Vol. 117 No. 3 March 2014

The influence of different registration positions on condyle displacement in symptomatic patients

Sabine S. Linsen, DrMedDent,[a] Farina Blattner, DrMedDent,[b] and Udo Stratmann, DrMedDent[c]
University of Bonn School of Dentistry, Bonn, Germany; Private Dental Practice, Remscheid, Germany; Danube Private University, Krems, Austria

Objective. This study aimed to evaluate effects of different registration positions on the condyle-disk position changes in the mandibular fossa in symptomatic individuals.
Study Design. Vertical and sagittal condyle position and thickness of the bilaminar zone were measured by magnetic resonance imaging during maximal intercuspation (MI) and with jigs in Gothic arch tracing guided centric relation (DIR method [Dynamics and Intraoral Registration]) and retruded contact position (RCP). Participants were 26 patients seeking treatment for temporomandibular disorders. Condyle and disk position in the fossa were calculated in the parasagittal plane.
Results. Significant differences were found for MI, DIR, and RCP for thickness of bilaminar zone and sagittal condyle position, dependent on diagnosis and registration position for vertical and sagittal condyle position and thickness of bilaminar zone.
Conclusions. DIR position ensures the widest posterior space for the retrodiskal tissues and the slightest sagittal difference between condyle zenith and glenoid fossa. (Oral Surg Oral Med Oral Pathol Oral Radiol 2014;117:312-318)

Temporomandibular disorders (TMDs) constitute a chronic syndrome consisting of masticatory dysfunction, orofacial pain, or both.[1,2] Approximately 25% of the Western population is said to be affected by TMDs,[3] with only 5% requiring management.[4-6] The etiology appears to be multifactorial and includes structural overload as well as lack of tissue adaptation.[7,8] In addition to physical therapy, medication, psychological treatment, and, for end-stage temporomandibular joint (TMJ) disease, surgery,[5,9] occlusal splints are one of the most common therapeutic interventions in patients with TMDs.[10,11] The advantages of splint therapy are the noninvasive and reversible aspects of its application. Nevertheless, its therapeutic effect has not been clarified. Clinical success of splint therapy is attributed to several factors; besides a placebo effect, they include alterations of occlusion, improvement of jaw muscle function, recruitment of different motor units, and new positioning of the disco-condylar complex.[12-18] The treatment goal of splint therapy is to achieve harmonious relationships among teeth, joints, and muscles. Controversial ideas exist about the splints' influence on the positioning of the disco-condylar complex.[19-22] Likewise, the effects of different intermaxillary recording positions in different splint types on the disco-condylar complex are contentious.[14,23-30] A lot of splints are constructed in centric relation (CR). To determine CR, different methods are used. Generally, a distinction is made between manually guided techniques[31] and instrumental methods such as Gothic arch tracing.[32]

The DIR (Dynamics and Intraoral Registration) System (Society for Functional Diagnostics DIR System GmbH & Co KG, Essen, Germany) is based on the Gothic arch tracing method and is obtained electronically and with computer support. The system is masticatory-force dependent. Previous studies comparing different registration techniques (MI, manual guided CR, and DIR) in asymptomatic volunteers found that the DIR method showed the highest reproducibility,[33] that the condyle position during DIR was significantly more anteriorly and inferiorly located,[33] and, with respect to muscular balance and activation, that the DIR position was capable of inducing the greatest motor unit activity.[34]

In view of the treatment goal of splint therapy to influence the positioning of the disco-condylar complex, the aim of this study was to assess by magnetic resonance imaging (MRI) the position of joint structures in a group of symptomatic patients in (1) maximal intercuspation (MI), (2) DIR position, and (3) retruded contact position (RCP). The hypothesis was that

Statement of Clinical Relevance

The Dynamics and Intraoral Registration (DIR) position proved to fulfill the definition of centric relation best when compared with maximal intercuspation and retruded contact position. Intermaxillary registration with DIR may result in higher occlusal stability and in a reduction of nonphysiologic condylar loads in patients with temporomandibular disorders.

[a]Associate Professor, Department of Prosthodontics, Preclinical Education and Dental Material Science, University of Bonn School of Dentistry.
[b]Private dental practice, Remscheid, Germany.
[c]Professor, Center of Anatomy of Danube Private University, Krems, Austria.
Received for publication Sep 29, 2013; returned for revision Nov 13, 2013; accepted for publication Nov 18, 2013.

2212-4403/$ - see front matter
http://dx.doi.org/10.1016/j.oooo.2013.11.498

different registration positions in symptomatic patients would result in different positions of the disco-condylar complex.

MATERIALS AND METHODS

Participants

The study population was composed of 26 patients seeking treatment for TMDs in 3 private dental offices during the period from December 2011 to February 2012. Clinical examination was performed according to a standardized clinical protocol including evaluation of patient history, palpation of TMJs and muscles, auscultation of joint noises, and measurement of mandibular range of motion according to the Research Diagnostic Criteria for Temporomandibular Disorders, German version (RDC/TMD-G).[35,36] Three experienced examiners, calibrated to perform all necessary RDC/TMD-G[35,36] evaluations, DIR registration, appliance delivery, and patient follow-ups, performed all procedures. Criteria for study inclusion were self-report of facial, joint, or masticatory muscle pain or discomfort and age 18 to 70 years. Exclusion criteria were diagnosis of other orofacial pain disorders, systemic diseases (presence of polyarthritis or other rheumatic disease), or contraindications for MRI recordings (implanted metal or medical devices, claustrophobia, tattoos). Informed consent was obtained from all participants, and approval from the ethics committee of the Rheinische Friedrich-Wilhelms-Universität Bonn (University of Bonn) was obtained (No. 075/11) for this study.

MRI technique

MRI was performed with a 1.5-T MR scanner (Symphony; Siemens Medical Solutions, Erlangen, Germany) using a quantum gradient coil (maximum gradient, 30 mT/m) and a double loop array (63 MHz/1.5 T). Based on coronal scouts to determine the midline bilateral proton density, weighted images in the sagittal plane were taken with the patient in the supine position using a fast-spin echo sequence (repetition time, 2000 ms; echo time, 14 ms; field of view, 110 $\times$ 110; matrix, 256 $\times$ 256; slice thickness, 2 mm; interslice spacing, 0.2 mm). MRI of the right and left TMJs was performed in MI, and with jigs in DIR and RCP in place. One radiologist performed all MRI examinations under standardized conditions.

DIR system

The DIR system consisted of a measuring sensor, an amplifier, and an electronic cross-table automatically controlled by stepper motors. The stylus was embedded in the maxillary clutch and could be adjusted vertically. The electronic measuring sensor in the mandibular clutch was combined with a complex amplifier and recorded mandibular movement (2-dimensional and interference-free). Mandibular movements during the registration process were recorded and displayed only within a predefined masticatory-force range (10 to 30 N). The corresponding Gothic arch was enlarged and displayed in real time on a computer screen. The participant controlled the masticatory force via a visual analog scale. The registration was performed under manual guidance (passive) into the RCP. The encoding position for the DIR position was marked by a cursor on the screen anterior (on the protrusion path) to the RCP, depending on the circumference of the cranium (CoC). Values differed from 0.6 mm (53 cm CoC) to 1.23 mm (62 cm CoC). An auxiliary system imported values of the encoding position directly from the computer and established a fixation aid on the cross-table. Maxillomandibular encoding (stylus enters fixation aid) with the respective material (Futar D fast; Kettenbach, Eschenburg, Germany) was performed under masticatory-force control (10 to 30 N).

Measurement protocol

Patients were clinically examined and given one or more of the RDC/TMD-G axis I group diagnoses.[35,36] Afterward, maxillary and mandibular complete arch impressions were made with irreversible hydrocolloid (Alginoplast fast set; Heraeus Kulzer GmbH, Hanau, Germany) and poured with ADA type IV die stone (Octa-Stone, Heraeus Kulzer GmbH). A facebow system (Arcus Bogen; KaVo EWL, Biberach, Germany) was used to mount the maxillary cast cephalically in a semiadjustable articulator (Protar 7, KaVo EWL). The mandibular cast was mounted by means of a manually guided CR record.[37] Subsequently, maxillary and mandibular intraoral Gothic arch tracing clutches were produced by a prefabricated bearing system (DIR clutches) and were individualized with autopolymerizing C-plast (Candulor AG, Wangen, Switzerland). The maxillary clutch was made so that the stylus was positioned on a line passing between the first and second premolars on each side.

At the next visit, clutches were inserted intraorally, the measuring sensor was placed in the mandibular clutch, and the absence of tooth interference in mandibular horizontal movements was verified. Gothic arch tracing was performed as described earlier. Maxillomandibular records were taken in RCP (encoding on the arrow head) and DIR position. All registrations were made with the patient seated upright in a chair, with the back of the chair forming a 90° angle with the floor. The participant's head was positioned so as to orient the Frankfort plane parallel to the floor. The mandibular cast was remounted in the articulator according to the respective record and lowered to the first occlusal contact. Interocclusal DIR and RCP jigs were constructed with an addition-curing occlusion registration material (Futar D fast; Kettenbach, Eschenburg, Germany) with high final hardness (Shore D hardness, 43). To compensate for possible effects of the patient's supine position during MRI (in terms of a posterior orientation of the mandible), jigs were designed with explicit occlusal impressions.

MRI data analysis

To standardize technique, the same investigator performed MRI analysis. The investigator was blinded regarding clinical diagnosis and registration position. For determination of the correct layer, bilateral segments were defined between the lateral and middle condyle pole at horizontal overview pictures. Within both segments, 17 parasagittal layers with a thickness of 2 mm were determined whose axes lay at right angles to the longitudinal axis of the condyles (line connecting right and left condyle pole). The middle layer image (position 9, between 8 lateral and 8 medial layers) was used for morphometric evaluation. The distance measurements were performed on laser-printed figures with a resolution of 2400 × 600 dpi, because these results showed a higher intra- and interindividual reliability in comparison to results from the morphometric computer program. The following anatomic parameters were quantified by the measurement of the reference lines (Figure 1) (the abbreviations are defined in the legend of Figure 1):

1. Thickness of the bilaminar zone (KH − T2)
2. Thickness of the posterior band of the disk (D)
3. Diameter / width of the condyle head (C − KH)
4. Diameter / width of the articular fossa (W − T1)
5. Vertical condyle position (ZK − ZF distance)
6. Sagittal condyle position (ZK − ZF difference)

To fulfill the criteria of a physiologic or centric condyle position, the apex of the condylar head had to lie in vertical line under the zenith of the glenoid fossa, and the width of the disk had to exceed 3 mm. Condyle displacement in the vertical plane to the superior direction (compression) was defined as disk compressions with cartilage strengths of the posterior band of the disk less than 3 mm or with proof of an anterior disk displacement (defined as a joint space of less than 3 mm). Condyle displacement to the inferior direction (distraction) was defined as an enlargement of the upper or lower joint space (or both) of more than 0.2 mm. Changes of the joint space were quantified by measurement of the vertical distance between the apex of the condyle and the glenoid fossa (ZK − ZF distance; see Figure 1). Condyle displacement in the sagittal plane to the anterior or posterior direction was quantified by measurement of the distances between condyle zenith and glenoid fossa (ZK − ZF difference; Figure 2). Thickness of the bilaminar zone was quantified by measurement of the distance between the postglenoid process of the condyle and the fossa (KH − T2; see Figure 1).

For a physiologic disk position (see Figure 1), the border zone between the disk and bilaminar zone could not exceed 0.5 mm anterior and 3 mm posterior to the apex of the condylar head. Anterior or posterior disk displacement was quantified by measurement of the distance between the border zone (posterior band of the disk and bilaminar zone) and the apex of the condyle (thickness of the posterior band of the disk).

Statistical analysis

The data from this study were evaluated with IBM SPSS (version 20.0 for Windows; IBM, Armonk, NY, USA). Data are shown as means and standard deviations. The within-participant factor registration position was compared by 1-way measures analysis of variance (ANOVA) with post hoc Bonferroni correction for multiple comparisons and with $\alpha = .05$. Multivariate analysis of variance was used for the measured anatomic parameters (comparison of vertical and sagittal condyle position [ZK − ZF distance and difference] and thickness of the bilaminar zone [KH − T2]) dependent on the registration position.

RESULTS

MRI was performed in 26 patients (16 women and 10 men). The mean age at the time of MRI was 46.2 ± 12.1 years (range, 25 to 64 years). Duration of the disease (first diagnosis until MRI) was 57.7 ± 71 months (range, 1 to 240 months). According to the RDC/TMD-G guidelines,[35,36] 8 patients were clinically diagnosed with group I disorders (muscle disorders), 4 patients with group II disorders (disk displacement), and 14 patients with both group I and II disorders. No patient was diagnosed with a group III disorder (arthralgia, osteoarthritis, or osteoarthrosis).

The results of MRI evaluation are provided in Table I. The results of ANOVAs indicated no significant differences in the vertical condyle position (ZK − ZF distance) between DIR, MI, and RCP. In the sagittal plane, DIR led to an enlargement of the retrodiskal area (thickness of the bilaminar zone; KH − T2) and to the slightest sagittal difference (ZK − ZF difference) between condyle zenith and glenoid fossa. The results of ANOVAs indicated significantly different thickness of the bilaminar zone (KH − T2) ($P < .05$) and sagittal condylar positions (ZK − ZF difference) ($P < .001$)

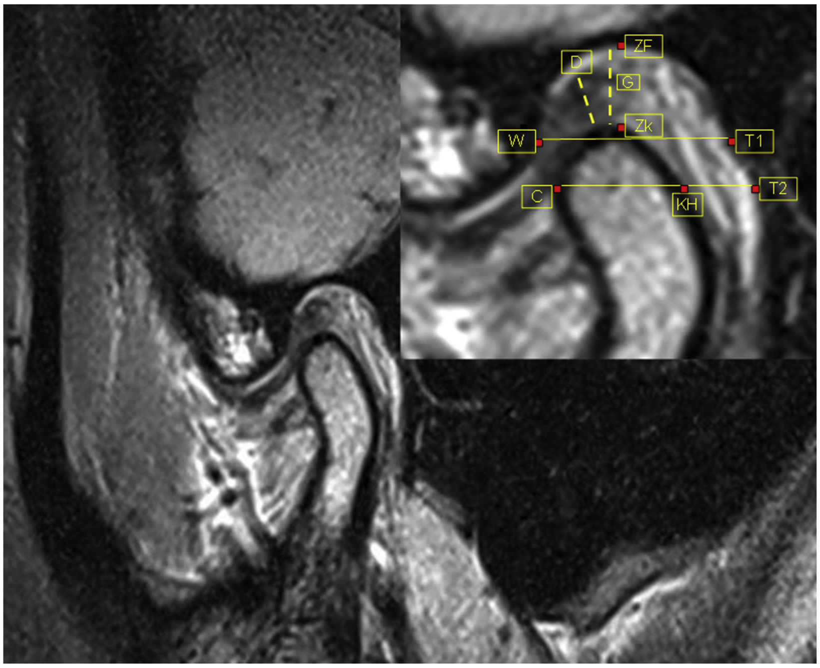

Fig. 1. Localization of the anatomic reference points and lines in the parasagittal plane by magnetic resonance imaging. (*C*, transversal crest at the junction between articular fibrocartilage and bone of the condyle head; *D*, thickness of the posterior band of the disk; *G*, border zone between posterior band of the disk and bilaminar zone; *KH*, postglenoid process of the condyle head; *T1/2*, postglenoid fossa; *W*, turning point [change in curvature] on the protuberance [between eminence and glenoid fossa]; *ZF*, glenoid fossa; *ZK*, apex of the condylar head.)

among CR, MI, and DIR. Post hoc testing found thickness of the bilaminar zone (KH − T2) being significantly ($P = .043$) wider during DIR than during MI, and sagittal displacement of the condyle (ZK − ZF difference) being significantly smaller in DIR than in MI ($P = .008$) or RCP ($P = .019$).

Using the Pillai trace, there was no significant effect of the registration position on the measured anatomic parameters (Value = 0.19; $F(10,180) = 1.84$; $P = .056$). Separate univariate ANOVAs on the outcome variables found significant effects for thickness of bilaminar zone (KH − T2; $F(2,93) = 3.91$; $P = .023$) and for sagittal condyle position (ZF − ZK difference; $F(2,93) = 3.54$; $P = .033$), whereas nonsignificant effects of separate univariate ANOVAs were found for vertical condyle position (ZF − ZK distance; $F(2,93) = 0.47$; $P = .63$).

DISCUSSION

The objective of this study was to analyze, by means of MRI, the effect of various registration positions, such as MI, DIR, and RCP, on the condyle-fossa-disk relationship in symptomatic patients. The positioning of the condyle in the glenoid fossa in mandibular equilibrium in TMD therapy is still a matter of controversy.[19,24,27,28] According to Okeson et al.[6] and Venturelli et al.,[30] mandibular equilibrium is met when joint structures are anatomically correctly positioned, the disk is juxtaposed to the condyle, and the condyle-disk assembly is placed against the posterior surface of the temporal bone, in agreement with the results of the muscular forces of the elevator muscles. Further, there must be enough space between the condyle and the posterior surface of the fossa to hold the retrodiskal area, which is rich in vessels and nerves.[6,30] CR as position of mandibular equilibrium is defined as the maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the complex in the anterosuperior position against the shapes of the articular eminences.[38] This position ensures posterior space for the retrodiskal tissues,[30] avoiding compression and inflammation[6] or alterations of the posterior edge of the disk,[39] which favor anterior displacement of the disk (DD).[40]

There are limited studies on the metric effects of different registration positions on the condyle-disk-fossa relationship in symptomatic patients.[24-27,29] Most studies in symptomatic patients comprise the effect of splint therapy on DD with reduction.[24-28] In asymptomatic individuals, different registration positions were not found to lead to statistically significant differences in condylar positions by means of MRI.[23,30]

Metrical analysis of the condyle-disk-fossa relationship before and after insertion of different types of splints (Michigan [CR] splints, protrusive splints, stabilization

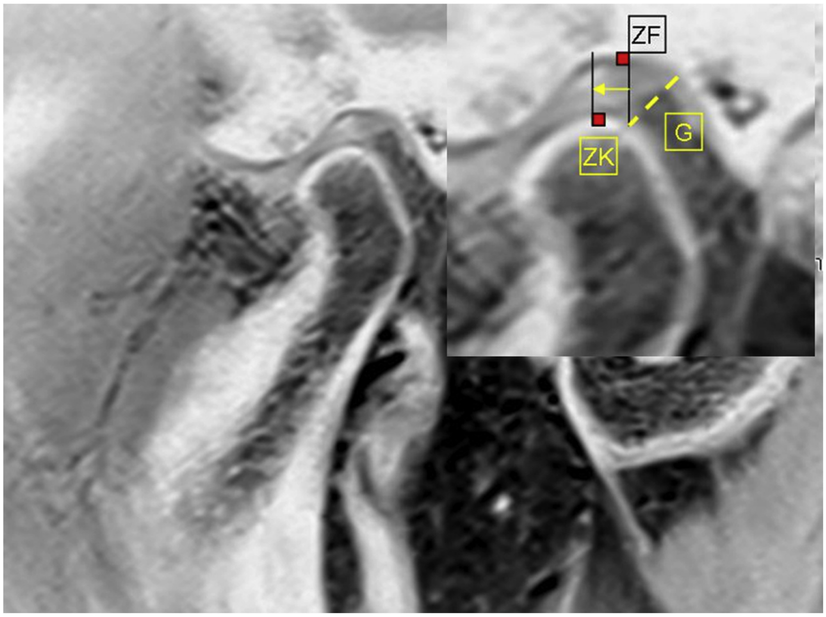

Fig. 2. Measurement of condyle displacement in the parasagittal plane by magnetic resonance imaging. The condyle is shifted about 1.5 mm to the anterior (*horizontal arrow*). With a distance of 1.8 mm between G and ZK, the disk shows a physiologic situation. (*G*, border zone between posterior band of the disk and bilaminar zone; *ZF*, glenoid fossa; *ZK*, apex of the condylar head.)

Table I. MRI analysis for vertical and sagittal condyle displacement and thickness of the bilaminar zone (all in millimeters) for different registration techniques

		Vertical condyle position (ZK − ZF distance)	*Thickness of the bilaminar zone (KH − T2)*	*Sagittal condyle position (ZK − ZF difference)*
MI	Mean	3.00	2.74	1.29
	SD	0.79	0.98	1.08
DIR	Mean	3.13	3.29	0.47
	SD	0.78	0.91	0.97
RCP	Mean	3.18	3.19	1.21
	SD	0.84	1.15	1.29
MI : DIR : RCP		0.345	3.3	6.57
F ratio (*P*)*		ns	.021	.000
MI : DIR (*P*)†		1	.043	.008
MI : RCP (*P*)†		1	.167	1
DIR : RCP (*P*)†		1	1	.019

$P < .05$ denotes statistically significant difference.
SD, standard deviation; *MI*, maximal intercuspation; *DIR*, Dynamics and Intraoral Registration System position; *RCP*, retruded contact position.
*Differences among MI, DIR, and RCP; 1-way analysis of variance was used for data analysis; df (3,187).
†Mean differences among techniques (MI, DIR, and RCP); post hoc Bonferroni correction was used for data analysis.

splints) using MRI found controversial results in symptom-free populations and patients with DD. Ettlin et al.,[14] using the Michigan splint in asymptomatic individuals, found that occlusal splints led to minor yet statistically significant increase of global TMJ space and to larger increase at defined condylar areas. Badel et al.,[24] using the same type of splint in patients with DD, found no influence in the repositioning of the DD joints without reduction but found a limited positive effect in joints with DD with reduction.

The use of anterior repositioning splints resulted in recapture of discs in 15 out of 18 reducing displacements, recapture of the disk in only 2 out of 4 joints with anterior DD with partial disk reduction, and no recapture in nonreducing joints,[25] whereas Kurita et al.[27] found in DD with reduction only a negligible amount of movement. Hasegawa et al.[26] found that application of a stabilization splint in patients with unilateral or bilateral anterior DD results in anteroinferior condylar movement and rotation in the opening direction and that TMJ pain is associated with decreased disk movement in response to splint placement.

Previous studies[33,34] comparing condylar position by jaw tracking in asymptomatic participants found that condyle position during DIR is significantly more anteriorly and inferiorly located than with manual guided CR and DIR. The slightly inferior condyle position in DIR and RCP compared with MI in the current study probably results from increased occlusal vertical dimension by the interocclusal jig. DIR was observed to provide the widest posterior space for the retrodiskal tissues (KH − T2) and showed the slightest condyle displacement in the sagittal plane (ZK − ZF difference).

Therefore, DIR position seems to best fulfill the criteria of a physiologic or centric condyle position, with the apex of the condylar head being in vertical line under the zenith of the glenoid fossa and ensuring posterior space for the retrodiskal tissues in symptomatic patients.

Previously, it has been described that in patients with TMDs, signs of faster neuromuscular fatigue[41] as well as higher levels of muscular asymmetry[42,43] are evident and may result in significant changes in condylar displacement during manual jaw guidance and MI. Surface electromyography found in asymptomatic individuals significantly higher muscular symmetry for the anterior temporalis and the masseter muscles during DIR than with CR and MI.[34] Therefore, it might be concluded that the correct condyle position, especially in symptomatic patients, benefits from a registration system that provides symmetric muscular activation to ensure a centering of the condyles in the glenoid fossa.

Nevertheless, the results of our study must be considered in the context of the limitations. Despite precise positioning of the patients with the help of reference planes, it is difficult to identify the same MRI layers in 2 successive recordings and to measure anatomic structures with sufficient accuracy.[44] We emphasize that the findings reported herein are the outcomes of MRI images in patients with functional disorders of different origin. This leads to a lumping together of patients with multiple specific TMJ conditions and pathologies, indicating functional therapy. Owing to the limited number of patients and the wide range of diagnoses, the present study permits only limited predictive values. Furthermore, participants in the present study were asked to bite effortlessly in contact (MI) or on the respective jig. It could be expected that during parafunction mandibular deformation would affect condyle-fossa measurements.[14] Given that Jiang and Ai[45] found that bilateral biting in the canine area with a force up to 150 N does not produce a mandibular deformation in the premolar area, it can be assumed that negligible deformation occurs in the TMJ area.[14]

CONCLUSION

Registration position significantly influences the sagittal condyle-disk position in symptomatic patients. In the sagittal plane, DIR position provides the widest posterior space for the retrodiskal tissues (KH − T2) and the slightest sagittal difference (ZK − ZF difference) between the condyle zenith and the glenoid fossa. With respect to the condyle-disk-fossa relationship, the DIR position was found to fulfill the definition of centric relation best when compared with MI and RCP.

The authors gratefully acknowledge Dr N. Kostovic, who performed the MRI technique used in this study, and Radprax (Gesellschaft für medizinische Versorgungszentren, Wuppertal, Germany) for use of the MRI facility. Dr J. Poth and M. Sommer are also gratefully acknowledged for patient recruitment.

REFERENCES

1. Lindenmeyer A, Sutcliffe P, Eghtessad M, Goulden R, Speculand B, Harris M. Oral and maxillofacial surgery and chronic painful temporomandibular disorders—a systematic review. *J Oral Maxillofac Surg*. 2010;68:2755-2764.
2. Voiner J, Yu J, Deitrich JP, Chafin C, Giannakopoulos H. Analysis of mandibular motion following unilateral and bilateral alloplastic TMJ reconstruction. *Int J Oral Maxillofac Surg*. 2011;40:569-571.
3. Wolford LM, Dingwerth DJ, Talwar RM, Pitta MC. Comparison of 2 temporomandibular joint total joint prosthesis systems. *J Oral Maxillofac Surg*. 2003;61:685-690.
4. Lipton J, Ship J, Larch-Robinson D. Estimated prevalence and distribution of reported orofacial pain in the United States. *J Am Dent Assoc*. 1993;124:115-121.
5. Schiffman EL, Fricton JR, Haley DP, Shapiro BL. The prevalence and treatment needs of subjects with temporomandibular disorders. *J Am Dent Assoc*. 1990;120:273-281.
6. Okeson JP. Differential diagnosis and management considerations of temporomandibular disorders. In: Okeson JP, ed. *Orofacial Pain: Guidelines for Assessment, Diagnosis, and Management*. Carol Stream, IL: Quintessence Publishing Co Inc; 1996:113-184.
7. Milam SB, Schmitz JP. Molecular biology of temporomandibular joint disorders: proposed mechanisms of disease. *J Oral Maxillofac Surg*. 1995;53:1448-1454.
8. Stegenga B, de Bont LGM. TMJ disc derangements. In: Laskin DM, Greene CS, Hylander WL, eds. *TMDs: An Evidence Based Approach to Diagnosis and Treatment*. Hanover Park, IL: Quintessence Publishing Co Inc; 2006:125-136.
9. Dionne RA, Feine JS, Thomason JM, et al. Therapeutic modalities. In: Laskin DM, Greene CS, Hylander WL, eds. *TMDs: An Evidence Based Approach to Diagnosis and Treatment*. Hanover Park, IL: Quintessence Publishing Co Inc; 2006:347-419.
10. Carlsson GE. Critical review of some dogmas in prosthodontics. *J Prosthodont Res*. 2009;53:3-10.
11. Ommerborn MA, Kollmann C, Handschel J, Depprich RA, Lang H, Raab WH. A survey on German dentists regarding the management of craniomandibular disorders. *Clin Oral Investig*. 2010;14:137-144.
12. Al-Ani MZ, Davies SJ, Gray RJ, Sloan P, Glenny AM. Stabilization splint therapy for temporomandibular pain dysfunction syndrome. *Cochrane Database Syst Rev*. 2004:CD002778.
13. Dao TT, Lavigne GJ. Oral splints: the crutches for temporomandibular disorders and bruxism? *Crit Rev Oral Biol Med*. 1998;9:345-361.
14. Ettlin DA, Mang H, Colombo V, Palla S, Gallo LM. Stereometric assessment of TMJ space variation by occlusal splints. *J Dent Res*. 2008;87:877-881.
15. Forssell H, Kalso E. Application of principles of evidence-based medicine to occlusal treatment for temporomandibular disorders: are there lessons to be learned? *J Orofac Pain*. 2004;18:9-22.
16. Nilner M. Does splint therapy work for temporomandibular pain? *Evid Based Dent*. 2004;5:65-66.
17. Schindler HJ, Rues S, Turp JC, Lenz J. Heterogeneous activation of the medial pterygoid muscle during simulated clenching. *Arch Oral Biol*. 2006;51:498-504.
18. Turp JC, Komine F, Hugger A. Efficacy of stabilization splints for the management of patients with masticatory muscle pain: a qualitative systematic review. *Clin Oral Investig*. 2004;8:179-195.

19. Ekberg EC, Sabet ME, Petersson A, Nilner M. Occlusal appliance therapy in a short-term perspective in patients with temporomandibular disorders correlated to condyle position. *Int J Prosthodont*. 1998;11:263-268.
20. Kuboki T, Takenami Y, Orsini MG, et al. Effect of occlusal appliances and clenching on the internally deranged TMJ space. *J Orofac Pain*. 1998;13:38-48.
21. Lau KU, Green WF 2nd. Orthosis thickness and its effect on temporomandibular joint space. *Cranio*. 2003;21:209-220.
22. Moncayo S. Biomechanics of pivoting appliances. *J Orofac Pain*. 1994;8:190-196.
23. Alexander SR, Moore RN, DuBois LM. Mandibular condyle position: comparison of articulator mountings and magnetic resonance imaging. *Am J Orthod Dentofacial Orthop*. 1993;104:230-239.
24. Badel T, Marotti M, Kern J, Laskarin M. A quantitative analysis of splint therapy of displaced temporomandibular joint disc. *Ann Anat*. 2009;191:280-287.
25. Eberhard D, Bantleon HP, Steger W. The efficacy of anterior repositioning splint therapy studied by magnetic resonance imaging. *Eur J Orthod*. 2002;24:343-352.
26. Hasegawa Y, Kakimoto N, Tomita S, et al. Movement of the mandibular condyle and articular disc on placement of an occlusal splint. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2011;112:640-647.
27. Kurita H, Kurashina K, Ohtsuka A, Kotani A. Change of position of the temporomandibular joint disk with insertion of a disk-repositioning appliance. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 1998;85:142-145.
28. Ohnuki T, Fukuda M, Nakata A, et al. Evaluation of the position, mobility, and morphology of the disc by MRI before and after four different treatments for temporomandibular joint disorders. *Dentomaxillofac Radiol*. 2006;35:103-109.
29. Tanaka EE, Arita ES, Shibayama B. Occlusal stabilization appliance: evaluation of its efficacy in the treatment of temporomandibular disorders. *J Appl Oral Sci*. 2004;12:238-243.
30. Venturelli FA, Zuim PR, Antenucci RM, Garcia AR. Analysis of mandibular position using different methods of location. *Acta Odontol Latinoam*. 2009;22:155-162.
31. Lauritzen AG, Wolford LW. Hinge axis location on an experimental basis. *J Prosthet Dent*. 1961;11:1059-1067.
32. Gilboe DB. Centric relation as the treatment position. *J Prosthet Dent*. 1983;50:685-689.
33. Linsen SS, Stark H, Klitzschmüller M. Reproducibility of condyle position and influence of splint therapy on different registration techniques in asymptomatic volunteers. *Cranio*. 2013;31:32-39.
34. Linsen SS, Stark H, Samai A. The influence of different registration techniques on condyle displacement and electromyographic activity in stomatognathically healthy subjects: a prospective study. *J Prosthet Dent*. 2012;107:47-54.
35. Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. *J Craniomandib Disord*. 1992;6:301-355.
36. John MT, Hirsch C, Reiber T, Dworkin SF. Translating the research diagnostic criteria for temporomandibular disorders into German: evaluation of content and process. *J Orofac Pain*. 2006;20:43-52.
37. Utz KH, Müller F, Lückerath W, Fuss E, Koeck B. Accuracy of check-bite registration and centric condylar position. *J Oral Rehabil*. 2002;29:458-466.
38. [Editorial Council of the Journal of Prosthetic Dentistry.] The glossary of prosthodontic terms. *J Prosthet Dent*. 2005;94:10-92.
39. Westesson PL, Bronstein SL, Liedberg J. Internal derangement of the temporomandibular joint: morphologic description with correlation to joint function. *Oral Surg Oral Med Oral Pathol*. 1985;59:323-331.
40. Farrar WB. Characteristics of the condylar path in internal derangements of the TMJ. *J Prosthet Dent*. 1978;39:319-323.
41. Svensson P, Burgaard A, Schlosser S. Fatigue and pain in human jaw muscles during a sustained, low-intensity clenching task. *Arch Oral Biol*. 2001;46:773-777.
42. Suvinen TI, Kemppainen P. Review of clinical EMG studies related to muscle and occlusal factors in healthy and TMD subjects. *J Oral Rehabil*. 2007;34:631-644.
43. Tripodakis AP, Smulow JB, Mehta NR, Clark RE. Clinical study of location and reproducibility of three mandibular positions in relation to body posture and muscle function. *J Prosthet Dent*. 1995;73:190-198.
44. Kordaß B, Assheuer J, Stüttgen U. Zur Auswertung sagittaler Kernspintomogramme des Kiefergelenkes. *Dtsch Zahnärztl Z*. 1993;48:37-44.
45. Jiang T, Ai M. In vivo mandibular elastic deformation during clenching on pivots. *J Oral Rehabil*. 2002;29:201-208.

Reprint requests*:*

Sabine S. Linsen
Rheinische Friedrich-Wilhelms-Universität Bonn
Welschnonnenstrasse 17
D-53111 Bonn
Germany
sabinelinsen@web.de; sabine.linsen@ukb.uni-bonn.de