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Application Of Digital Technologies For The Manufacturing Of Zirconium Dental Prosthesis Taking Into Account The Individual Parameters Of The Patient's Dentofacial System

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Annotation. The aim of this study is to improve the method for fabricating permanent fixed dental prostheses and implant systems from domestic zirconium dioxide-based materials using a CAD/CAM system. The prosthetic structures were fabricated under dynamic occlusion control using the Hint-Els CAD/CAM system and a virtual articulator. The "Virtual Articulator" software module allowed for the reconstruction, control, and adjustment of the anatomical shape of the structures based on the patient's individual static and dynamic occlusal parameters. Milling strategy parameters were also optimized by calculating milling paths and reducing the overall fabrication time, while maintaining high accuracy, as confirmed by a comparator microscope study. Evaluation of regional periodontal blood flow late after orthopedic treatment indicates normalization of periodontal tissue microcirculation in the functional aspect due to adjusted occlusal contacts.
Keywords: dentures; zirconium dioxide; CAD/CAM technology; dynamic occlusion; virtual articulator.

Introduction. At the current stage of development in orthopedic dentistry, the introduction of automated, high-tech equipment into clinical practice is required. This equipment is capable of meeting the increased demands for the production of functionally valuable denture structures with aesthetic parameters that closely resemble those of natural dental hard tissue. CAD/CAM systems, which have been steadily entering dental practice over the past 20 years, possess such capabilities [1–3].Currently, among the vast variety of high-tech digital equipment for the production of dentures and implant systems on the Russian market, four main CAD/CAM systems are widely represented: Cerec inLab (Sirona, Germany), Everest (KAVO, Germany), Hint-Els (formerly DigiDent, Germany), and DCS (Switzerland) [4, 5].According to the results of conducted research, the Hint-Els system has the most extensive software capabilities [6–9]. This is an industrial, open CAD/CAM system, fully compatible with other representatives of this technology, allowing the use of materials from any manufacturer, which provides greater freedom of choice. The Hint-Els system has a certain value in its ability to manufacture inlays, veneers, crowns, bridges of any length, and implant superstructures from a wide range of materials (zirconia- and aluminum oxide-based ceramics, glass ceramics, titanium alloys, cobalt-chromium alloys, plastic, wax). Furthermore, the cost per unit of construction (crown) is significantly lower compared to other representatives, which indicates the great possibilities and accessibility of manufacturing dental prostheses using the Hint-Els CAD/CAM system [4]. The aim of this study was to improve and test a method for fabricating permanent fixed dentures and implant systems from a domestic material based on yttrium-stabilized zirconium dioxide using the Hint-Els CAD/CAM system, taking into account individual parameters of mandibular movements in patients with occlusal pathology. This method also included a comparative assessment of the condition of periodontal tissues before and after treatment (at long-term follow-up).

Material and Methods

A comprehensive examination and treatment of 134 patients (aged 18–63 years) with defects in the hard tissues of the chewing teeth and dental arches was conducted. Inclusion criteria for the study included disruption of the occlusal surface of the chewing teeth due to caries, restoration, or prosthetics; unilateral and bilateral included or terminal defects of the dental arches; and the presence of lower incisors to determine the occlusal plane. The patients did not have significant inflammatory changes in the periodontium or a complicated general medical condition. Comprehensive treatment planning was conducted after complete oral rehabilitation. All patients underwent a dental X-ray prior to treatment. Static and dynamic occlusion of the dental arches was assessed. Static occlusion was assessed by recording the number of pairs of opposing teeth

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December 2025

on each side (using a wax base plate) in centric relation, where symmetrical contacts between the chewing teeth on the right and left sides were considered normal (to allow for the mandible to slide into habitual multiple occlusion).

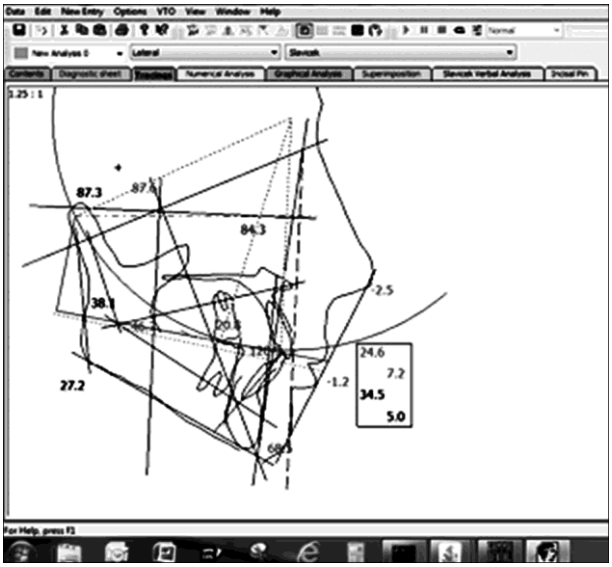

Fig. 1. Results of calculating the TR-gram in the lateral projection.

The centric (reference) relationship was recorded with the patient's dentition separated to prevent reflex contraction of the masticatory muscles in response to tooth contact and the mandible from slipping into its habitual static occlusion [10]. A high-hardness wax plate (3 mm thick) was used to record the reference position of the mandible, followed by correction with wax and aluminum shavings (Aluwax). The patient was in a horizontal position in the dental chair.

To analyze the clinical situation, plaster models were mounted in the articulator in the centric relationship position (posterior contact position). A fully adjustable Arkon-type articulator – Artex CR (Amann Girrbach) – was used. The maxillary model was positioned in the articulator using the Artex kinematic facebow, using the generally accepted method, along the orbital-hinge plane (Fig. 1, inset).

Occlusal surfaces and dynamic occlusion were assessed. Dynamic occlusion was assessed using plaster models in the articulator in two stages: on solid and dismountable models with the sequential removal of tooth dies, assessing the guiding function and the presence of occlusal obstacles. Normally, the tooth under study was expected to disengage distal teeth and the absence of hyperbalancing and balancing contacts. These data were recorded by photography.Each tooth is part of the overall occlusal plane, forming its own occlusal plane. Thus, each tooth is an element of a single coordinate system, but can also be considered its own coordinate system. In our work, we determined the relative angle of the sagittal articular path to the occlusal surface (plane) in the sagittal plane as the inclination of the first 5 mm of the trajectory of the protrusive articular path to the occlusal plane. In patients, this value was measured using a teleradiograph (TRG) of the head in the lateral projection (cephalometry) (Fig. 2 inset, 3). The distal landmark of the first molar position according to R. Ricketts [11] was found, which was then corrected on the diagnostic model based on the ratio of the sizes of the remaining teeth. For dynamic analysis, the value of the estimated average inclination angle was subtracted from the obtained value.

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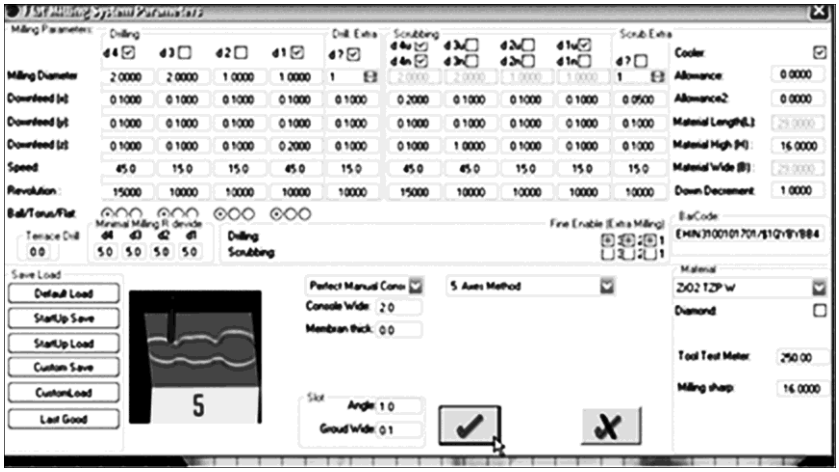

Fig. 2. Selecting and coordinating the diameter, direction, speed, and rotation of the cutter in the software. The yttrium-stabilized zirconium dioxide blocks were used. The zirconium dioxide block formulation was developed at the Scientific Center for Powder Materials Science (headed by Academician of the Russian Academy of Sciences V.N. Antsiferov).Using radiographic images obtained with an ISO-1 horizontal comparator microscope, the gap between the inner surface of the denture and the denture bed was assessed 2 to 10 days after cementation. A total of 15 measurements were taken on 15 premolar and molar restorations.Hemodynamic parameters of periodontal tissues were studied using Doppler ultrasonography before prosthetic installation and at late stages (6–8 months) after denture fabrication in 21 patients.

Results and Discussion

During the clinical examination, complaints of occlusal discomfort were presented.

The angle of disocclusion during dynamic movements, i.e., the dynamic disocclusion angle, was determined by measuring the inclination of the cusps of the first molar (30°) to its occlusal plane (Fig. 4, inset). According to some authors [10], the disocclusion angle should be no less than 8° but no more than 16°. Values less than 8° impede dynamic occlusion. Values greater than 16° reduce chewing efficiency.To determine the occlusal plane [12], a perpendicular to the occlusal plane was drawn from the average point of the hinge axis. The value was measured and compared with the average statistical norm. After analyzing the clinical and paraclinical diagnostic results, a preliminary comprehensive treatment plan was developed. This was agreed upon with the patient and included therapeutic and diagnostic temporary prosthetics, followed by permanent prosthetics after adaptation.To optimize the milling parameters for the structures in the corresponding block of the Hint-Els CAD/CAM system, the diameter, direction, and speed of the cutter, as well as its rotation speed and frequency, were selected and coordinated (Fig. 5). The cutting speed of zirconium oxide blocks was calculated using the formula:$\upsilon = \pi Dn/1000$ m/min,where D is the cutter diameter; n is the number of cutter revolutions; π is the ratio of the circumference to the length of its diameter.Permanent dentures were fabricated in 47.3% of patients, and 46.5% of patients reported hearing noises in the parotid region (crunching, clicking) when opening the mouth. In 37.3% of cases, we observed a decrease in the height of the lower face, in 35.6%, a shift in the central line was noted, unilateral defects were identified in 26% of cases, and bilateral defects were identified in 67.5%.When patients closed their teeth in a position of multiple habitual occlusion (static occlusion), the average number of pairs of opposing teeth was 10.When diagnosing occlusion of the dental

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December 2025

arches on plaster models in an articulator, deviations from the norm were detected in 43.6% of the patients examined. Evaluation of dynamic occlusion in the articulator revealed the following violations: lack of adequate occlusion during laterotrusion to the right and left in 37.4 and 36.5%, and during protrusion – in 12.3% of those examined. There was no adequate dissociation of the examined teeth located more distally; the presence of balancing (on the working laterotrusive side) and hyperbalancing contacts (on the non-working mediotrusive side) was noted.

Fig. 3. Scanning unit of the Hint-Els CAD/CAM system.

Fig. 4. Milling unit of the Hint-Els CAD/CAM system.

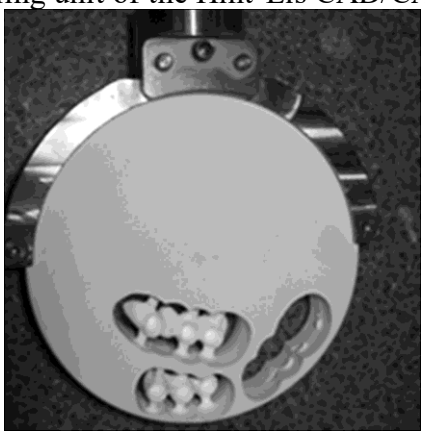

Fig. 5. View of the zirconium dioxide-based structure after the milling stage (block size 90×16 mm).

ISSN NO: 2770-2936
December 2025

Based on the results of measuring the occlusal plane level, deviations from the calculated individual norm were found in 31.2% of cases. Deviation in the sagittal articular path angle relative to the occlusal plane of the first permanent molar of the lower jaw compared to the average anatomical norm (38–40°) was 46.8% (37.6% – decreased, 19.2% – increased sagittal articular path angle). This indicator may indicate that patients with altered occlusal surface of molars and premolars have dynamic occlusion disorders that require correction. Based on the study results, deviations in the height of the lower face from the calculated individual norm were noted in 13.2% of those examined.

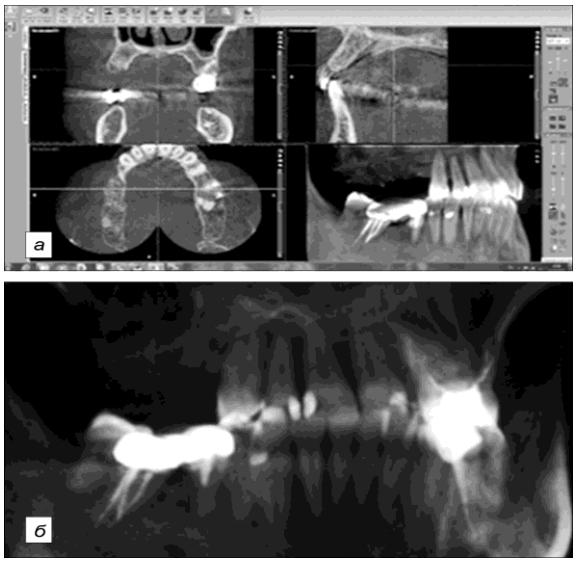

Fig. 6. Computed tomography of patient B. (before treatment) (a); fragment of OPG of this patient (before treatment) (b). For the manufacture of both temporary and permanent dentures, CAD/CAM technology was used according to the generally accepted algorithm with the Hint-Els system. We have improved and tested the technique of manufacturing permanent fixed structures of dentures and implant systems from a domestic material based on yttrium-stabilized zirconium dioxide, taking into account the individual parameters of the dental system and movements of the patient's lower jaw. The main principle of this technique is the combined use of individual articular and occlusal parameters of the dental system of a given patient with planned sliding trajectories of the teeth during virtual modeling in the Hint-Els CAD/CAM system software. After 3D scanning the working models in the Hint-Els CAD/CAM system (Fig. 6), the occlusal surfaces of the artificial teeth were modeled in the virtual articulator software module. This included simulating individual lower jaw movement trajectories along the planned tooth sliding trajectories using the calculated disocclusion angle parameters. This made it possible to create and adjust a 3D model of the teeth and dental arches for static and dynamic occlusion individually for each patient. The structures were then milled using the Hint-Els CAD/CAM system (Fig. 7) from yttria-stabilized zirconium dioxide blocks (Fig. 8). Calculating cutting speed indicators for zirconium oxide blocks, as well as selecting and coordinating the diameter, direction, and speed of the cutter, as well as its rotation speed and frequency, during the fabrication of dental prostheses and implant systems, reduced the overall milling time. At the same time, the high precision of the manufactured dental prostheses was maintained, as confirmed by data from a horizontal comparator microscope study. On average, the gap between the inner surface of the structure and the hard tissues of the tooth was approximately 40 μm and was uniform throughout.During the post-treatment examination, patient complaints from before treatment significantly decreased – to 98%. All patients had no complaints of occlusal discomfort.

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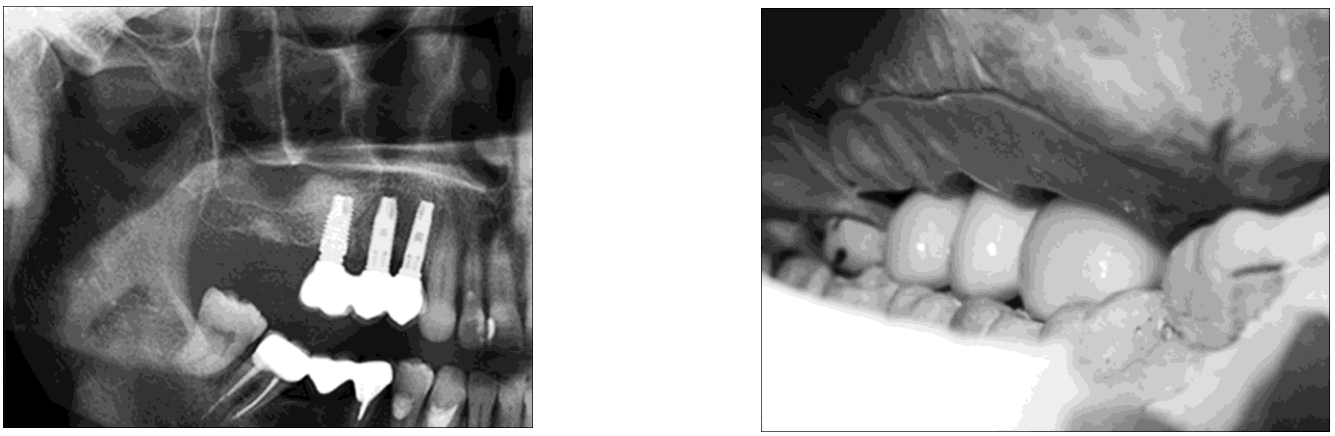

Fig. 7. Patient B. Model view of the completed orthopedic restoration on implants in the area of teeth 1.4, 1.5, and 1.6.

The average number of opposing tooth pairs in static occlusion in patients after treatment was 12. Dynamic sequential disocclusion of the dental arches (from the first molar to the maxillary canine) with canine guidance was created in 96% of cases, and static and dynamic occlusion of the dental arches was normalized in 98% of cases.During the process of reconstructing the occlusion of the teeth and dental arches, it was possible to normalize the angle of the sagittal incisor path relative to the occlusal plane of the first permanent mandibular molar, compared to the average anatomical norm (38–40°).Analysis of Doppler ultrasound results before orthopedic treatment revealed decreased linear and volumetric blood flow velocity characteristics in microvessels (see table). However, the calculated indices—the pulsatility index (PI) and resistance index (RI)—were increased. It is noteworthy that PI was significantly elevated relative to other indices, which may be due to the preservation of compensatory and adaptive mechanisms regulating tissue blood flow due to an increase in the shunt component. In the long-term study, an increase in maximum systolic blood flow velocity (Vmax) was noted, indicating increased tissue perfusion and improved microcirculation.

As an example of the application of this technique, we present a clinical case. Patient B., 50, presented to the orthopedic dentistry clinic in 2013 complaining of difficulty chewing food and an aesthetic problem.

History: teeth 17, 16, 15, and 14 were extracted due to complicated caries 2-3 years ago. Concomitant conditions: chronic gastritis. Treatment expectations: fixed dentures.

Physical examination: the oral mucosa is pale pink, even, smooth, shiny, and moderately moist. The existing dentures are metal-ceramic bridges supported by teeth 47 and 45, in satisfactory condition. No destructive changes were detected in the alveolar bone structures, and the pneumatization of the maxillary sinus was intact. The occlusion was orthognathic.Diagnosis: partial secondary tooth loss due to complicated caries, Class I in the maxilla according to the Kennedy classification, 38% loss of chewing efficiency according to Agapov (Fig. 9, a, b).

To restore the integrity of the dentition, after a joint consultation with a surgeon and an orthopedic dentist, a decision was made to perform dental implantation in the upper right segment. The surgical stage of the implantation proceeded without complications; three implant systems were placed in the upper right segment, and gingiva formers were installed five months later. After analyzing the results of the clinical and paraclinical diagnostics, a preliminary comprehensive orthopedic treatment plan was developed and agreed upon with the patient. Temporary structures were fabricated beforehand. During the adaptation period, the patient noted a significant reduction in discomfort with the temporary structures, after which she transitioned to permanent dentures. The temporary and permanent structures were fabricated using the Hint-Els CAD/CAM system, taking into account the individual parameters of the dental system and the movements of the lower jaw (according to the method described above) using the "Virtual Articulator" module (Fig. 10, a-c; 11-13 inset).The fit of the fabricated structure was assessed using an X-ray image taken with a comparator microscope; it was 27-36 μm.Comparison of Doppler ultrasound results before and after treatment revealed an increase in Vmax. Thus, improved microcirculation in the periodontal tissues surrounding the fabricated denture allows us to characterize the treatment measures as quite effective (Fig. 14).

Conclusion. Using the "Virtual Articulator" software module, we were able to precisely control the anatomical shape of the modeled restoration, taking into account the individual static and dynamic occlusal

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December 2025

parameters of each patient. The program's ability to adjust the occlusal plane allowed for the complete reconstruction of a virtual 3D model of teeth and dental arches.We optimized the milling strategy parameters in the Hint-Els software by calculating milling paths and reducing the overall manufacturing time for structures made from domestically produced yttrium-stabilized zirconia. Furthermore, an analysis of the fit of the fabricated structures, conducted with a comparator microscope, demonstrates their high manufacturing accuracy.Evaluation of regional periodontal blood flow in the long term after orthopedic treatment indicates normalization of periodontal tissue microcirculation due to adjusted occlusal controls.

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