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Review article

### The history of the concepts in treating craniomandibular dysfunctions using occlusal appliances. A review

Michael Behr<sup>1</sup>, Helge Knüttel<sup>2</sup>, Jochen Fanghänel<sup>3</sup>, Christian Kirschneck<sup>3</sup>, Peter Proff<sup>3</sup>

<sup>1</sup> Department of Prosthetic Dentistry, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93053 Germany

<sup>2</sup> University Medical Library, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11 D-93053 Germany

<sup>3</sup> Department of Orthodontic Dentistry, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93053 Regensburg, Germany

\*Corresponding author: Prof. Dr. Michael Behr, Department of Prosthetic Dentistry, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93053 Germany, Email: michael.behr@ukr.de

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#### Abstract

**Objectives:** The knowledge of the history of occlusal appliances and their treatment ideas help benchmark therapy concepts of today and in the future. **Material and methods:** The history of occlusal appliances was systematically reviewed. We analyzed 25 electronic data bases and additionally bibliographic catalogs by hand. Entirely 176 papers were included. **Results:** First appliances, made of wood or alloys, were only used to fix bone fractures. Later, appliances made of caoutchouc were added covering the entire dental arch. It was not until 1901 that occlusal appliances were systematically inserted to treat parafunctions. At that time, occlusal dysbalances were considered to be responsible for tooth lost (Alveolar pyorrhea) and furthermore, in the years 1920 to 1930, for dysfunctions of the tube, for vertigo and bad hearing (Costen syndrome). After the Second World War the dentists included the phenomena of stress in their treatment concepts and they considered more and more internal derangement of the temporomandibular joint as topic, which had to be treated by splints. The material of the appliances changed from natural rubber to acrylic resin materials, which offered the possibility to construct appliances in manifold ways. **Conclusions:** Beside appliances like the Michigan splint, that covered all teeth of the dental arc, concepts with reduced occlusal contact in anterior area (e.g.: jig-splints) or, posterior area (e.g.: pivot splints) were developed. **Clinical relevance:** Meanwhile a wide range of concepts and types of appliances were propagated, however, a final evidence based concept is still lacking.

**Keywords:** craniomandibular dysfunction; occlusal appliance; splint, history; treatment protocol; dental materials

#### Introduction

In the ‘Dictionary of Dentistry’ published by Hoffmann-Axthelm in 1983, ‘splints’ were defined as ‘Fixation of fractured or injured body parts’ [81] and, in the case of fractures of the jaw, ‘fixation of fragments with orthodontic wires, slabs, or osteosynthesis’. Thus, the term ‘splint’ was only used in the context of fracture treat-

ment (Table 1).

This definition was in line with the first intraoral splints described in the literature that were used for the fixation of fractures of the jaw. The first reports on using occlusal splints for treating dental deformities and the effects of dysfunctions of the masticatory organ were published in

the late 19th century [87,91]. The term ‘splint’ has now become more and more established in particular for treating craniomandibular dysfunctions (CMD) [127], because – in these cases – treatment should be focused on the neuro-muscular control of the masticatory system or occlusion but not on the ‘fixation’ of the fractures of the jaw.

The objective of this work was to trace the development and progress of occlusal splints and their concepts (ideas) for treating CMD during the last 100 years.

### Material and methods

In the context of a comprehensive and well-structured literature search (Supplementary Table 2), we looked for publications on the history of occlusal splints as well as for historical publications on occlusal splints using a wide variety of data bases, catalogues, and bibliographies. Each of the 25 electronic data bases hosted by the German Institute for Medical Documentation and Information (DIMDI, <http://www.dimdi.de/>) at the time of the research project was included in the literature search. Two separate searches were conducted, the first with the search term ‘splint’ and the second with the term ‘history and historical publications’. The hit lists of both search terms were connected with the Bool Operator AND. No restrictions concerning language were made. Further electronic searches included PubMed Central (full-text search), the IndexCat™ of the National Library of Medicine (<http://www.indexcat.nlm.nih.gov/>), and the catalogue of the German National Library. The detailed documentation guaranteeing the reproducibility of the literature search is included in supplementary table 2.

The following sources were checked manually using the following key words: alveolar pyorrhea, pyorrhea alveolaris, appliance, tooth guard, jaw joint disorders and their treatment, splint(s), dentistry, jaw, teeth, traumatic occlusion, bruxism, temporo-mandibular joint, temporo-maxillary joint.

- The Index Medicus for the reference years 1886 to 1955 (80 hits),
- the index of the German Dental Literature and the Dental Bibliography on behalf of the Central Association of German Dentists (Port G, ed.) for the reference years 1891 to 1907 (7 hits),
- the index of the periodical dental literature published in the English language for the reference years 1839 to 1938 (43 hits), and
- the Deutsche Zahnärztliche Zeitschrift (German Dental Journal) from 1946 to 1985 (26 hits),
- the index of the periodical dental literature published in the English language. Checked groups: ‘D3’, ‘D64’, ‘D713-15’, and ‘D422’.

All hits were checked manually with regard to the following questions:

- Indication for the splint (fracture, periodontal fixation, or treatment of CMD),
- choice of material (metal alloys, natural rubber, polymers, or gutta-percha),
- first mention of the type of splint and treatment concept, and
- the type of splint.

Cross-references in the body of literature already found were taken into account as additions. Altogether 176 references were evaluated.

### Results and discussion

Despite the fact that the focus of this review was the history of splints used for craniomandibular dysfunction treatment, we start with a short overview of splints used for fracture treatment. The reason is that a review of splints will become fragmentary by ignoring the first splints ever made in dentistry. Furthermore, the history of these early splints shows the progress our dental materials had made during that period. The description of the splints used for craniomandibular dysfunction tried to follow a chronological order, but some treatment ideas and concepts were tracked over decades. Therefore, overlappings are inescapable.

#### Shape of the first intraoral splints used for fracture treatment (only)

In 1642, Wiseman used a Y shaped wooden spatula for treating fractures because of the lack of other materials suitable for the manufacture of intraoral splints [176]. In 1771, Desault and Chopart coated metal splints with cork and used them for the intraoral fixation of fractures of the jaw (quoted from Covey [35]). In the ensuing period, the most widely used devices were preformed metal sheets with splint elements in the form of an impression tray that were intraorally and extraorally fixated with metal wires or bandages similar to a chin cup (Table 1). Fracture fragments were generally not occlusally aligned.

Important progress in fracture treatment was achieved by James Baxter Bean, who manufactured splints made of natural rubber to treat fractures of the jaw [7]. His work was published in the Southern Dental Examiner in 1862. A few years previously, Charles Goodyear had filed a patent for vulcanizing natural rubber, a method that enabled the flexible formation of material with a very high level of fitting accuracy for that time. The ground-breaking methodology invented by Bean was not just the use of the then novel material. Using wax impressions, Bean manufactured plaster models of the rows of teeth of both the dislocated and the uninjured jaw and correlated the two rows of teeth by means of the opposing

Table 1. Materials of splints for fixing jaw fractures from 1676 to 1945.

Author	Reference	Year	Construction-materials
Wiseman R.	[176]	1676	wood
Rutenich 1799 Bush 1822 Houzelot 1826 Lonsdale 1867 Hill u. Moon 1866	quoted from [47]  quoted from [111]	1799 bis 1866	preformed tin
Bean JB	[7]	1862	caoutchouc
Gunning TB	[68,69]	1868	caoutchouc
Covey EN.	[35]	1866	gutta-percha
Bolton J.	[21]	1866	gutta-percha
Allen H	[3]	1871	caoutchouc
Noel LG	[119]	1875	caoutchouc
Kingsley NW	[95]	1874	caoutchouc
Carroll T	[26]	1879	gutta-percha
Gunning TB	[69]	1884	caoutchouc
Fletcher MH	[47]	1893	preformed tin
Fowler GR	[50]	1897	caoutchouc precious alloy
Harbison HR	[74]	1901	leather bandage
Matas R	[111]	1905	preformed tin
Ganzer NN.	[53]	1916	preformed tin
Nies FH	[118]	1918	casted alloy

jaw to the original state prior to the fracture. Bean not only used plaster models of the rows of teeth for manufacturing oral splints but also fixated the upper and lower jaw models in a type of articulator in order to guarantee the anatomically correct alignment of the fractured parts of the jaws. In the sense of ‘model surgery’, Bean manufactured an intraoral splint made of natural rubber that was placed on the corrected injured jaw, and the form of this splint was very similar to that of modern splints made of methacrylate.

Bean’s method of treating fractures of the jaw quickly spread over the southern states of the United States of America during the American Civil War [123]. The Medical Inspector of the Confederate Northern States, Edward N. Covey [35], reported on Bean’s method for treating fractured jaws in the first issue of the Richmond Medical Journal published in 1866.

The extent to which Thomas Brian Gunning was familiar with Bean’s method or if Gunning had developed his method in parallel is not known [68,69]. What we do know for certain is that, in 1868, Gunning published four different methods for treating fractures of the jaw by means of splints made of vulcanized natural rubber. The splints were partially fixated with screws, but no articulator was used for the manufacture of the splints. Gunning had already treated the broken jaw of the secretary of Abraham Lincoln in 1865, so that his method had become known to a wider public. Many reports on splints made of natural rubber or on moldings made of gutta percha were published in the ensuing period. In 1866, Covey compared Bean’s method with previous methods in detail [35]. Covey described the metal splints used by Chopart and Dessault, the bandage method with leather splints developed by Hamilton, the silver-plated splints used by Smith, as well as the splint with a gutta percha plate fixated with ribbons that had been introduced by the French surgeon Corné in 1855 (quoted from Covey, Du Pont [35,41]). As evident from the reports by Kingsley in 1874 [95], by Noel in 1875 [119] (splints made of natural rubber), or by Carroll in 1879 (splints made of gutta percha) [26], Bean’s method seemed to prevail in the subsequent years.

The development of dental casts enabled the use of metal splints made of precious alloys and non-precious alloys. Many publications, particularly during the two World Wars, described the metal-supported splints that were easily manufactured for the treatment of fractures of the jaw [17,53,111,118]. Only from 1940 onwards was polymer used for manufacturing oral splints for treating fractures of the jaw [23]; in the ensuing period, methyl methacrylate became the dominant material used for all types of splints (Table 1).

## **Splints and concepts for treating craniomandibular dysfunction**

### **First splints and concepts for treating craniomandibular dysfunctions (1874 to 1901)**

Next to treating fractures of the jaw with oral splints, Kingsley proposed in 1874 to use vulcanized plates for manufacturing orthodontic appliances for tooth row extension and for controlling tooth eruption. In the ensuing period, dysgnathia was often orthodontically corrected with removable oral splints [6,27,38,44,78,9,85,107]. In contrast, dysfunctions of the masticatory muscles and the mandibular joints were rarely treated with oral splints. In 1884, a dentist in Berlin named Ritter [134] described the treatment of – what he referred to as – a hysterical spasm of the masticatory muscles with a plate made of natural rubber. In 1888, Farrar [45] described the use of splints made of natural rubber for a partial bite raising in order to control tooth eruption.

### **First splints and concepts for treating craniomandibular dysfunctions (1901-1945)**

By now, it is impossible to know for certain who the first person was to use splints for treating craniomandibular dysfunctions. Shortly after the turn of the century in the year 1901, a conference report of the presentation of a dentist named Karolyi was published in the Austrian-Hungarian Quarterly Magazine for Dental Medicine [91]. In his presentation, Karolyi suggested to treat chronic shrinkage of periodontal tissues (quoted from Groß, 1933 [67]) in the molar region with cap splints as relief therapy (quoted from Thielemann [165]). Karolyi regarded high chewing pressure as the main reason for pyorrhea alveolaris and the subsequent loosening and loss of teeth. The concept of traumatic occlusion leading to purulent inflammation of the periodontium was vehemently defended as ‘Karolyi effect’ up to the end of the 1930s (Peter 1904 [121], Szabo 1905 [162], Bertin 1905 [18], Belden 1908 [13], Spiess 1912 [156,157], Benson 1913 [14], Eusterman 1924 [42], Stillman 1925 [160], Hatton 1925 [77], Prinz 1924, 1926 [125,126], Withycombe 1931 [178], and Merrit 1934 [115]). However, this concept had been questioned even at that time, so that other causes of purulent inflammation of the periodontium were discussed [48,80,98,128,179]. The concept put forward by Karolyi was opposed by Sachs in 1906 and 1910 [135-137], by Senn in 1906 [147], by Landgraf in 1903 and 1905 [101-104], and by Gottlieb in 1925 [64]. Gottlieb and Landgraf drew particular attention to the fact that fixed cemented caps impede cleaning of the teeth, thus facilitating disease [63,64,103]. For this reason, teeth caps alone were not considered suitable for treating chronic shrinkage of periodontal tissues. Gottlieb criticized the one-sided occlusal stress put on capped

teeth – although caps should actually relieve stress on teeth – and reported the intrusion and vertical extrusion of uncapped teeth. Gottlieb regarded the capacity of teeth for lifelong elongation as well as unfavorable force vectors putting stress on the molars as causes of traumatic occlusion [64]. According to Gottlieb, unevenly distributed tooth eruption was one factor responsible for the development of pyorrhea alveolaris. Gottlieb thus favoured removable splints that occlusally covered all teeth for fixating loosened teeth. A metal cap was manufactured for each tooth, and the caps were then welded together to enable daily insertion and removal via a common axis. Gottlieb filled the occlusal surface of the metal caps with natural rubber that remained soft. These splints were assumed to reduce horizontal masticatory forces that were viewed as particularly damaging. According to Groß, the best material for this purpose was hard natural rubber [67]. Splints made of natural rubber that remained soft were often supplemented with voluminous intermediate padding to help absorb masticatory forces. However, many splints were impossible to wear because of the increased height of the occlusal surface [135]. Both Sachs 1929 [135] and Groß 1933 [67] advocated the manufacture of splints with the lowest possible increase in occlusal height and with a small volume. In 1933, Groß experimented with materials such as celluloid or cellon because of their low layer thickness [67]. Clinically, the tests were not successful because of the insufficient resistance to wear (water absorption) as well as the increasing brittleness and cloudiness of the materials. More favorable clinical results were achieved with the first pressed synthetic splints made of methacrylate as preferred by Thielemann in 1952 [165]. The material Hekolith™ was ivory colored and, despite its low layer thickness, sufficiently stable during mastication. The splints were manufactured in an articulator.

### Development of concepts of occlusion

At that time, many authors were convinced that both the periodontium and the mandibular joints were damaged by traumatic occlusion [70,49,142,154,159,166,167, 180]. However, this thesis required clarification how optimal occlusion looks like and how atraumatic occlusion may be reconstructed in a clinical setting. Respective suggestions were made by, among others, Christensen in 1905 [28], by Hanau in 1917 [773], by Wadsworth in 1919 [173], by Hall in 1920 [72], and by Monson in 1921 [116].

Wadsworth determined the radius of the individual curve of occlusion by means of the distance between the center of the condyle and the incisal point [173]. At about the level of the glabella, he projected the center of the condyle and the incisal point. The resulting intraoral circular segment indicated the point for setting the cusps

for the occlusal surfaces that needed to be restored. In 1930, Kirk corrected the location of the circular segment because the left and right mandibular joints are very rarely symmetrically arranged in a precise manner [96]. According to Kirk, the distance between the incisal point and the left center of the condyle might significantly deviate from the distance between the incisal point and the right center of the condyle. Kirk took this fact into consideration when determining the definite circular segment. For the implementation of these concepts, Goodfriend first of all manufactured temporary bite plates [60,61] to correct occlusion. These bite plates were then replaced by permanently fixed or removable dental prostheses, a procedure Goodfriend had termed ‘gnathologic orthomorphosis’ [60,61]. Monson proposed that occlusal surfaces should be assumed to be located on the section of a sphere because balanced occlusion might then be guaranteed not only in the sagittal dimension but also in the transversal dimension [116]. The center of the sphere was behind the lamina lacrimalis at the level of the orbita. Independent of Monson; the Danish scientist Christensen had already determined an occlusal curve as part of a circular segment by means of the occlusal surfaces in 1905 [28]. The center of the circle was in the orbita. Instead of a spherical segment, Hall chose the segment of a truncated cone in 1920 [72]. Hanau built an articulator [73] that took the range of motion of the lower jaw into consideration.

All described concepts were focused on treating traumatic occlusion due to tooth loss, tooth migration, or abnormal tooth eruption to restore physiological occlusion, both at jaw occlusion as well as during masticatory movements.

### Relationship between occlusion and otologic impairments (Costen syndrome)

Already in 1906, malocclusion was not only assumed to be a cause of purulent diseases of the periodontium (Karolyi effect) but also of joint noises, dizziness, and impaired hearing [19,62,76,131]. Goodfriend argued that creaking joints or restricted mouth opening as well as impaired hearing and disturbed Eustachian tube ventilation might also be caused by malocclusion [61, 149].

A widely accepted assumption was that if the occlusal height was too low, the condyles might be moved too far in a dorso-cranial direction (overclosure) [36,110]. Monson postulated [116] that overclosure might result in the deformation of the ear passage and subsequently in impaired hearing. Further negative consequences might be swallowing difficulties and dysfunction of the masticatory muscles as well as of the infrahyoid and suprahyoid muscles that control the entire lower jaw.

Monson was particularly concerned with the correct vertical height of dental prostheses [116]. In the case of dentures, occlusal height was determined by the dental

<sup>1</sup> Pyorrhea, pyorrhea alveolaris: Old term for purulent periodontopathy. The causes were not entirely clear in those days.

prosthesis. In the case of teeth, caps or respective elongation of molars were considered the treatment of choice by many authors, for instance by Gottlieb in 1925 [63,64], by Adler in 1929 [1], by Groß [67], by Thielemann in 1933 [165], by Costen in 1934 [32-34], by Maves in 1938 [113], and by Sved in 1944 [161]. This concept was integrated into medicine through the publications by Costen [32-34], who considered many symptoms such as loss of hearing, tinnitus, ear pain, burning tongue syndrome, feelings of discomfort in ears and throat, and headache to be caused by overclosure. Erosion of the bone in the fossa glenoida, joint compression in the fossa, as well as dorso-medial dislocation of the condyles were thought to irritate structures such as the auriculotemporal nerve, the chorda tympani nerve, the lingual nerve, and the Eustachian tube. Sicher showed in 1948 [152] that the theory of dislocated condyles compressing the above-mentioned structures was incorrect; furthermore, there was no sound anatomical basis for the assumption that overclosure may cause loss of hearing, tinnitus, or neuralgia in the region of the glossopharyngeal nerve or the trigeminus nerve.

However, the concept 'loss of the vertical dimension' as the cause of cranio-mandibular dysfunction remained popular throughout the 1950s and 1960s (Riedel 1958 [133] and Menke 1960 [114]). Christiansen [29] and Shore [150,151] mainly aimed at levelling out occlusal loss of height due to abrasion or missing teeth, whereas Gelb [56-58] as well as Witzig und Spahl [178] discussed the necessity of levelling out deficits in height caused by impaired growth processes. It was hypothesized that loss of molars and poor posterior support may lead to increased stress on the mandibular joints and subsequently to cranio-mandibular dysfunction. The retainer already introduced by Hawley in 1919 was used as an oral splint for the targeted elongation of molars [78,79]. However, the primary concern of Hawley had been an orthodontic problem, i.e. adjusting overbite and ensuring the result of orthodontic correction by wearing the retainer at night.

In the meantime, the thesis of loss of vertical dimension as a main cause of cranio-mandibular dysfunction had been considered obsolete. The one-sided increase in occlusal height in the molar region had also increased the number of patients developing parafunctions, and the therapeutic increase in occlusal height was subsequently decreased by bruxing [87]. Dawson strongly advised against an uncontrolled increase in vertical occlusion [39] and assumed that the vertical dimension of occlusion (VDO) is a specific constant factor in each patient that is controlled by muscles. The alveolar bone is adapted by the abrasion of the occlusal surfaces, thus compensating the difference in height. Both the vertical dimension and the resting position are usually set and maintained by swallowing (1000 to 2000 times per day). This view was

supported by Begg who investigated the teeth of Australian indigenous people [9,10] who had never undergone occlusal corrections by means of dental intervention in their lifetime. Over the course of time, the natural wear process had the teeth worn down to the dentin, both in the occlusal as well as in the circular dimension. However, occlusal and circular loss of tooth substance had been compensated by mesial migration and controlled elongation. The dental arch was closed, and the upper and lower jaws were mostly in the edge-to-edge bite position. Occlusal interlocking, just as after tooth eruption, had ceased to exist in elder people, but the vertical dimension of occlusion was still evident.

### **Splints and concepts for treating craniomandibular dysfunctions from 1945 to 1970**

In the 1940s and 1950s, splints mainly made of soft, flexible materials such as natural rubber, vinyl polymers, or latex was propagated for the treatment of bruxism [165]. Flexible splints were supposed to work like a cushion that absorbs high occlusal forces in order to protect the dental enamel and the periodontium. Because the bite is able to adjust, splints might help normalize the function of the masticatory muscles. Thus, both hard as well as soft occlusal splints made of natural rubber were recommended for the treatment of bruxisms by Schumacher in 1947 [142] and by Balters in 1955 [5]. The splinting of periodontally damaged teeth seems to have been a particular concern in that time [43,52,82,87,97]. Next to splints made of natural rubber (Falck 1949 [43]), splints were cast of metal alloys and cemented onto teeth such as the pin splint developed by Weigele (Reumuth 1951 [132]) or removable metal splints such as the Elbrecht splint (Kessler 1953 [93]) or von Weißenfluh's intradentally fixed 'Hülsen-Stiftschiene' (cartridge-pin-splint) that was furnished with tiny gold tubes and a bottom [163]. At that time, many authors such as Falck [43] considered polymers as too abrasive and thus unsuitable for periodontal splints.

From the 1950s onwards, the spreading of the material methyl methacrylate resulted in the development of many different designs and forms of splints. Figure 1 shows the main differences: Splints covering the occlusal surface of the entire dental arch need to be differentiated from splints that only cover the occlusal surfaces in the anterior, posterior, or premolar region when the jaw is closed.

In 1957, Böttger used splints made of polymer to treat arthropathia deformans of the mandibular joint [22]. This method was repeated by Riedel in 1958 [133] and by Menke in 1960 [114]. All authors tried to alleviate physical complaints termed 'overload arthropathy' by means of increasing vertical dimension. In his review in 1963, Hupfauf compared the advantages and disadvantages of removable polymer splints with those of cast and cement-

ed caps with regard to their effect on decreasing the load on the mandibular joint [84].

Decreasing the load on the mandibular joints was also a concern of Sears [144,145], who propagated an excessive increase in vertical dimension in the molar region so that the joint would be slightly moved from its socket in a caudal direction by means of a hypomochlion. Pivot splints made of polymer, excessively high prostheses for the molar region of only one jaw with teeth made of ceramics that withstand abrasion, or excessively high fillings were meant to have a distracting effect on the condyles, thus subsequently protecting the mandibular joints [83]. This concept is still called into question today and has thus been the subject of controversial debate [105,146].

Gelb recommended splints made of methacrylate that had occlusal contacts on the molars and premolars and thus left out the anterior and canine teeth [56-58], for which Gelb coined the term 'orthopedic repositioning splints'. These splints were inserted into the lower jaw in order to optimize the neuromuscular localization of the condyles in the fossa. The anterior teeth were left out in order to facilitate laterotrusion via the natural anterior teeth. Objections that this type of splint would lead to the intrusion of molars or elongation of the anterior teeth were rejected by Gelb, who regarded intrusion as a consequence of adjusting the condyles to their optimized therapeutic localization. According to Gelb, elongation should not occur if the contact patterns between the upper and lower anterior teeth in laterotrusion were adjusted correctly. The design of the neuromuscular mandibular repositioner manufactured by Weiss was similar to that of the splint made by Gelb [175]. The only difference was a model casting base fixated with a bracket in the molar and premolar region that was adapted with tooth-colored polymer in the myocentric position. The splint was meant to be used in the long term in order to avoid covering the occlusal surfaces with crowns or onlays in the case of malocclusion.

In the 1960s, splints that only allowed contact of the front teeth with a smooth flat surface – similar to the retainer designed by Hawley [78,79] – became rather popular. The splint named after Dessner (1960) reduced the bite to a flat surface reaching from one canine tooth to the other [15,16]. Posselt designed a similar splint in 1963 [124]. Both, the splint designed by Dessner and the splint developed by Posselt were made of polymer. Immenkamp [86] and Schulte [139] independently modified this splint in 1966. Immenkamp reduced the occlusal contact to a small surface in the lingual area of the upper canine, whereas Schulte used a bracket fixated to the upper premolars in the area of the approximal contact to block the bite. The first splint had a handbent clasp as premature contact area; but approximately in 1967, Schulte manu-

factured an 'interceptor', a casted premature contact area, formed like two Bonwill brackets for the regions 14/15 and 24/25 that were connected with a small palatal bow [20,140]. Immenkamp and Schulte considered it important that the resting position remained unaffected by the splint.

A contemporary splint with a frontal bite block (jig-splint) was the NTI iss splint [158] introduced in 1998. Preformed narrow jigs made of acrylate were padded with polymer in the region of the upper and lower central teeth. All splints with a partial support of occlusion result in the migration of teeth and should thus only be used for a limited period of time [11,20,30,31]. Barnes already mentioned the risk of elongation of the molars in his commentary on the Hawley plate in 1919 [79].

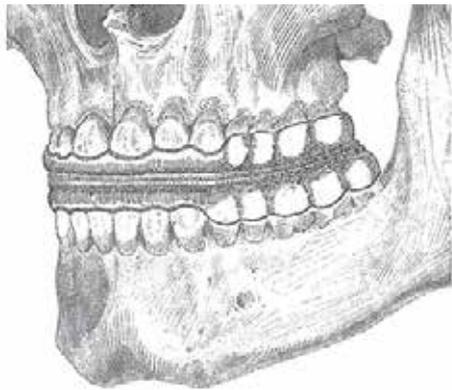
In contrast to splints with only anterior or more posterior occlusal contacts, splints with full coverage and occlusal support of all existing teeth had always been propagated [55,130], for instance by Voss in 1964 [172] and, with lasting impact until the present day, by Ramfjord and Ash [130]. The Michigan splint developed by Ramfjord and Ash that enables occlusion of the entire periodontium in central relation and frontal and canine teeth guidance is viewed as one of the gold standards in splint therapy to this day. This splint may be modified according to the respective therapeutic concept [129]. Ramfjord and Ash designed their splint to be inserted on the upper jaw; in contrast, Tanner [164] suggested to transfer the concept of the Michigan splint to the lower jaw because splints used on the lower jaw are more comfortable to wear for the patient, thus increasing patient compliance.

A simple splint covering all existing teeth in a jaw was the thermalformed miniplast splint developed by Drum (1966 [40]), who assumed that most splints were too voluminous in size and hence uncomfortable to wear for the patient. Crunching and gnashing should be treated with a quickly to manufacture, thin, and barely noticeable splint with a bite block of only minimal height. Drum recommended the initial design of the splint to protect against parafunctions when treating periodontal diseases. The miniplast splint developed by Drum is also often used as a basis for different types of splints such as positioning splints, protusion splints, or repositioning splints that are modified with cold processable polymers [106].

Several methods were suggested for the functional moulding of splints covering the entire dental arch. Shore manufactured plates for the upper jaw that had a jig for the anterior teeth in the area of the central incisors [106,150]. A short wearing period facilitated the relaxation of the masticatory muscles. This splint was subsequently enhanced with not yet polymerized acrylic in the molar and premolar regions. Both static and dynamic occlusion was moulded in the still soft acrylic with

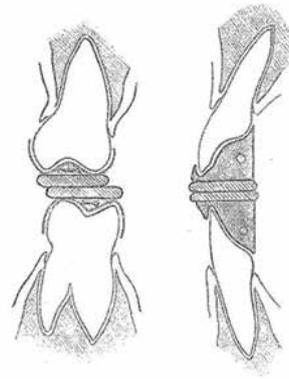
**Figure 1**

Example of a casted cap splint covered occlusally with gutta-percha [64].



a

Example of a casted cap splint covered occlusally with gutta-percha [64].



b

relaxed masticatory muscles. The splint was then hand-finished and polished.

Jankelson [88-90] also used the concept of moulding the basic form of a splint after relaxation of the masticatory muscles or after therapeutic positioning of the condyles. He also developed a myo-monitor for the detensioning of the musculature. Patients had electrodes fixed to the muscles of both cheeks and the neck. The muscles contracted due to a short electric pulse, thus facilitating muscle detensioning. After the application of the myo-monitor, the occlusal surfaces of the splint were moulded in the still malleable methacrylate. The types of splints introduced in the 1980s ultimately constituted modifications of the splints developed by Michigan or Tanner [24,106, 141]. These splints mostly showed moulded anterior or posterior teeth guidance. One example was the masticatory muscle synchronizer developed by Graber [65]. Contacts during fronto-lateral bruxism were prevented by a device termed dysfunction block. Other examples were the occlusal splint developed by Schöttl [138], the programmed functional splint developed by Gausch [54], and the occlusal splint with anterior teeth guidance formed with a contour curve former (CCF) [106].

#### *Splints for disc displacement of the temporomandibular joint*

Special splints had been suggested for the treatment of arthropathy and discopathy [153]. In the case of disc displacement, the above-mentioned pivot splints based on the concept developed by Sears were suggested for repositioning of the disc. Farrar chose another method (1971 [46]) and constructed a maxillary splint with “protrusion pathways” in the premolar and molar region, on which the distal cusps of the lower teeth moved in an anterior direction when the jaw was closed. In this protruded jaw

closure position, the disc previously dislocated in an anterior direction was repositioned again; thus, the cracking sound of the disc dislocation did not occur anymore when the mouth was opened in this protruded jaw position. The disadvantage of these splints was that the bite was opened in a distal direction in the molar region. In Angle class II2, this effect results in significant interocclusal distances measuring several millimeters that cannot be just simply corrected by prosthetic treatment such as crowns with a more voluminous occlusal surface or onlays. Because both cracking sounds as well as physical complaints had often recurred in anterior mandibular position shortly after occlusal reconstruction, the concept of repositioning splints as developed by Farrar was deemed unsuccessful, so that the use of such splints was discouraged [12,37].

#### **Hard or soft polymers as materials for occlusal splints**

Despite reports on the success of occlusal splints made of soft elastic polymers, there was increasing doubt if splints made of hard acrylate might not be more suitable for the treatment of parafunctions [25, 112, 117,120]. Ramfjord and Ash claimed that parafunctions were especially triggered by splints made of soft materials [129]. These authors also criticized the lack of adequate means to adjust the occlusal surfaces of soft splints because of the impossibility of grinding or adding more material. Furthermore, perforation occurring after just a short period of use could not be closed anymore. In 1999, Al Quran and Lyons [2] showed by means of electromyographic examination that muscular hyperactivity was reduced more efficaciously by hard occlusal splints than by soft elastic splints. After some initial successes with soft occlusal splints, several authors such as Ingerslev or Zarinnia [87,181] reported on the necessity to change to hard splints during treatment because of the loosening of teeth, permanent perforation, and unsatisfactory oral

hygiene. Harkins [75] suggested initiating pain reduction with a soft splint for a few days and then continuing treatment with a hard splint. This way, the partially rather controversial views on hard and soft splints might be brought together. This suggestion seemed to be reasonable because many authors concluded that the available data are insufficient to unequivocally verify the efficacy of the different types of occlusal splints [12,37,100].

### **Splints and concepts for treating craniomandibular dysfunctions today**

Nowadays, most occlusal splints are made of hard polymer (methacrylates), and the indications of splint therapy have become exceptionally varied [8, 51,59, 71,92, 108,148,169,170,174]. According to Dao and Lavigne, the following applications are possible [37]:

- Temporomandibular dysfunctions
  - Myofascial pain,
  - Disc dislocation, and
  - Arthritis.
- Pain in the head
  - Migraine,
  - Tension headache, and
  - Other headache.
- Sleep disturbances
  - Nocturnal bruxism, and
  - Sleep apnoea.
- Motor neuronal disorders
  - Parkinson's disease, and
  - Oral dyskinesia.
- Occlusal reconstruction
  - Functional orthodontic devices,
  - Splinting of with periodontally damaged teeth (also as prophylaxis), a
  - Prosthetic reconstruction of the occlusal surface / vertical dimension of the occlusion.
- Trauma prevention
  - Bruxism with loss of hard tooth substance,
  - Mouth guards to be worn over the teeth during special types of sports,
  - Protection against parafunctions such as nail biting or cheek biting, and,
  - Sinusitis.

Despite the intensive use of splints, most theories and concepts of splint therapy lack evidence on their efficacy; thus, many of these theories have been rejected over the years [8,12,31,51,108,170]. In 1999, Kurita observed 40 patients with CMD for two and a half years without initiating therapy [100]. In two thirds of the patients, pain symptoms were significantly reduced or had even abated completely without therapy [100]. The results of our

5-year and 13-year [12] follow-up examination of patients treated with occlusal splints yielded similar results to those described by Kurita in 1999: two thirds of patients were free of pain but reported the recurrence of symptoms such as joint cracking or difficulty to open the mouth. These findings give rise to the following questions: What effect does an occlusal splint have? What has been improved by endogenous regeneration processes without any therapy? Many studies on the efficacy of splint therapy [37, 51, 108,170] have two major flaws: In most studies, the observation time is only a few months and hence too short, and they lack a control group (which would not be ethically acceptable). Nevertheless, it is an undisputed fact that many patients benefit from treatment with occlusal splints, for instance with regard to reducing myofascial pain. Dao and Lavigne thus called occlusal splints 'the crutches in the treatment of temporomandibular dysfunctions and bruxism' [37]. In view of the unproven efficacy of many splint concepts it is advisable to use only designs that do not permanently change oral structures such as forward displacement of the lower jaw or tooth migration. To what extent occlusal splints may have a long-term curative effect is currently the subject of intensive research. The effect of occlusal splints is that – due to brain plasticity – new neurological patterns and muscle functions may be memorized with the aid of the splint. The researches of both Kordaß [99] and Pimenidis [122] point in that direction. If occlusal splints are understood and used as a temporary medical aid for the treatment of craniomandibular dysfunctions, splints – similar to crutches – may help patients getting over acute problems. In the case of long-term changes in functional patterns, the wearing of an occlusal splint may also result in curative effects for the patient.

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### **Conflict of Interest**

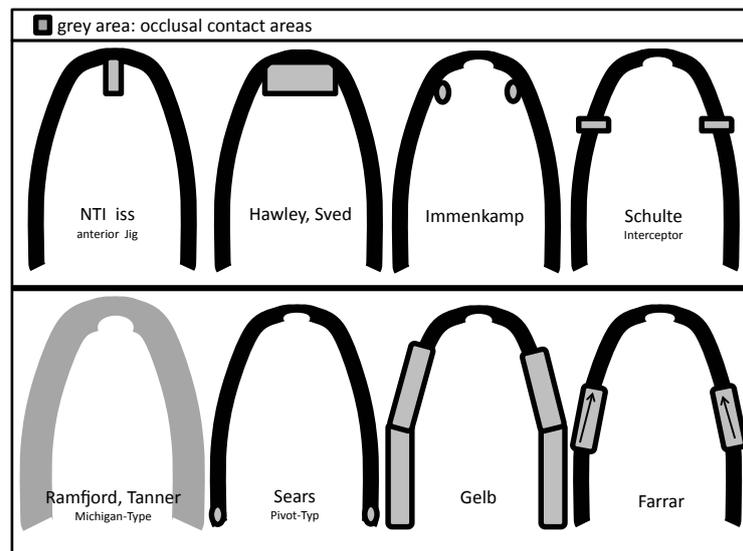
The authors state that they don't have any conflicts with interests.

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Consent was not required for this type of study.



**Fig.2** Occlusal contact areas of splints. Variations found within the last 120 years.

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