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DGFDT

S2k Guideline (Extended Version)

Instrumental Functional Analysis and Registration of Maxillomandibular Relationship in Dentistry

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The "guidelines" of scientific and medical societies are systematically developed statements designed to assist clinicians in making decisions in specific situations. They are based on current scientific evidence and good medical practice; they aim to ensure greater safety *in medicine while also taking economic aspects into account. As "guidelines" are not legally binding for clinicians, they have no legal effect as a basis for providing or refuting liability.*

Guidelines are subject to continuous quality control; at least every 5 years, new findings must be compared with the formulated recommendations for action. The current version of a guideline can always be found on the pages of the DGZMK (www.dgzmk.de) or the AWMF (www.awmf.org). If you have not downloaded the present guideline from one of the two websites mentioned, you should check again whether there is a more up-to-date version.

1 Contents

2 About this Guideline

In spite of the plethora of different examination techniques and instruments for dental functional analysis, action-steering guidelines were often lacking [474]. In 2015, the present guideline was published with the aim of providing a suitable reference work, particularly with regard to the classification and purpose as well as to the benefits and expected therapeutic consequences of the available techniques and tools of dental functional analysis [508]. A scheduled update of this guideline was performed in 2022.

2.1 Patient and Professional Target Groups

This guideline applies to all ambulatory patient groups receiving functional analysis and treatment for craniomandibular disorders, i.e., temporomandibular disorders (TMD). This guideline is intended for dentists.

2.2 About this Guideline Update

In addition to revising the content of all sections to reflect new study evidence, this guideline update includes two new sections: "Part 3 - Jaw Relation Recording" and "Part 4 - Facebow Transfer". Therefore, this version of the guideline supersedes the previous "Scientific Communication of the German Society for Prosthetic Dentistry and Biomaterials (DGPro, formerly DGZPW) on the aforementioned topics [327,517].

2.3 Key Questions

This guideline addresses three key questions:

(1) What is instrumental functional analysis in dentistry?
(2) What are the objectives of using specific methods of instrumental functional analysis in dentistry?
(3) What are the concrete benefits of using a given method of instrumental functional analysis in dental diagnostics and therapeutics?

Specific questions are also addressed in the individual chapters of this guideline.

2.4 Methodology

This publication was designed as a consensus-based S2k guideline in accordance with the specifications of the AWMF. The participating professional groups did not receive any financial or other support from commercial interest groups for the preparation of this guideline. A scheduled update of this guideline is to be performed 2027. For details regarding the methodology and editorial independence of this guideline, see the guideline report.

2.5 Editorial Note

The simultaneous use of male, female and other gendered language forms has been dispensed with in this guideline solely for reasons of better readability. This in no way implies any discrimination against respective other genders. Any gendered terms or pronouns used in this publication are to be understood as gender-neutral.

3 Preliminary Remarks

3.1 General Definition and Classification of Instrumental Functional Analysis in Dentistry

Instrumental functional analysis in dentistry is a term referring to examination methods in which special instruments and equipment are used to obtain a quantitative and/or qualitative functional assessment of the craniomandibular system. Such assessments may focus on various aspects of craniomandibular function, in particular, on the following five characteristics:

- Kinematic aspects of the mandible: mandibular movement recording and analysis (instrumental movement analysis) for articulator programming purposes and/or for functional assessment of the craniomandibular system,
- Condylar position
- Jaw relation (vertical and horizontal)
- Orientation of the dental arches relative to the skull/face and transfer of this information to an articulator / movement simulator
- Jaw muscle activity during specific mandibular postures, positions and/or movements as well as during complex tasks, such as chewing

This guideline on Instrumental Functional Analysis in Dentistry is divided into five parts reflecting these five areas of focus:

- Part 1: Instrumental Movement Analysis
- Part 2: Condylar Position Analysis
- Part 3: Jaw Relation Recording
- Part 4: Facebow Transfer
- Part 5: Surface Electromyography of the Masticatory Muscles – Dental Applications

4 Part 1: Instrumental Movement Analysis

4.1 Definition and Development

4.1.1 Definition

Instrumental movement analysis is a dental examination method used to record and evaluate functional movements of the mandible in patients with the aid of special systems for the registration of jaw movement ("recording systems"). Based on the assessment criteria, the dentist then analyzes the jaw motion recordings, which may include different movement sequences as well as a comparative analysis of different mandibular positions, and draws conclusions therefrom. These conclusions are related to diagnostic assessment of the function and structure of the masticatory system on the one hand, and to the occlusal and dental restorative aspects of treatment planning, treatment design, and masticatory system rehabilitation on the other.

Instrumental movement analysis must be distinguished from instrumental occlusal analysis [60,195,199,265,267,268]:

- **Instrumental movement analysis** captures functional movement with appropriate kinematic measurement systems and therefore focuses on jaw motion with tooth-guided and unguided movement components.

- **Instrumental occlusal analysis** deals mainly with specific aspects of jaw positions and movements, namely, occlusal parameters in static and dynamic occlusion. In these indications, it is generally performed using articulator-mounted study casts to visualize the occlusal situation. However, modern computer-assisted virtual articulators are increasingly used to visualize and analyze the occlusal situation by virtual simulation [261].

Such kinematic recordings can be combined with assessments of temporomandibular joint sounds (vibration analysis) or recordings of jaw muscle activity, in particular, activity of the masseter muscles and anterior temporalis muscles (kinematic surface electromyography) [216,260]. As mentioned before, the following information on instrumental movement analysis refers exclusively to purely kinematic aspects of jaw motion.

4.1.2 Development

In the field of dentistry, efforts to record and document mandibular movement intensified at the beginning of the 20th century [190]. Groundbreaking research in this field is associated with names like Gysi, McCollum, Stuart, Schröder and Gerber and was mainly carried out using mechanical recording systems. In addition to research-related aspects, these studies aimed to optimize the occlusal design of prosthodontic work to produce optimal dental restorations for the individual patient. Jaw motion recordings provide the patient-specific values needed to adjust the guiding elements of the articulator for this purpose (articulator programming) [49,65,82,171,280,281,368,369,386]. Since the 1970s, the recording of mandibular movements has become increasingly important for assessing the mobility and coordination of the mandible as well as the position and stability of the mandible at different starting positions relative to different excursive movement sequences [122,216,285]. Studies that examined the role of structural intra-articular changes in the temporomandibular joint (TMJ) in the development of functional disorders focused on this additional functional diagnostic aspect of mandibular movement recordings and used it as the basis for planning occlusal therapeutic interventions to treat these dysfunctions [111,377].

Building on developments in the 1970s and 1980s, increasing efforts have been made to reduce the sometimes high time, equipment and labor requirements associated with the use of mechanical recording systems [457], and to develop electronic measurement systems capable of improving the quality and practicability of mandibular movement recordings while at the same time increasing the accuracy and ease of interpretation of the recordings. Electronic devices for use in dental applications that make it possible to record and analyze mandibular movements based on various measurement technologies have been available for many years [15,41,104,260,321]. These motion analysis systems specifically designed for dental applications are essentially similar to those used for movement- and postural-related functional diagnosis in other areas of the musculoskeletal system, such as gait analysis in the orthopedic-surgical context or instrumental analysis methods in rehabilitation medicine, occupational medicine, and sports medicine [31,335,527].

In extraoral applications, the various practicable electronic measuring systems record mandibular movements by means of sensors positioned near the TMJ (near the condyles), near the incisors of the mandible, or near the occlusal plane, as needed. The following measuring system groups can be distinguished (modified according to [195]):

- Extraoral contact-based systems measuring near the TMJ
- Extraoral contact-free systems measuring near the TMJ
- Extraoral contact-free systems measuring near the occlusal plane
- Extraoral contact-free systems measuring near the incisors
- Intraoral contact-based measuring systems
- Intraoral contact-free measuring systems.

By recording all six degrees of freedom, these systems are able to calculate any desired points on the mandible [190,194,195,259,328].

4.2 Objectives

4.2.1 Main Aims of Instrumental Movement Analysis

Recommendation 1: Main aim of instrumental movement analysis (amended in 2022)	
The aim of instrumental movement analysis of the mandible **should be** to obtain additional information on one or more of the following items: • Individual patient-specific values with the aim of adjusting and optimizing dental and dental laboratory procedures to the specific functional characteristics of the individual patient (individual adjustment or programming of articulators and/or simulation of jaw movements). [Vote: 12 Yes / 0 No / 0 Abstain] • Clarification of dysfunctional movement-related findings in the context of function-oriented diagnostics (functional diagnostics). In the diagnostic process, instrumental movement analysis is an additional diagnostic procedure performed to obtain additional information that builds on the clinical functional analysis and facilitates the establishment of a clinically based diagnosis (qualitative aspect). Furthermore, it allows for differential assessment of the extent and severity of functional impairment (quantitative aspect). [Vote: 12 Yes / 0 No / 0 Abstain] • Evaluation and documentation of changes in movement-related parameters over time after the initiation of treatment measures, particularly in the scope of functional therapy. In the therapeutic context, instrumental functional analysis of mandibular movement provides reference points for the improvement of functional processes and documents functional changes over the course of treatment. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

4.2.2 Specific Objectives

In view of the constantly evolving digital workflows in restorative dentistry, instrumental functional analysis can be regarded as an important supplementary method of simulating the individual functional movements of the mandible to facilitate the occlusal design of dental restorations fabricated by the computer-assisted design and manufacturing (CAD/CAM) process [261,265]. The use of electronic systems for instrumental functional analysis makes it possible to generate individual patient-specific data for realistic simulation of tooth guided movements needed for the CAD/CAM manufacturing process [198].

Recommendation 2: Value of clinical functional analysis (reviewed & approved without change)	
In the field of dental functional diagnostics, instrumental movement analysis is based on clinical functional analysis. Clinical functional analysis is the first step in evaluating the functional status of the masticatory system in patients with functional disorders of the masticatory system and therefore **should** be performed prior to instrumental movement analysis. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
References: [104,260]	

In addition to documenting and evaluating subjective symptoms reported by the patient (especially pain but also restricted range of motion and disturbing joint sounds), it is crucial for the dentist to document clinical signs in order to objectify the subjective. This is important for two reasons: First, this is fundamental to a diagnostic process that enables one to identify the correct clinical diagnosis. Second, it allows the dentist to compare and contrast the patient's subjective impressions with the objective findings, which pro-vides important impulses (demonstration, motivation) at the patient-physician interaction level in the course of treatment. Instrumental movement analysis supplements and specifies the objective findings. In the case of mandibular movements, it allows for a differentiated assessment of functional status in qualitative and quantitative terms [266]. Therefore, instrumental movement analysis is *not* intended to *replace* clinical functional analysis or to make the diagnoses derived from it redundant, but rather is conceived as a method that specifically expands the examination of the masticatory system from the perspective of mandibular mobility (jaw movement capacity, coordination, and occlusal centricity) [13,14,192,198].

Nomenclature and Terminology:

The terms "functional disorders of the masticatory system", "craniomandibular dysfunction" (CMD) and *"temporomandibular disorders"* (TMD) are commonly used [197]. However, they are not synonymous and should not be used interchangeably to denote different musculoskeletal disorders in the craniofacial region because of their emphasis on two different clinical aspects that are related but different in terms of form and extent: dysfunction (CMD) and pain (TMD). Myoarthropathy of the masticatory system should thus be classified as a form of TMD. One example of a possible interaction between dysfunction and pain is that in patients with long-term pain, motor adaptation to pain may develop which may not disappear spontaneously after the elimination of pain due to the persistence of manifest changes at the structural level. Additionally, dysfunctional motor adaptation is to be expected in patients with certain functional impairments (e.g., tooth loss, elongation or migration), which are considered relevant from a prosthetic-restorative perspective [192].

Recommendation 3: Indications for instrumental diagnostics (reviewed & approved unchanged)	
Instrumental diagnostics and follow-up **may** be indicated in patients with impaired function (dysfunction). This also applies to biomechanical adjustment of the dentition of adults in the context of orthodontic and/or orthodontic-surgical treatment measures. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Recommendation 4: Instrumental movement analysis is not a method of pain assessment (reviewed & approved without change)	
Instrumental movement analysis is not a method of pain assessment and **should not** be used as such. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Instrumental movement analysis is not a method of "objectifying" or treating pain, but rather is used to assess the effects of orofacial pain on functional movement of the jaw. Moreover, it helps to elucidate possible associations between pain and functional capacity at the diagnostic level as well as the treatment follow-up level [15,482,483].

Statement 1: Objectives of instrumental movement analysis of the mandible (amended in 2022)	
Like clinical functional analysis, instrumental movement analysis performed in the context of dental functional diagnostics and therapy enables detailed identification and assessment of the extent of functional impairment for both the patient and the dentist based on specific parameters (movement capacity, coordination, occlusal stability and joint-related centering). [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

During the treatment phase (functional therapy), instrumental movement analysis can also be used as a feedback method to increase the involvement of the patient in the treatment process. Instrumental movement analysis can be used to visualize and monitor changes in functional capacity or functional efficiency; it is useful in clinical decision-making regarding issues concerning additional and/or supplementary measures in the scope of functional diagnostics and therapy or regarding the occlusal design in the scope of dental-restorative procedures [192,356,436].

4.3 Clinical Utility

4.3.1 Validity and Clinical Reliability of Electronic Axiography Systems

The currently available evidence based on data from appropriate studies regarding the validity and/or clinical reliability of electronic axiography systems for recording mandibular movement is presented below (for references, see sections on "validity" and "clinical reliability").

Validity: Based on the identified studies, it is determined that the maximum mean deviation of the hinge axis points calculated using electronic axiography systems is generally ≤ 2 mm. The mean deviation for distances is ≤ 0.3 to 0.5 mm, but hardware and/or software improvements for more optimal positioning and alignment of sensors and the use of correction algorithms will reduce the mean deviation to ≤ 0.1 to 0.2 mm. The mean maximum deviation of the angle values (especially sagittal condylar inclination and Bennett angle values) is estimated at ≤ 3 to 5 degrees.

Clinical reliability: Basically, every type of movement –regardless of whether related to incisal or condylar movement – exhibits natural biological fluctuations in terms of both intra- and inter-individual variability. Motion recordings made during a single appointment generally show better agreement than those made on different examination dates. As in all tests performed by humans, the type and level of training and experience with the examination method on the part of both the subject/patient and the examiner influence the degree of variation of the collected movement data. The current functional status of the masticatory system (normal function versus craniomandibular dysfunction of variable severity) also influences the reproducibility and/or range of variability of executed movements. Due to increased neuromuscular influences, opening and closing movements usually exhibit greater variability of movement patterns and greater variance of path length than tooth-guided and, thus, occlusally determined protrusive and lateral movements. Regarding condylar parameters, sagittal condylar path inclination values show greater intra- and inter-session agreement than Bennett angle values.

Recommendation 5: Recording movement sequences multiple times (reviewed & approved without change)	
Individual movement sequences **should** be recorded multiple times in order to distinguish random effects (qualitative and quantitative) from fixed effects. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**

Expert consensus

Statement 2: Reliability of mandibular movement recordings (amended in 2022)	
All in all, if acquired in consideration of system- and examination-related effects and with knowledge of physiological processes and evaluated together with the patient history and clinical findings, mandibular movement recordings are reliable enough to depict the movement capacity of the temporomandibular joints, both simultaneously and individually. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

4.3.2 Criteria for the Evaluation of Mandibular Movement Recordings

Recommendation 6: Analysis based on the DGFDT criteria (Consensus Paper) (reviewed & approved without change)	
Analyses of functional movement of the mandible **should** be based on the criteria specified in the Consensus Paper of the German Society of Craniomandibular Function and Disorders (DGFDT)[1] (summarized in a criteria matrix). [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Statement 3: Collection of data for articulator adjustment (reviewed & approved without change)	
Instrumental movement analysis can be used to collect the following data for the adjustment of an articulator or the programming of a motion simulator (parameters of dynamic function): • Sagittal condylar path inclination angle (angle of protrusive excursions) • Bennett angle (angle of mediotrusive excursion) • Immediate side shift (form of mediotrusive excursion)	**Strong consensus**

[1] "Expert statement for developing diagnostic criteria for dysfunction: Functional movement of the mandible – concept for structuring criteria for analysis and for standardizing computer-assisted recordings" (Consensus Workshop of the Working Group for Masticatory Function and Oral Physiology on 16 November 2012 at the 45th Annual Meeting of the DGFDT in Bad Homburg, Germany) [192].

• Sagittal and frontal anterior guidance angle [Vote: 12 Yes / 0 No / 0 Abstain]	
Expert consensus	

Statement 4: Other evaluable aspects of jaw movement function (amended in 2022)	
Instrumental movement analysis can also be used to evaluate the following aspects of jaw movement function for diagnostic and follow-up documentation purposes – assuming the use of appropriate measurement systems and standardized examination protocols: • **Movement capacity**, to determine the extent of maximum movement capacity of the mandible • **Coordination** of the sequence of movements at a given measurement site and relationship between the right and left side of the mandible • **Occlusal and joint-related stability**, to determine the reproducibility of the starting or reference position of the mandible. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Recordings of mandibular movement acquired during mastication (kinematic chewing function analysis, sometimes in combination with electromyography) can also be used to obtain data on specific parameters for characterization of masticatory function – taking into account the special conditions required for this (standardization of the bolus, etc.) – including: chewing frequency, duration of the chewing sequence, number of chewing cycles, duration of chewing cycles, and cumulative incisal path length during a chewing cycle [192,195].

The analysis of movements recorded near the TMJ (so-called condylar paths, which mainly refer to opening and closing movements and/or protrusive movements) also allows the investigator to draw diagnostic structure-related conclusions about the intra-articular situation, particularly the disk-condyle relationship [40,190,259,377].

4.3.3 Structure-related Diagnostic Potential of Mandibular Movement Recordings

Condylar path tracings are fundamentally different from incisal path tracings in terms of the diagnostic potentials of the mandibular recordings. *Condylar* path tracings have higher specificity than sensitivity, and yield detect true-negative results for internal derangement of the TMJ at a higher rate than true-positive results. In other words, the probability of a false-positive result is significantly lower than that of a false-negative result. In addition, the range of sensitivity values is considerably larger than that for specificity. If the sensitivity and specificity values for diagnostic accuracy are combined (quotient of the number of true positive and true negative results divided by the total number of results), the average values fall in the range of around 0.7 to 0.8.

Unlike *condylar* path traces, *incisal* path-based findings of deviation and deflection generally exhibit low to moderate sensitivity, specificity and accuracy. Likewise, incisal movement-based findings of sudden velocity changes show high sensitivity but very low specificity, resulting in a high probability of false-positive results, especially with this criterion [308]. Diagnostic reliability can be improved by selectively combining incisal and condylar path variables [266].

Based on *condylar* movement recordings, one can –with certain restrictions – draw conclusions about intra-articular conditions, especially regarding condyle-disc relationships and, to a limited degree, articular structural conditions. These limitations are related to the fact that the conclusions drawn from condylar movement findings are subject to uncertainty and to a higher probability of false-negative than false-positive results because the sensitivity of the method is lower than its specificity.

Recommendation 7: Limitations of purely incisal path-based diagnostics (amended in 2022)	
The diagnosis of joint disorders based solely on *incisal* movement abnormalities is associated with a higher risk of misdiagnosis than diagnosis based on *condylar* path findings and thus **should not** be performed in clinical practice. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Recommendation 8: Use of instrumental movement analysis for screening (amended in 2022)	
Due to its high complexity and low sensitivity, instrumental movement analysis **should not** be used as a screening method for intra-articular disorders. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

4.3.4 Patient Benefits and Therapeutic Consequences of Movement Recordings (Summary)

Statement 5: Implications of movement analysis for restorative and prosthetic dentistry (*NEW* in 2022)	
Individual values for dynamic function parameters (see Statement 3) are determined in mandibular movement recordings, especially of protrusive and lateral jaw movement, for *articulator adjustment* and *motion simulator programming* with the aim of planning, adjusting and optimizing dental procedures and dental laboratory processes based on the individual functional characteristics of the patient. [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

The purpose of transferring patient-specific individual values to the articulator or motion simulator is to make the movements simulated by the device (articulator or movement simulator) match the true patient movements as closely as possible. The purpose of this is to minimize the need for the correction of occlusal errors when dental prostheses made by the dental laboratory are inserted in the patient's mouth, among other things. When the occlusal surfaces of the work from the dental laboratory are optimally tailored to the actual functional conditions and biomechanical requirements of the individual situation, the patient can more easily adjust to the prosthesis [13,192,371].

Statement 6: Implications of movement analysis for functional therapy (*NEW* in 2022)	
Concrete conclusions *for dental functional therapy* can be drawn from patient-specific findings gathered in instrumental movement analysis based on the following key assessment criteria, • Movement capacity, • Coordination and • Occlusal and joint-related stability (see Statement 4). [Vote: 12 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Although the conclusions drawn from instrumental movement analysis can basically be determined by means of clinical functional analysis with or without manual structural analysis, as needed, instrumental movement analysis allows a more differentiated analysis (location of impairment at the condylar and/or incisal level), a more detailed and precise assessment (of extent, severity and temporality) and, last but not least, a metric assessment of the results [13,14,192,193,195,263,264]. Added value can be achieved by using instrumental movement analysis, for example, for analysis of:

- Limited jaw mobility (limitation)
- Excessive jaw mobility (hypermobility)
- Conspicuously altered or impaired coordination of mandibular movements (side-to-side comparison during opening and closing movements and lateral excursions)
- Occlusal and/or condylar instability.

5 Part 2: Condylar Position Analysis

5.1 Definition and Development

5.1.1 Definition

Condylar position analysis is a method of three-dimensional comparative analysis of condylar position relative to defined mandibular positions.

Three types of systems are used for condylar position analysis:

- Tomographic imaging systems,
- Indirect measurement systems (mechanical and/or electronic) consisting of a stationary measuring device and mounted models
- Direct patient-based measurement systems (electronic measuring devices are most commonly used today).

In *dentate patients*, the aim of condylar position analysis is to detect discrepancies between the maxillomandibular relationships determined with: (1) manual guidance by the dentist (the non-tooth-dependent mandibular position limited in the posterior-cranial, cranial and/or cranio-anterior direction) and (2) the position of the condyles in maximum intercuspation. This allows the dentist to determine the physiological range of variation of condylar position and to determine which mandibular positions might be suitable starting position for dental restorations.

5.1.2 Development

The principle of condylar position analysis was first described by Thielemann [471] in 1939, by Posselt [363,364] in 1957, and by other investigators in the years that followed [133,294,296,302,417,437]. With the early systems, condylar positions were determined indirectly using modified articulator-like devices with mechanical gauges positioned in the area of the jaw joints. Today, computer-assisted electronic condylar position measuring instruments can be used to perform the corresponding distance measurements either indirectly (on the articulator) [493,501] or directly (on the patient) [19,320,521].

Condylar position analysis was and is still used in research, for example, for descriptive analysis of variance between different mandibular movement recording systems in terms of reproducibility of condylar positioning. Historically, this mainly focused on the posterior border of the condyles (condylar retruded contact position), and this still applies today for centric condylar position (centric relation) [516]. Another aim was to identify the cause of functionally related complaints based on the significance of condylar deviation from the norm [221,303,424,442]. Against this background, one of the goals of condylar position analysis was to identify or at least narrow down “physiological (“correct”) versus “pathological (“incorrect”) positions of the mandible.

In clinical practice, the method is still used for qualitative and quantitative evaluation of the reproducibility of recordings (especially of centric condylar position), and for comparison with the position of the mandible determined by the teeth (see section 6.2). It is also used to determine spatial changes in mandibular/condylar position over the course of treatment. Condylar position analysis, like other procedures, is performed supplements functional analysis, allows for a more comprehensive assessment of functional status, and makes it possible to adjust treatment as needed.

5.2 Objectives

Describing the position of the condyles is key to evaluating the position of the mandible in relation to the skull. In completely and partially dentate patients with sufficient zones on antagonist tooth support, the maximal intercuspal position determines the position of the condyles in the glenoid fossae during jaw closure in via their occlusal contacts in static occlusion, i.e., maximal intercuspal position.

Statement 7: Practical implications of condylar position discrepancy (*NEW* in 2022)	
Knowledge about the position of the condyles in maximal intercuspation and on the magnitude and direction of deviation from border position of the condyles in the joint space is needed for different reasons. First, it plays a role in determining the presence and extent of deviation from the normal range. Second, this knowledge is needed to evaluate, describe and define the therapeutic position of the mandible in a given case. Third, condylar position analysis enables the detection of changes in mandibular position over the course of treatment (e.g., occlusal splint therapy). [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Direct visualization of the condyles is not possible because they are embedded in and covered by adjacent tissues. The position of the condyles relative to the neighboring tissues can only be determined indirectly by means of imaging techniques such as lateral cephalometric radiography, transcranial radiography, computer tomography (CT), cone-beam computed tomography (CBCT), high-frequency ultrasound (HFUS), and magnetic resonance imaging (MRI). Another approach is to attempt a direct comparative analysis of the change in position of the condyles using measuring devices attached to the patient (see above) in order to draw conclusions about the condylar positions and make an assessment.

Alternatively, when using indirect methods with stationary measuring instruments, position changes of the articulator condyles can be examined in combination with mechanical or electronic measuring systems independently of the patient (after making the necessary study casts and photographs).

The results of condylar position analysis consist of comparative, relative metric statements about spatial distances (differential measurements).

5.2.1 Methods of Describing Condylar Positions and their Assessment

A common feature of all methods of condylar position analysis is that a reference position must first be defined with which later condylar position measurements can be compared and their relative deviation from the reference position determined.

- *In dentate patients*, the condylar position at maximal intercuspation (determined by the hard tooth structure) and the centric condylar position (defined as the tissue border) generally serve as the reference positions [506].
- *In edentulous patients*, the natural maximal intercuspal position is lost as soon as the essential zones of antagonist tooth support are lost. Hence, the original maximal intercuspal position can no longer be identified in edentulous patients. However, even if a patient is completely toothless (and considering the entire range of motion of the mandible), the posterior-superior border position of the condyles in the fossae can still be identified with acceptable reproducibility. This position of the condylar heads is defined as centric relation (see section 6.2.1).

The term "centric relation" has been re-interpreted many times over the years [3–9,231]. Consequently, the definition of fundamental clinically and practically significant reference positions is to this day limited to theoretical considerations and descriptions. However, a concept has emerged in the international literature that if MIP no longer exists, a cranial-ventral posterior position should be used as the restorative starting position instead of a forced manually guided ("retruded") posterior mandibular position [9,15,59,447,485].

5.2.2 Imaging Techniques Used for Condylar Position Measurement

Statement 8: Conventional radiographic methods in condylar position analysis (*NEW* in 2022)	
Conventional radiographic techniques are unsuitable for condylar position analysis in the context of jaw relation recording for dental functional therapy and restorative dentistry. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Magnetic resonance imaging (MRI) allows for three-dimensional analysis of condylar position, but the accuracy of the determined positions is, to say the least, limited because the image resolution of this technology is sometimes insufficient for *exact* determination of condylar position with *MRI alone* (see [352] and the new edition of the AWMF guideline on the use of cone-beam computed tomography in dentistry (https://www.awmf.org/leitlinien/detail/ll/083-005.html). The need for the patient to hold the mandible in the required position for a relatively long time during MRI is another potential limitation. Moreover, standardized reference point specifications are lacking. Studies in symptom-free adults have shown that there is no “standardized position” of the mandibular condyles relative to bony landmarks, even when the teeth are in maximum intercuspation [248,373,374]. Ultimately, discrepancies between centric relation and maximal intercuspal position (CR-MIP discrepancies) cannot be measured with sufficient accuracy [174,282]. Dependence of the tomographically depicted condylar position on the layer depth of the imaging technique was also observed [485].

These limitations have led to high standard deviations in numerous studies [23,44,141,149,174,199,208,211,230,298,299,318,450,486,487,544]. Additionally, the guideline authors foresee significant problems with the transfer of a radiographically acceptable position to clinical practice.

The fact that all radiographic procedures are unable to visualize the cartilage covering the mandibular condyles and glenoid fossa is problematical. The idealized notion of a concentric position of the condyles and a uniform radiographic width of the temporomandibular joint space persisted in older studies because distance measurements were made by measuring the distance between bony surfaces and the cartilage covering attributed to the joint space. In MRI-sequences (which capture the cartilage coverings), volunteers with healthy temporomandibular joints exhibited a mean concentric position of the condyles in maximal intercuspal position, whereas disk displacement with reduction (DDR) was associated with reduction of the posterior joint space, and disk displacement without reduction (DDNR) presented with reduction of the anterior and posterior joint spaces [378]. Due to the error-prone nature of joint space measurement and the reliability of direct MRI diagnostics, there is no indication for the use of diagnostic radiographic imaging for the indirect diagnosis of disk displacement based on a dorsally eccentric position of the condyles [44,208,253,300,318].

Recommendation 9: Value of imaging techniques for assessment condylar position discrepancy (amended in 2022)	
Based on the available evidence, it is concluded that in clinical practice, imaging techniques, particularly those involving the use of ionizing radiation, **should not** be used to determine the position of the mandibular condyles *instead of* direct or indirect techniques of dental condylar position analysis. [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

5.2.3 Indirect Condylar Position Measurement Using Articulators or Stationary Condylar Position Measurement Instruments

Studies on the reproducibility of condylar position measurements made using commercial stationary measuring systems are available [37,521]. However, to the best of our knowledge, there is still only one study investigating the important question of agreement between direct patient-based measurements and indirect measurements collected using an articulator or stationary condylar position indicator [153].

Indirect measurement of the reproducibility of MIP in the condylar area

In spite of its great practical importance, the reproducibility of maximal intercuspal position has not been widely studied to date. According to the available data, the repeatability of MIP is approximately 0.1 to 0.2 mm [87,219,515,553]. In addition to articulator-based indirect electronic measurements or patient-based direct measurements with head/mandible-related registration bows, recently developed digital vestibular intraoral scanning systems can now be used to clarify this question. Virtual models provide the basis for these methods. The accuracy of the methodology *per se* is very high (about 50 µm [219,440,553]), so digital scans are able to depict the occlusion [334]. However, intraoral scans do not appear to achieve good accuracy across the complete dental arch [528–531]. Furthermore, it should not be overlooked that the indirect methods for the fabrication of tooth replacements involve different intermediate steps, which invariably have much lower limits of reproducibility (spatial reproducibility in the condylar area: ca. 0.1 to 0.2 mm [168,207,375,415,515,521]).

Indirect measurement of CR-MIP discrepancy

Articulator-based condylar position analysis is a method by which multiple measurement values can be determined and averaged to obtain an estimate of centric relation-maximum intercuspation discrepancies between individuals in a population sample. The distances in the condylar area range from 0.2 to 0.8 mm, depending on the study results, but approximately 10% of the population showed no measurable or statistically significant differences between these border positions [11,12,17,23,42,56,80,81,83,89,90,93,125,126,132,153,163,179–181,183,272,283,287,291,361,382,388,389,395,402,428,446,468,479,489,505,511,517,537,546,547]. When interpreting such measurements, one should take into account that the registration-related positions of the dental arches increase the measured values by projection in the joint area whereas at the same time, no limitation of condylar movements occurs in the articulator [115]. Precision of the records is thus an important factor.

5.2.4 Direct Measurement of Condylar Positon on the Patient

It can be assumed that the accuracy of direct electronic measurements obtained using head/mandible-related registration bows attached to the patient is slightly higher than that of indirect measurements obtained via several intermediate steps using study casts mounted on an articulator. Accordingly, studies of the reproducibility of MIP with direct measurement proximal to the condyles showed maximum variations of only 20 to 30 µm in the three spatial directions in some cases [47,48]. Moreover, direct electronic measurement systems offer additional possibilities for interpretation because they can detect immediate effects that only occur during occlusal contact.

However, unintentional changes in the position of the recording bow may occur due to changes in instrument position, head movement or muscle movement. This can lower the expected reproducibility of this method [39,42,46,288,447,448,479,505–507,521]. Another factor to remember is that even if a patient's individual hinge axes in CR are determined, errors of interpretation of condylar positions and movements may occur because centric hinge axes cannot represent all movements of the condyles [315–317].

This is why the articulator is still a useful and necessary tool for the dental assessment of occlusal relations. When using the direct method of patient-based condylar position measurement, this means that the same models and records as those required for indirect measurement using stationary measuring instrument are still required to transfer the measured changes in position (e.g., in centric relation) to the articulator in a dimensionally accurate manner.

5.3 Clinical Utility

Statement 9: Utility of condylar position analysis (reviewed & approved without change)	
In patients with tooth support in four quadrants, condylar position analysis is useful for the following assessments: 1. Quantitative and qualitative analysis of deviation of individual condylar reference positions from each other referring, in most cases, to discrepancy between centric relation and maximal intercuspal position (habitual occlusion), 2. Reproducibility of maximal intercuspal position, as determined in multiple repeat measurements, 3. Reproducibility of centric relation (centric condylar position), as determined in multiple repeat measurements, 4. Direction of displacement of reference positions relative to each other and distance between, 5. Reproducibility of condylar positions determined using different registration methods and materials, 6. Condylar position monitoring over the course of treatment. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Condylar position analysis also plays an important role in research. It can be used, among other things, to study the "distribution" of condylar positions in populations of sufficient size in order to develop and/or confirm the validity of clinical treatment concepts.

Statement 10: Diagnostic value of condylar position analysis (amended in 2022)	
The available evidence shows that condylar position analysis generally satisfies the methodological requirements for validity and reliability. However, the diagnostic value of condylar position analysis is ultimately dependent on the quality and reproducibility with which the respective condylar *positions* can be determined. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus (summary: [485,511])	

5.4 Summary

The mechanics of the occluding dental arches determines the position of the mandibular condyles. Consequently, **maximal intercuspal position** can be established with greater accuracy (ca. 0.1 mm) than centric relation on the patient as well as on castes mounted on the articulator**.**

The accuracy of the determined **centric relation**, an important reference position in a joint with a great "degree of freedom", will be lower: in the best case, ca. 0.2 mm in *direct measurements on the patient*, and ca. 0.3 mm in indirect measurements on the articulator (see section 6.2). Since this magnitude of error is inherent to all of the available methods, the significance of values less than approx. 0.5 mm in condylar position analysis can hardly be interpreted, not even with a very precise approach.

Statement 11: Conclusions drawn from condylar position analysis (amended in 2022)	
Clinical functional analysis is the prerequisite for comprehensive interpretation of the results of condylar position analysis. Condylar position analysis *alone* cannot provide any information needed to interpret a clinical situation. No invasive dental restorative treatment, orthodontic treatment or maxillofacial surgery can be justified based on the detection of condylar position discrepancy *alone*. Without suitable verification from imaging studies, it generally is not possible to unambiguously determine which concrete anatomical, condylar structures the right and left posterior reference positions used in condylar position analysis refer to in a given case. Without precise knowledge about the reference points, statements about presumed "condylar displacement" or "compression and distraction phenomena" in the joint area (mentioned here simply as examples) are merely speculative and should, at best if at all, be framed as a suspicion. [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

6 Part 3: Jaw Relation Recording

The subject of jaw relation recording has already been discussed in numerous scientific publications in the literature [500,508,517]. The content of these publications will be amalgamated and updated in this guideline.

6.1 Vertical Jaw Relation Recording

6.1.1 Definitions

The term *vertical jaw relation* is defined based on the following maxillomandibular relationships [9,15]:

> ***Occlusal vertical dimension (OVD)***: lower facial height when in maximal intercuspal position (static occlusion) or physiologic rest position (*syn.*: vertical dimension of occlusion, VDO)

> ***Maximal intercuspal position (MIP)***: the position of the jaws when the teeth are in maximum intercuspation and the mandible is not moving (*syn.*: intercuspal position, maximum intercuspation, static occlusion)

If jaw closure in maximum intercuspation is lacking stable support in the vertical dimension due to large edentulous spaces (see section 6.2.4), which is the case in all completely edentulous patients and in some partially edentulous individuals, the conditions needed to define the vertical dimension of occlusion via the mandibular and maxillary dentition are lacking. In these cases, the lower facial height must be determined via the *physiologic rest position* (vertical dimension of rest, VDR). In fully dentate patients, the physiologic rest position is a measurable (but quite variable) three-dimensional distance from the maximum intercuspal position.

> ***Physiologic rest position***: characterized by involuntary separation of the mandible and maxilla when the patient is resting comfortably in an upright position of the head and body (*syn.*: vertical dimension of rest, rest vertical dimension).

When the mandible of a fully dentate patient or denture-wearer with prosthetic intercuspation is in the physiologic rest position, the opposing teeth are not in contact. This space between the occlusal surfaces of the maxillary and mandibular teeth can be measured and defined as follows:

> ***Interocclusal distance***: space between the posterior maxillary and mandibular teeth when the mandible is in physiologic rest position or when the teeth are separated by the closest speaking space (*syn*.: interocclusal rest distance, freeway space).

> ***Closest speaking space***: closest distance between the occlusal surfaces or incisal edges of the maxillary and mandibular teeth during rapid speech.

6.1.2 Objectives

In the context of restorative dentistry, the aim of recording jaw relation is to establish a stable and tolerable (functional and esthetic) position of the mandible in relation to the maxilla in all three spatial dimensions.

6.1.3 Development, Influences and Procedures

If only a few individual teeth are restored in a healthy masticatory system, this generally does not affect the existing occlusal vertical dimension. This dimension is individually determined by the natural teeth and their interocclusal contact (see section 6.2.4).

By definition, the occlusal vertical dimension will remain unchanged in the presence of severe tooth wear in one or both dental arches in a fully dentate patient. Extensive loss of occlusal relief, dentin exposure on the occlusal and/or incisal aspects of the teeth, and a change in maximal intercuspal position frequently occurs over the course of time. In these cases, the OVD may gradually decrease over time due to the wearing away of tooth substance. If there is some reason why these teeth cannot be restored in a simple manner (e.g., because tooth preparation would result in an inadequate height of remaining tooth substance for crown restoration), then restoration in conjunction with bite-raising (OVD increase) is often the only option. However, it is always necessary to change both the vertical and the horizontal dimension of occlusion in these cases. Hence, the patient's baseline MIP will also be lost as a result of the intervention and will also have to be redefined (see section 6.2.4). OVD adjustment is therefore referred to as the "three-dimensional correlation" of maxillomandibular relationships, which is particularly obvious in edentulous patients. This is "one of the most important tasks in practical dental reconstructive and functional therapy" [484].

The beginning of the last century marked the start of development of fixed prosthetics procedures. In those days, the fabrication of dental prostheses mainly pertained to *full* denture construction. This explains the extensive focus on the problems of restoring vertical dimension during this period. Thus, many proposals for restoring vertical dimension with complete dentures have been put forward over the course of time.

Physiologic rest position

When it is necessary to alter or adjust the occlusal vertical dimension, the *physiologic rest position* (rest vertical dimension) plays a particularly important role: In fully dentate subjects, it is related to the maximum intercuspal position via the interocclusal distance, and it must be readjusted in edentulous patients as well. The aim of past and present research is to transfer the distances measured in test subjects to patients. Reflecting the importance of this, there are countless studies providing data on interocclusal distance measurements in dentate subjects. According to these studies, the size of this so-called “freeway space” is 1-3 mm on average (range: 0.5-10 mm) [29,33,130,189,205,275,324,336,347,406,472, 473,522].

“Relaxed closed lip posture” is generally required for the mandible *to assume the physiologic rest position* [312]. Therefore, when the mandible is in the physiologic rest position, the lips are closed, blocking the view “between the teeth”. As a consequence, the interocclusal space cannot be measured without sophisticated instruments. To solve this problem, some colleagues attempt to visually transfer the patient’s interocclusal distance to an extraoral model to enable an evaluation. A common approach is to place a mark on two anatomic landmarks (e.g., one on the tip of the nose and one on the chin) and measure the vertical distance between them with calipers or a ruler. However, the measured extraoral distance may deviate from the intraoral interocclusal distance because the extraoral marks are placed on soft tissues that are generally subject to displacement by the underlying muscles during jaw closure [74,101,151,314,477]. This is particularly true of marks placed on the tip of the chin, which are often greatly displaced by orbicularis oris muscle movement during jaw closure. When using this method, one should therefore watch the orbicularis oris muscle region carefully during jaw closure in order to detect any potential displacement of the marks due to movement of the perioral muscles. Increasing the occlusal vertical dimension does not always have an effect on esthetics [151,344].

In edentulous patients, it makes a difference whether dentures are worn or not: When dentures are inserted, the base acrylic and the dental arch constrict the tongue, narrowing and stretching it in the vertical direction. The mandible is inevitably displaced caudally, increasing the distance to the maxilla (1 ± 3.5 mm more) [131]. Therefore, it is advisable to use occlusion rims or dentures when determining the physiologic rest position (rest vertical dimension) whenever possible. This can also be achieved (to a limited degree) using a thickened upper maxillary plate.

Studies by Ott [347] and our own observations have shown that the following three methods can *identify the physiologic rest position* with sufficient repeatability and reproducibility:

- Closest speaking space
  (interocclusal space, mean: 2.6 mm [0.2 - 6.8])
- Lip closure after jaw opening
  (interocclusal space; mean: 2.1 mm [0.6 - 3.9]).
- Allowing the mandible to relax from maximum intercuspation
  (interocclusal space; mean: 1.3 mm [0.4 - 3.5]).

It is generally possible to increase the occlusal vertical dimension permanently without long-term health implications. The OVD is raised not only when fabricating dentures for edentulous patients [172,173,460], but also when making fixed prosthetic restorations for dentate subjects (see section 6.1.4). In some patients, an OVD increase is imperative due to space constraints impeding the insertion of dental prostheses.

Statement 12: Clinical value of physiologic rest position determination (*NEW* in 2022)	
A fundamental problem is that the *physiologic rest position of the mandible (vertical dimension of rest) is subject to very large, biologically determined influences* and therefore must only be used as *one* of multiple assessment parameters and must always be interpreted critically. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
References: [25–27,29,70–72,120,130,131,172,173,251,274,309,341,362,365,367,398,405,426,460, 461,472,488,539,540]	

Closest speaking space method

In the middle of the last century, Pound [366] and Silverman [430,431] observed that when the consonant S is pronounced, a slight space forms between the opposing maxillary and mandibular teeth (interocclusal space), and that this “*closest speaking space*” can be used as a phonetic means for determination of vertical dimension. Their studies have been confirmed many times. The closest speaking space is 1-3 mm and (like the rest vertical dimension) but may range from 0.5 to 10 mm; however, small spaces predominate [36,61–63,79,135,185,189,325,347,396–398,400,406,443,455].

The closest speaking space is of particular functional significance for the re-establishment of occlusal vertical dimension: If the prosthodontist increases vertical dimension beyond this amount, the teeth will always come in contact with each other during speech, making an audible noise that sometimes can even be heard by others. This “clattering” of the teeth or dentures when the patient is speaking can cause a feeling of "discomfort". In patients with removable dentures, this problem can also lead to excessive pressure on the integument: this could result tenderness or denture stomatitis.

Recommendation 10: Prerequisite for increasing the vertical dimension (*NEW* in 2022)	
If it is necessary to increase the vertical dimension beyond the closest speaking space due to a lack of interocclusal space for a planned restoration, preliminary functional therapy consisting of reversible procedures (e.g., occlusal splint therapy) **should** be carried out to test whether the patient can adapt to the proposed change in mandibular position. [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

A detailed description of functional therapy can be found in the “Scientific Communication on Dental Functional Therapy” [18].

Other methods

- ***Preferred vertical dimension of occlusion (PVDO):*** Patients are instructed to bite down on occlusion rims at different OVDs to determine for themselves which height is most comfortable for them [301]. This method was proposed in the hope that a fixed jaw relation could be re-established in a physiological manner (similar to the neuromuscular position in horizontal jaw relation recording, see section 6.2.4). However, follow-up studies have shown that the POVD method is not suitable for multiple reasons [32,57,58,129,404,523].

- ***Maximum bite force:*** Previously, it was assumed that the "proper" vertical dimension of occlusion could be found at the point of application of an individual's "maximum bite force" [52]. However, this also apparently functional method is not only time-consuming and has unacceptably large sources of error [118,478], but also does not yield better results.

- ***Electromyography (EMG)*****:** It seems reasonable to assume that the physiologic rest position of the mandible is the position where the "greatest relaxation" (i.e., lowest electromyographic activity) of the muscles of mastication can be detected [28,217,330]. However, follow-up studies have shown that the mandibular position at which the lowest EMG masticatory muscle activity occurs is significantly further caudal to the individual vertical jaw relation [130,217,218,545].

- ***Swallowing technique*****:** For many years, it was assumed that interocclusal contact between the teeth occurred during swallowing and that this phenomenon could be exploited to determine the OVD [187,256,336,425,444]. However, follow-up studies have shown that this method results in an unacceptably high range of scatter and that healthy subjects' teeth do not always remain in contact during swallowing [210,256,337,399,410,425,427].

- ***Cephalometric radiography*****:** At first glance, the potential to use cephalometric radiography-based measurements and calculations to determine the occlusal vertical dimension seems to be a possibility worth considering in order to get away from subjectively influenced, differentially assessed and difficult-to-learn parameters (facial height angle, ANS/Spa-Xi-Pm) [32,257,346,434,435,472,549,550]. However, studies have shown that this method is not really suitable for a number of reasons [99,105,277,365]. First, cephalometric radiography images are summation images and even the location of cephalometric points is subject to individual variation. Second, reference values for OVD determination can only be obtained as average values obtained by cephalometric analysis of a large sample of healthy, fully dentate subjects. Correlations are not sufficient. However, the individuality of edentulous patients is too great to be captured by average values or correlations. Third, current radiation safety rules set narrow limits the use of cephalometric radiography. Furthermore, there is no evidence that this method of OVD measurement results in an adequate - let alone better –restoration quality.

6.1.4 Special Considerations for Dentate Patients

The question of whether increasing the occlusal vertical dimension is feasible in dentate patients has been approached very cautiously in the past. If an increase was needed, it was recommended to increase the vertical dimension by only the necessary minimum. It was feared that the OVD increase would otherwise not be tolerated by the patient or would cause problems such as pain [64,422,467,480].

However, the available studies on this topic show that except for one limitation [76], an OVD increase of up to about 5 mm can in most cases be achieved without any problems (see also [433,524]), except for short-term difficulties in the brief transitional period, such as lisping, pressure-sensitivity of the teeth and muscle tenderness. However, studies investigating the upper limits of OVD elevation are lacking. However, it should be considered that increasing occlusal vertical dimension in dentate patients invariably alters the previous anterior occlusal contacts. Thus, if an OVD increase is needed for prosthodontic treatment, the pre-existing anterior contact must be re-established in order to obtain interference-free dynamic occlusion. Relaxed closed lip posture can also be a problem [2,72,85,86,146,152,326,345]. In the clinical experience of the guideline coordinators, mandibular position changes may also occur during occlusal splint therapy, so it is advisable to perform such functional therapy procedures prior to final restoration.

Recommendation 11: Functional pre-treatment before increasing occlusal vertical dimension (*NEW* in 2022)	
To ensure that the patient will tolerate the planned increase of occlusal vertical dimension (OVD), the change in OVD **should** be tested beforehand during a trial treatment period with occlusal splints or long-term temporaries (as per prosthetic requirements). Studies have shown that fixed OVD elevation procedures offer the advantage of shorter adaptation times and more reliable outcomes. If long-term temporaries based on conventional preparation methods are used, further treatment is inevitable. Therefore, the use of a cemented splint or a simulation splint as an alternative to long-term temporaries enables more open planning of the subsequent treatment. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

6.1.5 Summary

Statement 13: Relevance of the individual methods of OVD determination (*NEW* in 2022)	
Based on the aforementioned considerations, the following conclusions can be drawn: • All methods of determining the occlusal vertical dimension prior to prosthodontic treatment vary widely. • The methods sometimes produce inconsistent results (e.g., the physiologic rest position and closest speaking space techniques). No "gold standard" exists. • Therefore, several methods must be used - and repeated - to verify the occlusal vertical dimension. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Based on the available studies and in the clinical experience of the guideline authors, the following variables (ranked by order of importance) have proven to be effective for assessing and correcting the occlusal vertical dimension (see also [142]):

1. Closest speaking space (based on pronunciation of the consonant S);
2. Physiologic rest position (ask the patient to assume a relaxed lip closure after jaw opening, allowing the mandible to relax from maximum intercuspation);
3. Esthetic criteria (“limited”, only for “support”).
4. Pretreatment mandibular position established by existing dentures or interim dentures.

It must be emphasized that there is a margin of tolerance for the occlusal vertical dimension, which may also be altered due to pretreatment-related factors (e.g., OVD may increase due to splint therapy or decrease due to wear on denture teeth). Therefore, it is highly recommended that a critical evaluation of the aforementioned criteria be performed before implementing any planned restorative change in occlusal vertical dimension.

Recommendation 12: Increasing the occlusal vertical dimension for fixed dentures (*NEW* in 2022)	
It is feasible to increase the occlusal vertical dimension for the fabrication of *fixed dentures*. Not only because of the invasiveness of this, but also due to the time and effort required for it, the indication **should** be established based on strict criteria, taking financial considerations into account. Furthermore, it should be noted that any increase of occlusal vertical dimension in the anterior region will lead to disruption of the pre-existing *dynamic occlusal contacts*, and the planned	**Strong consensus**

prosthodontic treatment will result in changes in *tooth shape* (the anterior and posterior teeth will be longer). Therefore, model simulations and treatment sequence planning **should** be performed prior to clinical implementation of the planned changes. In fixed denture fabrication, the planned OVD increase **may** be tested using occlusal splints. If relatively large increases in occlusal vertical dimension are planned, temporary restorations fabricated chairside after indirect preparation or laboratory-fabricated long-term temporaries can be used in an additional test phase for trial wearing of the final restoration after successful splint therapy. [Vote: 9 Yes / 0 No / 0 Abstain]	
Expert consensus	

6.2 Horizontal Jaw Relation Recording

6.2.1 Definition

Horizontal jaw relation (HJR) recording is a term describing various procedures used by dentists to define the positional relationship of the mandible relative to the maxilla in the horizontal plane in order to check or establish the occlusion.

6.2.2 Objectives

The subject of determining the spatial relationship of the mandible relative to the maxilla in the sagittal-transverse plane is still causing disagreement and discussion today. However, there is general agreement regarding the basic objectives of recording horizontal jaw relations.

When the patient is positioned in upright head and body posture with tooth contact in maximal intercuspal position and performs mandibular closure, the following possibilities apply:

1. *Fully dentate patients and fixed denture wearers*: The natural antagonist teeth touch *simultaneously* and evenly at multiple points *on the right and left* sides of the jaw *without* deviation of the mandible in the horizontal direction. This applies not only to each individual tooth, but also to the entire rows of anterior and posterior teeth.
2. *Partially dentate patients with removable partial dentures or dental implants*: The *natural and prosthetic teeth* touch *simultaneously and evenly on the right and left sides*.
3. *Edentulous patients and complete denture wearers*: On jaw closure, the upper and lower denture teeth touch simultaneously *on the right and left* and *remain on the tegument without movement as far as possible*.

In cases 1 and 2, it has proven useful in practice to place restorations such that the anterior teeth have slightly weaker interocclusal contact than the posterior teeth (but there are no studies confirming this).

6.2.3 Proposed Methods and their Consequences

Methods of recording the horizontal jaw relation

A variety of different methods of recording horizontal jaw relations have been recommended in the literature over the decades. Most of these procedures are dependent on the existing dentition and are mainly used in *edentulous patients* whose original MIP can no longer be identified. Such techniques include:

- Extraoral Gothic arch tracing [154–157],
- Walkhoff method [533],
- Intraoral Gothic arch tracing [355],
- Wax wafer bite registration in centric relation (commonly referred to as “centric relation recording”), manually-guided jaw relation recording (former German term: *Handbissnahme*) [160,355],
- Schuyler technique (tip of tongue to the posterior border of the maxillary denture) [421],
- Skullcap or “calotte” method) [112],
- Disc method [238],
- Neuromuscular techniques, such as the adduction field [94], bite force [52], “swallowing” [187,444], corners of the mouth phenomenon [254], muscle resultant, bite point [432], and neuromuscular relation methods [215,417].

Lauritzen [278], Lucia [297] and Dawson [88], on the other hand, developed recording techniques for *fully dentate patients* with an identifiable maximal intercuspal position and a healthy craniomandibular system:

- Lauritzen grip: "chin-point guidance" with wax wafer registration in centric condylar position [278],
- Lucia grip: "chin-point guidance" with anterior deprogrammer (jig, leaf gauge) and registration material between the posterior teeth [295,297],
- Dawson grip: bimanual manipulation with wax wafer registration in centric condylar position [88].

Consequences of uneven interocclusal contact

In patients with *fixed dentures*, uneven occlusal contact may lead to nonspecific complaints such as: [30,66,78,124,139,162,188,242–244,247,279,293,323,351,379,393,394,409,535].

- Pain,
- Muscle fatigue, myoarthropathy, craniomandibular dysfunction,

- Searching for mandibular position ("control contacts"), motor restlessness of the mandible (patient “does not know where to position the jaw"),
- Tooth loosening,
- Triangulation, bone loss,
- Increased abrasion,
- Implant screw loosening.

In addition to affecting effects on the patient's tolerance, failure to achieve the goal of a simultaneous and uniform occlusal contact with *removable dentures* has the following consequences [116,117,134,349,350]:

- Change of appearance,
- Poor denture fit (more bone resorption),
- Pressure sores, mucosal irritation / burning sensation, denture stomatitis,
- Denture chatter, phonation problems,
- Clenching, grinding (indirect),
- Non-specific complaints: patient searching for mandibular position ("control contacts"), discomfort, muscle fatigue.

Consequences such as increased bone resorption and craniomandibular dysfunction *in denture wearers* have not been confirmed in scientific studies.

On the one hand, the requirement that opposing teeth on the right and left sides of the jaw touch *simultaneously and evenly* without horizontal deviation of the mandible during jaw closure is underpinned by practical dental experience. On the other hand, studies in dentate subjects have shown that experimentally induced occlusal interference to maximum intercuspation or occlusal balance may result in tooth, head and/or muscle pain and discomfort, joint clicking and bruxism and can have a negative impact on the masticatory pattern or limit the mobility of the mandible from thicknesses of only about 50 µm and larger. Various studies on interocclusal tactility: between opposing natural and prosthetic teeth (implants) indicate that people perceive discrepancies of approximately 20 µm in natural teeth and of ca. 200 µm in complete denture teeth as foreign bodies [106,107,476,490–492,520]. Consequently, non-simultaneous and non-uniform contact with the teeth of the opposing arch or occlusal interference can trigger symptoms of craniomandibular dysfunction or "discomfort" in susceptible individuals [30,98,124,161,244–246,276,279,304,322,323,379,391,409,475].

Horizontal jaw relation recording in patients with suspected craniomandibular dysfunctions

Recommendation 13: Need for pretreatment of patients with pain in the craniomandibular system / TMD pain (*NEW* in 2022)	
As a general rule, if craniomandibular dysfunction is suspected based on the clinical examination findings, dentures **should not** be fabricated using the patient's existing occlusion immediately but rather, functional pretreatment (e.g., occlusal splint therapy) **should** be carried out beforehand. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

This is because it is conceivable that the existing maximum intercuspation may promote the TMD symptoms or may be a *cofactor* for the health problems [21,22,121,164,233,242–244,247]. If functional therapy with occlusal splints promotes relaxation of the masticatory muscles, this may result in a change in mandibular posture in some cases, which in turn would have an effect on construction or reconstruction of the occlusal surfaces. Therefore, it only makes sense to decide whether to retain the existing mandibular position or to adopt the new mandibular position after it has been tested (e.g., using occlusal splints) and after the completion of functional pretreatment (“Scientific Communication on Dental Functional Therapy”, in preparation).

The subject of “the occlusion as a causative factor for craniomandibular dysfunction (CMD)” is a controversial topic of international debate. In this context, it is important to emphasize the multifactorial nature of TMD pain and the fact that systematic reshaping, grinding or buildup of the occlusal surfaces of the teeth is rarely needed for the treatment of craniomandibular dysfunction (CMD).

6.2.4 Reference Positions for Horizontal Jaw Relation Recording

The choice of reference position for jaw relation recording varies depending on the number and distribution of remaining teeth with interocclusal contact. Basically, the following scenarios are possible:

1. If there is a *sufficient number of remaining teeth* to provide the mandibular position stable and unambiguous three-dimensional interocclusal support, then maximum intercuspation exists. If the patient has a stable maximal intercuspal position, then the position of the mandible is determined by the static occlusal contacts of the occluding tooth surfaces. When possible, this position should be used for the fabrication of dental prostheses in functionally healthy patients because the accuracy of this method of recording horizontal jaw relations is superior to that of other methods.

2. If there is a *sufficient number of remaining teeth* to provide the mandibular position stable and unambiguous three-dimensional interocclusal support but their occlusal surfaces are in poor condition due, in particular, to *generalized tooth decay and/or very severe tooth wear (attrition, abrasion, erosion) extending into the dentin* (TWES grade 3 to 4) [20,401,541,542], or if there are wide edentulous spaces in association with severely tilted teeth, a collapsed bite or "secondary mandibular displacement", then maximum intercuspation may still exist but the position of the mandible may have changed so much that both the horizontal *and* vertical dimension of occlusion will have to be re-established in order to complete the planned restorative treatment.

3. Although natural teeth are still present, they no longer *provide the mandibular position stable and unambiguous three-dimensional interocclusal support* (i.e., if ≤ 2 support zones are present), then this situation is basically identical to that in edentulous patients. The patient's maximal intercuspal position has definitely been lost, so both the horizontal *and* vertical dimension of occlusion will have to be re-established in these cases. The remaining occluding teeth may be used as a guide to reconstructing the vertical dimension of occlusion.

However, there is disagreement over the handling of patients with an otherwise healthy stomatognathic system who lack sufficient interocclusal support for unambiguous identification of the maximal intercuspal position and whose maxillomandibular relationships must therefore be re-established. In addition to differences in the practical approach to doing this, there is still disagreement over the fundamental question of whether this should be done with manual guidance of the mandible by the dentist (manipulation) or by the patient alone, who is then instructed to relax the masticatory muscles and perform jaw closure movements while seated with the head and body upright (see section 6.2.4). This lack of agreement has led to methodological differences in horizontal jaw relation recording.

Maximal intercuspal position (MIP)

Recommendation 14: Indication for using maximal intercuspal position (*NEW* in 2022)	
Maximal intercuspal position (MIP) **should** be used as the reference position in *functionally healthy* patients whose dental arches have support in four quadrants and do not need to be restored for other reasons. The procedure involves asking the patient to place the teeth in the maximal intercuspal position with the jaw firmly closed. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

After conventional impression taking and cast fabrication, it seems reasonable to position the casts in a "manually jogged" intercuspal occlusion, because every interocclusally placed record leads to a bite elevation, the extent of which varies depending on the type of registration material used [385,449,459].

Recommendation 15: Indication for registration in maximum intercuspation (*NEW* in 2022)	
When mounting casts in maximal intercuspal position, an interocclusal record **should** only be used if the casts cannot be unambiguously positioned in relation to each other, i.e., if they "have leeway" when rotated against each other. The use of silicone registration materials is recommended in this case. If no record is required, positioning accuracy is approximately 0.1 mm (see section 5.2.3). [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
References: [510,515]	

Despite its great practical importance, few people know that the accurate transfer of a patient's maximal intercuspal position to an articulator using conventional dental casts made from open-mouth impressions frequently is not achieved, even in fully dentate patients, if no maximal interocclusal records are available. When the mouth is open and there in no interocclusal contact, the positions of the individual teeth are slightly different from those of teeth in a closed jaw situation. Presumably, this is mainly due to periodontal resilience and to bending of the mandibular arches on wide mouth opening, while impressioning errors and cast expansion play a lesser role. Consequently, interocclusal contact of casts mounted on the articulator does not correspond to that in the patient's mouth, but is substantially reduced [384,385,390,392,510,515].

Recommendation 16: Prevention of occlusal errors (*NEW* in 2022)	
To compensate for transfer errors (discrepancies between occlusal contact patterns in the mouth and on the casts mounted on a mechanical articulator), one **should** first mount the casts on the articulator in maximal intercuspal position. Subsequently, the interocclusal contact situation of the models in the articulator **should** be adjusted to the intraoral situation by slight modification of the occlusal surfaces of the denture teeth before use of the casts by the dental technician, e.g., for designing the restorations. If this "correction process" is omitted, the finished restorations often have an occlusion that is "too high" and require more or less time-consuming and extensive corrective grinding for occlusal adjustment. Recording the clinical occlusal situation helps to implement the corrective measures in a structured manner.	**Strong consensus**

[Vote: 12 Yes / 0 No / 1 Abstain]	
Expert consensus	

These errors can be avoided by making closed-mouth impressions using the *double-bite impression technique* [140,158,222,252,286,307,548]. Jaw closure in maximal intercuspal position with a given amount of force is one of the prerequisites for this [338]. The problem with this method is that only one impression of a quadrant can be taken, for example, because once the maxilla and mandible are firmly connected for the overall closed-mouth impression, mouth opening by the patient is no longer possible. Therefore, this method is only useful for making quadrant impressions and individual inlays or onlays for single-tooth restorations, but is recommended in these cases because of the good occlusal fit that it provides.
A serious practical problem for MIP transfer can arise in cases where the preparation of a posterior-occlusal abutment tooth is needed for a bridge etc. (e.g., teeth 35-37 or 15-17): Even if a preparation results in an objectively sufficient amount of interocclusal space at the posterior supporting tooth, contact between the now shortened occlusal surface and the opposing jaw still occurs on jaw closure in many cases. In these cases, it must be assumed that a significant change in position of the condyles in the temporomandibular joints has occurred due to the removal of terminal occlusal support. The reason for this is that in maximal intercuspal position, the condyles basically do not have a supported upper terminal position in the joint but rather, there is a large range of individual variation of condylar position (see also section 5) [44,248,282,447,485,506,512]. The only way to maintain the original maximal intercuspal position in these cases is to implement appropriate measures (e.g., "selective occlusal grinding" [252,497], Christiansen’s MemoBite procedure [77] or similar techniques) to address this issue before tooth preparation. Naturally, this means that the dentist must recognized the problem before tooth preparation.

Neuromuscular Position (NMP)

If the patient's teeth are unfavorably distributed, in poor condition, or are completely missing, then they can no longer be used to establish the horizontal jaw relation. In these cases, the clinician has only two options: either use the patient’s neuromuscular system to determine the position of the mandible on jaw closure (neuromuscular position) or manually guide the mandible into a repeatable border position of the jaw joints (centric relation position).
When fully dentate individuals assume an upright head and body posture, the musculature generally guides the mandible into maximum intercuspation on jaw closure without any problems. Therefore, it makes sense to use closing movements of the mandible after slight jaw opening to record the position of the mandible in cases such as edentulous patients. The underlying assumption is that a horizontal mandibular position closely corresponding to the original and thus unconstrained, "natural" and, above all, physiological maximal intercuspal position can be reproduced and determined in this manner because "joints do not function in border positions" (Krogh-Poulsen, personal communications, Bonn 1978). This line of argumentation, although undoubtedly convincing at first, has several weaknesses:

1. In neuromuscular bite registration, with myofunctional devices [214], only a small portion of the masticatory muscles is stimulated. Consequently, the resultant neuromuscular position is not fully equivalent to the terminal position of "physiological" jaw closure movement.

2. In edentulous patients, registration of the neuromuscular position ("myocentric record") does not yield a precise mandibular position of punctiform shape. Central bearing point registration, for example, yields “adduction fields" of completely different shape. Hence, it is difficult to determine which is the “correct” position of the mandible based on such recordings, and such interpretations are highly error prone [501]. With other muscle-oriented jaw relation recording methods as well, it is not easy to derive an unambiguous and reproducible "intercuspation position" that allows for the reliable positioning of occlusion rims outside the mouth. The reproducibility of the registration method inevitably suffers because of this [147,501]. Acceptable reproducibility of the mandibular reference positions determined by a given jaw relation recording method is, however, the key to obtaining repeatable and consistent results, even on multiple different days.

3. The practicability of methods using the muscles as the predominant basis of registration is debatable, at least in the case of central bearing point registration, because the involved musculature is subject to unforeseeable influences that may lead to a foreign body response of the muscles and to a myogenous change in position of the mandible. The registration process is influenced by manifold factors [43,52,251,501].

4. Study measurements show that the neuromuscular position determined by central bearing point registration is not identical to the patient’s maximal intercuspal position, not even in dentate patients [52,113,147,166,186,220,229,250,439,534]. The goal of transferring the original maximal intercuspal position in the ideal case was not achieved in any of the cases studied. The correlation in edentulous patients was even lower [501]. In fully dentate subjects, the results of a study of rapid jaw-closing movements from slight jaw opening painted a slightly different picture [168]: At small incisal edge distances, the condylar positions measured under these test conditions were not identical to the test subjects’ maximal intercuspal positions either, but the condyles were not in a forced posterior retruded position, but oriented slightly more towards the anterior. Moreover, the accuracy of registration was even surprisingly similar to that of the centric condylar position (see below) [168]. However, it appears that this registration technique will not be easy to implement in dental practice, and it has yet to be tested in edentulous patients. Moreover, completely different conditions apply in fully dentate patients (see below).

5. In complete denture wearers, the position of the mandible often changes to a more anterior position over the service lifetime of the dentures. Causes include embedding of the dentures in the tegument, abrasion of the denture teeth, and alveolar bone resorption. This results in displacement of the dentures and changes of the occlusion [165,223,380,381,414,454,462–466,493,495,496]. After initial healing, the process progresses slowly and the muscles adapt. In many cases, the mandible shifts to an increasingly anterior position over the years.

Recommendation 17: Indications for using the neuromuscular position (myostabilized centric relation) as the reference position (*NEW* in 2022)	
In *dentate* subjects, the neuromuscular position **should not** be used as the reference position for fabrication of final fixed dentures. As a general rule, neuromuscular position **should not** be used for definitive jaw relation recording for complete denture fabrication. Very old edentulous patients with a greatly reduced adaptation capacity who are in need of duplicate dentures are an exception to the rule. [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

Centric relation (CR), centric occlusion (CO)

Centric relation (*syn.*: centric condylar position, "centric") is a cranial border position of the temporomandibular joints that is independent of tooth contact [481]. The definition of centric relation as a "cranioventral, not laterally shifted position of both condyles in a physiological condyle-disc relationship and with physiological loading of the tissue structures involved" (see section 3) [15,59] has now been accepted in the USA as well after a long period of development [9].
<0}

Centric occlusion (CO) is the position obtained when a patient closes the jaw from the centric condylar position (centric relation) and the position of the condyles in their fossa does not change, even after reaching static occlusion (maximum intercuspation) [15,59]. Originally, gnathologists from the "old school" of dentistry mistakenly believed that centric occlusion was a universal ideal position of the mandible for all cases treated [278,456]. They failed to recognize that maximum intercuspation and centric relation correspond in only about 10% of subjects in the naturally dentate population, as was described in a recent literature review [506,511]. On the other hand, this does not mean that centric relation cannot be observed "in nature" – a fact that is often overlooked.

When defining the position of the mandible in centric condylar position according to purely theoretical concepts, the following practical problems must be addressed (see Section 5):

1. In dental practice, it is not possible to visualize the position of the condyles in the joints or, at best, this can only be done indirectly with sophisticated technical resources.
2. It is not possible for the patient to assume this position alone, unaided.
3. Consequently, some degree of mandibular guidance by the operator is always required.
4. This can result in incorrect positioning of the mandible and seems to contradict "physiological" positioning.

In spite of these limitations, centric relation is a suitable starting position for occlusal splint therapy [24,412,413], instrumental dental occlusal analysis and extensive occlusal reconstruction [100,144,169,235] because it meets the important prerequisites described below:

1. Like maximal intercuspal position, CR is a physiological mandibular position because it is present in approximately 10% of the naturally dentate, healthy population “by nature”. If the patient has a significantly deviated mandibular posture prior to treatment and a change in mandibular position is indicated, it is advisable to use an occlusal splint to test the proposed change beforehand.
2. Mandibular positioning errors by the operator can be avoided with practice/experience and, above all, by using multiple records for verification (split-cast method and condylar position analysis) [102].
3. The mandibular position is a much better and a more reliably reproducible reference position than the neuromuscular position [109,169,502,516]. Reproducibility is an essential prerequisite, for example, for checking the horizontal relation during the various stages of denture fabrication [517].
4. It is usually easy for patients to adapt to the mandibular position if there was not too great a difference between CR and MIP at baseline.

A number of different strategies may be used to define centric relation as the starting point for establishing the static occlusion (centric occlusion), depending on the number and distribution of natural teeth.

Statement 14: Conditions for registration in centric relation (*NEW* in 2022)	
In the context of restorative and prosthetic dentistry, bite registration in centric relation is subject to the following prerequisites: 1. The craniomandibular system must be free from pain and dysfunction as far as possible. 2. There must be no interocclusal contact between the existing teeth or occlusion rims during bite registration in centric relation (i.e., recording in centric relation is the only way to obtain a uniform, wobble-free bite registration). 3. At the same time, there must be only minimal vertical separation of the teeth compared to maximal intercuspal position. [Vote: 9 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Centric relation recording in dentate patients: centric relation record

Check bite registration is the most commonly used interocclusal method of recording centric relation *in dentate patients*. The type of mandibular guidance used during registration influences the position of the condyles. *Lauritzen’s* and *Lucia’s methods* of mandibular guidance force or guide the mandible to a more posterior position, whereas *Dawson’s method* of bimanual manipulation guides the mandible in a much more superior position and is thus considered more physiological. Clinical studies have shown that manual guidance with an anterior jig results in the most posterior position of the condyles compared to that of other manual guidance techniques. However, manual guidance using Dawson's technique with plate registration also did not result in the desired most superior position of the condyles in the fossae. Compared to the other methods, central bearing point registration is the only method that establishes centric relation in a more "superior and anterior" position [470,512] and thus seems to come closest to meeting the theoretical definition and criteria.

Statement 15: Different methods of making centric relation records (*NEW* in 2022)	
There is no external evidence that any given procedure or method of making centric relation records results in restorations that are either superior or inferior to those made using other CR recording methods. [Vote: 13 Yes / 0 No / 0 Abstain]	
References: [235,509,516]	

Recommendation 18: Central bearing point registration in partially dentate patients (*NEW* in 2022)	
Depending on the distribution of the patient's remaining teeth, there may be limitations to the use of central bearing point registration *in partially dentate patients*. The central bearing device **should** have support configured such that its position remains stable and unchanged during recording. Moreover, it **should** cause only a minimal increase of vertical dimension. [Vote: 9 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

The following applies to changes in horizontal jaw relation in *patients who still have occluding pairs of posterior teeth*: The maximal intercuspal position is an average distance of about 0.5-0.8 mm from centric relation in the condylar area, and is usually more anterior than centric relation [506,511]. If the mandible is guided posteriorly into centric relation when the tooth pairs are still occluding, this can only be done without interocclusal contacts if the jaw opens at the same time, thus increasing the occlusal vertical dimension. This is due to the cusp-fissure relief of the posterior teeth. If this mandibular position is recorded properly without interocclusal contacts, and if the casts are lowered by lowering the anterior pin length after mounting on the articulator, the first contact point will be in the posterior region and MIP will not be achieved. Hence, the vertical dimension remains increased and the anterior tooth contacts that may have present before are also lacking. Anterior guidance is thus lost. In order to obtain the correct centric relation along with the correct anterior occlusal relationship in these cases, it may be necessary to reduce the occlusal height of the posterior teeth by grinding, to decrease the occlusal vertical dimension and/or to restore the anterior occlusal relationship using additive techniques.

Recommendation 19: Using centric relation in patients who still have occluding posterior tooth pairs (*NEW* in 2022)	
In order to obtain the correct centric relation along with the correct anterior occlusal relationship in patients who still have occluding posterior tooth pairs, it **may** be necessary to reduce the occlusal height of the posterior teeth by grinding, decrease the occlusal vertical dimension and/or restore the anterior occlusal relationship using additive techniques [Vote: 9 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Registration of CR in edentulous patients: manually guided jaw relation recording

Manually guided jaw relation recording is the usual method of recording the horizontal jaw relation in *edentulous patients*. Compared to central bearing point registration, manually guided jaw relation recording has time advantages and can be performed on the patient without laboratory equipment. In addition to a lack of experience with other methods, these are the main reasons why manually guided jaw relation recording is the most commonly used method in private practice. Compared to central bearing point registration, however, manually guided jaw relation recording has slightly inferior reproducibility (ca. 0.7 vs. 0.5 mm in the condylar area) and a higher risk of recording error. It also has fewer options for checking the jaw relation recording [38,503,514]. A theoretical consideration to bear in mind is that no matter how precisely it is performed, manually guided jaw relation recording always tends to result in a posterior border position of the temporomandibular joints and thus in a mandibular posture manipulated by the clinician. It is not possible to perform jaw relation recording in edentulous patients unless the clinician provides mandibular guidance and simultaneous stabilization of the plates or prostheses. Use of the manipulation technique is not advisable in these cases because occlusion rims or dentures would also have to be stabilized at the same time.

Intraoral central bearing point registration of centric relation

Method

Central bearing point registration (syn.: Gothic arch tracing, arrow point tracing, needle point tracing, the graphic method, the McGrane full denture procedure [313]) is a method of recording maxillomandibular relationships in which recordings of the horizontal jaw relationship are made by registration of the apex of the Gothic arch. First, so-called "central bearing plates" for the maxilla and mandible are fabricated in the dental laboratory or attached to occlusion rims or dentures by the dentist. With the Gerber system, the metal recording plate for the mandible is mounted at the level of the occlusal plane and transversely, between the dental arches, thus displacing the tongue. The upper

plate for the maxilla has a vertically mounted “central bearing point” (stylus) that protrudes slightly above the occlusal plane and is attached approximately at the level between the second premolars and the first molars, on the midline of the patient’s palate (i.e., at the center of occlusal force). Once the central bearing device is in place, the height of the central bearing point can be adjusted such that, on jaw closure and in centric relation, there is only one “interocclusal” contact point between the central bearing point and the lower graph plate and minimal separation of the upper and lower teeth [136,138]. In edentulous patients, the central bearing point should be positioned such that the upper and lower occlusion rims or dentures do not tilt when vertical force is applied “at the center of occlusal force” (for discrepancies with a focus on the rest position of the mandibular denture). The position of the central bearing point on the lower tracing plate has a tremendous effect on the quality of the registration, especially in edentulous patients.
Once the recording plate opposite the central bearing point has been coated with a layer of marking material, the paths of horizontal border movement can be easily traced by the stylus without further interocclusal contact. Repeated right and left lateral excursions of the jaw result in the appearance of a “Gothic arch” or “arrow point” on the recording plate. The point where the two lateral movements meet in the median plane marks the apex of the gothic arch tracing ("the most retruded position of function" [313]). This point of the Gothic arch tracing is a well-reproducible superior and posterior border position of the condyles. In Gothic arch tracing, it is defined as centric relation (“centric condylar position”). If non-physiological force is used, the mandible and thus the condyles can sometimes be guided into a slightly more posterior position. If not only lateral posterior but also anterior and protrusive-lateral border movements are traced during contact with the central bearing point, a diamond-shaped pattern appears on the tracing. This pattern is equivalent to an individual horizontal cross-section of Posselt’s diagram [362].

Statement 16: Recording of lateral and protrusive movements with an intraoral central bearing tracing device in dentate patients (*NEW* in 2022)	
Complete recording of lateral and protrusive movements (border positions), which is mainly performed in dentate patients, usually requires a considerable increase of vertical dimension (due to the cusp-fissure relief pattern). *Complete* recording is not required for jaw relation recording. [Vote: 9 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Historical Development

Central bearing point registration was first described by Gysi as an extraoral registration method for the fabrication of complete dentures [154–157]. It was used by Gysi as a method for restoring horizontal jaw relationships in edentulous patients with full maxillary and mandibular dentures. He apparently believed that the apex of the intraoral tracing corresponds to patient's former maximal intercuspal position [353]. Over the course of time, however, investigators eventually realized that both the maximal intercuspal position and the neuromuscular position deviate by different distances from the apex of the Gothic arch tracing [94,159,183,184,228,362,438,501,554,555].

Phillips [355] is credited with describing and introducing the method as the intraoral tracing technique for full denture fabrication as it is essentially still used today. According to Gerber, the method is particularly well suited to the fabrication of complete dentures [137], but is also useful for the treatment of patients with craniomandibular dysfunctions (CMD) [136]. From its inception, the aim of central bearing point registration has been to insert dental prostheses (formerly only complete dentures but now also occlusal splints) in a mandibular position that is "physiological" and "easy to adapt to" in patients in need of extensive oral rehabilitation. Gerber, for example, considered horizontal jaw relation defined with manual guidance of the mandible to be "non-physiological" [160,421]. He was of the opinion that the TMJ, like other joints, requires a certain degree of freedom and that, due to the nature of the manual guidance involved, check bite-registration "forced" the mandible into a posterior retruded position. This view was contrary to that of the "gnathologists", who believed that placement of the mandible by means of check bite registration and firm guidance was "more appropriate" for this purpose [278]. These discussions and developments are reflected by the changes in the condylar position-based definition of centric relation (centric condylar position) over time, which has evolved from "the most posterior" to "the most anterior-superior" position of the condyles within the glenoid fossae [3–9,313]. The general consensus was that "joints do not function in border positions". Thus, it was assumed that central bearing point registration would result in a less extreme posterior border position of the mandible [353].

Factors Influencing the Accuracy of Central Bearing Point Registration

Concerns about central bearing point registration can be attributed to the following factors that can influence the accuracy of the registered condylar and thus mandibular position to a certain extent [166,167,209,212,213,225,226,241,271,287,289,290,305,331,339,340,343,376,526,538,552]:

- Position of the central bearing point (stylus) on the recording plate
- Restriction of the tongue space (muscular imbalance)
- Amount of force applied during recording or encryption
- Angle of the central bearing plates relative to the occlusal plane
- Setting time of the encryption material
- Type of mandibular guidance during registration

Statement 17: Assembly of central bearing devices for complete denture fabrication (*NEW* in 2022)	
The aim of central bearing point registration is to evenly distribute closing forces over the maxillary/mandibular occlusion rims and transfer bases of dentures in centric relation so that only minimal movement of the prostheses occurs on slight jaw closure, and subsequently increasing closing force in the maxilla and	**Strong consensus**

mandible. Forces on the tegument should also be evenly distributed and no dislocation of either denture should occur. [Vote: 13 Yes / 0 No / 0 Abstain]	
Expert consensus	

Diagnostic Potentials

In principle, no conclusions regarding the three-dimensional position of the condyles can be drawn from central bearing point registrations because such recordings only capture two degrees of freedom of mandibular movement.

In dentate subjects, a Gothic arch (arrow point) is formed when the vertical dimension is raised by left and right lateral excursion in the horizontal plane. The width of the excursions can be determined. However, interpretation of these results is often limited when a patient does not practice the necessary jaw movement sequences beforehand; in such cases, a reduction of the range of motion may not be caused by dysfunction, but to failure to execute the movements properly. Parts of mandibular occlusion rims or mandibular dentures sticking up in the retromolar region may also interfere with the movements. In edentulous patients, the apex of the Gothic arch tracing may be blunted or rounded due to horizontal mobility of the occlusion rims or dentures.

Statement 18: Diagnostic possibilities of central bearing point registration (*NEW* in 2022)	
The potential to derive diagnostically relevant information on condylar movement from a central bearing point registration is very limited. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Statement 19: Interpretation of the shape of the Gothic arch apex (*NEW* in 2022)	
In *fully dentate* patients, if the *tip* of the Gothic arch tracing does not form an actual arrow point but is rounded, this blunted apex should not be interpreted as a sign of "immediate side shift" movement in the condylar area unless the movements truly arose from a posterior starting point. [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

Reproducibility

The reproducibility of central bearing point registration has been investigated in many studies in both dentate patients and in complete denture wearers either two-dimensionally, at the level of the occlusal plane [53,75,148,166,167,182,186,209,227,232,311,331,438,554,555], or three-dimensionally, directly or indirectly, in the condylar area, with additional instruments [23,39,206,255,289,305,306,408,441,445,495,496,498,502,504,514,516]. Most studies have shown no statistically significant difference in the reproducibility of conventional and computer-assisted systems because they are based on the same underlying principle [224,554,555].The reproducibility of central bearing point registration was superior to that of manually guided horizontal jaw relation recording in the group of *complete denture wearers alone*, with an average of 0.5 mm versus 0.7 mm in the condylar area [504,514,518]). In *dentate patients*, the accuracy of central bearing point registration is estimated to be about 0.3 mm on average [502,516]. In these values, the precision of placement of the plastic disk on the tracing device is exactly integrated in the tip of the Gothic arch tracing on the recording plate (and it improved with the use of loupe magnification). The reproducibility of manually guided horizontal jaw relation recording of centric relation in the corresponding indications was exactly equivalent to this.

Statement 20: Reproducibility of central bearing point registration and other methods of recording centric relation (*NEW* in 2022)	
In dentate patients, there is essentially no difference in reproducibility between manually guided horizontal jaw relation recording and central bearing point registration, in spite of the fundamental differences between the two methods. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Condylar Position

It used to be assumed that manually guided jaw relation recording and central bearing point registration result in a very similar, if not the same, mandibular position and thus condylar position, but this hypothesis has meanwhile been refuted: Manually guided jaw relation recording and encryption of centric relation over the apex of the Gothic arch result in different mandibular postures, even when Gothic arch tracings are obtained with moderate mandibular guidance by the investigator [53,232,255,418,512–514,552]. In complete denture wearers, both the positions and the reproducibility levels of the two methods differ. Central bearing point registration with encryption of centric relation over the apex of the Gothic arch achieves slightly better precision than manually guided jaw relation recording: ca. 0.5 mm versus 0.7 mm, respectively [503,504,513,514].

Here, there is also a positive correlation between the accuracy and the precision required to establish the occlusion in the individual patient case [520]. However, this alone is not sufficient proof of principle to establish that central bearing point registration should be preferentially used. To our knowledge, there is only one study investigating the ultimately decisive question: Do patients adapt better to prostheses made by one of the methods versus another over the long term? Central bearing point registration also seems to have advantages in this respect, but the difference was statistically insignificant [514].

If one follows the assumption that Gothic arch tracing should be recorded using manual guidance of the mandible by the investigator (because constriction of the oral cavity would otherwise result in registration error) and that the jaw relation recording should generally be encrypted over the apex of the Gothic arch tracing, this may initially result in resistance (jaw relation too far posterior, non-physiological and manipulated mandibular position, etc.), in addition to the aforementioned arguments. Evidence shows, however, that the mandibular position determined by central bearing point registration with or without manual guidance of the mandible is approximately 0.5 mm more to the anterior [196,512]. Hence, it is neither advisable nor necessary (and only possible with this method) to encrypt the position "posterior to the apex of the Gothic arch tracing", for example, in order to establish an "average-value maximal intercuspal position".

<table>
<tr><th colspan="2">Statement 21: Contraindications to central bearing point registration (NEW in 2022)</th></tr>
<tr><td>Unlike manually guided jaw relation recording, intraoral central bearing point registration is subject to some mainly system-related contraindications. Intraoral central bearing point registration is contraindicated in patients with:
Flabby ridges so extensive that dentures are unevenly depressed into the tissue on loading,
Defective dentures that prevent even loading of the tegument from the start,
Major differences in the location of the center of gravity of the maxillary and mandibular denture,
Prosthetic positional instability due to reasons such as large tongue or uncontrollable mandibular movements (e.g., "proglissement"),
Insufficient capacity for compliance.
[Vote: 13 Yes / 0 No / 0 Abstain]</td><td>Strong consensus</td></tr>
<tr><td colspan="2">References: [517]</td></tr>
</table>

<table>
<tr><th colspan="2">Recommendation 20: Indications for manually guided horizontal jaw relation recording for complete dentures (NEW in 2022)</th></tr>
<tr><td>If prosthetic dislocation should occur during horizontal jaw relation recording for reasons such as those described above, it will also consistently occur with the finished prosthesis on jaw closure. Hence, central bearing point registration is contraindicated in patients with major differences in the location of the center of gravity of the maxillary and mandibular denture in the sagittal plane,</td><td>Strong consensus</td></tr>
</table>

significant differences in tissue resilience (e.g., flabby ridges), or missing jaw structures, i.e., jaw defects. In these situations, manually guided horizontal jaw relation recording **should** be performed instead. [Vote: 13 Yes / 0 No / 0 Abstain]	
References: [517]	

Computer-assisted central bearing point registration

In modern dentistry, Gothic arch tracing can also be performed using computerized systems [1,525]. Closing force measurements can also be made during computer-aided recordings. While the tracing is being generated, an enlarged view of the Gothic arch tracing can be displayed on the monitor and shown to patients. This feedback not only helps patients visualize and control their jaw activity, but also allows the investigator to make closing force measurements during registration or, in some cases, during encryption. The closing force needed to make such recordings ranges from 10 N to 30 N with many electronic recording systems, whereas those needed for conventional systems (without electronic control) are lower – typically less than 10 N [212,225,226,290,526,538].

Recommendation 21: Determination of deviating positions in central bearing point registration (*NEW* in 2022)	
Some computer-assisted systems *compute* mandibular position *estimates* that deviate from those of the (analog) apex of the Gothic arch tracing as well as from the maximal intercuspal position and centric relation [91,224,287,289,554,555]. If such position estimates are generated by a computer-assisted system without proper disclosure, they **should not** be used for definitive denture fabrication [45,150,333]. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

The extent to which the amount of closing force may negatively affect the outcome of central bearing point registration is a controversial topic [91,213,225,226,239,407]. Likewise, the question of whether a deviated position of the mandible a given distance away from the apex of the Gothic arch tracing is related to later denture acceptance by the patient also remains to be proven. Outcomes for conventional versus computer-assisted central bearing point registration do not differ significantly if the jaw relation of interest is encrypted over the apex of the Gothic arch tracing.

Practical Tips for Error Avoidance

Recommendation 22: Central bearing point registration in partially dentate patients (*NEW* in 2022)	
The central bearing point and recording plate **should** be set up so as to provide a central point of bearing or support between the maxillary and mandibular arches and to ensure wobble-free positional stability of the plates during registration. To prevent dislocation of the central bearing device during recording, the central bearing point and recording plate **should** have optimal support in centric relation. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

During central bearing point registration, patients should be seated in an upright position in order to decrease the risk of swallowing small parts of the central bearing device assembly; this also increases the precision of the results [1]. The process of fabricating the central bearing plates involves a tremendous amount of time and effort and this is easier to accomplish in patients who are either fully dentate, restored with a removable complete denture, or fully edentulous. In partially edentulous patients, attempts to perform central bearing point registration may be difficult or futile, depending on the distribution of the remaining teeth.

Recommendation 23: Central bearing point registration in complete denture wearers (NEW in 2022)	
In edentulous patients, the central bearing point **should** be placed in the "center" of the occlusion rims or dentures in order to ensure that they are evenly loaded and remain firmly in place on the tegument on jaw closure (i.e., that they are evenly depressed into the tegument on loading). [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

The goal is to obtain a completely even distribution of force on the tegument below the maxillary and mandibular dentures in centric relation (centric condylar position). When these conditions are met, the mandible receives "tripod support" from the right and left condyles and the central bearing point vis-á-vis the cranial base [138]. It is also important to adjust the height of the central bearing point so as to minimize the degree of vertical separation of the teeth on the right and left in centric relation. This should be checked using articulating film (no antagonist contacts should be present).

Recommendation 24: Increase of vertical dimension during central bearing point registration (*NEW* in 2022)

The degree of vertical separation of the teeth required for complete recording of all border movement is usually too large, especially in dentate patients. Therefore, maximal excursive movements **should not** be performed during central bearing point registration. Interocclusal distances of approximately 2 to 3 mm (but not less) are generally sufficient for interference-free registration. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Recommendation 25: Patient instructions during central bearing point registration (*NEW* in 2022)	
Central bearing point registration **should** be performed while *gently* guiding the mandible in the posterior direction (more forceful guidance triggers a reactive protrusive muscle response) while simultaneously giving the patient clear instructions, such as: Move your lower jaw forward → back → to the left → back to the middle. Now move the jaw forward → back → to the right → and back to the middle. Patients **should** repeatedly practice these sequences before registration until they become becomes familiar with the required movements. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Some patients may be initially unable to perform the required movements according to these instructions, and it may even seem that central bearing point registration will not be possible. Two ways to still obtain a usable "recording" in such cases are described below.

1. Instruct the patient to perform the following jaw movements during moderate manual guidance from the dentist: "Please close your mouth. Now move the lower jaw "backwards" and to the left and right several times". It may be helpful to combine these instructions with those described above.
2. If this fails, the patient's mandible can be positioned during manually guided horizontal jaw relation recording with the central bearing device in place.

Recommendation 26: Registration material for central bearing point registration (*NEW* in 2022)	
After setting, the registration material used for central bearing point registration (encryption) **should** be rigid enough to ensure the reliable and unambiguous mounting of casts in relation to each other.	**Strong consensus**

[Vote: 13 Yes / 0 No / 0 Abstain]	
Expert consensus	

6.2.5 Summary

Recommendation 27: Procedures to perform before tooth preparation (*NEW* in 2022)	
As a general rule, if a functionally healthy patient has good tooth support from the natural dentition in maximal intercuspal position, this mandibular position **should** be used. If a supporting tooth in a patient with a readily identifiable maximal intercuspal position is to be prepared, resulting in the probable loss of its support capacity, the jaw relation of interest **should** be recorded by appropriate methods *before* tooth preparation [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Recommendation 28: Selection of a suitable reference position (*NEW* in 2022)	
In patients with an insufficient number of teeth providing interocclusal support, secondary mandibular displacement, or an occlusal surface complex requiring restoration as a whole, the existing habitual occlusion **should not** be transferred to restorative setting. Centric relation, which becomes the centric occlusion here, has proven to be the appropriate reference position in these cases. [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

Recommendation 29: Careful evaluation of existing jaw relations in patients in need of new complete dentures (*NEW* in 2022)	
In functionally healthy *edentulous* patients in need of new complete dentures, the tooth positions as well as the vertical and horizontal dimension of occlusion of their previous dentures **should** be carefully evaluated by the dentist and modified as needed.	**Strong consensus**

If such patients have already worn complete dentures for a long time, it can be assumed that both the vertical and horizontal dimension of occlusion will have changed over time due to settling of the dentures in the mucosa, jaw bone resorption, and wearing of the denture teeth. Therefore, overall readjustment of jaw relation in both the vertical and horizontal dimension of occlusion is advisable and usually unavoidable in these cases. Centric relation has proven to be the best position for horizontal jaw relation. [Vote: 9 Yes / 0 No / 0 Abstain]	
References: [143,144,170,234]	

7 Part 4: Facebow Transfer

7.1 Definition

A facebow can be used for individualized anatomic transfer of spatial distances between the occlusal surfaces of the teeth and the (centric) hinge axis of the mandible—a reference position located near the temporomandibular joints—from the patient to an articulator / movement simulator. In other words, the facebow defines the relationship between the rows of teeth of physical or digital jaw models to the hinge axis of rotation of the articulator / movement simulator (to position the casts relative to the skull and temporomandibular joints). Thus, it serves to *customize the Bonwill triangle* [50,51], which is defined as the equilateral triangle formed when an imaginary line is drawn from the contact points of the mandibular central incisors to the two condyles. The length of each side of the Bonwill triangle is 100 to 110 mm. If no individual patient data from the facebow are available for cast positioning, it is recommended to use average values for the Bonwill triangle.

When the facebow is oriented along the centric hinge axis of the mandible, i.e., to the right and left hinge axis points on the skin in the temporomandibular joint region, it reflects the centric condylar position from which jaw opening movements can be performed at a vertical distance of up to 15 to 20 mm (above the edges of the incisors) with a more or less purely rotational component with external guidance [252,362,494,497,499]. The transverse axis of rotation corresponds to the centric hinge axis (see also sections **Error! Reference source not found.** and 6.2), which can be recorded using average values or individually determined values.

Thus, a facebow allows us to transfer the spatial relationship between the hinge axis of rotation of the mandible and the dental arches to a suitable articulator / movement simulator and to simulate the situation during patient-guided jaw opening on the articulator / movement simulator. Consequently, slight changes (increases or decreases) in occlusal vertical dimension in centric relation can be simulated on an articulator / movement simulator without altering the patient's maxillomandibular relation and then having to make a new CR record (strictly speaking, this only applies if centric relation was used as the reference position).

7.2 Objectives

The use of a facebow to position casts in an articulator / movement simulator results in a decrease of occlusal error in designing contacts in static and dynamic occlusion during the fabrication of dental prostheses in the laboratory compared to average-value or arbitrary cast mounting. The use of a facebow in the process of fabricating dental prostheses has the following advantages:

- Minimizes occlusal adjustments
- Largely preserves the functional integrity of dental prostheses, leaving them as designed by the dental technician in the laboratory
- Minimizes grinding and the associated risk of damaging the prostheses
- Reduces the overall time required for fabrication of dental prostheses

As for instrumental occlusion analysis, it is further assumed that the use of a facebow improves the simulation of individual static and dynamic occlusal contacts in the articulator / movement simulator.

7.3 Methods

When performing facebow transfer in dental practice, the maxillary cast is commonly positioned on the articulator in relation to the skull and temporomandibular joints. When using the method proposed by Albert Gerber (Zurich), facebow transfer is mandible-driven [136], i.e., the mandibular cast is mounted in the articulator first. Depending on the type of articulator system, either the *Frankfurt horizontal plane* or *Camper's plane* is used as the reference plane for cast positioning. Sagittal condylar path inclination values vary according to the choice of reference plane.

Three reference points are needed to transfer jaw models to the articulator: two posterior reference points and an anterior reference point.

The two posterior reference points relate to the so-called centric hinge axis and can be determined:

a) Arbitrarily, based on average values, e.g., by palpating the external auditory meatus and relating the average values to it (average-value method),
b) Individually, after kinematic determination of the axis of rotation of the mandible during slight to moderate jaw opening movement.

The location of the anterior reference point is determined by different methods: either by palpating osseous structures, such as the inferior infraorbital rim (right or left), or by marking points on the skin in the area of the nasal-cheek junction located a given distance cranial to the incisal edges of teeth 12 or 22 [54,55,119,155,292,348,371,383,469,519,532,543].

In the conventional method of facebow transfer, a transfer plate (bite fork) covered with wax, thermoplastic material or silicone is pressed onto the occlusal surfaces of the teeth of one arch (usually the maxilla). In skull-related systems, the transfer plate is immobilized manually or, in some cases, by having the patient close down on it. The facebow itself is aligned to the average-value or patient-specific individual centric hinge axis points and to the anterior reference point, and is then mechanically connected to the transfer plate. In mandible-driven systems, the transfer plate is held in position by jaw closure (by a support pin in case of the *Gerber system*). The facebow is attached and aligned with the centric hinge axis. Spatial, skull-related and joint-related transfer of the position of the maxilla or mandible to the articulator / movement simulator is then performed on the basis of the jaw model.

7.4 Clinical Utility

7.4.1 Conventional Facebow Transfer

After several authors had launched a critical debate on the meaningfulness of facebow transfer [327], the available evidence in support of the clinical utility of facebow transfer in functionally healthy individuals in the context of restorative dentistry was extensively evaluated and discussed in a guideline entitled “Scientific Communication of the German Society for Prosthetic Dentistry and Biomaterials (DGPro)” published in 2010 [67,68,73,200,429,536]. The guideline authors conducted a literature search to identify randomized clinical trials on the use of facebow devices as well as studies based on experimental laboratory measurements and mathematical geometric model simulations to demonstrate or predict the effects of functional determinants of facebow use that influence the occlusion.

No general conclusions regarding the value of facebow transfer could be drawn based on data from the identified randomized clinical trials [96,103,177,178,236,270,332,423,429]. The reasons for this included the investigators’ focus on the fabrication of complete dentures or occlusal splints, differences in the selected methods and procedures, and incomplete data on the specifics of the study design [327].

A number of studies involving model simulations based on clinical data allowed the investigators to identify factors affecting the occlusion in different methods of transferring model positions to an articulator / movement simulator and to predict the order of magnitude of the expected occlusal errors [10,145,191,328,329,357,370,387,403,419,420]. Two types of occlusal errors can be distinguished: 1) static occlusion errors caused by a change in occlusal vertical dimension in the articulator after jaw relation recording in centric relation and 2) dynamic occlusion errors caused by differences in mandibular movement parameters between the patient and the articulator while the horizontal occlusion level remains unchanged [327].

Effects on static occlusion (MIP): When changes in occlusal vertical dimension occur in the articulator / movement simulator, occlusal error is greater when facebow transfer is performed using arbitrary hinge axis points and average values (for the Bonwill triangle and the Balkwill angle) compared to patient-specific hinge axis points. These errors are strongly dependent on the magnitude of vertical dimension change and are greater when using average values compared to arbitrary axis points. In the case of average-value facebow transfer, the value of the Balkwill angle, which describes the angle between the occlusal plane and the Bonwill triangle at the incisal point, has a significant effect on the magnitude of occlusal error. If the vertical dimension has to be changed in the articulator / movement simulator after jaw relation recording, the use of arbitrary hinge axis points for facebow transfer leads to a clinically relevant reduction of errors in static occlusion (MIP) compared to the use of average values [328]. One study revealed that a 4 mm vertical dimension change in the articulator / movement simulator leads to occlusal errors of ≥ 700 µm in the second molar area at the 10% probability level in the case of arbitrary hinge axis mounting, and that with mean-value mounting without a facebow, the magnitude of occlusal error increased with the size of the Balkwill angle, from ≥ 920 µm with a Balkwill angle of 17 degrees to ≥ 2.37 mm with a Balkwill angle of 25 degrees, at the 10% probability level [329]. This error size may be related to the accuracy of positioning the mandible in relation to the maxilla during recording.

Effects on the dynamic occlusion: Studies predicting the effects of facebow transfer on *dynamic occlusal contacts* revealed that occlusal errors are not solely dependent on the use of a facebow to transfer jaw models to an articulator. Other parameters such as the Bennett angle, sagittal condylar path inclination angle, intercondylar distance, the angle of incisal guidance (incisal path), and the occlusal surface viewing angle sometimes have a greater impact [328]. Assuming that occlusal errors of 200 µm or less in the second molar area can hardly be avoided and this is defined as the tolerance limit, occlusal errors exceeding this threshold will occur with a probability of 14% for tooth-guided lateral excursions to the working side and with a probability of 11% on the balancing side when average values are used. When calculated for condylar path inclination alone, the probability of occlusal errors exceeding this threshold decreases to 11% and 9%, respectively. If a facebow was used to transfer the casts to an articulator / movement simulator, the probability would decrease to 5% on the working side and increase to 11% on the balancing side. Individual setting of Bennett angles further reduces the probability of exceeding the 200 µm limit to 7% on the working side and to 2% on the balancing side. These results suggest that the use of a facebow alone would only marginally reduce the occlusal errors. Therefore, for dynamic occlusal contacts, it seems advisable to either use patient-specific values for all important dynamic functional parameters, or to dispense with the facebow and to correct the error on the occlusal surface intraorally, if necessary [328].

An update of the status of the literature on facebow transfer was performed in April 2021. In addition to the randomized clinical trials on the use of facebow devices identified in 2010 [327], we found another seven publications that can be classified as belonging to the field of prosthetic and restorative dentistry and/or dental functional diagnosis and therapy [84,92,128,237,342,451,452]. The reproducibility of model mounting with and without a facebow was investigated in another [16]. Six systematic reviews on the clinical use of facebow devices were also identified [69,110,240,269,458,551].

The new randomized clinical trials focused not only on the use of facebow devices in the context of complete denture fabrication and insertion [84,92,237,342,451,452], but also for the fabrication of occlusal splints [128]. No significant differences in outcomes for clinical occlusal contacts and patient satisfaction were observed with and without facebows. In the clinical simulator study, however, facebow transfer of casts to an articulator resulted in significantly less variability than the average-value method [16].

However, clinical study of the utility of facebow devices in cases where edentulous patients are restored with new complete dentures does not appear to be feasible. In addition to the new occlusion, there are simply too many other factors to which edentulous patients must adapt, including the fit of the denture bases, the position of the dental arches in the neutral zone, the OVD, the horizontal dimension of occlusion, and esthetic parameters. In clinical studies using occlusal splints to assess the "efficacy" of using a facebow device, on the other hand, the expected change in vertical dimension is minimal: The vertical height of the occlusal splint will roughly correspond to the vertical height of the centric relation record.

7.4.2 Facebow Transfer with a Focus on Esthetics

Facebow transfer is generally performed using average values or individual centric hinge axis points and thus according to functional criteria. In patients with significant facial asymmetry, the occlusal plane and hence the incisal edge lines may therefore end up in a position that is neither parallel to the bipupillary line on the patient nor parallel to the table plane in the articulator. Hence, it is more difficult for the dental technician to construct, for instance, a maxillary incisal edge line according to esthetic criteria.

Therefore, manufacturers have long since started developing facebows that no longer focused on the functional transfer of centric hinge axis points [34,417], but rather on mounting casts according to, for instance, the bipupillary plane and thus according to primarily esthetic criteria (see also [35,359,360,416]). Inevitably, hinge axes transferred on facebows focused on esthetic parameters deviate more or less significantly from true functional hinge axes. To our knowledge, there are no studies investigating the magnitude of such deviations and their effects in a large number of subjects exist; we found only one estimate in a study focusing on a different research question [453]. Based on theoretical considerations, however, it can be assumed that significant occlusal errors can occur when transferring true hinge axis points to the articulator in patients with significant facial asymmetry.

7.4.3 Digital Facebow Techniques

With the advent of digital technologies in dentistry, the principle of facebow transfer has gained new significance as a method of skull- and joint-related transfer and referencing of jaw models and data from the patient to the articulator. The "digital facebow" opens up the possibility to couple different types of system-compatible anatomical "structural" data (e.g., from intraoral scans of the dental arches and facial scans) with "functional" data on jaw movement and positions (e.g., from electronic jaw movement recordings) [260,262,273,284,372,440].

A conventional analog facebow is basically a U-shaped metal or plastic frame connected to a bite fork (transfer plate) that is inserted in the patient's mouth. The digital facebow, on the other hand, merely requires a bite fork equipped with sensor and measuring technology (which is placed on dental arches like a coupling tray) and the spatial detection of reference points. With increasing implementation of digital workflows in prosthetic and restorative dentistry, the principle of facebow transfer has gained fundamental and increasing importance as a method for spatial referencing of digital data, and new and specific applications for the virtual articulator and for digital occlusal analysis in the fields of restorative dentistry and dental functional analysis have arisen from these developments.

7.5 Summary

Statement 22: Indications for use of the analog facebow (*NEW* in 2022)

In the context of reconstructive dentistry or dental functional analysis, the use of a facebow can have a quality-improving and/or quality-assuring effect above all if it is regarded as *part of a process chain* in which all work steps with a major impact on occlusal errors are to be carried out with a high degree of quality awareness (particularly in *jaw relation recording*). The use of (analog) facebow transfer *alone* is not an adequate indicator of quality. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Statement 23: Indications for use of the digital facebow (NEW in 2022**)**	
In the context of implementing digital workflows in dentistry and dental technology, the principle of the facebow transfer (patient-specific cast positioning) plays an important and fundamental role in referencing and linking (coupling) system-compatible patient-related digital “structural” data (from intraoral scans, facial scans, etc.) with “functional” data (from jaw movement recordings). [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Statement 24: Significance of facebow transfer (*NEW* in 2022)	
With many facebow devices, due to the patient-specific skull- and joint-related transfer of the maxillary cast to the articulator / movement simulator achieved, individual peculiarities (such as significant asymmetry of the jaws or facial skeleton) that have an impact of function and esthetics can be detected at an earlier stage of prosthetic rehabilitation planning compared to methods using average values (e.g., for the Bonwill triangle), and thus taken into account in the fabrication of dental prostheses. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

Recommendation 30: Indications for transfer of casts using average values (*NEW* in 2022)	
If a *stable habitual occlusion/maximum intercuspal position* is used for jaw relation recording *without* changing the occlusal vertical dimension *and* if canine	**Strong consensus**

guidance and/or moderate inclination of central cusp slopes is also present, the use of average values for the transfer of casts to the articulator / movement simulator without a facebow **can** be regarded as a satisfactory method. [Vote: 13 Yes / 0 No / 0 Abstain]	
Expert consensus	

Recommendation 31: Indications for facebow transfer in increasing the vertical dimension (*NEW* in 2022)	
If a vertical dimension change in the articulator / movement simulator is required after jaw relation recording *in centric relation*, facebow transfer with arbitrary or patient-specific hinge axis points **should** be used in order to reduce errors in reproducing the static occlusion. The magnitude of the occlusal errors is mainly dependent on the magnitude of OVD change. [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

Recommendation 32: Indications for facebow transfer in special occlusal situations (*NEW* in 2022)	
To reduce errors associated with *dynamic occlusal contacts* (for example, when establishing group guidance in restorative dentistry *or* in patients presenting initially with edge-to-edge bite, crossbite, or open bite), a facebow **should** be used while at the same time determining further functional parameters of mandibular movement (e.g., sagittal condylar path inclination angle and Bennett angle). [Vote: 12 Yes / 0 No / 1 Abstain]	**Strong consensus**
Expert consensus	

If a vertical dimension change has to be done in the articulator/movement simulator after clinical jaw relation recording (in centric relation), the use of *arbitrary* hinge axis points (e.g., with so-called earbows) leads to a clinically relevant reduction of errors associated with the static occlusion compared to the cast mounting using average values, and the potential occlusal errors are clearly dependent on the extent of vertical dimension change. If true *individual* hinge axis points are included in the comparison, model calculations based on clinical data show that occlusal errors are greater for mounting casts using average values compared to arbitrary axis points. In this case, the use of true hinge axis points would be considered optimal.

8 Part 5: Surface Electromyography of the Masticatory Muscles – Dental Applications

8.1 Definition and Development

8.1.1 Definition

Electromyography (EMG) is a technique used to record and evaluate the bioelectrical signals produced by the muscles. EMG signals are recorded using either surface electrodes attached to the skin or using needle or wire electrodes inserted directly into the muscle. EMG signals are generally detected using monopolar (intramuscular) or bipolar (skin surface) electrodes [411].

The muscle is composed of motor units (MU), which consist of numerous individual fibers; these fibers are activated simultaneously but are not located at the same distance from the detection site. Consequently, signals from muscle fibers of the same motor unit reach the electrodes at slightly different times and interfere with the action potential of the motor unit. The electrical activity in parts of the muscle located closer to the electrodes (leads) makes the greatest contribution to the measured difference in potential. Each muscle contraction is characterized by the activation (recruitment) of several motor units, which may occur at different times and frequencies. The spatial distribution of motor units in the overall muscle is complex and, in the case of the muscles of mastication, limited to a very small area. Therefore, the propagation of action potentials in different parts of the muscle is not synchronous; instead, the potentials overlap and interfere with each other, resulting in what is referred to as the EMG interference pattern. The electrical activity developed in the process is directly proportional to the number of activated muscle fibers. Since the strength of muscle contraction depends on the number of innervated muscle fibers and the number of action potentials per unit time, the innervation of motor units and muscle groups can be evaluated by studying the summated EMG values. The recorded action potentials reflect the neuromuscular excitation of the investigated muscles and are an indirect measure of the mechanical activity of the muscle [194].

Electromyography basically provides information about the state of excitation of peripheral muscles. It detects time-dependent intra- and inter-muscular activation patterns and thus provides information about the underlying central control mechanisms [123].

Electromyography (EMG) is most commonly performed using *bipolar surface electrodes* because this electrode configuration method can be performed quickly and atraumatically and it provides reliable and largely reproducible results. When EMG activity of the masticatory muscles is to be recorded for dental functional analysis, this non-invasive technique is the method of choice in view of the superficial location of the clinically most important muscles – the masseter and temporalis.

8.1.2 Historical Development

In 1791, the cornerstone of electromyography was laid by Galvani [127], who discovered in experiments with nerve-muscle specimens that electricity could generate muscles contractions in isolated skeletal muscles. In 1848, du Bois-Reymond was the first to report that muscle action potentials can also be detected, amplified and recorded in humans [97]. The first surface electrodes suitable for systematic use in electromyography were introduced by Piper in 1912 [358]. The first successful use of electromyography for analysis of muscles in the head region was described by Moyers (1950) [330]. Following this seminal publication, Eschler (1952) and others quickly recognized the value of electromyography for dentistry [108].

Electromyography has been used in a variety of different applications in experimental and clinical basic research from its inception until the present [95,114,310]. Significant inter-individual differences in EMG recordings are frequently observed in such studies [249]. These differences can be attributed to physiological, anatomical and technical differences [319]. The different strategies used by different individuals to solve identical motor tasks may be reflected in differences in EMG patterns. Electromyography is the only method that provides metric data on the functional activity of individual muscles based on the summation of action potentials [95,114,354].

8.2 Objectives

In dental practice, surface electromyography is a relatively unproblematic procedure performed by attaching bipolar electrodes to the skin in the masseter and anterior temporalis region. In combination with a careful clinical assessment of function in compliance with the specific methodological recommendations [175,176,258], surface electromyography allows one to gather valid and reliable additional quantitative data on the functional state of individual masticatory muscles for the purpose of "neuromuscular functional analysis" [194]. EMG can be used to gather useful data on the parameters of resting activity, maximal muscle activation, spectrum of frequency during prolonged occlusal loading, and the symmetry of EMG activity (contraction behavior) of muscles on both sides of the jaw [201,202].

8.3 Clinical Utility

8.3.1 Electromyography in Prosthodontics

Technical performance of the device and patient satisfaction are the factors generally considered when assessing the functional value of a reconstructive procedure. When included in such an assessment, EMG provides additional information that takes neuromuscular aspects into account. In clinical practice, EMG signals may be recorded, for example, for comparison of neuromuscular balance in intercuspation before and after restorative dentistry or after occlusal correction following the insertion of restorations. Studies indicate that electromyography can demonstrate asymmetrical recruitment patterns in muscles due to occlusal height differences in the individual patient [203,204].

8.3.2 EMG in Dental Functional Diagnosis and Functional Therapy

Statement 25: Limitations of surface electromyography (*NEW* in 2022)

Pain induces reproducible changes in the neuromuscular system that can be detected by electromyography. Surface electromyography *is not* a direct measurement method for the objectification of pain. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
References: [202]	

The most important changes for the clinical evaluation are observed in maximal voluntary contraction, during resting activity, and in the spectrum of frequency during loading. Differences in the symmetry of EMG activity in muscle contraction have also been reported [201,202].

- ***Maximal voluntary contraction:*** According to the Pain Adaptation Model, it is hypothesized that reduced maximal muscle activation and lower force development can be observed during static muscle contractions in patients with myoarthropathy (MAP).
- ***Resting activity:*** The consistently observed increase in resting activity in MAP patients can be interpreted as a pain adaptation mechanism (mainly muscle stiffness) designed to protect the affected muscles or muscle regions. Conversely, strong phasic activity leads to pronounced muscle inhibition. Experimentally induced muscle fatigue also causes increased resting activity. Recent studies indicated that pain patients have increased resting activity.
- ***Fatigue:*** Numerous studies have shown that, with increasing muscle fatigue, the median frequency of the power spectrum (MPF) of the muscles of mastication, like that of the limb muscles, shifts to lower median values more rapidly than in a healthy system.
- ***Symmetry of muscle contractions:*** There is evidence that MAP patients exhibit asymmetry of contractions on the left and right sides of the jaw. However, perfect symmetry of EMG activity is not generally observed in healthy subjects either.

Statement 26: Implications of EMG recordings (reviewed & approved without change)	
The following information can be derived from EMG recordings: • Increased fatigue as an indicator of the extent of the individual muscle lesion • Reduced contractility as an indicator of the extent of the individual muscle lesion • Increased resting activity as an indicator of lesions in or around the temporomandibular joint, clinically non-manifest muscle lesions, stress factors, or a hypervigilant disposition of the patient • Visualization of changes in recruitment patterns of the muscles during occlusal modification of occlusal splints (change in maximum contractility, change in right-left balance patterns) as an indicator of therapeutic efficacy and for follow-up monitoring. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**

Expert consensus

8.4 Summary

Since electromyography provides additional information about the dynamic *muscle-related activity*, it seems to be a suitable method for additional dental functional analysis if this is appropriately *focused on specific questions.*

The knowledge gained from such a *neuromuscular functional analysis* can be directly incorporated into functional therapy measures and used for occlusal design and adjustment purposes in restorative and prosthetic dentistry.

The clinical use of surface electromyography in dentistry requires specific knowledge of the method and its application in patients.

Recommendation 33: Indications for surface electromyography (modified 2022)	
Data collected in surface electromyography **should** always be evaluated and interpreted in conjunction with the results of a prior thorough history and clinical functional analysis, as is also the case with kinematic studies. [Vote: 13 Yes / 0 No / 0 Abstain]	**Strong consensus**
Expert consensus	

9 Future Research Needs

9.1 Instrumental Movement Analysis

- Clinical randomized controlled studies comparing the importance of individual functional parameters determined by instrumental movement analysis versus the average-value method of occlusal surface design for fixed and fixed-removable dentures are still lacking. Such studies are extremely challenging to perform in several respects due to their high financial burden (costs for examiners and patients, for the acquisition of suitable candidates, and for the tooth replacement to be manufactured), complexity and time burden associated with the standardization of processes in the dental laboratory and with the definition and determination of relevant outcome parameters (both patient-centered and oral physiology-based variables). Given the number of patients required for such studies, a multicenter study design with the associated challenges of examiner calibration appears necessary.
- Mandibular movement recording studies in a large, representative population of patients are scarce. In combination with clinical functional analysis and, if appropriate, manual structural analysis and any other additional examinations needed (instrumental or imaging studies), the results of such studies make it possible to differentiate the range of functional movements defined as *physiological* from those defined as disturbed or dysfunctional, to define diagnostic criteria for dysfunction, and to compare them with existing data and concepts.
- Clinical follow studies capable of demonstrating the clinical value of instrumental movement analysis in the context of functional therapy using well-defined, adequately sized and representative *subgroups* of CMD or TMD/MAP patients are lacking.
- Studies on of the question of whether, in implementation of the digital workflow by dental laboratory technicians, the results obtained with digital data are equivalent to those of analog methods are likewise missing.

9.2 Condylar Position Analysis

- The question of the extent to which different registration techniques result in spatially different positions of the joints and of whether such differences in registration result in differences in the quality of adaptation when the dentures are inserted in the patient's mouth still has yet to be studied sufficiently.
- There is a lack of studies on how precisely the position determined on the patient can be transferred to computer-assisted systems (e.g., CAD/CAM) and articulators in the dental laboratory.
- Supporting studies on the reliability of condylar position analysis and on the precision of transfer of the measured results to both conventional analog articulators and virtual articulators are also lacking.

9.3 Jaw Relation Recording

9.3.1 Vertical Jaw Relation Recording

There is a lack of prospective studies comparing multiple different vertical jaw relation recording methods in a large sample of patients and taking the following parameters into account:

- Adaptability, coping
- Reproducibility
- Time and effort
- Clinician-related factors
- Costs.

9.3.2 Horizontal Jaw Relation Recording

There is a lack of prospective studies and, where feasible, blinded clinical trials comparing multiple different horizontal jaw relation recording methods in a large sample of patients and taking the following issues into consideration:

- What are the effects of differences in the activation of the jaw-closing muscles (force during recording and the actual registration) on the position of the condyles in central bearing point registration?
- Do differences in closing force during encryption lead to differences in patient acceptance of full dentures?
- Are there differences in patient satisfaction with dentures designed by manually guided horizontal jaw relation recording versus central bearing point registration?
- How does moderate mandibular guidance during central bearing point registration affect the position of the condyles compared to unguided mandibular movements performed solely by the patient during registration?
- How does constriction of the oral cavity and/or tongue displacement affect the position of the condyles in central bearing point registration?
- Where is the “central point of bearing” of maxillary and mandibular complete dentures located?
- When performing central bearing point registration, to what extent does the *joint* “central point of bearing” of complete dentures during jaw closure differ from the individual center of occlusal force of the maxilla and mandible, respectively?
- How high are the technical and time requirements for manually guided horizontal jaw relation recording compared to those of central bearing point registration?

9.4 Facebow Transfer

- Randomized controlled trials – which, ideally, should also be blinded with regard to the dental technician and the dentist – investigating the extent to which average-value or individual value facebows may decrease the time required for the fabrication of fixed dentures and dental prostheses are lacking. Such RCTs must include the separate analysis of target variables for the static and dynamic occlusion.

9.5 Surface electromyography of the masticatory muscles

- Studies designed to determine reference values for EMG parameters for different age groups in a large, maximally representative population of functionally healthy individuals and to utilize the collected data to assess the reliability of EMG-specific examination techniques have yet to be performed. Clinical trials in patient populations large enough to generate comparative values for EMG parameters for well-defined subsets of patients with craniomandibular disorders would also be desirable.
- Clinical studies that characterize the impacts of different functional and dental-restorative treatment modalities in terms of induced changes in EMG parameters are useful. In this context, the question of the extent to which EMG parameters are associated with clinical findings on the one hand, and with self-reported evaluations by the patient on the other is a subject of interest.
- Kinematic electromyography, a method of combining kinematic data with electromyographic data, offers the potential to perform an objectifying assessment of the masticatory process and chewing capacity, including data on the degree of comminution of food or test food and particle size distribution. Clinical studies in well-defined patient populations and clinical trials with sample sizes large enough to obtain valid comparison values or reference values in the physiological context are needed to reliably confirm the validity of the assessment strategy in the context of an expanded dental functional analysis.

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