Function of Scalene Muscles Under Conditions of Quiet Breathing and Inspiratory Resistive Load

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Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 128, No. 12, pp. 623-626, December 1999
Original article submitted April 27, 1994

Low-threshold slow motor units in feline scalene muscle generated spontaneous discharges (6-8 imp/sec) during resting ventilation, which were independent of the respiration cycle. Under conditions of resistive load, activity of these motor units and its electromyographic pattern changed from tonic towards phasic type, synchronized with the inspiration phase. Removal of the load restored the initial pattern of activity. Clear dependency of activity transformations on respiratory load implies a functional modulation of respiratory neural drive to the scalene muscles and the role of these muscles in compensation of inspiratory load.

Key words: *scalene muscles*; *motor units*; *inspiratory resistive load*; *accessory respiratory muscles*

According to currently accepted functional classification [8], the scalene muscles (SM) belong to accessory inspiratory muscles and play a primary role in this group. However, the data on their contribution to inspiration is fragmentary [13] and controversial [2,8-11,14]. In this connection, it is important to study SM activity during quiet breathing and under conditions of inspiratory load.

MATERIALS AND METHODS

Experiments were performed at room temperature on 20 cats anesthetized with α-glucochloralose (50 mg/kg, intraperitoneally) and urethane (500 mg/kg). Bipolar wire electrodes were fixed to isolated SM and to the diaphragmatic crura for recording of integral electrical activity (IEA). Concentric needle electrodes (0.45 mm diameter) were used for recording discharges in single SM motor units (MU). Integral EMG of SM and the diaphragm, as well as activity of individual MU were recorded on a 4-channel Medicor electromyograph at 200 mm/sec paper rate. Changes in the firing rate, rhythmicity, and pattern of MU discharge at rest and parameters of MU recruited during loading were quantified. Total electrical activity was recorded with an MI-1 myointegrator, the initial level was taken as 100%. Inspiratory resistive load (75% of maximum static pressure during inspiration) was modeled as in the model of diaphragmatic fatigue [1,4]. EMG parameters were monitored at rest and under conditions of resistive load for 30 minutes until diaphragmatic fatigue with a 10-min interval [4]. EMG fragments containing 4-5 respiratory cycles were used for the analysis of MU activity. Respiratory cycles were determined by diaphragmatic EMG characterized by phasic activity during inspiration and silence during expiration. Interspike intervals (ISI) were measured with an accuracy of 5 msec. Dependency of MU activity on the respiration (Fig. 1) was evaluated by a method described earlier [3,5]. The following groups of MU were identified according to the pattern of activity and their relation to the inspiration phase (Fig. 2): late- and early-inspiratory MU, and inspiratory MU with increasing activation [6]. In the latter group, MU were active practically throughout the inspiration phase, and sometimes continued to fire at the beginning of expiration. Firing rates in these MU increased during the inspiration period, decreased by the end of this

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0007-4888/99/0012-1199$22.00

phase, and sometimes involved the early expiratory period. MU of the first group were characterized by a short burst discharge at the end of inspiration. Early-inspiratory MU were characterized by burst activity at the very beginning of inspiration or just before it. Mean ISI (X, msec), ISI standard deviation (σ, msec), coefficient of variation (CV), and mean rate (f, imp/sec) were calculated to characterize MU activity. Student's *t* test was used for comparison of ISI means. Rhythmicity of MU discharge was evaluated by CV. CV>20% indicated arrhythmic discharge due to high variability of ISI [15].

RESULTS

Analysis of EMGs of 34 MU during quiet breathing revealed a slight background activity without respiratory oscillations. This activity lasted throughout the entire respiratory cycle and was generated exclusively by spontaneously active MU, 94% of which fired independently of breathing (Fig 1, *b*). Mean discharge rate varied from 4 to 9 imp/sec, predominantly 6-8 imp/sec (71%), which corresponded to the duration of ISI 130-185 msec. Discharges with rates 4.0-6.5 imp/sec were mainly produced by arrhythmic units with high ISI variability (36-54 msec), while those with rates 6.5-9.0 imp/sec were generated by rhythmic MU with lower ISI variability (27 msec). Rhythmic MU constituted 70% of total MU population (Table 1). Activity in these MU lasted for 10-20 min during quiet breathing and in most cases throughout the entire period of resistive loading. Therefore these units were classified as fatigue-resistant low-threshold slow MU. In contrast to diaphragmatic EMG, inspiration and expiration phases on integral EMG of SM could not be distinguished, indicating that SM is not involved in quiet breathing.

These findings are consistent with the idea that SM does not participate in resting ventilation and are recruited only during forced ventilation [12]. However, study with needle electrodes demonstrated persistent activity of SM during quiet breathing, and, hence, these muscles can be assigned to primary respiratory muscles together with the diaphragm and intercostal muscles in humans [8].

Some authors emphasize the important role of SM muscles under conditions of resistive load [10,11,14]. Hypertrophy of SM under conditions of chronic airway resistive load confirms this speculation [14]. By contrast, other authors point out low functional capacity of SM, because SM α-motorneurons are characterized by very low central respiratory drive potentials comparing to their firing threshold [9].

We found that after the onset of resistive loading, the integral activity of the SM increased by 53% and after 10 and 20 minutes by 66% and 40%, respectively. Inspiratory and expiratory phases could be distinguished on EMG, but, in contrast to diaphragmatic activity, tonic activity persisted also during expiration. Analysis of activity of 74 MU revealed such mechanisms of enhancement of muscle contraction as the increase in the number of active units (recruitment) and firing rate [7], and synchronization with the phase of inspiration. Predominant recruitment of phasic units with burst discharges synchronized with inspiration (90%) during respiratory loading alters the pattern of MU activity in SM, which becomes a superposition of bursting and tonic discharges in a proportion of 2:1. The most part (85%) of phasic MU were fatigue-resistant units with the mean firing rate of 13.51 imp/

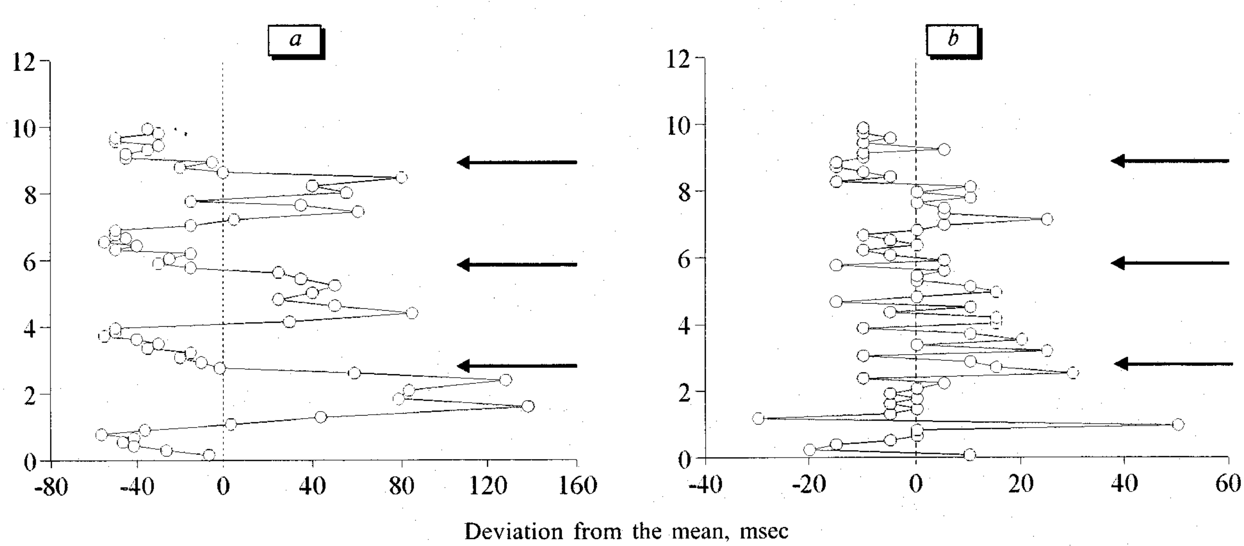

Fig. 1. Interspike interval deviations from the mean in spontaneously active respiratory-dependent (*a*) and independent (*b*) motor units of scalene muscles. Arrows show the onset of inspiration. Ordinate: time in sec.

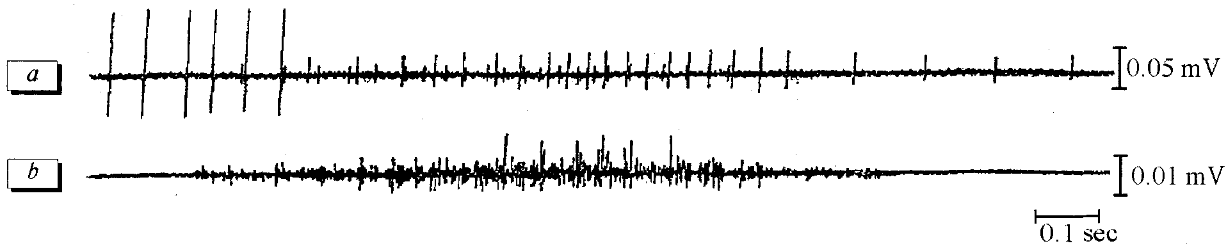

Fig. 2. Electromyogram of phasic inspiratory motor units in scalene muscle (*a*) and interference EMG in the diaphragm (*b*). Three types of inspiratory motor units activity can be distinguished.

TABLE 1. Changes in Electromyographic Pattern of Motor Units (MU) in Scalene Muscle

Type of MU	Parameters	Ventilation at rest	Inspiratory load
Tonic	$X \pm m$, msec	156.95±9.61	141.85±6.94
	f, imp/sec	6-7	7-8
	Rhythmicity (CV<20%)	70% MU (*n*=34, 100%)	53% MU (*n*=45, 100%)
	Dependence on inspiration	6% MU	30% MU
Phasic	$X \pm m$, мс	—	93.34±8.89
	f, imp/sec	—	10-13

sec (from 10 to 16 imp/sec, which corresponds to ISI within 70-100 msec), while 10% MU were high-amplitude fast-fatiguable (fatigue latency 10 min or less) with discharge rate of 22-25 imp/sec. Firing rates and the number of spikes in a burst in these MU decreased before inactivation. In some experiments, low-frequency (6-8 imp/sec) phasic fatigue-resistant MU were recruited into inspiration: their firing rate gradually increased by the 20th-30th minute, when activity of high amplitude fast-fatigue MU decreased. The observed mechanism probably reflects the functional "choice" between the motorneurons to be activated depending on the respiratory load [7]. By the pattern of respiratory activity, most of MU could be assigned to inspiratory type with increasing activity (81%), while early- and late-inspiratory MU contributed 5 and 14%, respectively (Fig. 2). This implies that respiratory motorneuronal pool actually includes different functional groups of respiratory neurons innervating SM.

In the whole population of tonic MU, changes in the mean firing rate associated with increased ISI variability under conditions of respiratory load were insignificant (Table 1). However, in some units the firing rate increased significantly (by 25-45%, $p<0.05$). Facilitation of MU activity during inspiration was more evident (number of respiratory-dependent units increased by 30%). Shortening of ISI (150-90 msec) in combination with increased σ values (>40 msec) observed after application of inspiratory load indicates that tonic MU with arrhythmic inspiratory-related discharges play the most important role in this group (Fig. 1, *a*). By minute 20, the pattern of activity in some respiratory-related fatigue-resistant MU monitored throughout the 30-min experiment changed from initially uniform to inspiration-related burst-like discharge. After cessation of the load, MU discharges lost their phase dependency and the uniform pattern restored.

Thus, our findings contribute to the idea that SM are accessory inspiratory muscles which have no respiratory-related activity at rest but become active under conditions of inspiratory load. Thus, SM motorneurons receive input signals providing their tonic activity, while phasic inspiratory activity is superimposed over this tonic discharge during loading. Though enhanced EMG activity during resistive load results from recruitment of both respiratory and late-inspiratory tonic MU, inspiratory MU play the crucial role. Respiratory and non-respiratory functions of SM remain to be clarified. It can be hypothesized that in patients with chronic respiratory disorders, MU activities in the SM during repeated respiratory load are rearranged depending on the «tonic» or «phasic» type of motorneurons, which can be used as the marker of respiratory insufficiency.

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