Acta Scientific Dental Sciences
Volume 9 Issue 6 June 2025
Research Article

Involvement of Intervertebral Disc Degeneration in Masticatory Efficiency and Range of Mandibular Movements

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Received: May 09, 2025
Published: May 23, 2025

Abstract

Loss of intervertebral disc function is considered a degenerative disease that can affect the human body systems, especially orofacial anatomical structures. This observational study aimed to evaluate the efficiency of masticatory cycles through the electromyographic signal of the masseter and temporalis muscles and the amplitude of mandibular movements in subjects with degeneration of the intervertebral discs. Thirty-two subjects were divided into two groups: those with degeneration of the intervertebral discs (n = 16) and the control group (n = 16). The efficiency of masticatory cycles through the electromyographic signal of the masseter and temporalis muscles was analyzed during habitual (raisin and peanut) and non-habitual (parafilm) chewing using the linear envelope integral. The amplitudes of mandibular movements (maximum mouth opening, right laterality, left laterality, and protrusion) were measured using a digital caliper. A significant difference was observed between the groups (Student's t-test, $p < 0.05$) in the habitual chewing of raisins in the right ($p = 0.003$) and left ($p = 0.005$) masseter muscles. The group with degeneration of the intervertebral discs showed greater electromyographic activity for the masseter and temporalis muscles. There was a significant difference in maximum mouth opening ($p = 0.002$). The group with intervertebral disc degeneration had a lower range of mandibular movements. The authors of this study suggest that subjects with degeneration of the intervertebral discs present deficient masticatory efficiency and a lower range of mandibular movements. Understanding the relationship between the stomatognathic system and degeneration of anatomical structures of the spine is relevant to health science, especially when considering diagnosis, prognosis, and orofacial treatment.

Keywords: Degenerative Disease; Intervertebral Disc; Electromyography; Masticatory Efficiency; Mandibular Movement; Masticatory Muscles

Introduction

The intervertebral disc consists of the internal nucleus pulposus, external fibrous ring, cartilaginous endplates, and has a complex specialized tissue rich in an extracellular matrix of proteoglycans and collagen, with the ability to absorb mechanical loads and stabilize and dampen impacts on the spine [1,2].

Over the years, the spine can be affected by functional changes resulting from degenerative disease of the intervertebral discs, which promote painful symptoms and muscle disorders [3]. Intervertebral disc degeneration, a progressive and chronic musculoskeletal pathology that affects 5% of the world's population throughout life, making it a disabling condition (Ravichandran et al., 2022), is considered a highly prevalent public health challenge [4] that represents the main cause of painful symptoms in the back and neck [5].

The spine is a unique anatomical unit and is considered one of the most vital parts of the human body, and any imbalance or modification in its function can promote compensatory changes in other levels of the craniocervical system [6]. Functional movement disorders of the human body when observing the spine have hardly been considered from the point of view of the stomatognathic system, which comprises dynamic and static anatomical structures that are monitored by the central nervous system [7,8].

Given the above and the ability of degenerative intervertebral disc disease to promote important changes that may compromise the function of the human organism through systemic physiological processes [9], it is important to understand what happens to the stomatognathic system of people who are affected by this disease and verify the possible impact on dynamic orofacial structures [10,11].

Therefore, this study aimed to evaluate the efficiency of masticatory cycles through the electromyographic signal of the masseter and temporal muscles, and the amplitude of mandibular movements in subjects with degeneration of the intervertebral discs. The null hypothesis of this study was that the group with degeneration of the intervertebral discs did not present changes in relation to the normalized electromyographic activity of the masticatory cycles and amplitude of mandibular movements when compared to the group without the degenerative disease. This study presents two alternative hypotheses: the group with degeneration of the intervertebral discs has higher normalized electromyographic activity during habitual and non-habitual chewing in the masseter and temporalis muscles and a lower range of mandibular movements when compared to the group without the degenerative disease.

Material and Methods

The observational study was approved by the ethics committee of the Faculty of Dentistry of Ribeirão Preto, University of São Paulo, Brazil (process # 29014620.1.0000.5419), and all subjects signed an informed consent form.

Sample

To determine the minimum sample size, which was 16 subjects for each group, the software G* Power 3.1.9.2 (Franz Faul, Kiel University, Kiel, Germany) was used to calculate the sample size (a priori) considering $\alpha = 0.05$, an effect size of 1.71, and power of 96%, applied from the pilot project with five subjects.

In this cross-sectional observational study, a total of 80 subjects were evaluated, and following the inclusion and exclusion criteria, 36 subjects of each sex, aged between 20 and 59 years, with normal occlusion (Angle Class I), and presence of all teeth (except third molars) without temporomandibular disorders (Research Diagnostic Criteria for Temporomandibular Disorders) were selected.

These subjects were divided into two groups: a group (GI) comprising 16 subjects (eight men and eight women) with degeneration of the intervertebral discs (mean ± standard deviation [SD]: 37.0 ± 8.3 years), diagnosed by specialist physicians through clinical and imaging examinations (magnetic resonance imaging) and a group (GII) considered the control, comprising 16 subjects without intervertebral disc degeneration (mean ± SD: 37.1 ± 8.6 years), matched for age, sex, and body mass index with those of the GI (Table 1).

The exclusion criteria were as follows: presenting neurological and systemic pathologies, use of complete or removable dentures, mental or physical discomfort during the evaluations, congenital anomalies, previous spinal surgery, evidence of tumors on imaging studies, spinal infection, and fracture and/or spinal deformities.

Groups	Age	Body Mass Index
GI	37.0 ± 8.3	25.9 ± 3.4
GII	37.1 ± 8.6	25.6 ± 4.3
p-value	0.96	0.83

Table 1: Differences in characteristics (mean ± standard deviation) between the intervertebral disc degeneration group (GI) and the control group (GII).

Significant difference, student's t-test (i.e., $p < 0.05$).

Masticatory efficiency analysis

The analysis of masticatory efficiency through dynamic evaluations with regard to mastication was determined through the normalized electromyographic activity of the mastication cycles of the masseter and temporal muscles, and the linear envelope integral was observed using the Delsys Trigno TM wireless electromyography (Delsys, Boston, MA, USA).

Electromyographic signals (microvolts) were collected during habitual chewing of soft food (raisins), hard food (peanuts), and non-habitual chewing of inert material (10 s each clinical condition). The inert material consisted of a folded paraffin sheet (Parafilm M®, Pechiney Plastic Packaging, Batavia, IL, USA) (18 × 17 × 4 mm, weight 245 mg), which was inserted between the occlusal faces of the upper and lower molars, on the right and left dental archés [12]. The test foods belonged to the same batch and the quantity was established by units until 5g.

The sensors were positioned on the masseter and temporalis muscles according to the norms determined by surface electromyography for the non-invasive assessment of muscles [13]. The tooth clenching maneuver in maximum voluntary contraction was performed to locate the desired motor point (muscle belly). Before placing the sensors in the masticatory muscles, the integumentary tissue was cleaned using 70% alcohol to reduce impedance [14]. The sensors were fixed after a few minutes of the skin cleaning procedure.

The value of the linear envelope integral of the masticatory cycles was obtained from the average of the central cycles established during habitual and non-habitual chewing. The initial masticatory cycles were not used because changes in the pattern of mandibular movements occurred at the beginning of the masticatory process [12].

Range of mandibular movements analysis

A digital caliper (Mitutoyo, Santo Amaro, São Paulo, Brazil) was used to measure the range of mandibular movements considering the patterns of maximum mouth opening, right laterality, left laterality, and protrusion [15]. Before carrying out the mandibular range of motion protocol, which was performed by a single trained researcher, instructions were given, asking the participant to remain seated, keeping the thighs parallel to the ground, and the head positioned upright. The reference standard for examination was the dental midline.

To measure the maximum mouth opening at the limit without discomfort or pain, the digital caliper was positioned in the incisal and mesial of the upper right central incisor and incisal region of the lower right incisor, in addition to measuring the overbite. During protrusion, the mandible was slid forward, and the horizontal distance from the buccal aspect of the maxillary incisors to the incisal edge of the mandibular incisors was measured.

The value of the overjet at the sagittal distance between the incisal margins of the maxillary central incisors and mandibular incisors in the protruded position was added to the mandibular movement. Right and left lateralities were quantified by observing the horizontal distance between the midline of the maxillary and mandibular central incisors. When there was a deviation from the midline (between the lower and upper central incisors), the appropriate adjustment of the measured values was used [16].

Statistical analysis

After obtaining data on masticatory efficiency through the normalized electromyographic activity of the masseter and temporalis muscles and amplitude of mandibular movements, the Shapiro-Wilk normality test was applied, demonstrating normality data. Due to the need for comparisons between different research subjects, the electromyographic values obtained in habitual and non-habitual clenching were normalized by the mandibular task of clenching teeth during voluntary contraction.

Normalized electromyographic data and mandibular range of motion were subjected to statistical analysis using IBM SPSS 26.0 statistical software (IBM SPSS Inc., Chicago, IL, USA). The results were obtained through descriptive analysis (mean and standard error). The values obtained were compared using Student's t-test, and statistical significance was set at $p < 0.05$.

Results

The data on the linear envelopment integral of the masseter and temporalis muscles and mandibular range of motion of the two groups are shown in Table 2. A significant difference was observed between the groups (Student's t-test, $p < 0.05$) in habitual clenching with raisins for the right ($p = 0.003$) and left ($p = 0.005$) masseter muscles. The group with degeneration of the intervertebral discs demonstrated greater electromyographic activity for the masseter and temporalis muscles (Table 2). Table 3 shows the significant difference in maximum mouth opening ($p = 0.002$) between the groups. The group with intervertebral disc degeneration had a lower range of mandibular movements.

Mandibular Mobility	GI	GII	p-value
Mouth opening	44.02 ± 1.22	50.01 ± 1.44	0.002
Right laterality	10.12 ± 1.46	11.03 ± 1.83	0.70
Left laterality	9.60 ± 1.34	11.02 ± 1.75	0.52
Protrusion	5.10 ± 0.35	5.80 ± 0.54	0.29

Table 2: Mouth opening, right laterality, left laterality, and protrusion (millimeters) in the intervertebral disc degeneration group (GI), presented as mean ± standard error of the mean, with p-values for comparisons to the control group (GII).

Significant difference, student's t-test (i.e., $p < 0.05$).

Chewing/muscle	GI	GII	p-value
Habitual (Raisins)			
Right masseter	0.75 ± 0.05	0.51 ± 0.04	0.003
Left masseter	0.95 ± 0.07	0.61 ± 0.07	0.005
Right temporal	1.27 ± 0.21	1.23 ± 0.19	0.91
Left temporal	1.26 ± 0.25	1.21 ± 0.15	0.86
Habitual (Peanuts)			
Right masseter	0.83 ± 0.12	0.56 ± 0.09	0.08
Left masseter	1.02 ± 0.14	0.71 ± 0.13	0.13
Right temporal	1.49 ± 0.17	1.33 ± 0.16	0.51
Left temporal	1.36 ± 0.18	1.22 ± 0.18	0.59
Non-habitual (Parafilm)			
Right masseter	0.66 ± 0.08	0.57 ± 0.05	0.42
Left masseter	0.89 ± 0.15	0.72 ± 0.10	0.37
Right temporal	1.15 ± 0.16	1.14 ± 0.10	0.97
Left temporal	1.21 ± 0.17	1.19 ± 0.13	0.93

Table 3: Electromyographic data (habitual and non-habitual chewing) of the right and left masseter muscles and the right and left temporalis muscles in the intervertebral disc degeneration group (GI), presented as mean ± standard error of the mean, along with p-values compared to the control group (GII).

Significant difference, student's t-test (i.e., $p < 0.05$).

Discussion

The null hypothesis of this study was rejected because there was a significant difference between the groups in the normalized electromyographic activity of the masticatory cycles during habitual chewing of soft food (raisin) and maximum mouth opening, which demonstrates that there may be a relationship between degenerative intervertebral disc disease and dynamic structures that make up the stomatognathic system.

One of our alternative hypotheses was that the group with degeneration of the intervertebral discs would have higher normalized electromyographic activity of the masseter and temporalis muscles during habitual and non-habitual mastication. This hypothesis was based on the principle that degenerative intervertebral disc disease is determined by anatomical structural failures as a consequence of the response of cells to multifactorial situations (pro-inflammatory cytokines) that promote excess catabolism, resulting in muscle atrophy [17].

For adult skeletal striated muscle tissue maintenance, there is a need for a balance between the rates of protein synthesis and degradation [18]. The main characteristic of degenerative disease of the intervertebral discs is the increase in the levels of pro-inflammatory cytokines such as interleukin-6, which is secreted by the disc cell itself, promoting matrix degradation and consequently protein imbalance, which leads to biological implications including muscle atrophy [19]. Muscle atrophy, in turn, occurs when the rate of protein degradation exceeds the rate of protein synthesis [20], which can occur in subjects who develop degeneration of the intervertebral discs.

For the masticatory process dynamics to be functional, there must be repetitive isotonic contraction movements, with isometric contraction intervals [12]. During the masticatory process of subjects with morphofunctional alterations of the stomatognathic system, there is an increase in the recruitment of the number of muscle fibers to perform the same function of the process considered healthy, promoting an increase in neuromuscular activity. This increase in myoelectric activity when evaluating the masticatory cycles is considered to be deficient in the stomatognathic system [21].

Studies that used this methodology and sampled groups with chronic degenerative diseases showed that these diseases negatively impact masticatory efficiency using the linear envelope integral of the electromyographic signal of the masticatory muscles [22]. Deficient masticatory efficiency in subjects with intervertebral disc degeneration can be explained through human physiology. Metabolism is an important process for the balance of organic functions, especially when obtaining energy that allows the functioning of the body [23]. Catabolism is a process of metabolism involving complex organic molecules, which are transformed into smaller molecules [24]; however, when there is an excess of catabolism, changes may occur in the skeletal striated musculature, which triggers muscle atrophy [25].

Atrophied musculature, for example, of the masseteric muscle, can deregulate the sensory pattern of periodontal mechanoreceptors, which are well-refined neuronal receptors that are important in the function of the stomatognathic system that has integrated dynamic structures, which are involved in the activation of masticatory muscles, leading to negative consequences in the organization of the masticatory process [26]. This could explain the deficient masticatory efficiency in the group with degeneration of the intervertebral discs compared to the control group, where atrophy of the masticatory muscles would influence their functional performance [27].

Therefore, this alternative hypothesis of the study was accepted because the group with degeneration of the intervertebral discs presented greater normalized electromyographic activity of the masseter and temporal muscles during mastication compared to the control group, with a significant difference in chewing soft food (raisin) for the masseter muscles, demonstrating worse masticatory efficiency. In this study, atrophy of the masticatory muscles and sensory information from periodontal mechanoreceptors were not evaluated.

The results of this study demonstrated that the temporal muscles showed higher normalized electromyographic activity of the masticatory cycles compared with the masseter muscles in habitual and non-habitual chewing in both groups. Our results are in agreement with international studies that evaluated the masticatory efficiency of subjects with chronic degenerative diseases and healthy subjects and demonstrated that the temporal muscles present this pattern of neuroanatomical response [28]. This type of neuroanatomical pattern of the temporal muscles may be related to muscle adaptations in response to numerous physiological conditions with different etiologies [29], which could promote a functional overload and consequently an increase in the myoelectric activity of the temporal muscles. This hypothesis should be addressed in future studies to confirm our results.

The second alternative hypothesis of this study was that the group with degeneration of the intervertebral discs had a lower range of mandibular movements. This hypothesis was based on a study that showed that degenerative diseases of the intervertebral discs promote postural changes that directly reflect on the forward posture of the head, which leads to hyperextension, causing a functional imbalance in the stomatognathic system, more precisely in mandibular movements, because the position of the head is a factor with an impact on mandibular function [30].

The positioning of the head is related to the usual path of opening the mouth; wherein, in the anterior position, the path of the mouth is displaced posteriorly and, during the lateroflexion, the path of opening the mouth deviates to the side where the head is located [31]. Measurement of the range of mandibular movements is relevant for assessing the masticatory system, in addition to being an interpretation method that may have numerous variables interfering with the result [32].

The second alternative hypothesis of this study was accepted because there was a significant difference between the groups for maximum mouth opening. The group with degeneration of the intervertebral discs had a lower range of mandibular movements (mouth opening, right laterality, left laterality, and protrusion) compared to the control group. Mandibular movements allow changes in intraoral spaces, allowing displacement of orofacial soft tissues, defining several functional characteristics of the stomatognathic system, especially those of masticatory performance [33]. The intact and adequate functions of the mandible associated with the head and neck are important for maintaining mouth opening movement as a mandibular function [34].

When structures of the spine are affected by degenerative processes, functions of the human body systems, such as the stomatognathic system, are compromised and may decrease the range of mandibular movement that favors the presence of functional limitations such as difficulty in chewing [35]. Mandible movement for the resting task does not mean a simple mandibular opening rotation movement; however, it has a great influence on the support of the head position and body posture [36].

When considering joint dysfunction of the spine, it is relevant to demonstrate that this anatomical structure works as a unit and can stimulate compensatory changes in other levels of the structure itself or the skeletal striated musculature, showing the interrelationship of the stomatognathic system with the body posture that determines the impact on mandibular kinematic function [37].

The value of the mandibular range of motion varies across studies because different studies used different protocols in the assessment of craniocervical posture, given that the head posture can compromise the range of mandibular movements [38]. In this study, the postural assessment of subjects in both groups was not performed.

This study presents several limitations. First, data collection occurred during the COVID-19 pandemic, caused by the SARS-CoV-2 virus, which hindered the recruitment of participants. Second, the study did not measure levels of pro-inflammatory cytokines that could indicate muscle atrophy, nor did it assess the postural alignment of the head and neck-factors that might help explain the range of mandibular movements observed in the group with intervertebral disc degeneration.

Conclusion

Based on the methodology used, degenerative disease of the intervertebral discs modifies the functionality of the stomatognathic system, especially when deficient habitual and non-habitual masticatory efficiency is observed, particularly with soft food, on the masseter muscles and lower range of mandibular movements, highlighting the maximum mouth opening. With these data, the authors show that future studies are necessary to add more scientific evidence that can elucidate the relationship between diseases related to the spine and orofacial dynamics, depicting that there are still gaps in knowledge in this field that encompasses the dental and medical sciences.

Acknowledgements

The authors declare that they have no conflicts of interest. This study was supported by a grant from the FAPESP and National Institute and Technology - Translational Medicine (INCT.TM).

Bibliography

1. Johnson ZI., *et al*. "Extracellular osmolarity regulates matrix homeostasis in the intervertebral disc and articular cartilage: evolving role of TonEBP". *Matrix Biology* 40 (2014): 10-16.
2. Madhu V., *et al*. "Role of autophagy in intervertebral disc and cartilage function: implications in health and disease". *Matrix Biology* 100-101 (2021): 207-220.

3. van Roy P., *et al*. "Anatomical background of low back pain: variability and degeneration of the lumbar spinal canal and intervertebral disc". *Schmerz* 15 (2001): 418-424.

4. Kos N., *et al*. "A brief review of the degenerative intervertebral disc disease". *Medical Archives* 73 (2019): 421-424.

5. Cheung JPY and Luk KDK. "The relevance of high-intensity zones in degenerative disc disease". *International Orthopaedics* 43 (2019): 861-867.

6. Spadaro A., *et al*. "Effects of intervertebral disc disorders of low back on the mandibular kinematic: kinesiographic study". *BMC Reseach Notes* 7 (2014): 569.

7. Gonçalves LMN., *et al*. "Alterations in the stomatognathic system due to amyotrophic lateral sclerosis". *Journal of Applied Oral Science* 26 (2018): e20170408.

8. Hunger Malek-Zadeh C., *et al*. "Evaluation of stomatognathic system parameters after bariatric surgery". *Obesity Surgery* 32 (2022): 374-380.

9. Phillips KL., *et al*. "Potential roles of cytokines and chemokines in human intervertebral disc degeneration: interleukin-1 is a master regulator of catabolic processes". *Osteoarthritis Cartilage* 23 (2015): 1165-1177.

10. Bettiol NB., *et al*. "Intervertebral disc degeneration: functional analysis of bite force and masseter and temporal muscles thickness". *Prague Medical Report* 123 (2022): 101-112.

11. Cecilio FA., *et al*. "Effect of intervertebral disc degeneration on the stomatognathic system function in adults". *Cranio* 43 (2025): 401-409.

12. Siéssere S., *et al*. "Masticatory process in individuals with maxillary and mandibular osteoporosis: electromyographic analysis". *Osteoporosis International* 20 (2009): 1847-1851.

13. Hermens HJ., *et al*. "Development of recommendations for SEMG sensors and sensor placement procedures". *Journal of Electromyography and Kinesiology* 10 (2000): 361-374.

14. Di Palma E., *et al*. "Effects of the functional orthopaedic therapy on masticatory muscles activity". *Journal of Clinical and Experimental Dentistry* 9 (2017): e886-e891.

15. Magnani DM, *et al*. "Evaluation of oral-motor movements and facial mimic in patients with head and neck burns by a public service in Brazil". *Clinics (Sao Paulo)* 70 (2015): 339-345.

16. Spagnol G., *et al*. "Impact of midface and upper face fracture on bite force, mandibular mobility, and electromyographic activity". *International Journal of Oral and Maxillofacial Surgery* 45 (2016): 1424-1429.

17. Zhang C., *et al*. "Skeletal organoids". 5 (2024): 390-410.

18. Witard OC., *et al*. "Making sense of muscle protein synthesis: a focus on muscle growth during resistance training". *International Journal of Sport Nutrition and Exercise Metabolism* 25 (2021): 1-13.

19. Şerifoğlu L., *et al*. "Investigation of microRNA-17 expression, tumor necrosis factor-α, and interleukin-6 levels in lumbar degenerative disc disease: case-control study". *Journal of Clinical Medicine* 14 (2025): 1772.

20. Miller BF., *et al*. "Muscle-specific changes in protein synthesis with aging and reloading after disuse atrophy". *Journal of Cachexia, Sarcopenia and Muscle* 10 (2019): 1195-1209.

21. Woda A., *et al*. "The regulation of masticatory function and food bolus formation". *Journal of Oral Rehabilitation* 33 (2006): 840-849.

22. Righetti MA., *et al*. "Osteoarthrosis: analyze of the molar bite force, thickness and masticatory efficiency". *Prague Medical Report* 121 (2020): 87-95.

23. Hollstein T and Piaggi P. "Metabolic factors determining the susceptibility to weight gain: current evidence". *Current Obesity Reports* 9 (2020): 121-135.

24. Yang J., *et al*. "Autophagy and energy metabolism". *Advances in Experimental Medicine and Biology* 1206 (2019): 329-357.

25. Yoshida T and Delafontaine P. "Mechanisms of IGF-1-mediated regulation of skeletal muscle hypertrophy and atrophy". *Cells* 9 (2020): 1970.

26. Veyrune JL and Mioche L. "Complete denture wearers: electromyography of mastication and texture perception whilst eating meat". *European Journal of Oral Sciences* 108 (2000): 83-92.

27. Umeki K., *et al*. "The relationship between masseter muscle thickness and appendicular skeletal muscle mass in Japanese community-dwelling elders: A cross-sectional study". *Archives of Gerontology and Geriatrics* 78 (2018): 18-22.

28. Palinkas M., *et al*. "Evaluation of the electromyographic activity of masseter and temporalis muscles of women with rheumatoid arthritis". *Hippokratia* 22 (2018): 3-9.

29. Greene CS. "Managing the care of patients with temporomandibular disorders: a new guideline for care". *Journal of the American Dental Association* 141 (2010): 1086-1088.

30. Rathee M and Jain P. "Anatomy, head and neck, lateral pterygoid muscle". StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing (2022).

31. Visscher CM., *et al*. "Kinematics of the human mandible for different head postures". *Journal of Oral Rehabilitation* 27 (2000): 299-305.

32. Best N., *et al*. "Measurement of mandible movements using a vernier caliper--an evaluation of the intrasession-, intersession- and interobserver reliability". *Cranio* 31 (2013): 176-180.

33. Ow RK., *et al*. "Relationship of masticatory mandibular movements to masticatory performance of dentate adults: a method study". *Journal of Oral Rehabilitation* 25 (1998): 821-829.

34. Higbie EJ., *et al*. "Effect of head position on vertical mandibular opening". *Journal of Orthopaedic and Sports Physical Therapy* 29 (1999): 127-130.

35. Beltran-Alacreu H., *et al*. "Intra-rater and inter-rater reliability of mandibular range of motion measures considering a neutral craniocervical position". *Journal of Physical Therapy Science* 26 (2014): 915-920.

36. Miles TS. "Postural control of the human mandible". *Archives of Oral Biology* 52 (2007): 347-352.

37. Sforza C., *et al*. "Mandibular movements at maximum mouth opening and EMG activity of masticatory and neck muscles in patients rehabilitated after a mandibular condyle fracture". *Journal of Cranio-Maxillofacial Surgery* 37 (2009): 327-333.

38. Zawawi KH., *et al*. "An index for the measurement of normal maximum mouth opening". *Journal of the Canadian Dental Association* 69 (2003): 737-741.