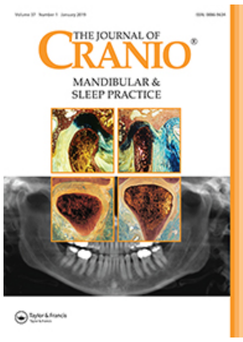

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CRANIO®
The Journal of Craniomandibular & Sleep Practice

ISSN: 0886-9634 (Print) 2151-0903 (Online) Journal homepage: https://www.tandfonline.com/loi/ycra20

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To cite this article: Rodolfo Miralles, Natalia Andrea Gamboa, Mario Felipe Gutiérrez, Hugo Santander, Saúl Valenzuela, Ricardo Bull, Aler Daniel Fuentes & Rosa Córdova (2019) Effect of breathing type on electromyographic activity of respiratory muscles during tooth clenching at different decubitus positions, CRANIO®, 37:1, 28-34, DOI: 10.1080/08869634.2018.1470274

To link to this article: https://doi.org/10.1080/08869634.2018.1470274

Published online: 07 May 2018.

CRANIO®: THE JOURNAL OF CRANIOMANDIBULAR & SLEEP PRACTICE
2019, VOL. 36, NO. 1, 28–34
https://doi.org/10.1080/08869634.2018.1470274

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REHABILITATIVE MEDICINE

Effect of breathing type on electromyographic activity of respiratory muscles during tooth clenching at different decubitus positions

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ABSTRACT

Objective: To compare the effect of breathing type on electromyographic (EMG) activity of respiratory muscles during tooth clenching at different decubitus positions.
Methods: Forty young men participants were included, 11 with upper costal, 9 with mixed, and 20 with costo-diaphragmatic breathing type. EMG recordings of diaphragm (DIA), external intercostal (EIC), sternocleidomastoid (SCM), and latissimus dorsi (LAT) muscles during tooth clenching in the intercuspal position were performed in dorsal, left lateral, and ventral decubitus positions.
Results: DIA EMG activity was higher in subjects with upper costal or mixed than with costodiaphragmatic breathing type ($p = 0.006$; 0.021, respectively), whereas it was similar between upper costal and mixed breathing types. EIC, SCM, and LAT activity was similar among breathing types.
Conclusion: Higher DIA activity would be a risk factor to exceed the adaptive capability of healthy subjects with upper costal or mixed breathing type.

KEYWORDS
Tooth clenching; breathing type; decubitus positions; respiratory muscles; electromyographic activity

Introduction

Breathing type has been defined depending on the expansion of the abdomino-thoracic region during inspiration at rest [1–3]. Three breathing types have been described: (i) Costo-diaphragmatic breathing, when the abdominal and lateral costal expansion predominates over the superior thoracic expansion. This is considered the optimal breathing type because it improves the efficiency of ventilation, gas exchange and oxygenation and decreases the work of breathing [1,4–6]. (ii) Upper costal breathing, when the superior thoracic expansion exceeds the abdominal and lateral costal expansion during inspiration. This breathing type produces a smaller expansion of the rib cage and thus a smaller lung capacity and less gas exchange. Therefore, the use of accessory muscles may be required to breathe properly, particularly at high respiratory demand. (iii) Mixed breathing, when no clear predominance of superior thoracic expansion or abdominal and lateral costal expansion exists.

Respiratory muscle contraction is a continual requirement to ventilate the lungs. It is usually under automatic control by the respiratory centers in the pontomedullary region of the brainstem, inspiration being the crucial active phase of the respiratory cycle in mammals [7,8]. The diaphragm (DIA) is a respiratory muscle that is primarily responsible for inspiration in normal individuals, acting synergistically with the external intercostal (EIC) muscles [9–11]. Additional muscles contract when demand on the respiratory system increases, for example in deep breaths, e.g. sternocleidomastoid (SCM) [12]. In addition, the latissimus dorsi (LAT) muscle appears to have an inspiratory action in patients with hyperpnea, emphysema, and asthma [13,14].

EMG recording is a non-invasive method that can be used to evaluate the work of respiratory muscles, since it is well known that there is a linear relationship between the electrical activity and the force developed by a muscle, and therefore, the muscular work [15–17].

Decubitus positions are habitual during sleeping [18], and tooth clenching is frequent while awake or asleep [19–25]. Little is known about the effect of tooth clenching on the activity of respiratory muscles among awake subjects with different breathing types at different decubitus

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positions. Therefore, the aim of this study was to compare EMG activity of DIA, EIC, SCM, and LAT muscles during tooth clenching among subjects with upper costal, mixed or costo-diaphragmatic breathing type, in the dorsal, left lateral, and ventral decubitus positions. High EMG activity of respiratory muscles, depending on the breathing type, could be a risk factor to exceed the adaptive capability of respiratory muscles in healthy subjects, driving in the long-term to an imbalance of their respiratory system homeostasis. This new knowledge could be useful in the kinesiological evaluation of subjects in the context of a respiratory reeducation therapy.

Materials and methods

The participants were students enrolled at the Dental or Medical School of the University of Chile. They volunteered for the study and signed an informed consent form after a detailed explanation of the experimental protocol and the possible risks involved. None of the procedures were dangerous or painful, and all were made in accordance with the Helsinki declaration of 1975, as revised in 1983. The Ethics Committee of the Faculty of Dentistry, University of Chile, approved the study protocol (0098/2015).

This cross-sectional study included 40 healthy male subjects classified into three groups according to their breathing type; upper costal ($n = 11$, mean age 20.18 years; range, 18-24 years), mixed ($n = 9$, mean age 19.66 years; range, 18–22 years), and costo-diaphragmatic ($n = 20$, mean age 21.65 years; range, 18–27 years). To be included, all participants had complete natural dentition (excluding the third molars), Angle Class I molar relationship, no presence of unilateral or bilateral crossbite, no history of orthodontic treatment within the last 12 months, no history of orofacial pain or craniomandibular-cervical disorders, and no heart or respiratory disease. Subjects with a history of trauma in the orofacial region, suffering from environmental allergies or the common cold, and those on medication that could have affected their muscle activity were excluded. Recruited subjects were male, in order to avoid difficulties with breast size, asymmetry of the breasts, and the use of a bra as related to female subjects during EMG recording.

Determination of the breathing type

Breathing type was determined in the dorsal decubitus position by two expert examiners independently, as follows: First, the examiners gently placed the right hand on the upper chest. Next, they placed the right hand on the upper abdomen and the left hand on the lower right costal region. After checking for 10 breaths at rest, the subject was classified as upper costal breathing type if the superior thoracic expansion was predominant, as mixed breathing type when no clear predominance of superior thoracic expansion or abdominal expansion existed, and as costo-diaphragmatic breathing type if the abdominal expansion was predominant. Both examiners have been trained to diagnose breathing type in the Faculty of Medicine, University of Chile since 2004. In the case of no agreement, the subject was excluded. Regarding the classification of breathing type, the authors are aware that inductance plethysmography is a better objective method to measure changes in thoracic and abdominal movements, but the clinical classification was preferred due to their clinical expertise.

Electromyography

Bipolar surface electrodes (BioFLEX, BioResearch Associates, Inc., Brown Deer, WI, USA) were placed on the DIA, EIC, SCM and LAT muscles (Figure 1). Careful skin abrasion with alcohol was performed to decrease impedance. Electrodes were placed as follows [26,27]: on the DIA muscle, 1 cm below the xiphoid process; on the EIC muscle, between the 6th and 7th ribs on the imaginary vertical line that passes through the nipple; on the SCM muscle (middle portion), in the anterior border; and on the LAT muscle, in the projection of the 12th rib or lumbar vertebra L1, following the thoracolumbar fascia edge. The electrodes were located on the right side (except in the DIA muscle), because each subject was arbitrarily asked to lie on his left side. A large surface ground electrode (approximately 9 cm^2) was attached to the forehead. The electrode impedance between both electrodes was measured (Kaise Electric Works, LTD., Model SK-200, Japan); maximal acceptable impedance was 10 KΩ.

EMG activity was recorded using a 4-channel computerized instrument in which the signals were amplified (Model 7P5B preamplifier, Grass Instrument Co., Quincy, MA, USA) and filtered (10 Hz high pass and 2 kHz low pass), with a common mode rejection ratio higher than 100 dB. The output was filtered again (notch frequency of 50 Hz), full-wave rectified and then integrated (time constant of 0.1 s) and recorded online on a computer exclusively dedicated to the acquisition and processing of EMG signals. The EMG signal was acquired at a sample rate of 200 Hz (50 Hz each channel) with a 12 bits A/D converter (MAX191) connected to the computer through an RS-232 port. The system was calibrated before each recording. Each subject underwent three EMG recordings while lying in a kinesiological bed during maximal tooth clenching in the intercuspal position. EMG recordings

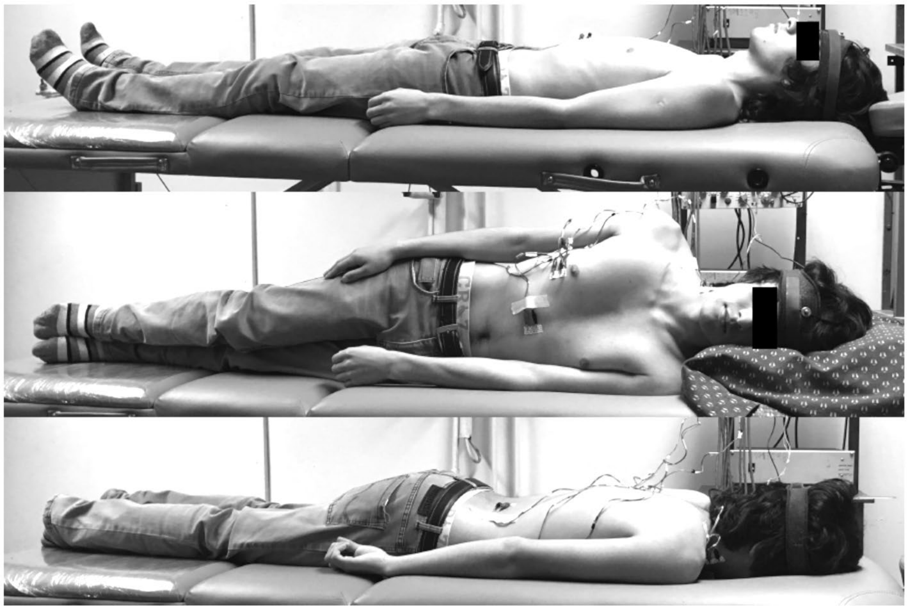

Figure 1. Participant at different decubitus positions studied: dorsal, left lateral, and ventral.

were performed in the following body decubitus positions (Figure 1) while the participants breathed normally, with their arms relaxed on the respective side of the body:

- *Dorsal decubitus*: the participant lay with the head supported on the kinesiological bed.
- *Left lateral decubitus*: head, neck and body horizontally aligned, checked by an external operator located approximately 3 m from the bed. The head and neck of each participant were supported by a Sleep Easy Pillow (Interwood Marketing Groups, Ontario, Canada).
- *Ventral decubitus*: the participant lay with his face resting on the contours of an oval space that allowed him to breathe naturally.

The decubitus position sequence of each participant was randomly assigned using a random function (Excel, Microsoft Corporation, USA). Recordings were performed in one single session.

The room light was turned off, and the subject kept his eyes closed during the EMG recordings. Before the EMG recording, an examiner explained the task to each participant so that he could perform correctly. The subject was asked to clench his teeth as hard as he could for ten seconds. This period was arbitrarily selected to ensure maximum and sustained muscle activity without producing pain and/or muscular fatigue. A 20 s resting period was allowed between each EMG recording. To obtain the average value of 10 s recording of each curve, measurements were obtained every 0.1 s using a computer program. The mean value of the three curves obtained for the task, for each body position and for each subject, was used.

The body mass index (BMI) was obtained for each subject, dividing the weight (kg) by the square of the height (m^2). Age, BMI, index waist (cm)/ height (cm) ratio were used to confirm the homogeneity of the three groups.

Statistical analysis

Regression analysis for repeated measures between EMG activity and each of the explanatory variables (age, BMI, index waist (cm)/ height (cm) ratio, breathing types, and decubitus positions), was performed for DIA, EIC, SCM, and LAT muscles in the mixed model with unstructured covariance matrix. A value of $p < 0.05$ was considered significant. The data were analyzed using STATA, Release 10.0 (SAS Institute, Inc., Cary, NC, USA).

Results

The explanatory variables age, BMI, and index waist (cm)/ height (cm) ratio showed no significant effect on EMG activity of DIA, EIC, SCM and LAT muscles, except BMI in the activity of SCM muscle (Tables 1–4, respectively).

EMG activity of DIA muscle was significantly higher in subjects with upper costal or mixed than in subjects with costo-diaphragmatic breathing type ($p = 0.006$; 0.021, respectively), whereas it was similar between subjects with upper costal or mixed breathing type (Table 1). EMG activity of EIC, SCM, and LAT muscles showed no significant difference among breathing types (Tables 2–4).

The comparison among the different decubitus positions showed that activity of DIA muscle was significantly higher in the dorsal and ventral decubitus than in the

Table 1. Comparison of diaphragm EMG activity during tooth clenching among breathing types adjusted for age, body mass index (BMI), waist/height ratio (WHR) and body positions (mixed model with unstructured covariance matrix).

EMG activity	Coef.	Std. Err.	z	$P>\|z\|$	[95% Conf. Interval]	
Age	−0.09	0.62	−0.15	0.881 NS	−1.31	1.12
BMI	0.20	0.73	0.27	0.789 NS	−1.24	1.63
WHR	−67.50	47.92	−1.41	0.159 NS	−161.43	26.42
Mixed breathing type	−0.66	3.78	−0.18	0.861 NS	−8.06	6.74
Costo-diaphragmatic breathing type	−8.89	3.23	−2.75	0.006 **	−15.22	−2.56
Left lateral decubitus	−4.06	0.74	−5.47	0.000 **	−5.52	−2.61
Ventral decubitus	−0.68	0.74	−0.91	0.361 NS	−2.13	0.78
Constant	71.89	14.52	4.95	0.000	43.42	1100.36

Breathing type reference: Upper costal.
Mixed breathing type vs. Costo-diaphragmatic breathing type: $p = 0.021$*
Body position reference: Dorsal decubitus.
Left lateral decubitus vs. Ventral decubitus: $p = 0.000$**.
*$p < 0.05$; **$p < 0.01$; NS = not significant.

Table 2. Comparison of external intercostal EMG activity during tooth clenching among breathing types adjusted for age, body mass index (BMI), waist/height ratio (WHR) and body positions (mixed model with unstructured covariance matrix).

EMG activity	Coef.	Std. Err.	z	$P>\|z\|$	[95% Conf. Interval]	
Age	−0.06	0.48	−0.13	0.896 NS	−0.99	0.87
BMI	0.27	0.56	0.48	0.634 NS	−0.83	1.37
WHR	−43.13	36.81	−1.17	0.241 NS	−115.27	29.01
Mixed breathing type	2.58	2.90	0.89	0.375 NS	−3.11	8.26
Costo-diaphragmatic breathing type	−2.36	2.48	−0.95	0.341 NS	−7.22	2.50
Left lateral decubitus	−4.08	0.61	−6.64	0.000 **	−5.28	−2.87
Ventral decubitus	−3.09	0.61	−5.03	0.000 **	−4.29	−1.88
Constant	39.40	11.16	3.53	0.000	17.54	61.27

Breathing type reference: Upper costal.
Mixed breathing type vs. Costo-diaphragmatic breathing type: $p = 0.071$ NS.
Body position reference: Dorsal decubitus.
Left lateral decubitus vs. Ventral decubitus: $p = 0.108$ NS.
**$p < 0.01$; NS = not significant.

left lateral decubitus position. EMG activity was similar between dorsal and ventral decubitus positions. Activity of EIC and LAT muscles was significantly higher in the dorsal than in the other decubitus positions. EMG activity was similar between left lateral and ventral decubitus positions. EMG activity of SCM muscle was similar among the different decubitus positions studied.

Discussion

The main finding of the present work was the higher EMG activity recorded in DIA muscle in subjects with upper costal or mixed breathing than in subjects with costo-diaphragmatic breathing type. This finding suggests a difference in the pulmonary ventilation, and therefore, a greater effort of DIA muscle during tooth clenching while the subjects breathe normally. A higher EMG activity means higher muscular effort based in the well-known linear relationship between the electrical activity and the force developed by a muscle, and therefore, the muscular work [15–17]. The higher EMG activity in healthy subjects with upper costal or mixed breathing during tooth clenching implies a higher use of their adaptive capability than in subjects with costo-diaphragmatic breathing. In a future study, it would be interesting to assess if higher DIA activity depending on the breathing type is also present in subjects with myogenous facial pain. Chen et al. [28] observed that the frequency of non-functional tooth contact was approximately four times higher in patients with myogenous facial pain than in healthy subjects. This result agrees with the finding that tooth contact even without high clenching forces may be associated with TMDs, since patients with temporomandibular dysfunction have 3.6 times more non-functional tooth contacts than healthy subjects [29]. Cioffi et al. [30] observed that individuals with masticatory muscle pain have an increased frequency of both high and low-intense daytime clenching episodes. This is relevant because DIA is a respiratory muscle that is primarily responsible for inspiration in normal individuals [10]; therefore, upon increased frequency of clenching episodes, the adaptive capability of subjects with upper costal or mixed breathing type could be more easily exceeded than subjects with costo-diaphragmatic breathing type.

EMG activity of EIC, SCM and LAT muscles did not differ significantly among healthy participants with

Table 3. Comparison of sternocleidomastoid EMG activity during tooth clenching among breathing types adjusted for age, body mass index (BMI), waist/height ratio (WHR) and body positions (mixed model with unstructured covariance matrix).

EMG activity	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Age	0.20	0.57	0.35	0.724 NS	−0.91	1.31
BMI	1.81	0.67	2.70	0.007 **	0.50	3.12
WHR	−65.47	43.93	−1.49	0.136 NS	−151.57	20.63
Mixed breathing type	−3.13	3.46	−0.90	0.366 NS	−9.92	3.65
Costo-diaphragmatic breathing type	−3.42	2.96	−1.15	0.248 NS	−9.21	2.38
Left lateral decubitus	−0.61	0.86	−0.72	0.474 NS	−2.29	1.07
Ventral decubitus	−1.17	0.86	−1.37	0.171 NS	−2.85	0.51
Constant	−1.40	13.32	−0.11	0.916	−27.50	224.70

Breathing type reference: Upper costal;.
Mixed breathing type vs. Costo-diaphragmatic breathing type: $p = 0.931$ NS
Body position reference: Dorsal decubitus
Left lateral decubitus vs. Ventral decubitus: $p = 0.515$ NS
$^{**}p < 0.01$; NS = not significant.

Table 4. Comparison of latissimus dorsi EMG activity during tooth clenching among breathing types adjusted for age, body mass index (BMI), waist/height ratio (WHR) and body positions (mixed model with unstructured covariance matrix).

EMG activity	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Age	0.26	0.53	0.49	0.623 NS	−0.77	1.29
BMI	−0.07	0.62	−0.11	0.912 NS	−1.29	1.15
WHR	−15.95	40.77	−0.39	0.696 NS	−95.86	663.96
Mixed breathing type	−3.28	3.21	−1.02	0.307 NS	−9.58	3.02
Costo-diaphragmatic breathing type	−4.39	2.75	−1.60	0.110 NS	−9.77	0.99
Left lateral decubitus	−2.63	0.57	−4.60	0.000 **	−3.75	−1.51
Ventral decubitus	−1.59	0.57	−2.78	0.005 **	−2.71	−0.47
Constant	32.23	12.36	2.61	0.009	8.01	556.45

Breathing type reference: Upper costal.
Mixed breathing type vs. Costo-diaphragmatic breathing type: $p = 0.714$ NS.
Body position reference: Dorsal decubitus.
Left lateral decubitus vs. Ventral decubitus: $p = 0.069$ NS.
$^{**}p < 0.01$; NS = not significant.

different breathing types in the decubitus positions studied, suggesting that the main mechanism of adaptation occurs in the diaphragm muscle. Therefore, it could be interesting to replicate this study in subjects presenting myogenous facial pain or respiratory distress with difficult breathing and reduced oxygen saturation.

EMG activity of DIA, EIC, and LAT muscles showed some significant differences among the decubitus positions. This may be due to a differential modulation of the motor neuron pools of respiratory muscles arising from different types of receptors, such as skin mechanoreceptors, leg muscular proprioceptors, knee articular proprioceptors, vestibular and visual receptors. It is reasonable to assume that afferences stemming from these receptors could differ upon change in the decubitus position [31,32].

This study has at least three limitations. First, the subjects examined were only male, which limits the ability to extrapolate these findings to the general population; second, surface electrodes on the chest could capture electrocardiogram (ECG) and/or pick up activity from neighboring muscles. The authors did not filter the ECG signal from the recordings, even though this activity is superimposed on EMG activity, since its influence should be similar in the three groups; and third, the authors did not check with regard to possible or probable bruxism of the participants [23]; but all participants were healthy, without orofacial pain or craniomandibular-cervical disorders.

Significance of the finding

Since it has been demonstrated that subjects with costo-diaphragmatic breathing present efficient ventilation, gas exchange, and oxygenation, and therefore, low work of breathing [11–13], the higher EMG activity observed in participants with upper costal or mixed breathing type suggests a greater effort of the diaphragm muscle during tooth clenching. It could be speculated that, as frequency of tooth clenching episodes increases, the adaptive capability could be more easily exceeded in subjects with upper costal or mixed breathing than in subjects with costo-diaphragmatic breathing. Thus, higher muscular effort in healthy subjects depending on their breathing type would be a predictor for exceeding the adaptive capability of respiratory muscles, leading in the long-term to an imbalance of the respiratory system homeostasis.

Conclusion

- EMG activity of DIA muscle during tooth clenching was significantly higher in healthy participants with upper costal or mixed breathing than in healthy participants with costo-diaphragmatic breathing in the decubitus positions studied.
- The higher activity of DIA muscle during tooth clenching could lead, in the long-term, to an imbalance of their respiratory system homeostasis. This new knowledge could be useful in the kinesiological evaluation of subjects in the context of a respiratory reeducation therapy.

Ethics approval

Protocols based on ethical principles that have their origin in the Declaration of Helsinki were used.

Contributors

R.M., N.A.G., H.S., S.V., contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; M.F.G., R.B., A.D.F., R.C., contributed to design and data interpretation, drafted and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

Disclosure statement

No potential conflict of interest was reported by the authors.

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