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METHOD PRESENTATION ARTICLE

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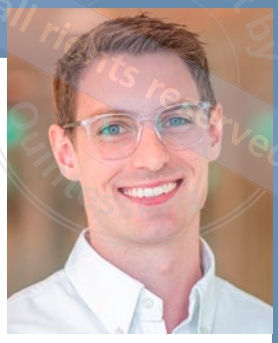
Workflow for in-office aligner orthodontics using the virtual articulator



Paul Grunau

KEYWORDS *Digital Motion Decoder, in-office aligner, Modjaw, occlusion, temporomandibular dysfunction, temporomandibular joint, virtual articulator*

Aligner therapy has been an integral part of orthodontics for over 20 years since it was first introduced by Align Technology (San Jose, CA, USA). There is now a vast range of aligner providers to choose from, but there is little to distinguish them. Owing to the virtual treatment simulation software that is now available and the rapid advancements in 3D printing technology that have occurred, it is now possible for orthodontists to produce aligners independently, and in-office aligner therapy is becoming increasingly important. Almost all tooth movements can be performed with aligner treatment. Temporomandibular dysfunction can also be treated using bonded onlay elements in phase one of treatment. In the present study, the authors outline a workflow for in-office aligner treatment that utilises the advantages of a virtual articulator to treat patients with and without temporomandibular dysfunction.

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Introduction

Treatment of temporomandibular dysfunction (TMD) is possible using bonded onlay elements in phase one of aligner treatment.[1] Recent advancements in joint space recording technology and the high level of efficacy of clear aligner treatment in controlling orthodontic tooth movement[2] allow this first phase to be omitted.

The aim of orthodontic treatment should be to achieve neutral adjustment of the temporomandibular joints (TMJs) and the occlusion, and harmonisation of the skeletal relationship.[3] Only once this has been achieved can treatment be considered successful. The dentofacial aesthetics at the end of treatment should be optimal.

The TMJ is loaded with 50 to 80 kPa. Overloading of the TMJ due to incorrect occlusion leads to erosion.[4] In the majority of cases, pain in the joint area is associated with condylar displacement with distal, disto-cranial and/or transverse components, as previously described by Gerber.[5,6] The establishment of physiological conditions in the TMJ is the primary goal of gnathological and orthodontic treat-

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ment. In the optimal intercuspal position (ICP), the condyle is assigned to the turning point at the temporal bone and not to the fossa.[3]

In the absence of disease activity, it is structural joint damage that explains the irreversible loss of physiological function. There is widespread opinion among clinicians that joint space narrowing (JSN) has a more significant impact than erosion. JSN causes more irreversible physical loss of function than erosion. It is to be assumed that JSN on radiographs indicates a loss of cartilage. Subluxation is a major contributor to irreversible loss of function. Patients who receive the worst scores on the Health Assessment Questionnaire (HAQ), a self-test related to rheumatoid arthritis, also have the worst radiological scores with JSN. JSN is more significant with regard to explaining loss of physical function than erosion.[7]

Degenerative osteoarthritis

It is undisputed that the mechanical factor is the key to the progression of degenerative osteoarthritis (OA). The joint is the load-bearing structure of the body. The presence of synovial fluid and discs allows the bones to move with little friction. Nevertheless, different joints react differently to loading. When biting, the TMJ can be loaded with the equivalent of the body weight.[8] In the early stages of osteoarthritis, a microfracture develops and the cartilage is first to show microarchitectural changes combined with mitochondrial dysfunction of the chondrocytes.[9] The mechanical stress may also affect chondrocytes, which release extracellular vesicles (EVs) containing mechanosensitive substances such as miR-221-3p to regulate cell communication during bone remodelling[10]; however, the effects of mechanical impact are usually self-limiting. If intervention is performed in a timely manner, the cartilage dysfunction will recover and be rebalanced.[11]

Degenerative osteoarthritis of diarthrotic joints (true joints), the most common kind of arthritis, can be triggered by biomechanical causes such as changes in loading pattern. The affected joint is often associated with degeneration of the non-calcified articular cartilage, thickening of the calcified cartilage and remodelling of the subchondral bone, which affects not only the trabecular but also the subchondral cortical bone. The main histological change in the subchondral trabecular bone is the loss of bone volume at an early stage. This increases later, whereas the change in the subchondral cortical bone involves consistent thickening, often combined with thickening of the calcified cartilage.[12]

TMJ disorders are characterised by arch dysfunction and pain in the TMJs and masticatory muscles and affect around 10% to 15% of the adult population.[13] As early as 1971, Rakosi[14] pointed out that children aged 8 to 10 years exhibit initial symptoms of TMJ disorders. These are predominantly functional in origin, and the most common causes are muscular disorders and hyperactivity of the musculature, hypermobility of the TMJ, posterior dislocation of the condyle and dysgnathia.

Degenerative osteoarthritis is a joint disease characterised by synovial inflammation, progressive cartilage degeneration and subchondral bone remodelling, which lead to joint pain, deformity and dysfunction.[15] Osteoarthritis can affect synovial joints, and both the peripheral joints and the TMJs are examples of these.[16] Unlike peripheral osteoarthritis, TMJ osteoarthritis is the final stage of TMJ disorder and is often characterised by abnormal arch movements and restricted mouth opening, and sometimes accompanied by tinnitus, headaches and other symptoms.[17] The nerve-rich structure could be the reason why TMJ osteoarthritis patients are more susceptible to neurological symptoms.[11,18] TMJ osteoarthritis leads to hyperalgesia and neurological symptoms, including tinnitus, headaches and mental disorders.[19]

Especially in TMJs with anterior disc displacement, the antagonistic joint surfaces are incongruent. This leads to small joint contact surfaces with high repetitive loading, particularly with a compressed joint space. However, even with a centred disc position, the load leads to compression of the joint surfaces in the mandibular and maxillary joint space and thus to high repetitive load vectors. In combination with posterior displacement of the condyle, this also leads to compression in the bilaminar zone and repeated stimulation of mechanoreceptors and nociceptors. The TMJs are "stress-loaded", meaning the force of the bite in occlusion is transmitted to the skull via the TMJs.[20]

The TMJ has a direct biomechanical relationship with the occlusion. This makes it easy to disrupt the biomechanical environment of the TMJ by changing the occlusion through orthodontic and prosthetic treatments without invasive

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intervention in the TMJs.[21] This also explains why it is necessary to pay special attention to the TMJs when performing functional orthodontic adjustment of the mandible in growing children.

Altered or disturbed joint dynamics can lead to over- or underloading, which can in turn cause an inflammatory process with subsequent triggering of nociceptors.[22] The altered proprioceptive afference has a direct effect on the sensory regulation of the musculature. As a result, the nociceptive system leads to further arthrogenic dysfunction with a change in movement regulation. The mechanoreceptors and nociceptors themselves become a starting point for sensorimotor disorders and lead to activation of the nociceptive system. The resulting additional triggering of the neurons leads to activation of muscle spindles. As a result, motor units react disproportionately to even small, perhaps otherwise still subliminal contractile strain amplitudes or others, for example peripheral or central triggers. The conclusion that can be drawn from this is that altered or impaired joint function causes altered muscle function.[22,23]

Digital joint recording in in-office aligner orthodontics

Every functional diagnosis starts with a clinical examination.[24] Each patient should undergo a brief assessment of the TMJs, mandibular mobility and masticatory muscles. The present authors use the short screening test established by Ahlers and Jakstat[25] in the modification according to Meyer.[26] Only then is a decision made as to whether additional imaging procedures are necessary and useful, and if so, which ones. The further functional diagnosis, which can be directly transferred to treatment, is improved and visualised by the digital joint examination.[27] This procedure for patients with and without temporomandibular dysfunction (TMD) is demonstrated in the flowchart in Fig 1.

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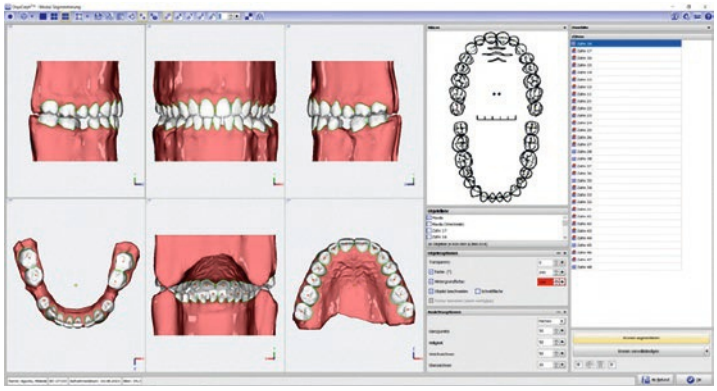
Fig 1 Flowchart of the in-office aligner technique.

1. Scan (without virtual articulator)

- Maxillary and mandibular arch, maxillary arch with palate
- Occlusion
  - *TMD no → scan in habitual intercuspation*
  - *TMD yes → scan in therapeutic condyle position*

2. Match and prepare (without virtual articulator)

- Matching scan into OnyxCeph^3 software
- Preparation and segmentation of virtual models



3. Digital joint recording (Dental Motion Decoder [DMD]/Modjaw)

- Scan maxilla and mandible, maxilla with palate
- Bonding sensors on maxillary left premolars and mandibular right premolars for Dental Motion Decoder (DMD) (Ignident, Ludwigshafen, Germany)
- Adjustment of headband with sensory markers, adaptation and bonding of paraocclusal bite fork as holders for sensory markers, calibration of the system to the sensory markers, virtual selection of intraoral reference points for Modjaw (Villeurbanne, France)
- Recording joint space and track
  - *Determination of arbitrary axis points for DMD and Modjaw*
    - *12 mm in front of the upper margin of the tragus and 3 mm below the line connecting the tragus and the lateral corner of the eye*
  - *Drawing of the axis points and the tip of the nose (Camper plane) for DMD*
  - *Determination of subnasal point and selection of intraoral occlusal reference points for Modjaw*
  - *Recording of the joint space*
    - *Right/left dorsal joint space*
    - *Right/left dorsocranial joint space*
    - *Right/left cranial joint space*
    - *Right/left transversal joint space*

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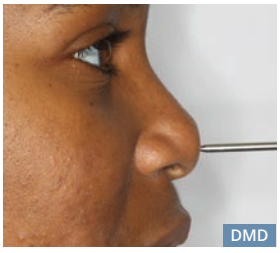
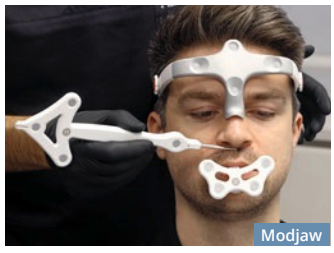
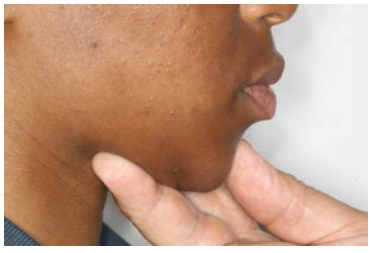
3. Digital joint recording (Modjaw)

- *Recording of the condyle track*
  - *Opening with and without compression*
  - *Opening three times*
  - *Protrusion with and without compression*
  - *Protrusion three times*
  - *Right and left mediotrusion*

3. Digital joint recording







- Matching DMD data with scan data
- Analysis of DMD data
  - *3D joint space*
    - *Endfeel in joint play present*
      - *Yes: by mobilising the mandible dorsocranially, a space can be taken dorsocranially, left TMJ*
      - *No: by mobilising the mandible dorsocranially, a space cannot be taken dorsocranially, left TMJ*
  - *Condyle track*

    Physiological track

    Pathological track
    - *If a pathology is present, the following phenomena can be observed:*
    - *Insufficient length*
    - *No concavity; more straight or convex*
    - *Excursive and incursive path not congruent*
    - *Stop and go phenomena*
    - *Rebound effect*
    - *Jump*
    - *Deviation*

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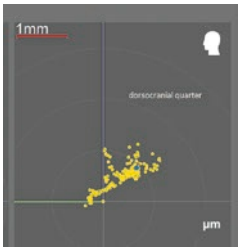
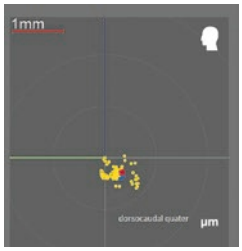
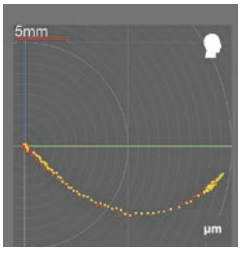
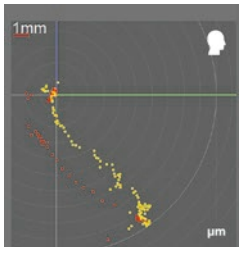
3. Digital joint recording (DMD)





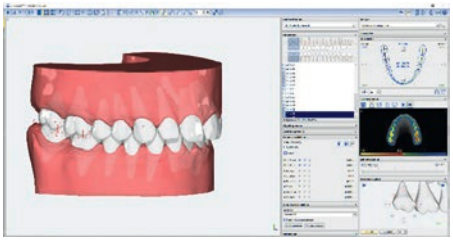


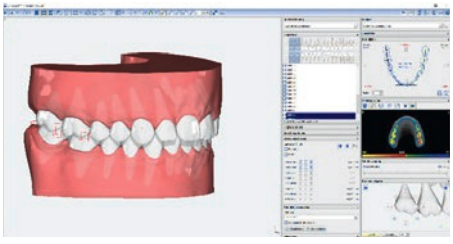


- Determination of the condyle axis (DMD)
  - *TMJ space*
    - *0.6–0.8 mm vertical (finding orientated)*
    - *0.6–0.8 mm sagittal (finding orientated)*
    - *No or minimal right/left transversal deviation*
  - *If there is no TMD, the axis is defined in the habitual intercuspation in symmetrical setting.*
- Determination of hinge axis by selecting range of rotational movement during opening and closing movement (Modjaw)
- Closed jaw position: first occlusal contact in the new condyle position in DMD
- Rotate around axis and find contacts by visualising contact points and export first contact position in Modjaw
- Matching of the mounted scan models and the individual arch movement into OnyxCeph^3 (VTO 3D)

4. Basic considerations in orthodontic treatment planning

- What is the main goal of the treatment?
- Which teeth should not be moved?
  - *No movement of these teeth at this stage because of anchorage*
  - *No movement of these teeth is necessary*
  - *TMD – treatment with craniomandibular orthopaedic positioning appliance (COPA) – onlay in phase 1, do not move the teeth with COPA onlay and the antagonists*





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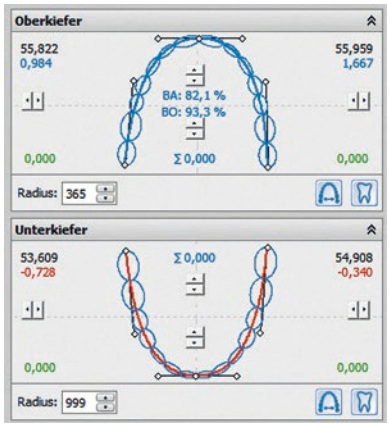
4. Basic considerations in orthodontic treatment planning

- Transverse movement
  - *If necessary, start virtual treatment simulation (VTS) with transverse movement*
  - *Transverse correction tooth by tooth*
  - *Transverse correction for the entire arch*
  - *Not necessary*
- Sagittal movement
  - *Necessary; see Class II/III*
  - *Not necessary*
- Vertical movement
  - *Necessary; see deep bite, open bite*
  - *Not necessary*



5. Treatment planning related to the anomaly in VTS in OnyxCeph³ – VTO 3D

1 Spacing

- Space closure
  - *From anterior, from posterior or in combination*
- Space allocation for symmetry and possible later restorative dentistry
- Avoid tipping especially when closing space from posterior → slow staging and angulation with translation
- Avoid space closure by means of mesialisation of molars of more than 3 mm → auxiliaries needed

2 Crowding

- Extraction
  - *Planned before the VTS*
  - *Planned within the VTS*
- Anterior proclination if sufficient buccal alveolar bone and gingiva
- Expansion
  - *In combination with buccal corridors*
  - *If compatible with periodontal situation and gingiva type*
- Maxillary/mandibular distalisation

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2 Crowding

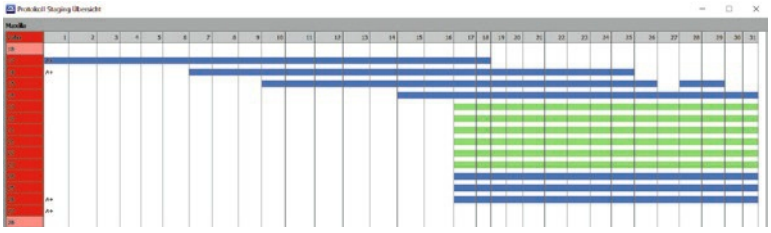
- Interproximal reduction (IPR) (Fig 11)
  - *Only in areas of crowding within the limitation range*
  - *Also in neighbouring areas: If there is a lot of crowding in the incisor area, start IPR from mesial first molar to distal canine in all approximal spaces and distalise premolars and canines to obtain anterior space*
  - *Simultaneous reshaping and treatment of black triangles*
  - *Priority on present restorations (crowns, restorations)*

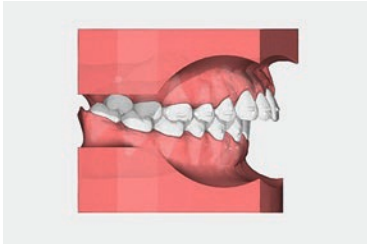
3 Bolton discrepancy

- Solve completely with IPR
- Space allocation for symmetry and possible later restorative dentistry

4 Angle Class II

- Creation of an Angle Class I occlusion
  - *Extraction*
    - *Class II – elastics*
    - *Temporary anchorage devices (TADs) possibly*
  - *Sequential distalisation in the maxillary arch*
    - *Class II – elastics, TADs possibly*
  - *Orthognathic surgery*
    - *Set up with presurgical decompensation and surgical simulation in VTS*
  - *Teen – treatment*
    - *Combined with Class II – elastics, no sequential distalisation in mild dental Class II occlusion with children*
    - *Combined with Frankel appliance for skeletal Class II with children*





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5 Angle Class III

- Creation of an Angle Class I occlusion
  - *Distalisation in the mandibular arch*
    - *Class III elastics*
    - *TADs possibly*
  - *Orthognathic surgery*
    - *Set up with presurgical decompensation and surgical simulation in a Class I – occlusion in the VTS*
  - *Teen treatment*
    - *Combined with Frankel III for skeletal Class III with growing children*
    - *Class III elastics for frontal crossbite correction (caution: check TMJ)*

6 Deep bite

- Raise deep bite
  - *Intrusion of maxillary incisors (caution: 2 mm of incisor crowns remain visible when the upper lip is in a resting position)*
  - *Intrusion of anterior mandibular segment (incisors and/or canines)*
  - *Extrusion of posterior mandibular segment (4, 5, 6, 7)*
    - *With fixed COPA – onlay*
    - *Without COPA – onlay, if only minimal extrusion is needed*
  - *Combined intrusion and extrusion in the mandibular arch*
  - *Teen treatment: level curve of Spee with aligners and Frankel appliance in growing children*

7 Open bite

- Close open bite
  - *Extrusion of anterior teeth and intrusion of molars, sometimes premolars, with virtual articulator; control of intrusion and extrusion is precise*
    - *Aligner orthodontics only*
    - *Combined with TADs for posterior intrusion*
  - *Orthognathic surgery with presurgical decompensation and surgical simulation in VTS*
  - *Myofunctional therapy if tongue dysfunction exists*

8 TMD

- Establish a physiological condyle position in a pain-free area
  - *COPA onlay during first treatment phase after completion of pre-treatment by means of removable COPA or VTS with virtual articulator*
  - *Eliminate occlusal factors that may lead to a pathological condyle position*
  - *With virtual articulator, COPA onlays are not needed (see 3)*

9 Growing patients

- Space opening for eruption of permanent teeth
- Expansion in crossbite patients
  - *Expansion with aligners*
    - *Cover palate with aligner material, monolayer 0.75 mm*
    - *Overcorrection and buccal root torque of maxillary premolars and molars and distorotation of first molars*
  - *Removable rapid palatal expansion appliance with attachments for maxillary expansion*
    - *Overcorrection*
  - *Expansion in both arches*
    - *Cover palate with aligner material, monolayer 0.75 mm*
    - *Overcorrection and buccal root torque in both arches*

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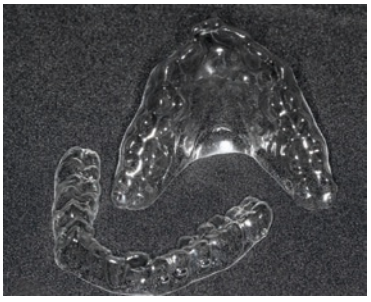
9 Growing patients

- *Angle Class II*
  - *Aligner orthodontics with Frankel appliance*
  - *Maxillary expansion*
  - *Distorotation of the maxillary first molars*
  - *Sufficient horizontal overlap for remaining growth*
- *Angle Class III*
  - *Aligner orthodontics with Frankel appliance or Class III – elastics*
  - *Myofunctional therapy if tongue dysfunction exists*



10 Extraction treatment

- Root movement before crown movement → uprighting/angulation of roots
- The smaller the staging, the more bodily movement is possible
- Vertical rectangular attachment for bodily movement
- Buccal root torque
- Sometimes anchorage with elastics and/or TADs needed
- Sequential tooth movement, no en-masse retraction
- Start with 1 mm IPR on the mesial aspect of the tooth that is to be extracted and a separator on the mesial aspect of the neighbouring tooth that is to be distalised for 3 days. Remove the separator for the scan; retention splint is needed until aligner is made
- Alternative frequent practice:
  - *Scan*
  - *Perform virtual IPR planning on the tooth that is to be extracted (1–2 mm)*
  - *Perform IPR with the inset of the first aligner*
  - *Perform virtual extraction planning after the IPR space is closed*
  - *Extract the tooth when planned in the VTS*
- Mesialisation of molars by means of bodily movement more than 3 mm is not possible with any aligner system (only in combination with skeletal anchorage)

11 Maxillary or mandibular distalisation: the sequence

1.	Second molars	50%		
2.	Second molars	50%	First molars	50%
3.	First molars	50%	Premolars	25%
4.	Premolars	50%	Canine	25%
5.	Premolars	25%	Canine	50%
6.	Canine	25%	Incisors	100%

- *Vertical rectangular attachments on first and second molars, premolars and canines*

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12 Maxillary or mandibular distalisation: the sequence

- *Horizontal rectangular attachments on central and lateral incisors (once movement starts) plus torque elements if additional torque is planned*
- *Always: Anchorage with elastics (canine to first molar, hook/button)*
- *Angulation and buccal root torque of first and second molars, premolars and canines*
- *Lingual root torque of incisors*

13 Expansion

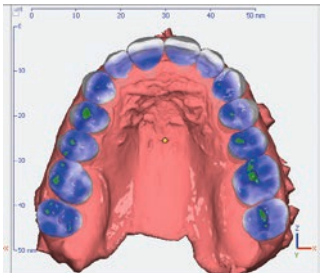
- Buccal root torque
- Slow staging
- Monolayer 0.75 mm
- Upper with covered palate
- Avoid recessions; depending on gingiva type and bone, sometimes a CBCT scan is needed and matched in OnyxCeph[3]

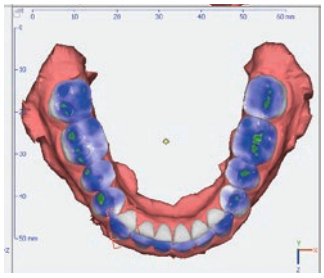
14 Space management

- Finish virtual treatment planning, then check for spaces or overlapping between teeth
  - *Close spaces if possible*
  - *If not possible, decide where space creation is reasonable and where additive measures make most sense by means of aesthetics and symmetry*
- Plan IPR from the beginning:
  - *The higher the amount of anterior space deficit, the more IPR needs to be planned between premolars and on the mesial aspect of first molars to distalise premolars and canines before aligning the incisors*
- IPR needed
  - *IPR values stay within the limitation range*
    - *Distribution of IPR to create equal IPR values within the limitation range*
    - *Whenever interproximal fillings or artificial crowns are present, more IPR should be performed on these*
- IPR values exceed the limitation range
  - *Distribution of IPR to other interproximal spaces (are there fillings or artificial crowns to perform more IPR on?)*
  - *More proclination/expansion/distalisation if possible?*
  - *If none of the above work, extraction treatment becomes inevitable*

15 VTS/virtual articulator

- First preference and start of the VTS involves establishing a physiological occlusion.
- Start with predictable movement first.
- Elimination of the first false occlusion contact, followed immediately by rotation of the mandible in the vertical articulator (“Rotation” icon).
- At the beginning of the VTS, always move only one to three teeth out of the malocclusion, then rotate mandible.
- Correct occlusal disturbance in small steps with corresponding rotation for DMD.
- Create contact points in the VTS without penetration, green contacts only.
- Check rotation, angulation and torque of the single teeth.
- Check space and IPR and align them.





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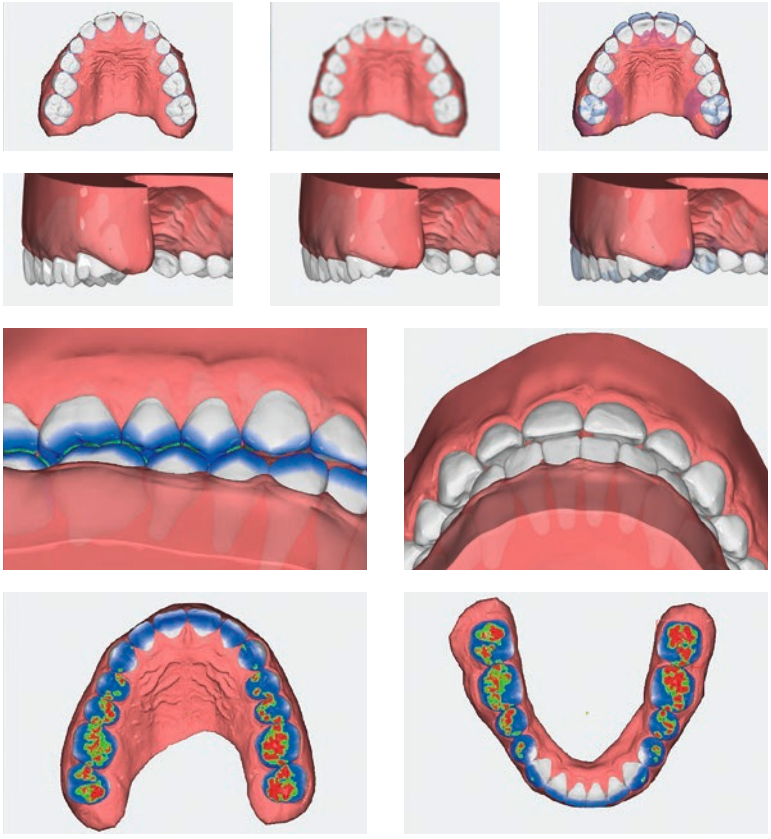
6. Check occlusion in the VTS → Finishing (without virtual articulator)

- Distorotation of maxillary molars (specifically in Class II treatment)
  - *Installation of Class I occlusion*
  - *Space creation*
- Buccal root torque of maxillary molars to create a physiological curve of Wilson (specifically combined with expansion)
  - *Horizontal rectangular attachments needed*
- Canine guidance (install light occlusal contact points in static occlusion)
- Position of incisors with freedom in centric occlusion (no occlusal contact – Shimstock open)
- Occlusal contact points for penetration/collision, Shimstock open incisor area in the VTS
- Vertical relation of maxillary incisors to the upper lip
  - *During intrusion: maintain 2 mm visible incisors*
  - *During extrusion: install 2 mm visible incisors*
- Buccal corridor
  - *If periodontal situation allows – fill buccal corridor by means of expansion*
- Smile arc preservation
  - *Curve of maxillary dentition follows curvature of lower lip*
- Before the VTS can be confirmed, the IPR list and the occlusal contacts should always be checked as the final stage



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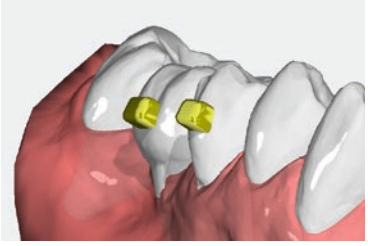
7. Planning of attachments and torque elements

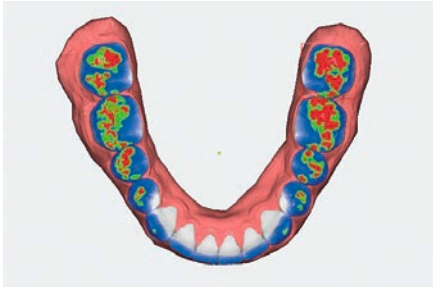
- Plan in Module Aligner 3D OnyxCeph³™
- Intrusion/extrusion → bevelled horizontal rectangular attachments
- Derotation → possibly bevelled vertical rectangular attachments
- Angulation → vertical rectangular attachments
- Buccal root torque of premolars and molars → horizontal rectangular attachments
- Mesial/distal translation → vertical rectangular attachments
- Torque → Torque elements



8. Staging – Limitations of movement

- The maximum movement defines the number of stages/steps
- Check collision in “distance crown-crown”
- 0.1–0.2 mm bodily movement depending on periodontal status and age of patient
- 2 degrees derotation depending on periodontal status and age of patient
- 2 degrees torque depending on periodontal status and age of patient
- 2 degrees angulation depending on periodontal status and age of patient

Vestibulo- oral translation	0.1–0.2 mm
Mesial/distal trans-lation	0.1–0.2 mm
Angulation	2°
Rotation	2°
Intrusion/Extrusion	0.2 mm
Torque	2°



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9. Material and number of aligners per step

- Attachment template 0.4 mm, monolayer
- Aligner material monolayer Biolon (Dreve, Unna, Germany) or Duran (Scheu Dental, Iserlohn, Germany)
  - *0.5/0.625/0.75 mm*
  - *e-module 2020 N/mm²*
  - *Expansion*
  - *To obtain higher material stability in patients with bruxism or younger patients who play with their aligners*
- Aligner material, multilayer (three-layer) CA Pro, UNIQ or Scheu
  - *0.5/0.625/0.75 mm*
  - *e-module 1600 N/mm² (CA-Pro), 1462 N/mm² (UNIQ)*
  - *Older children and adolescents*
  - *Adults*
  - *All movements except full-arch expansion*
  - *Multilayer is advisable in treatments with extensive movements*
  - *Often a combination of multilayer and monolayer is advisable, for example 0.5-mm multilayer followed by 0.625- or 0.75-mm monolayer for one stage/step*
- Aligner material
  - *TC-85 (Graphy)*
  - *0.5 mm*
  - *Shape memory*
  - *One aligner per step*
  - *Max. 10 days*

10. Preparing and transferring setup models to the 3D printer

- Tooth movement is as individual as the fingerprint of a human being. Therefore, it is likely to remain difficult to define individually precise staging. The orthodontist's experience seems to be and remains a decisive factor.

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Fig 2a to h Initial intra- and extraoral records.

Patient example 1

The following treatment is based on the analysis using the Digital Motion Decoder (DMD; Ignident, Ludwigshafen, Germany). A 29-year-old woman attended the present authors' practice due to bilateral TMJ pain as well as neck pain and headaches. She also reported back, hip and knee pain. Physiotherapy was unsuccessful.

Initially, the patient had a Class I relationship. In the mandible, rotations and crowding could be observed (Fig 2). In the clinical functional analysis (Fig 3) there were five positive findings; two or more positive findings give a clear indication of pathology.[25,26] The CBCT scan of the TMJs (Fig 4) showed retral-cranial condylar displacement on the left in sagittal view and JSN in the left TMJ in frontal view. The evaluation of the digital TMJ examination revealed significant TMJ pathology. Figure 5 visualises the joint play test and more JSN is visible on the left than on the right side.

In addition to analysing the joint space, unguided movements such as opening/closing and protrusion/retrusion in the patient were recorded. Figure 6 shows the protrusion and retrusion tracks of the condyles. Both condyles exhibited a straight and steep path with rebound and jump phenomena, and the right condyle had an especially short and straight path. Figure 7 presents the opening and closing tracks. Both tracks showed jumps as well as speed differences (only visible in motion). The right condyle also displayed a rebound phenomenon. A detailed analysis of all tracks and movements was documented on a diagnosis sheet for future reference and comparison with possible future joint recordings as another metric of treatment success (Fig 8).

Due to the JSN, the joint space was increased vertically by 0.65 mm in the DMD software (Fig 9). In the newly adjusted joint position, the mandible was closed in centric relation to the maxilla in the patient's individual axis to the

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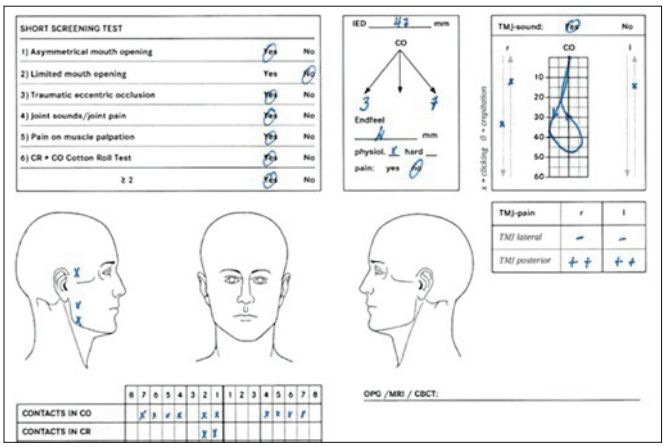

Fig 3 Short screening test with five positive results.

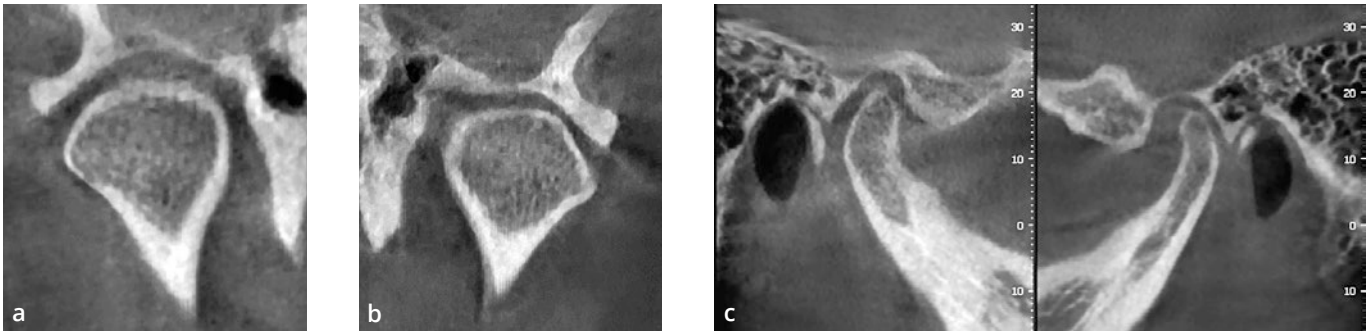

Fig 4a to c CBCT scan with retral-cranial condyle displacement on the left in sagittal view and JSN in the left TMJ in frontal view.

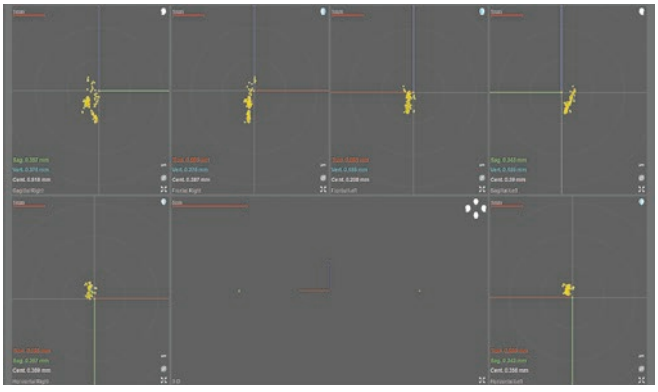

Fig 5 The joint space is narrowed in a cranial-dorsal direction. Visualisation of the joint play shows a pathological endfeel.

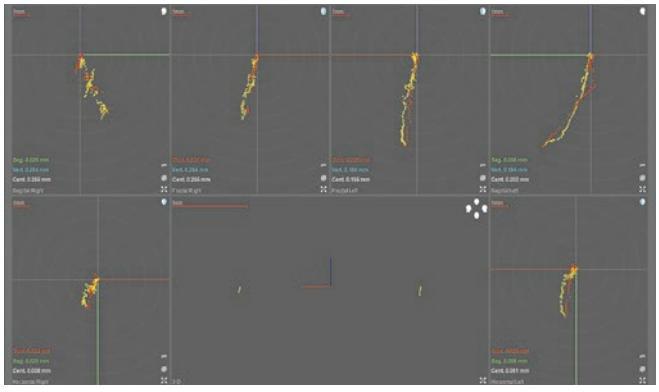

Fig 6 The protrusion (excursion marked in yellow; incursion marked in red) shows a shortened and straight trajectory with a speed difference, jump and rebound. The left trajectory is straight and shows a jump and rebound.

new first occlusal contact using the closed jaw function. The occlusal contacts were located on the mandibular right lateral incisor, canine and first molar (Fig 10). Posterior support was missing on the left side, matching the findings in the CBCT scan. Figure 11 shows the mounting of the mandible to the maxilla in the DMD software, which in the next step was transferred together with the patient's individual axis to the virtual treatment simulation (VTS) software (OnyxCeph^3, Image Instruments, Chemnitz, Germany) (Fig 12). Virtual treatment was carried out in the module "VTO 3D". Figure 13 shows the treatment of the anterior crowding in the mandible, the torque of the maxillary inci-

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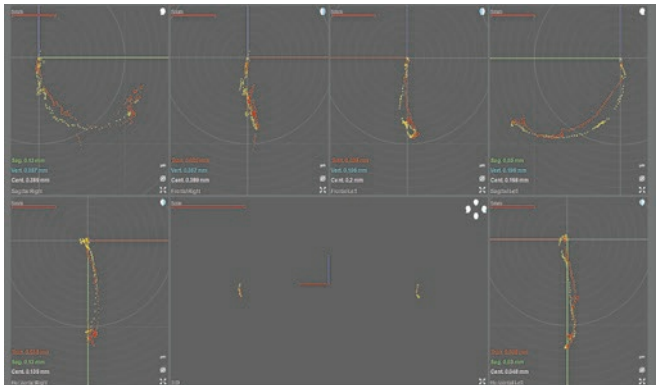


Fig 7 A jump and speed difference can be seen in the opening movement, with an additional rebound on the right. The tracks in excursion and incursion are different.

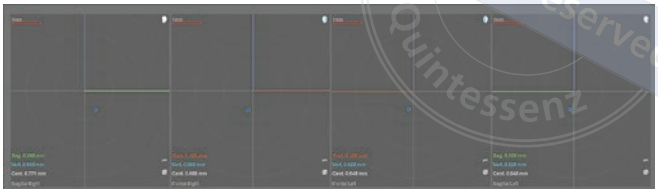
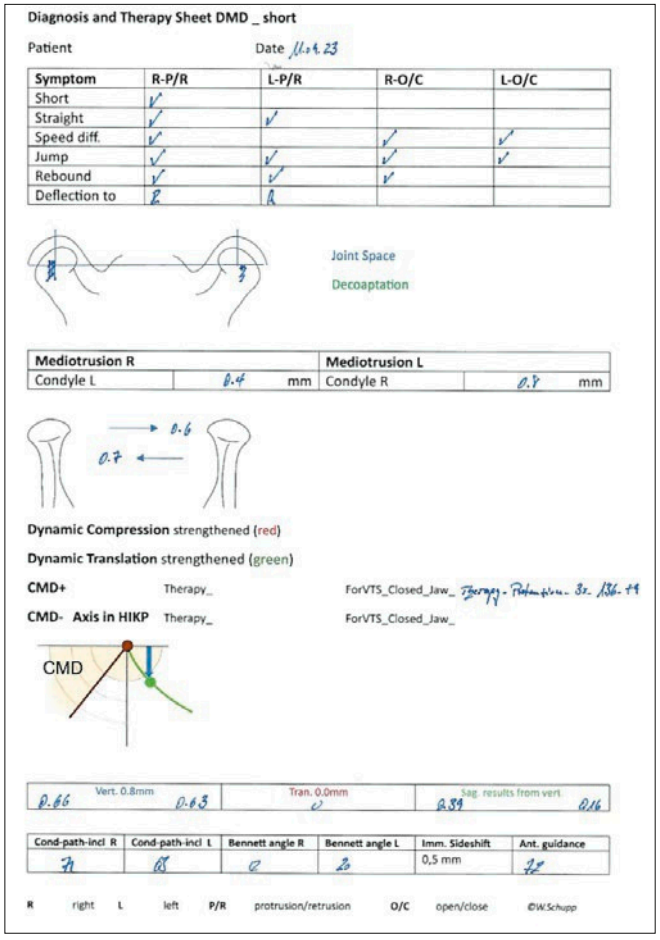


Fig 9 In the therapeutic setting, the vertical condylar position was changed by +0.65 mm, thus increasing the joint space.



Diagnosis and Therapy Sheet DMD _ short

Patient Date 11.04.23

Symptom	R-P/R	L-P/R	R-O/C	L-O/C
Short	✓			
Straight	✓	✓		
Speed diff.	✓		✓	✓
Jump	✓	✓	✓	✓
Rebound	✓	✓	✓	
Deflection to	R	R		

Joint Space
Decoaptation

Mediotrusion R		Mediotrusion L	
Condyle L	0.4 mm	Condyle R	0.7 mm

0.6
0.7

Dynamic Compression strengthened (red)
Dynamic Translation strengthened (green)
CMD+ Therapy_ ForVTS_Closed_Jaw_ Therapy - Protrusion 3x. 11.04.23
CMD- Axis in HIKP Therapy_ ForVTS_Closed_Jaw_

CMD

Vert. 0.8mm		Tran. 0.0mm	Sag. results from vert.	
0.66	0.63	0	0.89	0.16

Cond-path-incl R	Cond-path-incl L	Bennett angle R	Bennett angle L	Imm. Sideshift	Ant. guidance
71	68	0	23	0,5 mm	45

R right L left P/R protrusion/retrusion O/C open/close ©W.Schupp

Fig 8 Evaluation of the DMD findings and determination of the condylar position.

sors and physiological occlusal contacts. These contacts were identical at the end of treatment (Fig 14). The treatment consisted of two phases of aligners. In the second phase, some residual rotations were addressed, and the occlusion was optimised further. After this, the patient no longer reported TMJ, head and neck pain, and other initial symptoms were greatly reduced.

A joint motion recording from the end of aligner treatment showed a significant improvement. Both joints revealed an increase in joint space in the dorsocranial direction (Fig 15). The track of the condyles during protrusion was not physiological but improved. Jumps and rebounds were less pronounced, and the right track was less steep (Fig 16). The lack of concavity was due to the altered anatomy of the joint, which was not impacted by the treatment. The opening track, while still not physiological, also showed improvements in terms of a more even path (Fig 17).

The procedure is the same for patients without TMD; however, with these patients the joint position is not corrected. The mounting of the mandible is transferred to the maxilla in an unchanged joint position and thus gives an exact assignment in the VTS software, which in the present authors' practice is OnyxCeph[3]. As with TMD patients, the patient's individual axis is also transferred to the VTS software to simulate mandibular movement using the virtual articulator after each tooth movement.

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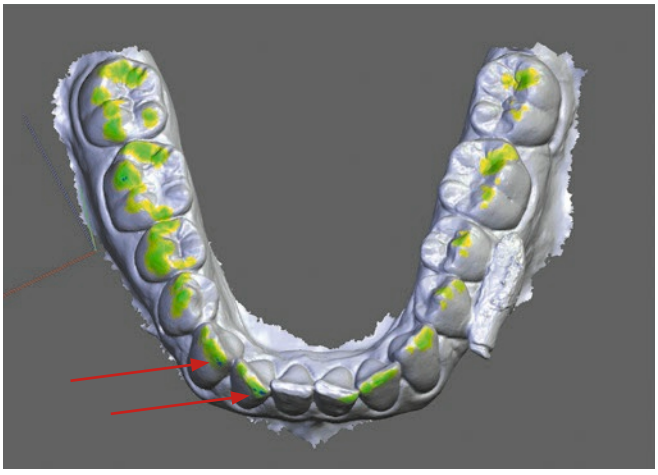

Fig 10 The closed jaw position in the improved joint position shows the first occlusal contacts in centric relation at the mandibular right lateral incisor and canine, then the first molar.

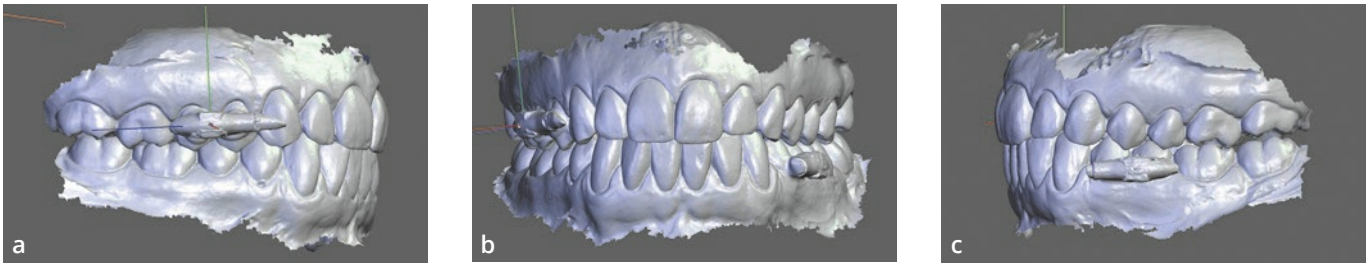

Fig 11a to c Adjustment of the mandible to the maxilla in centric relation (in DMD): left **(a)**, frontal **(b)** and right **(c)**.

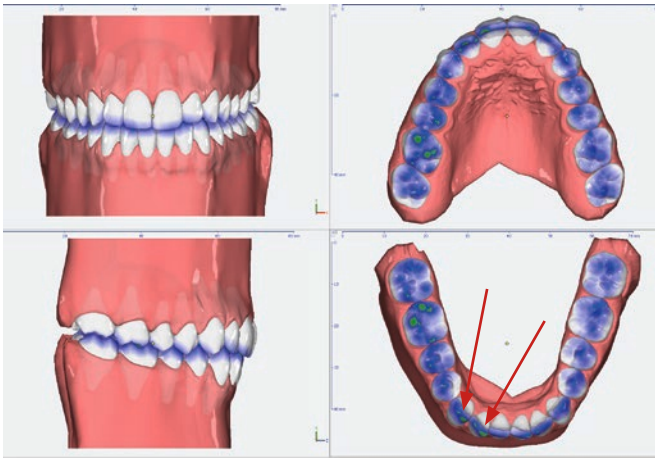

Fig 12 The mounting of the mandible to the maxilla in centric relation is matched from the DMD software to the VTS software (OnyxCeph³).

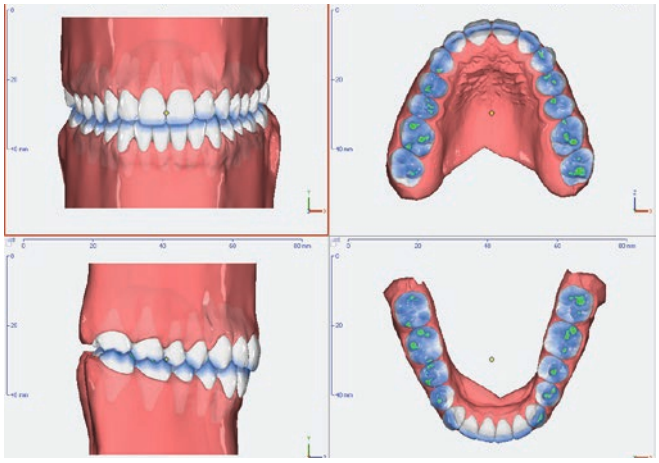

Fig 13 Virtual treatment objective with even occlusal contacts on premolars and molars and Shimstock foil open in the anterior region.

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Fig 14a to h Intraoral and extraoral records taken at the end of aligner treatment.

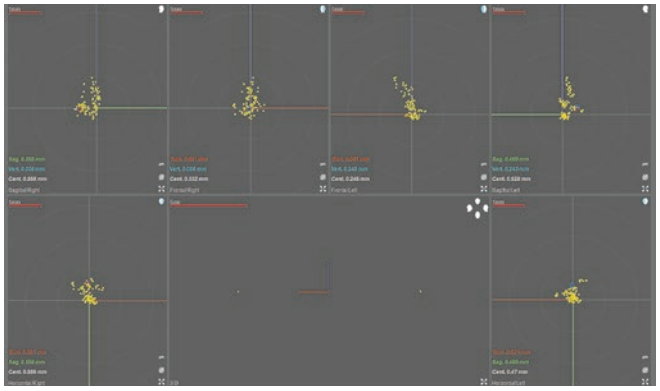

Fig 15 At the end of treatment, the joint space had improved significantly. Bilaterally, there was a dorsocranial endfeel in the joint play.

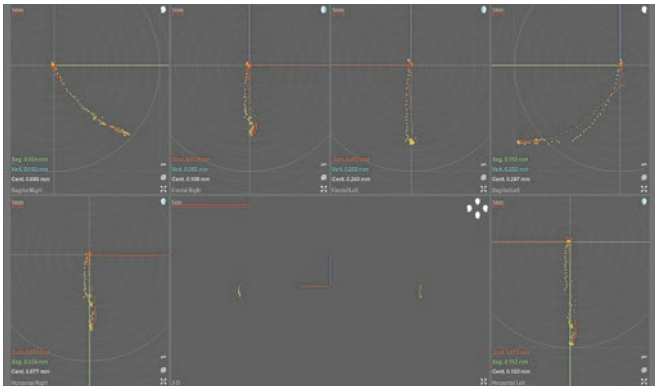

Fig 16 At the end of treatment, the protrusion path was not physiological, but significantly better than before. The right path remained straight due to the anatomy, but was less steep and only had one jump.

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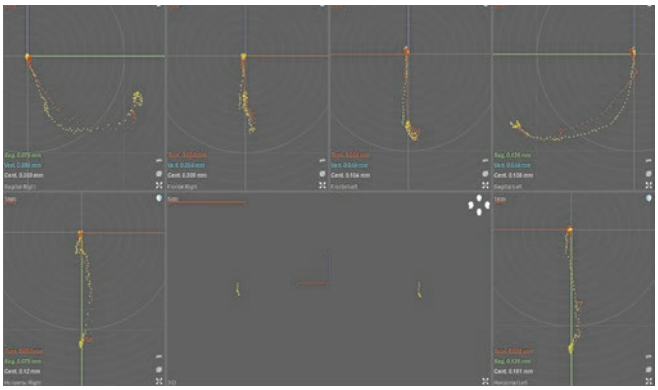

Fig 17 The opening path was not physiological, but significantly improved.

Fig 18a to d Intraoral situation before removal of the multibracket appliance. Gaps are still visible in the anterior maxilla and the maxillary incisors have an irregular incisal edge.

Patient example 2

The following treatment is based on the analysis using Modjaw (Modjaw, Villeurbanne, France). At the time of the initial presentation, the patient had a Class II division 2 malocclusion with an asymmetrical distal bite and a mandibular midline shift to the right. With mandibular retrognathia and a brachyfacial growth pattern, she exhibited a pronounced deep bite and an increased horizontal overlap of 5 mm, with retroclined fronts and a moderate lack of space in both arches.

A decision was made to procline and intrude the anterior maxilla and maintain the anterior mandible, supported by interproximal reduction. A fixed functional orthodontic appliance was used to correct the maxillomandibular relationship and harmonise the midlines. Fixed appliance treatment took 2.5 years (Fig 18). When the multibracket appliance was removed, the patient, who was at that point aged 16 years, still showed a slight midline shift with correct vertical and horizontal overlap and a mild distal bite on the right side, indicating a relapse of the functional orthodontic treatment (Fig 19). To optimise the treatment result, a decision was made to improve the occlusion using finishing aligners as positioners. For this purpose, a joint-orientated assignment of the intraoral scans was first carried out using Modjaw. In this arch tracking system, which uses a stereo

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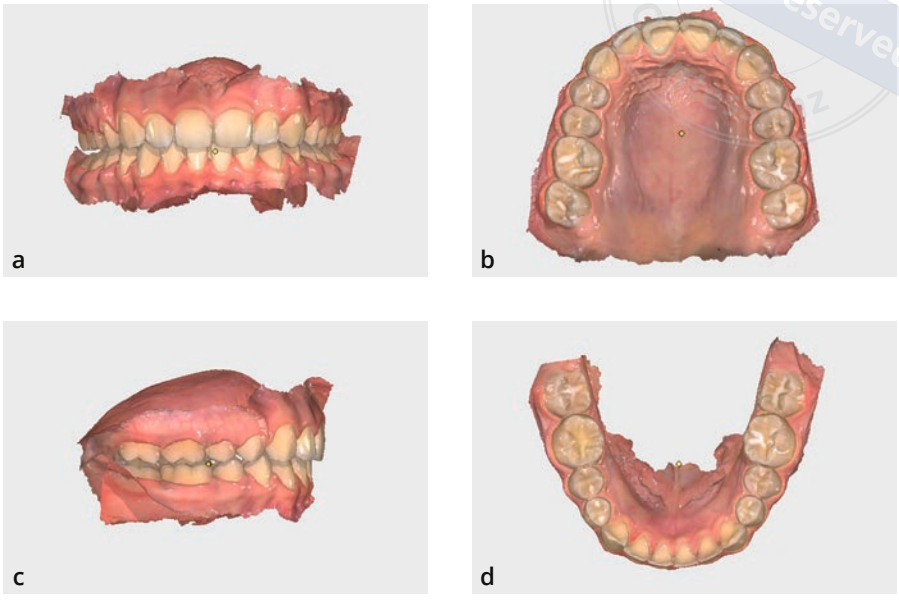

Fig 19a to d Intraoral scans of the situation at the time of removal of the multibracket appliance. A slight relapse of the bite position could be observed.

Fig 20 Determination of the subnasal point using markers on a pointer, the headband and a holder attached using a paraocclusal tray on a sample patient.

camera and markers on a headband and a paraocclusal tray (Fig 20) to recognise arch movements, first a hinge axis is calculated (Fig 21). This axis is then used to visualise the first occlusal contact on the intraoral scans through active rotation in the software (Fig 22 and 23). This situation, together with the individual hinge axis, is transferred to VTS software OnyxCeph^3 to produce the in-office finishing aligners (Fig 24). Masticatory as well as excursion movements can also be recorded (Fig 25), and can be transferred to the VTS software. Within this software, starting from the first occlusal contact, corrections are made to the respective tooth position to optimise the occlusion, to then finally produce the finishing aligners (Fig 26). The software also allows rotation around the hinge axis according to a lowering of the support pin in the articulator and thus provides the option of joint-orientated finishing. The treatment has not yet been finished; the focus is on demonstrating the workflow.

Discussion

The movement of the mandible from the centric position to habitual intercuspation is always associated with muscle contraction, usually asymmetrical. In a situation of malocclusion, the initial response is neuromuscular. This is typic-

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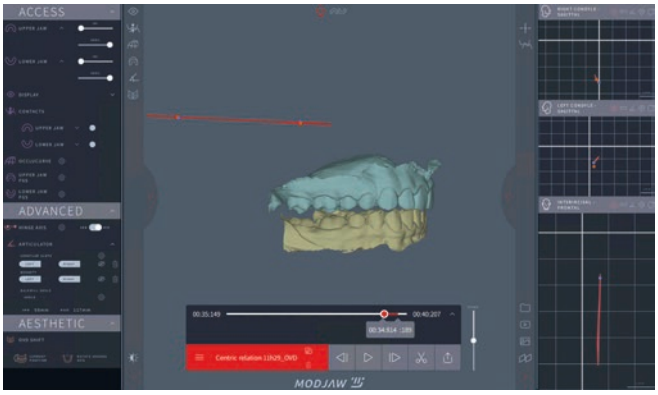

Fig 21 Determination of the kinematic hinge axis using an algorithm in TWIM software (Modjaw).

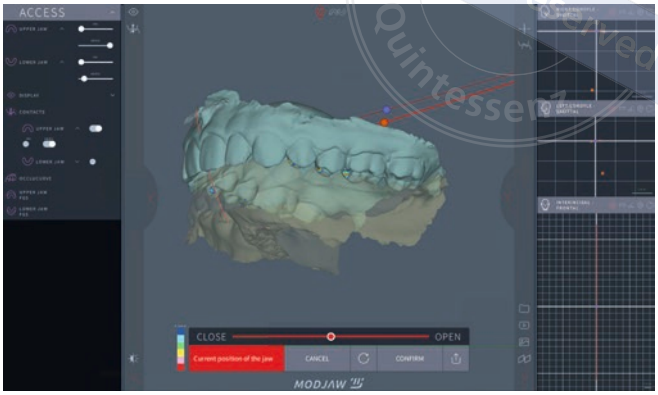

Fig 22 Active rotation of the mandible on the kinematic to the first occlusal contact.

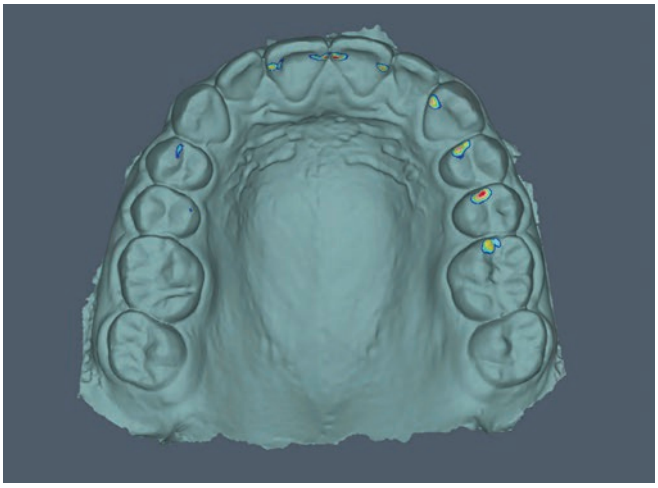

Fig 23 Visualisation of the first contacts with an occlusal view of the maxilla.

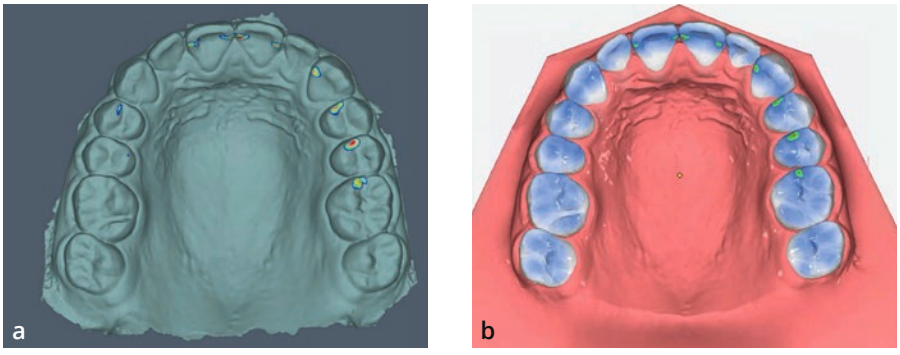

Fig 24a and b Transfer of the contact point situation to OnyxCeph[3].

ally followed by an adaptation, a new stability through change, or allostasis. If the capacity for adaptation is exhausted while the malocclusion is maintained, an allostatic overload occurs. Incorrect loading in the periodontal ligament (PDL) and the bilaminar zone can lead to pain in adjacent areas, even if the PDL and TMJ themselves are pain-free. Neurologically, the TMD develops into a musculoskeletal dysfunction, which can be defined in the pars caudal nucleus spinal nervi trigemini as trigeminocervical convergence and interconnection in the wide dynamic range com-

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Fig 25 Visualisation of the patient's individual chewing movements.

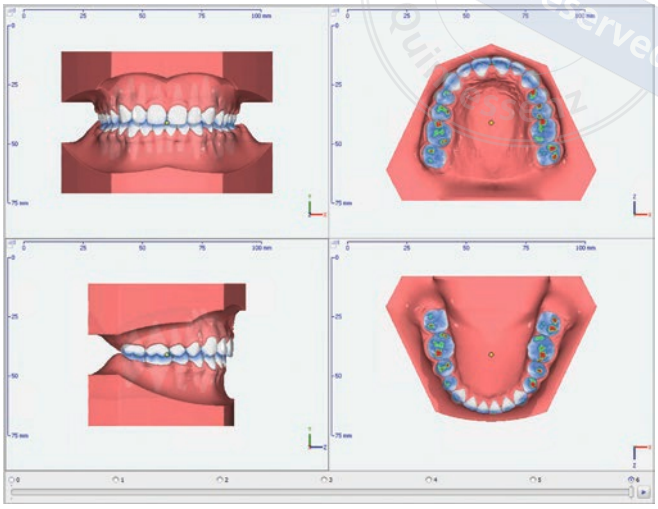

Fig 26 Virtual treatment objective and occlusal contacts with "hard occlusion".

plex (Fig 27). Coordination of the cranial nerves in the reticular formation results in cervicovestibular convergence with the interconnection of the trigeminal nucleus and the vestibular nuclei and other cranial nerve nuclei such as the oculomotor nucleus (Fig 28).[20] It is therefore important to avoid incorrect occlusal contact situations arising between centric relation and habitual occlusion. Orthodontic treatment can be considered successful if the newly adjusted occlusion matches the physiological condylar position.[28] To achieve this workflow digitally with aligner treatment, jaw motion tracking systems are used for digital joint path recording of the patient, which enables the scans or digital models to be mounted in the position of the first occlusal contact. These systems differ in the type of technology used to measure the individual patient movement. Photometric, magnetic field-based, ultrasound-based and infrared-based systems are available on the market.[29] The magnetic field-based DMD system appears to provide clinically reliable values for measurements of the condylar path inclination and Bennett angle.[30] Similarly, the photometric Modjaw system has been shown to be precise to 10 µm and accurate to 11 µm for maxillomandibular relation measurements, which is within the accuracy range of industrial scanners.[31] Jaw motion tracking systems not only allow joint-orientated aligner treatment; they also make it possible for the first time to integrate the patient's individual chewing pattern and arch movement during speech into orthodontic treatment. The palatal surfaces of the maxillary incisors should be in a harmonious relationship with the masticatory movements, as otherwise this could result in excessive tooth mobility or pathological tooth wear.[32] An occlusal equilibration during finishing can be depicted precisely using virtual articulators via colour-coded distance measurements.[33]

Conclusion

To summarise, correct and precise adjustment of occlusal contacts is crucial to avoid allostatic overload and maintain healthy neuromuscular function. The use of jaw motion tracking systems and VTS software as virtual articulators offers new diagnostic and therapeutic possibilities and highlights the importance of a holistic and individual approach in modern orthodontics. Using the described workflow, the above-mentioned goals can be achieved for in-office aligner treatment.

Declaration

The authors declare there are no conflicts of interest relating to this study.

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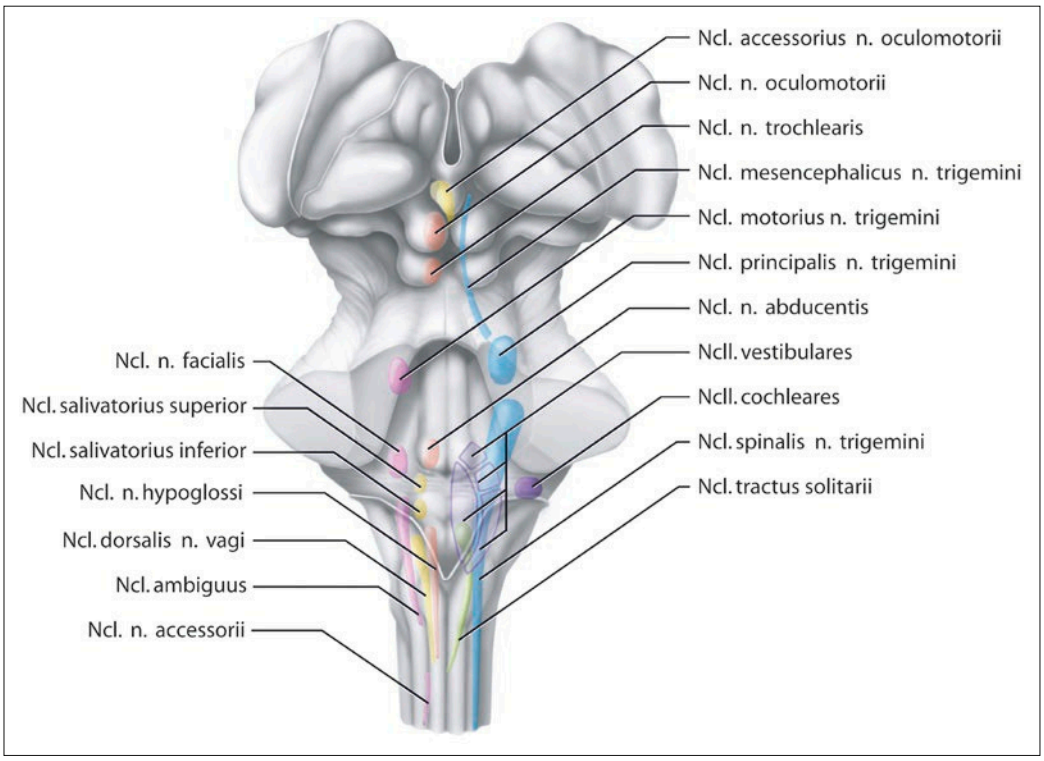

Fig 27 Convergence of nociafferences from different structures in the wide dynamic range neurons and their signal transduction. (Reprinted from Boisserée and Schupp[34] with permission.)

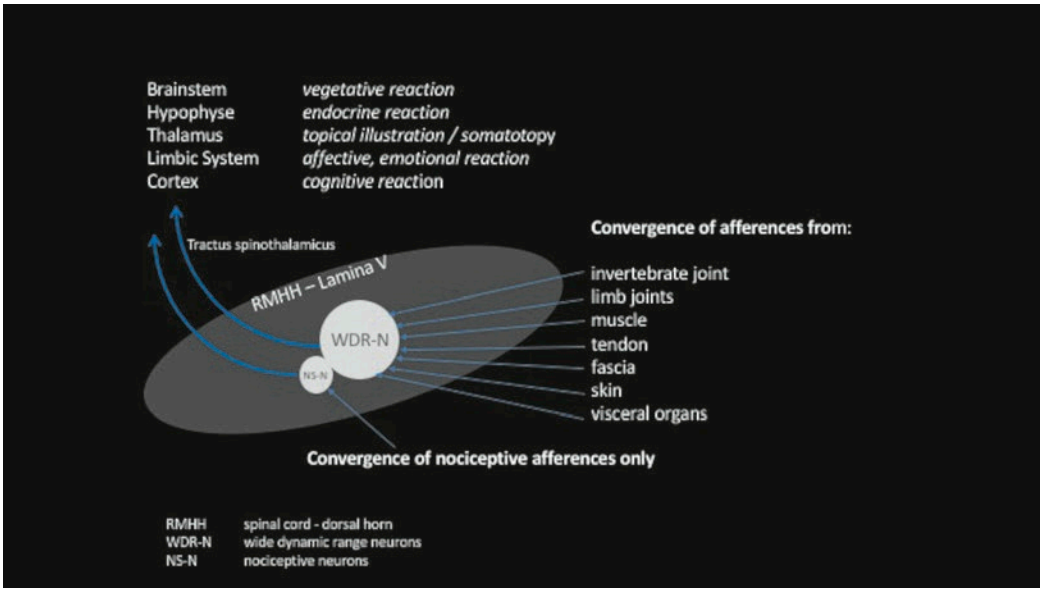

Fig 28 The cerebral nuclei. For the sake of clarity, only the motor cores on the left side and only the sensitive cores on the right side are shown. (Reprinted from Boisserée and Schupp[34] with permission.)

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