Complete digital approach for bruxism management
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Напълно дигитален подход при справяне с бруксизма
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Summary
Introduction: Bruxism has been defined as a parafunction in dental medicine since the early twentieth century. Despite its treatment still being a controversial topic, occlusal splint application is proven to be the most efficient way of prevention. The implementation of digital technologies in dentistry for the last decade has become more advanced with higher accuracy and new possibilities.

Aim: To aprobate and formulate and entirely digital approach for prevention of bruxism’s negative effects with occlusal splints – from diagnosing to prevention and follow up.

Material and methods: Twelve patients were clinically diagnosed with sleep bruxism, using a standard questionnaire and an oral examination. A BiteStrip® miniature electromyography device was used to objectively confirm the diagnosis. Registration and analysis of the position and the movement trajectories of the mandible were performed with a digital axiograph. Patient’s upper, lower jaw and intercuspation were scanned with an intraoral scanner Medit I500. The design of the occlusal splint was carried out in Exocad. The splint was manufactured by means of 3D printing. Before the start of occlusal splint prophylaxis and on the set control examinations thermal imaging was used with Flir T335 infrared thermal camera.

Results: The investigated described methodology is aprobated and proves fully applicable for bruxism management, including functional diagnostics of the position, movement and trajectories of the lower jaw. This entirely digital approach has been applied as a complex solution to bruxism cases and proves to be superior and more precise than the methods using average parameters.

Conclusion: The applied digital methods of scanning the dentition, design and production of the occlusal splint prevent any data loss, ensure precision and guarantee a proper solution for a complete and correct bruxism management. With great attention to the individual trajectories of the lower jaw movements, the effectiveness of the occlusal splint prophylaxis is no longer hypothetical.

Key words: bruxism, occlusal splint, digital methods, axiograph, 3D printing

Резюме
Въведение: Бруксизмът е определен като парафункция в денталната медицина от началото на ХХ век. Въпреки че лечението му е все още спорна тема, приложението на оклузални шини е доказано най-ефективният начин за профилактика. Внедряването на дигиталните технологии в стоматологията през последното десетилетие напредва с по-висока точност и нови възможности за приложение.

Цел: Да се апробира и формулира изцяло дигитален подход за предотвратяване на негативните последствия от бруксизма чрез оклузални шини – от диагнозата до превенция и проследяване.

Материал и методи: Дванадесет пациенти са диагностицирани клинично с бруксизм по време на сън, като са използвани стандартен въпросник и преглед. За обективно потвърждаване на диагнозата е използван миниатюрен електромиограф BiteStrip®, Регистрацията и анализът на положението и траекториите на движение на долната челюст бяха извършени с дигитален аксиограф. Горната,
Introduction

Bruxism has been defined as a parafunction in dental medicine since the early twentieth century. Its prevalence examined in diverse populations with different research methods is between 6% and 38% [1]. A clear consensus has been reached in literature regarding the multifactorial etiology and clinical manifestation of bruxism. With regard to the therapeutic behavior of this parafunction though, there is a lack of unambiguously accepted treatment approaches and convincing evidence for their effectiveness. Bruxism as a parafunction may result in abnormal tooth wear, mobility, fracture, intrusion, opening of contacts, drifting, erosion, or pulp pathology. Amongst the effects of bruxism on the dentition are pathologic tooth migration, bone alterations, temporomandibular joint disorders (TMD) and pain [2].

The use of occlusal splints for the management of the bruxing patient has been advocated for many years. [3]. Therefore no specific, reliable treatment capable of cancelling bruxism is yet available and all efforts are directed towards the prevention of bruxism’s destructive effects [3]. The primary role of the occlusal splint is the protection of tooth tissue by preventing tooth-to-tooth contact and help reduce muscular activity [4, 5].

The implementation of digital technologies in dentistry for the last decade has become more advanced with higher accuracy and new possibilities. Laboratory and intraoral optical scanners, computer-assisted design and computer-assisted manufacturing (CAD/CAM), 3D printing and various laser and/or sensor-equipped devices (such as infrared thermal cameras and axiographs) represent some of the applications.

The term 3D printing is generally used to describe a manufacturing approach that builds objects one layer at a time, adding multiple layers to form an object. This process is more correctly described as additive manufacturing, and is also referred to as rapid prototyping [6, 7]. A stereo-lithography 3D printer uses a scanning ultraviolet laser beam to harden (cure) photopolymer resin layer by layer. Parts are manufactured on a building platform, which is located in liquid resin. After a layer is cured, the building platform descends by one layer thickness, and a new layer of resin is spread over the previous one. This procedure is repeated until the parts are completely built [8]. The accuracy of structures produced varies according to geometries being replicated, the method of manufacture, and the materials being used.
SLA can fabricate structures with a layer thickness of 25 µm up to 100 µm. The x/y axis exposure of each distinct layer can be modified as the z axis incrementally evolves in the build process. In the SLA approach, the depth of cure, which ultimately determines the z axis resolution, is controlled by the photoinitiator and the irradiant exposure conditions (wavelength, power and exposure time/velocity) [9, 10].

The axiograph (also known as facebow) records the path of a condylar point or the path of a point in the vicinity of the condyle. Opening, closing, and protrusive movements have been investigated using axiography [11]. The clinical use of axiography includes location of the transverse horizontal axis and the detailed gathering of data needed to adjust a fully adjustable articulator [12].

Digital (electronic) axiography is an applicable promising technology with proven accuracy, equivalent to conventional axiographs. Due to the modern day technical and software enhancements it is superior to them by data acquisition and interpretation [13]. Electronic axiography studies allow analysis such parameters as: quality indicators, quantity indicators (range), symmetry, synchronicity of movement rates (between left and right temporomandibular joints (TMJ)) [14].

A number of studies have investigated the diagnostic potential of digital axiographs in relation to programming an articulator according to individual parameters of mandibular movements of the patient and its application in the diagnosis of TMJ [15, 16, 17]. There is a variety of systems available: Dentograf (Prosystom, Russia), Zebris (Amann Girrbach AG, Austria), Proaxis (Prosystom, Russia), Cadiax (Whip Mix Corp., USA), Modjaw (Modjaw, France), Sicat JMT+ (Sicat GmbH, Germany). Despite the technological differences, digital functional diagnostics and jaw motion registration are integrated in modern day dentistry [18].

**Aim**

To aprobate and formulate and entirely digital approach for prevention of bruxism’s negative effects with occlusal splints – from diagnosing to prevention and follow up.

**Material and methods**

**Material**

12 patients were clinically diagnosed with sleep bruxism, using a standard questionary and an oral examination. A BiteStrip® personal disposable miniature electromyography device (figure 1) was used to objectively confirm the diagnosis. Patients’ complaints include visible signs of tooth attrition, stiffness in the masseter muscles area and occasional clicking in the right temporomandibular joint (TMJ). Patients are aged 23-45 years old, have all teeth of the dentition present (third molars noncrucial) and no prosthetic restorations.

Registration and analysis of the position and the movement trajectories of the mandible were performed with a digital (electronic) axiograph – Dentograph (Prosystom, Russia). A novel device for complex functional diagnostics of the lower jaw articulation, it consists of the following parts (figure 2):

- a three dimensional (3D) camera, embedded in a special head piece;
- a central marker and two side markers, equipped with a grid of sensors, designed to be detected by the camera on the head of the patient;
- a software program (P-Art, Prosystom, Russia), developed particularly to process the data obtained with the axiograph.

Patient’s upper and lower jaw, intercuspation (occlusal relation) included were scanned with a powderless intraoral scanner Medit I500 (Medit Corp., South Korea, figure 3 (a), (b), (c). The scanner has an optimized workflow and interface (figure 3 (b) and works efficiently in high speed. It provides a high level of accuracy, which for the purpose of this study’s scans of the upper and lower dental arch was crucial.
The design of the occlusal splint was carried out in Exocad (exocad GmbH, Germany) – dental software for computer-aided design (CAD). The splint was manufactured by means of 3D printing with Form 2 (Formlabs Inc., USA) digital stereolithography (SLA) printer (figure 4 (a)). The ultraviolet (UV) laser cures the consecutive layers with a power of 250 mW and 140 µm diameter of the laser spot. The material selected is liquid photopolymer resin Dental LT Clear (Formlabs Inc., USA), developed for occlusal splint production in particular and certified as biocompatible Class IIa CE-certified. It is a monomer based on acrylic esters. Contains methacrylic oligomer > 70% w/w, glycol methacrylate < 20% w/w, pentamethyl-piperidyl sebacate < 5% w/w (co-photoinitiator) and phosphine oxide < 2.5% w/w (photoinitiator). For the mandatory post polymerization processing of the material the attendant Formlabs devices were used (Form Wash – figure 4 (b) and Form Cure – figure 4 (c) [19]. Before the start of occlusal splint prophylaxis and on the set control examinations thermal imaging was used with Flir T335 (FLIR Systems, Inc., USA, figure 3) infrared thermal camera with 0.1°C precision (figure 5).
Methods

1. To fulfil the aim of this study the following completely digital protocol was developed:

2. Acquiring patient’s data – intraoral scanning of upper and lower dental arch, left and right occlusion.

3. Importing the individual scans in the software of the digital axiograph. – P-Art.

3.1. Performing axiography:
Registration with the central marker.

Bite registration additive silicone material is applied onto the axiograph’s bite fork (figure 6) and with regard to its indentation for obtaining the sagittal plane, the fork is fixed to the upper dental arch. The patient closes the mandible until contact with the fork to support it (figure 7). Preferably this can be executed by means of two dental cotton rolls. Once the silicone sets, the central marker is switched on and the spatial position of the prosthetic plane is registered through wireless connection (figure 8 (a) and (b)). Registration is visible in the software simultaneously.

3.2. Fixing the side markers (figure 9):

a. Marker on the maxilla – situated in I. quadrant (right), canine area;
b. Marker on the mandible – situated in III. quadrant (left), canine area.

Fixation of the side markers can be achieved by using photopolymer composite (paste consistency) or glass ionomer cement (for fillings). It is recommendable to have a dental assistant retract the lips of the patient until the fixing material used is set. Important is to follow the direction sign in the outer corner of the sensor grid on each side marker – the sign should be distally placed; this gives the proper left and right position (figure 10).
3.3. Placing the head piece (3D camera) on the head of the patient and connecting it with the computer.

3.4. Taking reference frames:
   c. First reference frame – central marker and right (maxillary) marker (figure 11);
   d. Second reference frame – right and left (mandibular) marker (figure 12).

3.5. Axiography record.
   Recording the spatial location of the mandible and all lower jaw movements: mouth opening and closing, protrusion, left and right laterotrusion, dynamic function (can also be achieved by the patient chewing gum). While being recorded, all trajectories are visible in different colour in the software.

3.6. Analysis of the results.
   This final step is executed in the software entirely. We chose to merge all data acquired in the Complex diagnostics module of the program:
   • Upload of individual models of the patient – intraoral scans of maxilla, mandible and occlusion. Occlusal contacts are also made visible;
   • Upload of CBCT scans of the patient – the CBCT findings are united with the models from the intraoral scan according to dentition markers; nevertheless, the scans alone can be used in the software for the creation of virtual models.
   • Alignment of the individual models – using an intraoral scan with the bite fork returned in the patient’s mouth. Part of the fork should be also visible in the scan.

3.7. Export to CAD software (Exocad).
   After running the analysis, the final step is to export the individual models of the patient in current position, the recorded trajectories of the lower jaw (lower incisal, right and left articular), values of all lower jaw angles (sagittal, frontal, transversal) and the alignment of the upper jaw individual model on the bite fork. By completing the import with these parameters, the need of using a virtual articulator in Exocad is optional.

4. Occlusal splint design in Exocad (figure 13).

5. Export of the design in Form 2 SLA printer’s software, material selection, printing and post processing.

6. Preparation for printing – the design file is imported into the printer’s software PreForm v. 3.4.2 (Formlabs Inc., USA). A few parameters need to be set before printing starts – layer thickness, orientation of the printed object, layout onto the printer platform, adding supporting structures.
7. 3D printing with the Form 2 SLA printer (figure 4 (a)).

8. Post polymerization processing consists in two consecutive steps:

8.1. rinsing the parts with 99.5 % isopropyl alcohol (IPA) for 5 min in Form Wash, which removes any uncured liquid resin before post-curing. A minimum of 30 minutes in the open, at room temperature is required for the IPA to completely dry (figure 4 (b)).

8.2. post-curing with UV light for 20 minutes with 80oC heating in the Form Cure (Formlabs Inc., USA) polymerization unit (figure 4 (c)).

9. Removal of supporting structures and polishing of the splint (figure 14 (a)).

10. Adjustment of the splint in the patient’s mouth (figure 14 (b), (c) and instructions for maintenance.

Infrared thermography imaging. Thermal and digital images of the patients were taken directly before starting the preventive treatment with the splint, 2 weeks, 1 and 3 months after the start on each control visit in the dental office with Flir T335 infrared thermal camera.

The recording of the temperature was performed in the temporomandibular joint and masseter muscle area. Patients were acclimatized for 15 minutes to a temperature of 22°C preliminary to the imaging in order to normalize body heat. Images (infrared + digital) were taken perpendicularly in a distance of 1 m from the patient in the following order: frontal, right and left profile. The image data was analyzed in Flir Reporter Pro 9 (FLIR Systems, Inc., USA) software (figure 15, 16 and 17). Digital images are taken for the data analysis in order to eliminate any skin origin inflammation that may corrupt the results of the investigated area by showing a false positive increase in temperature. Infrared and digital image are matched in Flir Reporter Pro before the analysis by means of three reference points.

Figure 14. 3D printed occlusal splint: (a) – before supports removal, (b), (c) – in patient’s mouth

Figure 15. Analyzed thermal images of a patient – in 2 weeks of splint wear (right (a) and left (b) profile)

Figure 16. Analyzed thermal images of a patient – in 1 month of splint wear (right (a) and left (b) profile)
Results

The investigated described methodology is approbated and proves fully applicable for bruxism management, including functional diagnostics of the position, movement and trajectories of the lower jaw. The validated protocol steps are clearly formulated and the objective of each one is well defined. This protocol has been applied as a complex solution to bruxism cases and proves to be superior and more precise than the methods using average parameters.

In all 12 patients a difference in the registered temperature of the left and right TMJs and the two masseters is observed, noting that 75% of the patients (9 subjects) had unilateral symmetry – the increased temperature of the TMJ corresponds to an increased temperature of the respective masseter muscle. The following percentage distribution of the results was observed: in 67% of the patients an increase in temperature was registered in both TMJs and masseters after 14 days of splint wear. In 1 and 3 months there is a gradual decrease in temperature to levels below baseline. In 8.4% of the patients a decrease in temperature is observed in the second week. In 16.7% of the examined patients on day 14 there was a decrease in the temperature of the one side TMJ and masseter and an increase on the other side. In 8.4% of all patients there was a slight increase of the temperature after 3 consecutive months of the occlusal splint prophylaxis.

Discussion

The implementation of digital technologies reveals new possibilities in diagnosing, treating and tracking bruxism and any accompanying TMJ dysfunctions. The higher accuracy of the method used was ensured by the supplementary tomography data.

The axiograph’s software gives options to import scanned individual plaster models (semi-digital method) or to calculate individual parameters for mounting plaster models in a fully adjustable mechanical articulator (regular analog method).

The semi-digital method allows the absence of an intraoral scanner – impressions are taken from patient’s upper and lower jaw with additive silicone impression material, plaster models are poured from the impressions and scanned in a desktop optical scanner (Ceramill Map 600, Amann Girrbach AG, Austria). In cases where it’s necessary to work with a virtual articulator, the virtual models from any of the two types of scans can be uploaded and mount. The movement trajectories can also be visualized and the splint is designed in the CAD software.

For the analog method the plaster models are mount in Artex CR (Amann Girrbach AG, Austria) fully-adjustable articulator. For this purpose is used the alignment of the bite fork on the special 3D stand, preliminarily adjusted according to the values calculated in the software. While the bite fork with the bite registration material from the patient is on the 3D stand, the upper jaw plaster model is placed on the bite fork. After adjusting the mechanical articulator to the angle values given from the axiography. The bite splint can be manufactured from wax directly on the models and then polymerized by means of lost wax technique and polymethyl methacrylate (PMMA) heat curing resin.
If comparing the methods by number of laboratory steps, the analog method is the most time consuming. At greatest risk of error is again the transfer of the upper jaw’s spatial position giving the prosthetic plane in the mechanical articulator. On the other hand when the same transfer is done in a virtual articulator, there is no potential risk of error occurrence. If comparing the approbated protocol with the semi-digital approach, the intraoral scans performed are the most accurate. A number of mistakes can be made when taking regular impressions: from mixing and placing the impression material in the impression tray, its temperature to improper impression technique of the dentist. Furthermore when casting the impressions the expansion of the plaster must correspond to the shrinkage of the impression material used. Even with the most precise desktop optical scanner one can possibly scan any mistake just as precisely. Any inaccuracy it the process of planning, producing and adjusting the occlusal splint can result in inducing bruxism.

In the presence of pathological changes splint therapy aims to return the joint-muscular complex of the masticatory apparatus to normal, which is associated with the activation of the adaptive capabilities of the organism. This dynamic process is associated with a rise in temperature. When achieving balance after wearing the splints for 1 and 3 months, a decrease in the registered temperature is naturally observed due to the created preconditions for elimination of the inflammation of the joint and the overload of the muscles.

Conclusion

The developed thorough digital workflow algorithm for treatment of the bruxing patient allows a complete and predictable outcome. With every single individual parameter of the patient considered, the occlusal splint manufactured is in full accordance to the end purpose – prevention of the parafunction. Digital axiography provides the opportunity of repetition of the recordings under exact same conditions, which makes it a proficient method for patient follow up. With great attention to the individual trajectories of the lower jaw movements, the effectiveness of the occlusal splint prophylaxis is no longer hypothetical.

Contemplating the lower jaw’s dynamic behavior has intrigued researchers in the field for many years. With digital axiography appropriate treatment in accordance to every patient’s individual features is effectively attainable.

Well performed occlusal splints in patients with bruxism are crucial for relieving the joint-muscular component of the masticatory apparatus and together with the prevention of tooth abrasion are a basic prerequisite for preserving all its functions. In patients who make an exception to this trend, the different types of pathologies of the joint and muscle complex should be taken into account and to what extent they can be affected only by splints, as well as the possibility of another, additional etiological factor that is not removed. Infrared thermography can be considered a complementary diagnostic method and a reliable follow-up tool for registering the changes of muscular activity in the course of splint prophylaxis.

The applied digital methods of scanning the dentition, design and production of the occlusal splint prevent any data loss, ensure precision and guarantee a proper solution for a complete and correct bruxism management.

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