Forming an Occlusal Splint to Support the Therapy of Bruxism

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Abstract The present work proposes a computerised and algorithmic approach to a procedure which has traditionally been performed in hardware, by milling and polishing a physical object. While some fine physical final adjustments will still be necessary, we hope a digital approach will make the process less labor-intensive and allow for a more explicit positioning of the mandible.

Keywords Bruxism · Occlusal splint · 3D imaging · 3D prototyping

1 Principle of Operation

Bruxism is a common condition associated with nocturnal or daytime teeth clenching or grinding. Some authors classify it as a parafunction (an activity which is not related to physiology).

Although bruxism is known to be treatment-resistant, its effects (teeth wear, headaches, gingival recessions, disorders of the temporo-mandibular joint—TMJ) can be diminished. The prophylactics includes mainly behavioral (daytime bruxism) and splint therapy (both nocturnal and daytime bruxism) [4, 6]. The concept of treating bruxism with an occlusal splint relies on a reflexive path: proprioceptive receptors detecting pressure on the front teeth (canines and incisors) cause mastication muscles to relax, while a similar stimulus on the back teeth (premolars and molars) stimulates them to contract. The splint should be formed in such a way that grinding or clenching of teeth will cause equilibrated contact of the anterior teeth, triggering a relaxation [6].

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Graber et al. [5] point to more reasons why occlusal devices in general reduce various symptoms related to temporo-mandibular joint disorders (TMD). Those of them that are relevant in the context of bruxism can be summarized as:

1. adjusting the position of the mandible to one that:
   - increases the vertical direction.
   - is more comfortable (optimal, stable) both from an occlusal and neuromuscular point of view.

   all of which factors help reduce muscular activity.
2. influencing the central nervous system (CNS):
   - the device acting as a reminder for the patient to cosciously avoid undesirable behavior.
   - inhibiting the CNS during sleep, reducing muscle hyperactivity.
   - creating a placebo effect.

2 Existing Procedure

The splint is initially formed with an impression of the upper teeth on one side and only of the cusps of the lower teeth on the other. The lower surface is then cut, by a technician, in the areas surrounding the cusp impressions so as to reduce it to nearly a plane, where the points corresponding to cusp tips (which remain intact) are no longer depressed. This near-plane is finished by the doctor, in the patient's mouth, with the use of marking paper, to ensure that only the cusps and edges of lower teeth create contact points with the splint. Then, again with the use of marking paper, the patient is asked to move the mandible somewhat sideways and forward. Then, with a marking paper of another (second) color, the patient taps the teeth against the splint (in the neutral position of initial contacts). The splint is then reduced along the lines that were drawn on the lateral teeth (premolars and molars), while avoiding the points marked in the second color. Certain lines (drawn by canines and incisors) are left intact on the front part of the splint, namely:

- lines representing lateral movements of the canines are left on the side of the movement direction.
- lines representing movement forward [protrusion] are left in the area corresponding to incisors and/or canines [6].

There is some disagreement whether the incisors should be in contact during protrusion [1]. The effect is that lateral and frontal movements of the mandible, typical of grinding, are countered by the splint pressing against the front teeth (canines and incisors), causing the masticatory muscles to relax. The back teeth (premolars and molars) do not come under pressure, so that their proprioceptors—which would stimulate the masticatory muscles—are not activated.

We propose a partly computerized method which seems likely to achieve the same physiological effect while using less manual cutting and operating in a coordinate system related to CBCT (cone beam computed tomography) data.

3 Outline of the Method

The principal idea of the method is to duplicate the occlusal surface of the maxillary teeth and use its shape in two ways: in the exact negative, to form an upper surface of the splint to tightly match the maxillary teeth, and in a modified positive, to form the lower surface to accomodate the mandibular teeth in a natural way while allowing some motion and selectively providing support in the areas where it is desirable from the therapeutic point of view.

The solid of the splint is completed by adding an arbitrary smooth surface on the lingual and labial/buccal side.

A more detailed description of the proposed method is given in the following pseudocode:

1. Forming the upper surface:
   (a) taking an impression of the upper dental arch, casting a positive model and scanning it to obtain a 3D digital representation.
   (b) subtracting (in set-theoretic sense) this volume from a predefined, horse-shoe-shaped solid slightly wider than the dental arch.
   (c) increasing the contact area by morphological post-processing operations such as opening and closing.
2. Forming an initial position of the lower surface of the splint by moving (virtually) a copy of the upper surface downwards by a predefined distance d (Fig. 1). This distance becomes the initial thickness of the splint.
3. Determining the contact points between this surface and the lower dental arch during jaw closure (algorithm described by Skabek and Tomaka [7]) and the corresponding position of the TMJ resulting from the initial thickness.
4. Determining the desirable position of the mandible by manipulating its 3D CBCT model, in a virtual setting, placing the condyles against the fossa and disc of the temporo-mandibular joint. The position, optimized for rotation-point centering and right-left symmetry identical to Centric Relation [4], is expressed as a rigid-body transformation T (rotation and translation) from the position obtained in step 2.
5. Forming the lower surface of the splint by:
   (a) taking the copy of the upper dental arch shifted in step 2.
   (b) moving it further by applying T—Fig. 1.
   (c) adding (in a set-theoretic sense) the resulting volume to the solid created in step 1c. whose thickness may have to be increased to avoid gaps.
   (d) filling and smoothing the edges created at the joining.

6. Prototyping the splint in a 3D printer. If a printer capable of working with biocompatible materials is not available, prototyping a mold in which a medical-grade splint will be cast.
7. Finishing the splint by using marking paper (in two different colors) and a dental bur as in the existing procedure described at the beginning of this paper [3, 7] (Fig. 2).

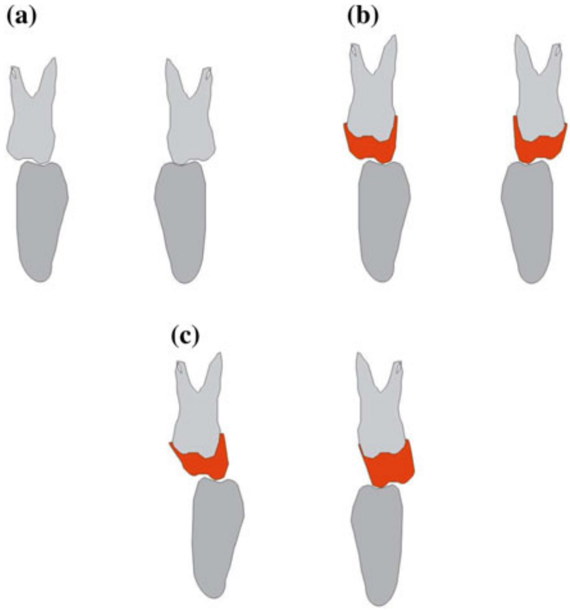

Fig. 1 Moving a copy of the lower surface of the maxillary arch. **a** Natural occlusion, **b** vertical shift, **c** general rigid-body movement

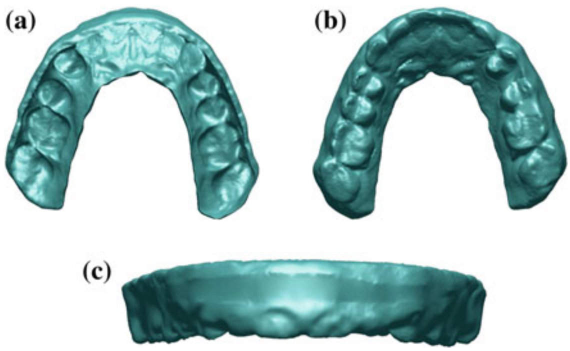

Fig. 2 Draft of occlusal splint. **a** *Top side* shape of maxillary teeth in negative, **b** *bottom side* shape of maxillary teeth in positive, **c** *frontal view* showing labial and buccal surfaces

3.1 User Interface Issues

In point 4 above, we mentioned a virtual setting in which the doctor should maniputate a CBCT model of the mandible, seeking its optimal position from a therapeutic point of view. Although various application programs are available on the market that allow the user to position two solids relative to each other, doing so with the mandible and maxilla requires some dedicated verifying functionalities. The interface should allow the doctor to manually modify the position of the mandible relative to the maxilla by small increments, while verifying, at each increment, both the occlusal and condylar conditions. Small increments here mean rotation by small angles and translation by small vectors. Occlusal conditions—the contact between the dental arches—can be verified by analyzing the cross-sections of the interacting solids, while condylar relations (position of the TMJ) can be visualized by a virtual X-ray projection [8]. The use of virtual X-ray mirrors the long practice of evaluating the position of the TMJ by means of 2D X-ray images. 2D has long been the norm in medical imaging in general, and many experienced practitioners can interpret this type of images better than a perspective or axonometric projection. A number of criteria which the practitioner will use when evaluating the desirable position of the mandible are also defined in 2D terms. While future implementations can obviously use 3D screens or goggles as well as 3D pointing devices, X-ray mode visualization is likely to remain a desirable option.

After each adjustment of the position, the system should check for any colisions, to rule out any move that would make the two solids (the maxilla and the mandible) intersect.

As an illustration of concept only, Fig. 3 is a screenshot of a model of the mandible being moved by means of a virtual trackball. It was taken under RapidForm (by InUs Technologies), a general-purpose 3D editor which does not automatically prevent

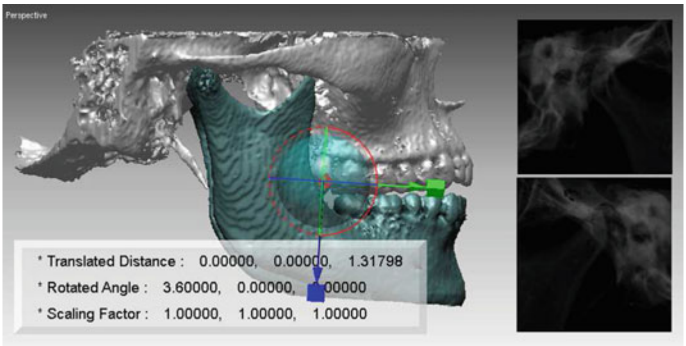

Fig. 3 Moving the mandible in a virtual environment

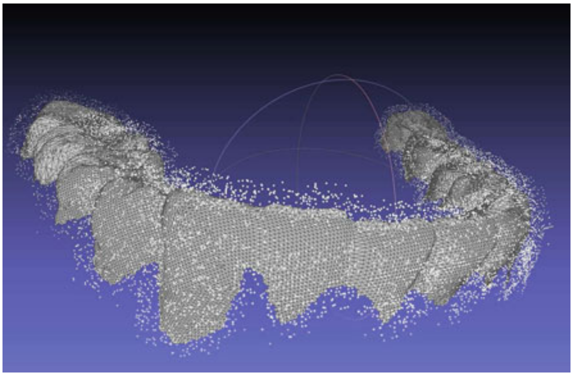

Fig. 4 Thickened model of the mandibular dental arch

collisions. The procedure uses a standard 2D computer screen and mouse, and the user can switch between several modes of using the mouse:

- translational movement in either the XY, YZ, or XZ plane;
- rotation around the X, Y or Z axis.

4 Virtual Finishing

A part of the physical finishing process might be replaced by mathematical morphology operations such as thickening and thinning, performed in the virtual domain. These operations are similar to erosion and dilation (from mathematical morphology) but are easier to implement for the 3D meshes we are working with, whereas erosion and dilation are better suited for volumetric data.

In a first version, our algorithm only moves the vertices—the topology of the mesh remains unchanged. As the direction of the movement, we use a pseudo-normal vector calculated using adjacent facets. The normal vector is calculated as a weighted average, where we use the adjacent angle as a weight for face normal (the method for calculating pseudo-nomal is described in [2]). Results are shown in Fig. 4.

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References

1. Ash, M.M. Jr., Ramfjord, S.P., Schmidseder, J.: Terapia przy użyciu szyn okluzyjnych (Occlusal splints in therapy). Wyd. polskie red. Teresa Maślanka, Urban & partner, Wrocław (1999) (in Polish)
2. Baerentzen, J.A., Aanaes, H.: Signed distance computation using the angle weighted pseudo-normal. IEEE Trans. Vis. Comput. Graph. **11**(3), 243–253 (2005)

3. Baron, S.: Bruxism and Occlussion. In: Palla, S., Kato, T., Provaznik, I., Tkacz, E., Baron, S. (eds) Novel Methodology of Both Diagnosis and Therapy of Bruxism, Lecture Notes of the ICB Seminar, 137th Seminar, Warsaw (2014)
4. Dawson, P.E.: Functional Occlusion. From TMJ to Smile Design. Mosby-Elsevier, St. Louis (2007)
5. Graber, L.W., Vanarsdall, R.L., Vig, K.W.L.: Orthodontics: Current Principles and Techniques. Elsevier Health Sciences (2011)
6. Okeson, J.P.: Leczenie dysfunkcji narządu żucia i zaburzeń zwarcia (Treatment of masticatory disfunction and malocclusion). In: Drobek, W. (ed) Wydawnictwo Czelej, Lublin (2005)
7. Skabek, K., Tomaka, A.A.: Techniques of processing and segmentation of 3D geometric models for detection of the occlusal area of dental arches. In: Palla, S., Kato, T., Provaznik, I., Tkacz, E., Baron, S. (eds) Novel Methodology of Both Diagnosis and Therapy of Bruxism, Lecture Notes of the ICB Seminar, 137th Seminar, Warsaw (2014)
8. Tomaka, A.A.: Analiza obrazów wielomodalnych dla potrzeb nieinwazyjnej diagnostyki ortodontycznej (Multimodal image analysis for noninvasive orthodontic diagnosis). Instytut Informatyki Teoretycznej i Stosowanej PAN, D.Sc. thesis (2013) (in Polish)