economic efficiency of the digital dental treatment planning implementation. To assess satisfaction, we conducted a survey of 48 patients who needed prosthetics for the aesthetic defects in the anterior teeth at the stage of prototyping. The study compared the patient's satisfaction with the quality of the provided medical service for planning dental treatment using the proposed digital and traditional analog protocol. As a result, a conclusion was made about the advantage of the proposed digital method over the analog one in terms of the positions of patients 'own participation in the choice of smile parameters, the absence of discomfort associated with intraoral manipulations in the traditional method, justifying the expectations of the coincidence of planning and results, and an unconditional advantage in saving patients' personal time.

Conclusion

The high efficiency of the technology for the radiographic analysis, which works on the artificial intelligence principle, has been established, which reduces the number of diagnostic errors by 2.75 times and accelerates the CBCT scan report by 9.4 times, which makes it possible to include it as an obligatory element in the complex of digital dental treatment planning for the diagnostic stage optimization.

Prosthetic dental rehabilitation of patients using the proposed digital planning protocol allows to get a guaranteed predictable treatment result. The use of modern digital technologies at various stages of treatment doubles the quality of dental patients' life. The results obtained confirm the high clinical feasibility of introducing digital technology for the provision of treatment planning services into dental practice.

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