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RESEARCH ARTICLE

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Does increasing vertical dimension of occlusion in centric relation affect muscular activity? An electromyographic study

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Abstract

Objective: In many esthetic treatments, clinicians may consider the option to modify the maxillo mandibular position. A raise of the vertical dimension of occlusion (VDO) may help restore esthetics, increase the space for dental materials, and reduce the invasiveness of dental procedures. Traditionally, VDO increases are done by using the centric relation (CR) position. Despite a long history of use, the neuromuscular effects of different maxillo mandibular relations are not fully studied. The aim of this study was to investigate the effect of alterations of maxillo-mandibular relation from maximal intercuspal position (MIP) to a raised VDO CR position on jaw-elevator muscle activity.

Materials and Methods: Fifteen healthy individuals were asked to carry out maximal voluntary clenching (MVC) in MIP and in CR on individual splints. Electromyographic (EMG) activity of the masseter and anterior temporalis muscles was assessed in μV as the root mean square of the amplitude. Specific indexes and ratios were also computed. Data analyzed in MIP and CR were compared by paired student's *t*-tests.

Results: MVC levels were not negatively affected by a VDO increase in CR position. On the contrary masseter muscles showed a statistically significant increase ($p < 0.005$). No significant effect on the anterior temporalis was observed.

Conclusion: These results suggest that no immediate negative effect on maximum voluntary clenching was induced by a VDO increase in CR position. A slight increase observed in EMG clenching levels could be explained by the increase in VDO when clenching on the splint.

Clinical Implications: The results of this study support the use of CR position as a pragmatic reference position due to the absence of relevant or negative changes in neuromuscular function.

KEYWORDS
CR, EMG, occlusion, oral rehabilitation, VDO

1 | INTRODUCTION

Centric relation (CR) has been traditionally used as a reference position for maxillo-mandibular relation in restorative dentistry.[1–7] In the past some authors, albeit without supporting data, have been advocating a supposed biologic advantage given by CR.[8] However, the clinical concepts of considering CR as a preventive measure to protect the temporomandibular joint (TMJ) compared to maximal intercuspal position (MIP) as well as of utilizing a precise maxillo-mandibular relation to treat dysfunctions have been rejected.[8–14] There is currently a wide consensus to avoid irreversible changes in dental occlusion as the target for temporomandibular disorders (TMD) treatment.[12–19]

Currently, rather than dysfunctional patients, clinicians routinely face conditions requiring important occlusal modifications in otherwise functionally healthy subjects, typically in esthetic restorative cases, where extensive prosthetic reconstructions, orthodontic therapy, and complex surgical-orthodontic treatments may be necessary to achieve the required esthetic goals (Figure 1). Regardless of the reasons why treatment has been decided (restoring tooth wear, replacing extensive tooth loss, periodontal breakdown, a combination of all the previous conditions or even just an improvement in esthetics required by the patient), there is a general consensus around the advantages to refer to some reference position starting from which the patient's occlusion can be reorganized after the maximal intercuspal position has been modified.[1–7,13,14] Indeed, in spite of decades of philosophical controversies,[3–5] in a clinical perspective the role of a maxillo-mandibular relation change should be rather a practical than a biological goal.[13,14] The position should allow for easy reproducibility and be harmless to the patient.[13,14]

Unfortunately, the focus on dental occlusion that characterized the past decades was more theoretical and philosophical than scientific. No conclusive evidence has been obtained concerning the effect of CR on muscular function yet. Despite CR past and current use in dental treatments, if we rely on existing literature investigating EMG of masticatory muscles its use should be discouraged. In the past, the use of CR as a reference position has been criticized in favor of neuromuscular reference positions, based on the purported hypothesis that it is a non-physiological position that is usually not achieved during function. Contrasting results exist in the literature on this topic,[20–26] (Table 1) but due to lack of homogeneity in the adopted research protocols no study provided clear evidence of the immediate muscular effects of a change in maxillo-mandibular relation from a stable MIP to a stable CR. Most of the authors who evaluated CR through EMG reported a potentially negative change in muscular activity in CR position, with a decrease in maximum voluntary clenching (MVC) levels and/or an increase in postural activity.

A decrease in masticatory muscles MVC levels due to CR position itself would clearly mean that the use of this position as a reference position for treatment involving extensive modifications of occlusal relationships, as in the conditions previously described, should not be considered.

A reference position should allow the masticatory muscles to perform at least the same levels of MVC as in MIP.

Based on the above premises, the aim of this study was therefore to test the null hypothesis that centric relation position is compatible with normal muscular activity, as evaluated through MVC levels.

2 | MATERIALS AND METHODS

A group of 15 adults (9 females and 6 males, mean age 52 years) were recruited among all subjects requiring preventive and or cosmetic procedures (oral hygiene, tooth whitening) attending a private practice. All subjects included in the research protocol underwent a routine diagnostic evaluation by a clinician (CEP).

To be included all subjects had at least 28 teeth, no tooth pain, a stable maximal intercuspal position with some mild degrees of crowding and or tooth malpositions, no or limited tooth wear, no anterior or posterior open bite, no TMJ and/or muscular pain, and gave informed consent for the following research protocol.

2.1 | Clinical protocol

Each subject's dental arches were scanned with an intraoral scanner (3Shape, Copenhagen, Denmark). Standard maxillo mandibular relationship in MIP was recorded. Acquisition was then duplicated, the bite scan in MIP was deleted and a new maxillo mandibular relationship in CR position was recorded by using a CR wax as an anterior jig (Delar Bite Registration Wax, Delar Corporation), following a modified Roth technique.[27]

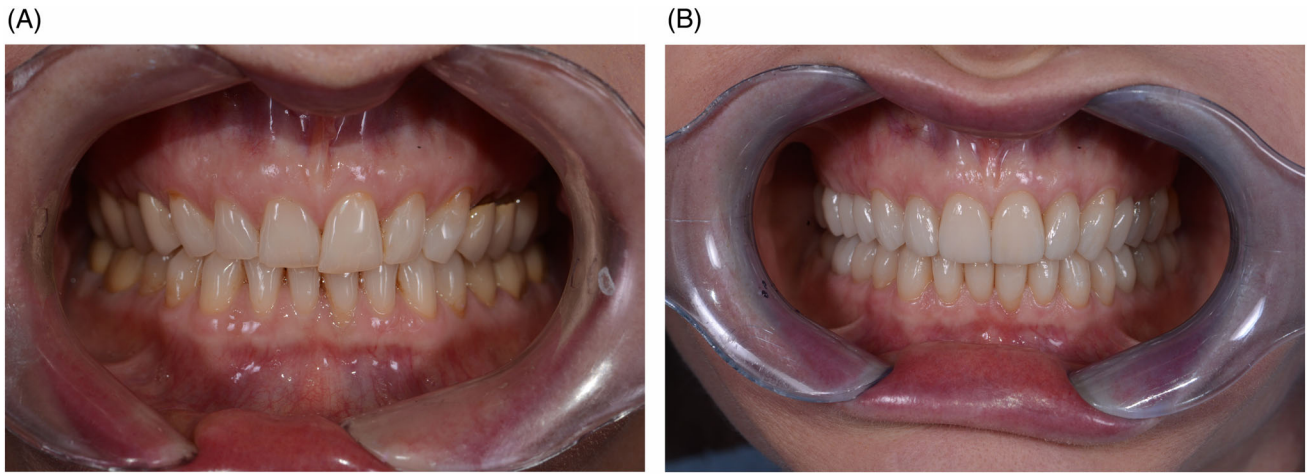

FIGURE 1 (A, B) A typical clinical condition of a patient requiring an esthetic improvement of the smile. Treatment was performed by remaking old crowns in the posteriors and using veneers in the anteriors. VDO was raised in CR position.

TABLE 1 The effect of maxillo-mandibular relations on electromyographic (EMG) activity; comparison of results obtained in studies comparing clenching performed in different positions.

		Hickman et al.[23,24]	Jimenez[21]	Jimenez[22]		Williamson et al.[25]	Al Quran & Lyons[26]	
Sample		20 Healthy volunteers	37 Subjects, 3 groups: (1) normal occlusion, (2) cl. II division 2 (3) dual bite			26 TMD patients, 10 healthy control	10 Healthy subjects	
Mandibular positions	MIP	MIP with splint	MIP with splint	MIP without splint	MIP with splint	MIP without splint	MIP without splint	
	CR	CR: Dawson bimanual manipulation	RCP: retruded contact position. Manually applied force at the chin in the posterosuperior direction (Ingervall, Helkimo, Carlsson)	RCP without splint	RCP with splint	CR:mandibular manipulation with the best possible superior-anterior condylar position attained	CR:retruded position	
			MP: muscular position (mandibular manipulation till relaxaton occured; mandible arcing freely, without muscular endurance)					
		LG: leaf-gauge by Williamson						
	Ant					Anterior repositioning splint		
	NM	NM: neuromuscolar position (TENS) by Jankelson						
	Rest					Rest position		
Splint		MIP-CR-NM: full arch from 6 to 6. LG: 2 posterior sections without coverage of the incisor	Posterior from 4 to 7		Posterior stabilization splint from 4 to 7	SRS: mandibular CR splint max/ARS: maxillary anterior repositioning splint man/ARS: mandibular anterior repositioning splint	Superior hard splint	Soft splint
EMG protocol		MVC, TA and M	MVC and 10% MVC, TA TP M	MVC, TA TP M		MVC	MVC, 10%–50% MVC	
Results MVC	Mean EMG potentials	LG: lowest potentials. NM: highest. T > M in each condylar position				Max/ARS < MIP, SRS and man/ARS, MIP, SRS, man/ARS n. s. different. No differences between the control and the experimental group		
	Masseter mean EMG potentials	LG and CR < NM and MIP	RCP < MIP and MP n.s. differences between MIP and MP	RCPwithout < RCPwith MIPwithout = MIPwith RCPwith = MIPwith and MIPwithout			CR < MIP (n.s.)	MIPwith > MIPwithout
	Temporalis anterior mean EMG potentials	LG < CR, MIP, NM n.s. differences between NM and MIP					CR < MIP (n.s.)	MIPwith < MIPwithout (n.s.)
	Temporalis posterior mean EMG potentials		RCP > MIP and MP n.s. differences between MIP and MP					
	Masseter/temporalis ratio	LG and CR < MIP and NM	RCP < MIP and MP n.s. differences between MIP and MP				CR < MIP (n.s.)	MIPwith < MIPwithout (n.s.)

(Continues)

TABLE 1 (Continued)

		Hickman et al.[23,24]	Jimenez[21]	Jimenez[22]	Williamson et al.[25]	Al Quran & Lyons[26]
Partial MVC	Mean EMG potentials					
	Masseter mean EMG potentials					
	Temporalis anterior mean EMG potentials		RCP > MIP and MP n.s. differences between MIP and MP			
	Temporalis posterior mean EMG potentials		RCP > MIP and MP n.s. differences between MIP and MP			
	Symmetry					
	Masseter/temporalis ratio					CR < MIP (n.s.) MIPwith < MIPwithout (n.s.)

Abbreviations: CR, centric relation; LG, leaf gauge position; M, masseter muscles; MIP, maximal intercuspal position; MVC, maximum voluntary contraction; n.s., not significant; NM, neuromuscular position; RCP, retruded contact position; TA, temporalis anterior muscles; TMD, temporomandibular disorders; TP, temporalis posterior muscles.

A CR splint in PMMA was milled for each subject in a full digital workflow utilizing the maxillo mandibular position of the CR wax record (Figures 2 and 3). The splints were clinically verified to achieve simultaneous and even contact of centric cusps on the splint surface using a 12 μm occlusion foil (Hanel Foil, Roeko), anterior disclusion verified with 8 μm thick shim stock (Hanel Shim Stock, Roeko) and immediate posterior disclusion in protrusive and lateral movements (Figure 4). Minimum thickness of the splints was approximately 2 mm.

2.2 | Electromyographic protocol

All subjects underwent surface EMG with (CR) and without the splint (MIP). For the EMG investigation, disposable Ag/AgCl electrodes, 24 mm diameter and with an interelectrode distance of 20 mm (Kendall, Covidien) were used. Prior to the placement of the electrodes, the muscles were carefully palpated while the subjects were asked to perform MVC.

FIGURE 2 Maxillo mandibular position recorded in full digital workflow.

FIGURE 3 Milled splint in CR position at increased VDO.

FIGURE 4 Occlusal contacts at the time of delivery of the splint (Hanel 12micron Occluding paper).

The electrodes were then positioned parallel to the temporalis and masseter muscle fibers, i.e., vertically along the anterior margin of the anterior temporalis muscle (roughly on the coronal suture), and parallel to the masseter muscle fibers with the upper pole of the electrode at the intersection between the tragus-labial commissura and the exocanthion-gonion lines. EMG activity was recorded using a dedicated device (Teethan, Teethan S.p.A.). The analogic EMG signal was amplified, digitized, and digitally filtered. The analog EMG signal was first amplified (gain: 150; bandwidth: 0–10 kHz; peak-to-peak input range: 0–2.000 μV) via a differential amplifier with a high common mode rejection ratio (105 dB; frequency range: 0–60 Hz; input impedance 10 GOhm), A/D converted (resolution: 12 b; sampling frequency: 2300 Hz), and digitally filtered (high-pass cut-off frequency: 30 Hz; low-pass cut-off frequency: 400 Hz; notch cut off frequency for electrical noise removal: 50–60 Hz). The signals were averaged over 25 ms, with muscle activity of the four tested muscles assessed as the root mean square (RMS) of the amplitude (unit: μV). EMG signals were then recorded for further analysis. Raw data analysis was conducted according to the protocol described by Ferrario and Sforza,[28] with a dedicated software (Teethan, Teethan S.p.A.). All EMG examinations were performed after clinical verification of the occlusal contacts following the described protocol.

A standardized recording of EMG potentials was made immediately prior to the actual recording of the electric activity during clenching. For each subject, two 10-mm thick cotton rolls were positioned in the left and right mandibular first molar areas, and a 3-s maximum voluntary clench was recorded. The maximum EMG potential for each muscle was set at 100%, while all further EMG potentials were expressed as a percentage of this value (unit: μV/μV × 100). The relative percentage values that are found with this approach are affected only by the contacts on occlusal surfaces, because this kind of standardization should eliminate the variables induced by skin and electrode impedance, electrode positioning, and relative muscular hypo- or hypertrophy.[29] For the actual test, three further seconds of EMG activity were then recorded during a MVC. The test was performed while clenching on the teeth in MIP and in CR, the latter immediately after the adjustment of the splint. The two tests were performed without changing the electrodes. During testing, the patients sat with their head unsupported and were asked to maintain a natural erect position.

The EMG signals of coupled muscles were compared by computing four specific indexes, as described by Ferrario and coworkers[29]: impact value, percentage overlapping coefficient (POC), torque coefficient (TC) and activity index (AC). Impact value expresses the total electrical activity measured by calculating the area under the muscular waveforms of all four analyzed muscles (unit: μV/μV × 100 × s). This figure assesses the overall muscular work performed during the selected task.[29] POC (unit: %) is an index of the symmetric distribution of the muscular activity determined by the occlusion: if two muscles contract with perfect symmetry, a POC up to 100% is to be expected.[29] Calculations were automatically performed for each pair of muscles (masseter and temporalis anterior) and for all four muscles together by dedicated software, thus obtaining a temporal, a masseter, and a mean POC.

An unbalanced activity of contralateral masseter and temporalis muscles, such as that of right temporalis and left masseter (and vice versa), might give rise to a force couple generating a lateral displacing component, viz., the torque coefficient (TC, unit %)[29] TC ranges between 0% (absence of lateral displacing force) and 100% (full effect of lateral displacing force). Obviously, TC is 0% when both the differences between left and right temporalis, and between left and right masseter, are null, and simultaneously POC = 100% (complete symmetry of paired masseter and temporalis waves).

The mean muscular potentials in the 3-s span were computed, and the activity index (AC, unit %; ratio between the mean potentials of the temporal and masseter muscles) was calculated.[30] This index ranges between −100% and +100%, where a positive number indicates a masseter muscle dominance, and a negative number indicates a temporal muscle dominance.

Data of the described indexes computed in MIP and CR were compared by paired Student's *t*-tests, with a level of significance set at 5% ($p < 0.05$).

3 | RESULTS

The POC coefficient was higher in CR, although normal values were found also in MIP (Table 2). Muscular activity was on average more equilibrated in CR, for the temporalis anterior and the masseter couples, with higher total POC index, and lower TC coefficients. POC values were calculated for the temporalis, the masseter couples individually in CR and MIP and were not found to be statistically different, thus only the mean value is reported in Table 2. A negative number was found for the AC coefficient in MIP (temporal prevalent); this value showed statistically significant increase to a positive (masseter prevalence) value in CR (Table 3).

4 | DISCUSSION

CR position did not show any reduction or significant changes in MVC levels as measured by EMG. Thus, the null hypothesis of CR being compatible with muscular function was not rejected.

	lTA		rTA		lMM		rMM	
	Mean	SD	Mean	SD	Mean	SD	Mean	sd
MIP	205.67	86.52	196.17	77.02	177.15	52.94	206.39	93.22
CR	225.13	97.94	197.67	79.10	213.13	63.44	239.03	109.79
p	n.s.		n.s.		0.005		0.02	

TABLE 2 Left and right temporalis and masseter EMG amplitude expressed as root mean square (RMS) of the amplitude (unit: μV).

Abbreviations: CR, Centric relation position; lMM, rMM, left and right masseter medialis muscles; lTA, rTA, left and right temporalis anterior muscles; MIP, Maximal Intercuspal Position; n.s., not significant ($p > 0.05$); *p*, probability of paired Student's *t* test.

	Impact		POC		TC		AC	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MIP	2392.80	721.28	85.13	4.46	1.55	7.16	−3.37	7.16
CR	2624.80	855.56	87.01	2.81	0.04	4.46	2.60	6.70
p	0.05		n.s.		0.02		0.008	

TABLE 3 Impact values, unit: μV/μV × 100 × s; total percentage overlapping coefficient (POC); activity (AC), and torque coefficients (TC) values.

Note: Unit: percentage.
Abbreviations: CR, Centric relation position; MIP, maximal intercuspal position; n.s., not significant ($p > 0.05$); *p*, probability of paired Student's *t* test.

All subjects entering the study showed normal electric activity when clenching on their natural dentition (MIP). Mean computed parameters were comparable to those measured in a different sample of healthy subjects by using the same instrumentation and the same indexes.[29] When clenching in CR position all the subjects could achieve at least the same EMG levels as in MIP.

Some of the evaluated parameters showed a better performance in MVC in CR compared to MIP. Statistically significant changes were found for right and left masseter RMS, impact (global activity of all muscles considered) as well as the activity index. Rather than due to the position itself it is plausible to consider these changes as a consequence of the slight VDO increase in CR, due to the presence of the splint and the equilibration of contacts on the appliance.

These data are hard to compare with the literature, due to the paucity of investigations on the EMG effect of different maxillomandibular relations. The study by Buxbaum and coworkers[20] reported negative effects of CR position on muscular functional activity, suggesting critical limitations to the use of CR in clinical practice. Nonetheless, the EMG values reported by Buxbaum are not related to MVC as in the case of the present research, thus making any comparison impossible.

To avoid the negative consequences of unstable contact positions most experimental studies have analyzed the effects of CR position through the use of splints, since they allow for easy and reversible occlusal changes. The results in our study are in partial agreement with data reported by Jimenez.[21,22] Clenching in CR without the splint was found to inhibit masseter and temporalis activity. Muscular activity returned to normal values during clenching in a stable position both in CR through the use of a splint and in MIP. According to the author's conclusions, these results indicate that a proper efficiency of muscular contraction is determined by occluding on stable contacts rather than by any specific mandibular position.

On the contrary, our data are in disagreement with Hickman and coworkers.[23,24] Examined positions were MIP, CR (obtained through bimanual Dawson technique), LG (centric relation achieved through the leaf gauge technique), and NM (a neuro-muscular position reached through trans-cutaneous nerve stimulation TENS). For each patient and position a splint was fabricated in self-curing acrylic resin that was as thin as possible without perforations. The splints were all full-occlusal coverage except for the ones fabricated through LG in which the anterior segment was left uncovered. In that study, the authors found a statistically significant difference for mean electric activity in different condylar positions. When compared to MIP, there was a reduction of temporalis and masseter muscular activity in CR and especially LG positions, while the highest electric activity was found when clenching in the NM position. No significant differences were found between MIP and NM position. Thus, the authors concluded that NM is the best position on the basis of which to set treatment plans, because it determines an improvement in muscular function.[23,24]

Williamson and coworkers compared the effects of an anterior repositioning splint (ARS) with no posterior occlusal contacts with a full coverage upper arch splint fabricated in CR and having bilateral symmetric occlusal contacts and anterior guidance.[25] The authors found that the ARS determined a significant reduction of temporal and masseteric muscular activity during MVC relative to the CR splints and clenching in MIP, with no significant differences between MIP and CR positions.

In another study, Al Quran and Lyons,[26] applied a 2 mm thick upper arch CR stabilization splint. The authors found an overall (although not statistically significant) reduction of EMG activity of temporalis and masseter muscles, with a very large variability within the sample studied. The authors suggested this variability could be due to different splint thicknesses, the number of

contacts, and the varying degrees of subjective comfort while wearing the appliances.

Some of the conclusions by Hickman and coworkers,[23,24] should be questioned, according to the results by Jimenez[21,22] and to the present study. According to the data reported in their study, while NM resulted inferior and anterior to MIP, both CR and LG position resulted posterior and superior to MIP. Moreover, the occlusal devices used to test different positions were made directly at chairside with autopolymerizing acrylic resin, and no detail was given about their equilibration prior to testing. Comparing the present study results as well as those by Jimenez,[21,22] it could be assumed that the tested positions were uncomfortable and or rather unstable. Clenching in an unstable position would probably create a decrease in EMG muscular activity in the tested positions. According to both Hickman and coworkers,[23,24] and Jimenez,[21,22] as well as most of the published researches, a therapeutic occlusal position should provide a stable condition, thus allowing for the maximum expression of muscular activity in voluntary clenching.

Few authors have argued that a reduction of MVC levels in TMD patients should also be achieved,[30,31] but the rationale to consider a reduction in voluntary contraction levels, and not in postural activity of the muscles, as a positive effect is difficult to understand. It would seem more likely that an uncomfortable position and/or an unstable or not carefully checked occlusal surface would cause a reduction in MVC. Both Jimenez and Hickman[21–24] studies applied directly made splints of autopolymerizing acrylic resin. Splints in this study were constructed by milling of PMMA resin, allowing a high degree of precision.

For each patient, equilibration of the splints was performed until all the required contacts were achieved to the amount that was verified through the use of different thickness of occlusal paper. Thanks to the precision allowed by full digital workflow, this procedure required a rather limited time, usually less than 15 min. The procedure described by Hickman and coworkers[23,24] makes it difficult to understand whether the reduction in EMG activity was due to changes in position rather than unstable contacts, as those that could be provided by an unchecked autopolymerizing acrylic resin surface.

The selection criteria for subjects included in the current study was based upon characteristics similar to previous studies conducted with the same protocol on healthy individuals.[28,29] A possible limitation of this study was the limited number of subjects, which indeed was based on the number of subjects in previous similar studies. A larger number of subjects could allow to differentiate better some specific occlusal characteristics.

The debate over maxillo-mandibular relations covers several decades in the history of clinical dentistry.[3–5] Controversies in dental literature concerning centric relation and clinical application of different positions have become less common in recent years. This is probably not due to questions being settled but rather to a general decrease of interest in occlusion in the last years. The recognition of the increasing importance of non-occlusal factors in TMD as well as weak or absent evidence supporting the use of occlusal therapies in the treatment of TMD,[8–19] are probably important reasons for this decreased interest.

Within these premises, it seems nonetheless important to distinguish between the abandoned concept of treating patients to CR due to a supposed biologic advantage and the use of CR as a reference position, whenever MIP results unsuitable for restorative needs or is going to be modified.

5 | CONCLUSIONS

Within the limitations of this study, results suggest that no immediate negative effect on maximum voluntary clenching was induced by centric relation position. A slight increase observed in electromyographic clenching levels could be explained by the increase in vertical dimension when clenching on the splint.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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