The influence of different registration techniques on condyle displacement and electromyographic activity in stomatognathically healthy subjects: A prospective study

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Statement of problem. It is unclear whether different intermaxillary registration techniques are related to a physiological condylar position that permits neuromuscular equilibrium.

Purpose. This study analyzes and quantifies the effects of different registration techniques on the condyle position and how the registration technique modulates bilateral masseter and anterior temporalis muscle electromyographic activity.

Material and methods. Three-dimensional electronic condylar position analysis (EPA) with an ultrasound-based jaw-tracking system and surface electromyographic activity (sEMG) was recorded during the registration of a manually guided centric relation (CR), maximal intercuspation (MI), and Gothic arch tracing guided centric relation (DIR method). Participants were 26 stomatognathically healthy volunteers (mean age, 30.6 ±9.5 years). Data were analyzed by 1-way ANOVA and post hoc Bonferroni correction (α=.05).

Results. EPA showed significant differences (*P*<.001) for CR, MI, and DIR in the vertical, sagittal, and horizontal axes. The condyle position during DIR was found to be significantly more anteriorly and inferiorly located than with CR (*P*<.001) and MI (*P*<.04). There were no significant differences in the mean muscle activity among CR, MI, and DIR. Muscular symmetry ranged from 63.87 to 81.47%. Significantly higher symmetry for the anterior temporalis (*P*=.03) and the masseter (*P*=.03) was found during the DIR than with CR. Torque coefficients (potential laterodeviating effect) were between 88.02% (CR) and 89.94% (MI).

Conclusions. Registration technique significantly influenced the condyle position, while mean muscular activity was minimally affected. With respect to muscular balance and activation, the DIR position proved to be capable of inducing the greatest motor unit activity when compared with manually guided CR and MI. (J Prosthet Dent 2011;106:•••-••)

Clinical Implications

Within the limitations of this study, the registration technique has an influence on condylar position and muscular symmetry. Greater symmetry in muscular activity and anterior condyle position during intermaxillary registration may result in higher occlusal stability and a reduction of nonphysiological condylar loads after prosthetic restorative and orthodontic treatments.

Recording maxillomandibular relationships is a central aspect of prosthodontics. For both dentate and edentulous patients, this measurement has an important role in prosthetic rehabilitation, temporomandibular dysfunction (TMD) therapy, and orthodontic and maxillofacial planning, the treatment goal of which is to achieve harmonious relationships among teeth, joints, and muscles. Different methods are used for intermaxillary recordings such as registration in maximum intercuspation (MI) or centric relation (CR). MI refers to the complete

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intercuspation of the opposing teeth independent of condylar position and, sometimes referred to as the best fit of the teeth, regardless of the condylar position.[1] CR 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 anterior-superior position against the shapes of the articular eminences.[1] This position is independent of tooth contact, is clinically discernible when the mandible is directed superiorly and anteriorly, and is restricted to a purely rotary movement in the transverse horizontal axis.[1]

To determine CR, different methods are used. Generally, a distinction is made between manually guided techniques such as the 3-finger technique, also known as the Lauritzen grasp,[2] and instrumental methods such as Gothic arch tracing.[3] The newly developed 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, according to the manufacturer, obtained electronically and with computer support. The system is masticatory-force dependent.

The activity of masticatory muscles has no role in the definition of CR and MI.[1] Manually guided CR registration is accomplished when the operator feels that the patient is relaxed and hinging freely, resulting in probable low muscular activity,[4] whereas it is to be assumed that muscle activity in MI varies depending on the patient's clenching force. The DIR system operates within a predefined clenching force range (10-30N), suggesting a defined range of muscular activity.[5] Various reports have provided qualitative or quantitative data describing condylar position relative to different jaw positions.[3,4,6-10] MI was found to be more anteroinferiorly and laterally positioned than CR,[4,9-11] while the central bearing point method resulted in a more anteroinferior condylar position.[4] Similarly, much has been written regarding muscular activity during clenching on interocclusal appliances in different jaw positions.[12-15] Anteroposterior changes in jaw position were reported not to affect muscle behavior,[12,13] whereas increased occlusal vertical dimension was found to reduce postural activity.[14-16] Little has been reported on condylar position and muscular activity during the recording of different jaw positions. Since all parts of the masticatory system (occlusion, joints, and muscles) are interrelated, they must work in anatomically and functional harmony during intermaxillary registration, or dysequilibrium may result.[7]

The purpose of this study was to evaluate the effects of different techniques (CR, MI, and DIR) during maxillomandibular registration on the vertical, sagittal, and horizontal condyle positions and on the simultaneous electromyographic patterns of jaw-closing muscles (anterior temporalis, and masseter). The hypothesis was that different registration techniques would result in different condylar positions, altered muscle activity, and different degrees of symmetry in muscle activity and lateral displacing force.

MATERIAL AND METHODS

Participants were 26 volunteers (18 women and 8 men) with a mean (SD) age of 30.6 (9.5) years and healthy jaw function. Inclusion criteria consisted of a complete dentition (no extractions or missing teeth other than third molars), absence of craniomandibular disorders (according to Axis I of the Research Diagnostic Criteria for TMD),[17] no history of orthodontic treatment, and a vertical overlap of less than 2 mm. One operator completed all clinical evaluations and procedures. Informed consent was obtained from all subjects, and approval from the ethics committee of the Rheinische Friedrich-Wilhelms-University of Bonn was obtained (146/08) for this study.

EPA technique

The condylar position was electronically (electronic position analysis, EPA) measured 3-dimensionally (3-D) with an ultrasound-based jaw-tracking system (WinJaw 10.6.50 Software; Zebris Medical GmbH, Isny, Germany) to record rigid body motion with 6 degrees of freedom. The system is based on measuring the real-time latency periods of sequentially transmitted ultrasound pulses among 4 emitters attached to a mandibular frame (weight: 42g) and 8 receivers mounted on the head with a face bow (weight: 190g). The measuring device is supported with the software program (WinJaw 10.6.50; Zebris Medical GmbH). The measurement accuracy of the system is 0.1 mm.[18] The horizontal reference plane for the analysis system included, posteriorly, the kinematic center of the right and left condyles and, anteriorly, the orbitale, which was defined before registration by digitizing the 3-dimensional coordinates of the anatomical orbitale of the left eye and the lateral palpated poles of both condyles. The origin of the coordinates was the middle of the intercondylar axis. According to the WinJaw software program, the kinematic center is the condylar point at which the protrusive path coincides as closely as possible with the opening path and is automatically calculated with special logarithmic equations. The EPA module permits a 3-D static positioning of the condyles relative to a reference position. The x-axis represented the sagittal [positive value (+) = anterior, negative value (-) = posterior], the y-axis the vertical (+ = superior, - = inferior), and the z-axis the transverse axis (+ = lateral, - = medial).

sEMG technique

For EMG recording, a surface electromyography system (EMG-8; Zebris Medical GmbH) was used. Four channels from 2 bilateral muscles (masseter and anterior temporalis) were recorded. The analog sEMG (surface electromyography) signal was captured with differential electrodes and conditioned with a preamplifier [voltage gain 1000, bandwidth 7 to 500 Hz (anti-aliasing band-pass filter), high common mode rejection ratio (CMRR 110 dB in the range 0 to 60 Hz, input impedance 10 E +12 Ω)]. The preamplifier was powered by DAB (Digital Audio Broadcasting)-Bluetooth (Zebris DAB-Bluetooth; Zebris Medical GmbH) and resulted in the amplified/conditioned sEMG signal to DAB for processing. DAB's input voltage ranges from 0 to ± 2048 mV. The signal was digitized (12-bit resolution, 2230 Hz A/D sampling frequency) and transferred to a computer via a Bluetooth interface. The sEMG Software features digital filtering (high-pass filter set at 30 Hz, low-pass filter set at 400 Hz, and band rejection filter for common 50 to 60 Hz noise). The sEMG signals were amplified 1000 to 5000 times, filtered in the bandwidth 4 Hz to 310 Hz, sampled at 4 kHz, and stored for off-line analysis.

DIR system

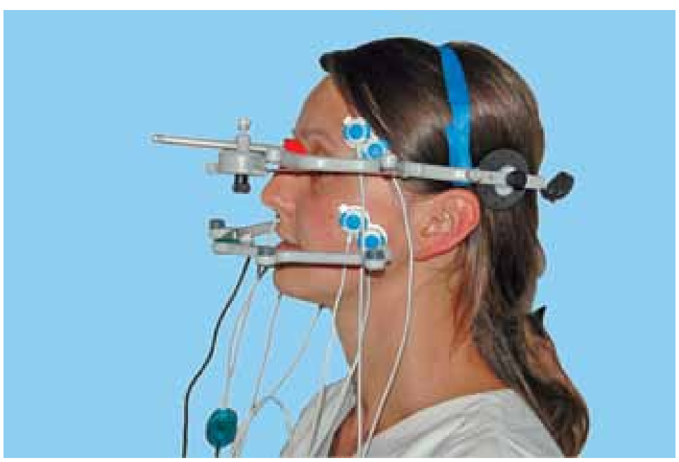
The DIR system (Society for Functional Diagnostics DIR System GmbH & Co. KG) consisted of a measuring sensor, an amplifier, and an electronic cross-table automatically controlled by stepper motors. The stylus was embedded in the maxillary clutch and could be adjusted vertically. The electronic measuring 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 (10N-30N). The corresponding Gothic arch was enlarged and displayed in real time on a computer screen. The participant controlled his/her masticatory force via a visual analog scale. The registration was performed under manual guidance (passive) into the retruded contact position (RCP). The encoding 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 (62cm 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 was performed under masticatory-force control (10-30N).[5]

Measurement protocol

At the first visit, 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-Scan dental stone, Heraeus Kulzer GmbH). A face bow system (ARCUS Bogen; KaVo Dental GmbH, Biberach, Germany) was used to mount the maxillary cast cephalically in a semiadjustable articulator (PROTAR evo 7; KaVo Dental GmbH). The mandibular cast was mounted with a manually guided (Lauritzen grasp)[2] CR record. A double layer of wax (Beauty Pink Wax; Miltex Inc, York, Pa), tempered at 50°C as described previously,[19] was used. Following maxillary and mandibular intraoral Gothic arch tracing, clutches were produced with a prefabricated bearing system (DIR clutches; Dynamics in Intraoral Registration) and individualized with autopolymerizing C-Plast (Candulor AG, Wangen, Switzerland). The stylus on the maxillary clutch was positioned on a line passing between the first and second premolars on each side. The prefabricated bearing system for the measuring sensor was embedded into the mandibular clutch.

At the second visit, participants were briefed on procedures and completed a consent form. 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 under mandibular guidance (Lauritzen grasp, 25 N)[2] with the DIR system. The fixation aid for the later maxillomandibular encoding was created according to the previously specified procedure. The central bearing point clutches were subsequently removed.

An sEMG system (EMG-8, Zebris Medical GmbH) was applied with disposable, self-adhesive Ag/AgCl dual-snap electrodes for sEMG (Noraxon Dual Electrode Type 272, Noraxon USA Inc, Scottsdale, Ariz). The dimen-



1 Experimental design. Snap-electrodes for sEMG of masseter and anterior temporalis muscles and ultrasound-based jaw-tracking system.

sions of the figure-8-shaped adhesive area were 4 × 2.2 cm; the diameter of each of the 2 circular conductive areas was 1 cm, and the interelectrode distance was 2 cm. Electrodes (impedance less than 20 kV) were placed parallel to the direction of the fibers of the muscle belly as described previously.[20] The skin over the recording positions was cleaned with alcohol. Placement of the electrodes was controlled for activity of other facial muscles by the subjects' performing different facial expressions. The electrodes were repositioned to record the temporalis and masseter muscles if visible sEMG activity was detected due to movement. A common reference electrode was placed over the 7th cervical vertebral segment. The sEMG was observed for malfunctions, failed basic voltage, and regular basic patterns. Initially, muscle tone at rest (RTR) and muscular activity during maximal voluntary clenching onto natural dentition (MVC) were recorded.

The ultrasound-based jaw-tracking system (WinJaw, Zebris Medical GmbH) was then applied.[21] The horizontal reference plane and the kinematic center were defined as described above.

After EPA and sEMG, activities during different registration positions (CR, MI, and DIR) were measured simultaneously (Fig.1). [F1] For this test, participants were manually guided into CR (Lauritzen grasp)[2] until first tooth contact and asked to close into maximum intercuspation with the stylus entering the encoding position of the DIR method under masticatory force control (10N to 30N). Three trials of 1 second each were completed for every position. The first condyle position in CR served as the EPA reference position.

All registrations were made with

Table I. Three-D electronic condylar position analysis (EPA) and muscular activity (sEMG) for different registration techniques. Mean values (MV) and standard deviations (SD) measured in mm/µV for maximum intercuspation (MI), centric relation (CR), and DIR in X-axis (anterior-posterior), Y-axis (superior-inferior), and Z-axis (medial-lateral) in anterior temporalis and masseter muscles.

Registration Technique	Condylar Movement (EPA)						Muscular Activity (sEMG)			
	X-axis		Y-axis		Z-axis		Anterior Temporalis		Masseter	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
CR (MV)	0.05	0.07	0.10	-0.04	0.05	0.00	17.13	18.63	16.78	18.63
(SD)	0.48	0.46	0.33	0.41	0.22	0.14	13.90	15.76	11.81	17.72
MI (MV)	1.21	0.82	-0.56	-0.67	0.19	0.21	22.85	21.11	23.64	23.21
(SD)	0.84	0.75	0.52	1.01	0.35	0.35	15.28	15.47	18.95	15.51
DIR(MV)	1.69	1.39	-1.27	-1.89	0.37	0.38	17.21	20.52	16.86	18.67
(SD)	1.28	1.07	1.25	1.14	0.45	0.46	7.18	20.26	12.76	13.35
CR:MI:DIR										
F	29.34	21.23	18.45	27.89	7.53	7.79	0.15	0.74	1.78	1.83
P[a]	.001	.001	.001	.001	.001	.001	.18	.86	.17	.48
CR:MI										
P[b]	.01	.001	.01	.05	.13	.11	.32	1	.30	.88
MI:DIR										
P[b]	.001	.04	.01	.001	.23	.23	.33	1	.31	.90
CR:DIR										
P[b]	.001	.001	.001	.001	.001	.001	1	1	1	1

[a] Differences among MI, CR, and DIR; 1-way ANOVA was used for data analysis; df (2, 75).

[b] Mean differences among techniques (MI, CR, and DIR); post hoc Bonferroni correction was used for data analysis.

$P<.05$ denotes statistically significant difference.

Table II. Percentage overlapping coefficient (POC) and torque coefficient (TC) for different registration techniques. Mean values and standard deviations (SD) for POC and TC measured in % for maximum intercuspation (MI), centric relation (CR), and DIR in anterior temporalis and masseter muscles.

Registration Technique	POC coefficient (%)		TC coefficient
	Anterior Temporalis	Masseter	%
CR (MV)	63.87	68.32	88.02
(SD)	18.13	24.53	13.68
MI (MV)	71.66	74.84	89.94
(SD)	15.31	14.39	8.59
DIR(MV)	75.99	81.47	89.86
(SD)	15.54	11.88	8.17
CR:MI:DIR			
F	3.66	3.56	0.28
P[a]	.03	.03	.76
CR:MI			
Pb	.27	.57	1
MI:DIR			
P[b]	1	.55	1
CR:DIR			
P[b]	.03	.03	1

[a] Differences among MI, CR, and DIR; 1-way ANOVA was used for data analysis; df (2, 75).

[b] Mean differences among techniques (MI, CR, and DIR); post hoc Bonferroni correction was used for data analysis.

P<.05 denotes statistically significant difference.

each volunteer seated upright in a chair, with the back of the chair forming a 90-degree angle with the floor. The participant's head was positioned so as to orient the Frankfort plane parallel to the floor.

EPA and sEMG data analysis

Bilateral EPA during CR, MI, and DIR was measured (in mm). The first condyle position in CR served as reference position. Deviations between the reference position and other condyle positions were performed for the sagittal (X), vertical (Y), and horizontal (Z) axes.

RTR, MVC, and muscular activity during the maxillomandibular recording of CR, MI, and DIR were recorded as mean values over the selected time span. RTR was measured with closed eyes over a period of 8 seconds. MVC was recorded for 3 seconds. Mean total muscle activities in CR, MI, and DIR were measured and additionally computed as the areas of standardized sEMG potentials (50-ms normalized root mean square of the amplitude) over 1 second (in μV) for 3 trials.[22,23] After sEMG, waves of paired muscles were compared for symmetric distribution of muscular activity by computing a percent-overlap coefficient (POC, %).[22] POC ranges between 0% (no symmetry) and 100% (perfect symmetry).[22,23] Torque coefficient (TC, %) was assessed to detect any unbalanced contractile activity of contralateral masseter and temporalis muscles.[22,23] TC ranges between 0% (complete presence) and 100% (complete absence) of lateral displacing force.[22,23]

Descriptive statistics are presented as mean (SD) values. The within-subject factor registration position (CR, MI, DIR) was compared by 1-way ANOVA with post hoc Bonferroni correction for multiple comparisons and an α=.05. Statistical analysis was performed with software (SPSS 17; SPSS Inc, Chicago, Ill). Right and left sides were analyzed separately.

RESULTS

The results of EPA are provided in Table I. On average, MI was found to be anteroinferior to CR (mean differences: right condyle, 1.16 mm anterior - 0.66 mm inferior; left condyle, 0.75 mm anterior - 0.63 mm inferior). Condyles during DIR were anteroinferior to MI (mean differences: right, 0.48 mm anterior - 0.71 mm inferior; left, 0.57 mm anterior - 1.22 mm inferior). The results of ANOVAs indicated significantly (*P*<.001) different condylar positions among CR, MI, and DIR for all axes. Post hoc testing showed condyles being significantly (*P*<.04) more anteroinferior during DIR than during CR and MI, with the condyles in the latter position being likewise significantly (*P*<.05) more anteroinferior than in CR. In the Z-axis, significant condylar displacement (*P*=.001) was found between CR and DIR.

Mean (SD) values for RTR were 6.46 (4.61)μV (right masseter) and 5.03 (4.99)μV (left masseter) and 6.22 (4.51)μV (right anterior temporalis) and 5.67 (2.34)μV (left anterior temporalis). For the MVC with natural dentition, the results of the masseter surpassed (statistically nonsignificant) those of the anterior temporalis [165.86 (100.94) μV versus 144.78 (75.77) μV, *P*=.06]. Masseter/anterior temporalis sEMG means and standard deviations for different registration positions are presented [T1] in Table I. There were no significant differences in the mean muscle activity parameters among CR, MI, and DIR. The POC varied with registration technique for the anterior temporalis (*P*=.03) and masseter (*P*=.03) (Table II). Post hoc testing showed significantly higher symmetry in DIR than CR [T2] for both muscles (*P*=.03) (Table II). Differences for TC were not significant.

DISCUSSION

According to the research hypothesis, different registration techniques were found to result in different condylar positions and different degrees of symmetry in muscle activity and lateral displacing force. Thus the research hypothesis was accepted.

In agreement with previous findings, condylar displacement was found to be small and limited by joint space, initial condyle-disk relationships, and the ability of the disk to undergo viscoelastic deformation with compression.[24] Because of its diarthrotic anatomy, the temporomandibular joint (TMJ) is capable of moving in many directions.[4] In stomatognathically healthy subjects, MI would ideally correspond with CR,[11] but several studies have reported that, in the majority of patients with natural dentition, condyles in MI are in a more anteroinferior and lateral position than those in CR.[4,9-11] The current study confirms this finding. Mean tolerances between CR and MI are in agreement with previous findings, where the range of tolerance was reported as 1.5 mm in the X-axis and Y-axis and 0.5 mm in the Z-axis.[6,8] The largest anteroinferior condyle displacement was found during DIR. Previously, it has been described that the central bearing point method causes a more anteroinferior position of the condyles than MI.[4] The inferior condyle position in DIR probably results from increased occlusal vertical dimension to avoid tooth interference during mandibular movement, whereas higher clenching forces in CR were found to induce condylar displacement toward the anterior.[7,13] Anterior displacement also depends on the technique of the central bearing point method (passive or manually guided by the dentist versus active or patient-guided) and on the chosen enclosing position (arrowhead, DIR position). Other studies[14,25] investigating anterior mandibular repositioning splint therapy have shown improved clinical outcomes in subjects with TMJ internal derangement and a statistically significant change in sEMG activity at RTR (decrease) and during MVC (increase), which might suggest that anterior condyle displacement during DIR may lead to relief for TMJ structures.

Generally, it must be considered that EPA measures condylar positional changes in relation to a reference position. Verifying condylar position with EPA is difficult because the position of the condylar-disk complex relative to the TMJ structures cannot be substantiated clinically.

Different registration techniques resulted in different mean muscle activity, symmetry, and lateral displacing force. This is in agreement with findings that clenching with splints in different jaw positions has an effect on muscle activity in asymptomatic subjects.[12,13,15,26] Other authors reported that the balance of synergistic muscle activity is critical for efficient muscle action and maximum muscle activation, and that the primary determinant of muscle behavior with anteroposterior changes in mandibular position is the amount of dental stability, rather than the jaw position.[12,25] In the present study, muscular activity was measured without occlusal support during CR and DIR. Nevertheless, mean muscle activity varied only minimally among CR, MI, and DIR. Muscular activity during CR was comparable with that during DIR; even so, CR was performed only when the operator felt that the subject's muscles were relaxed. Woda et al[27] found that the condyle position in CR is determined by the equilibrium between passive anatomic structures such as ligaments, intraarticular disks acting as a physical barrier to further posterior movement, and active forces generated by the tonic contraction of the jaw muscles. The role of muscle contraction in establishing CR confirms that this term actually covers several condyle positions that also may change with time.[27,28] Tripodakis et al[9] concluded that the condylar position in CR depends not only on the method of manipulation, but also on the activity-hyperactivity status of the musculature. MI, in contrast, is known to vary depending on the patient's voluntary clenching force, but may depend more on the guidance of the occlusal incline surfaces of the teeth than on automatic closure guided by muscles.[9] DIR operates within a predefined clenching force range (10-30N), requiring both positioning (temporalis) and masticatory muscle (masseter) activity to hold the pressure. However, crosstalk or mimetic effects in other, especially adjacent, muscles may lead to variable activity.[26,29] Nevertheless, mean muscle activity in CR, MI, and DIR was measured in a similar range, suggesting that the registration technique in asymptomatic subjects, though exerted within a biologically acceptable range, has only limited influence on mean muscular activity.

In patients with TMD, signs of faster neuromuscular fatigue[30] as well as higher levels of muscular asymmetry[31] are evident and may result in significant changes in condylar displacement during manual jaw guidance and MI.[9] Therefore, it might be concluded that the correct registration depends more upon the diagnosis of an asymptomatic masticatory system and, if necessary, the initial treatment of any functional problem, than on the technique used.[32]

In the present study, significantly higher POC was found during DIR than during CR, whereas TC differed only slightly between registration positions. The POC was lower than that of previous studies investigating asymptomatic young adults during maximum voluntary clench, with an average standardized symmetry, ranging from 75.4% to 87.9% and a TC >89%.[23,33] The explanation for this is that muscle symmetry depends upon the clenching level, with a significant tendency for subjects to masticate more asymmetrically at low contraction levels than at high levels.[33] Other studies showed that asymptomatic individuals have a prevalent side, on which they display higher relative levels of muscle activity during bilateral clenches, resulting in asymmetric muscular activity.[22] In this study, higher POC was observed in the masseter than the anterior temporalis in all registration positions. However, Naeije et al[34] found, in asymptomatic subjects at different clenching levels, greater asymmetry in the masseter than in the temporalis muscle. Conflicting results may be attributed to the differences in interocclusal stabilization during the recording of sEMG activity and different data analyses (asymmetry index[35] versus POC[22]).

CONCLUSIONS

The results of the present study suggest that condylar position and muscular symmetry are significantly influenced by jaw manipulation technique, while mean muscular activity is only minimally affected. Condylar position during DIR is located anteroinferior to both CR and MI, which may lead to relief for TMJ structures. Concerning muscular symmetry, the DIR position was shown to be capable of recruiting the greatest motor unit activity, implying a higher muscular stability in this registration position. Registration technique, though exerted within a biologically acceptable range, has only limited influence on mean muscular activity in asymptomatic subjects.

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