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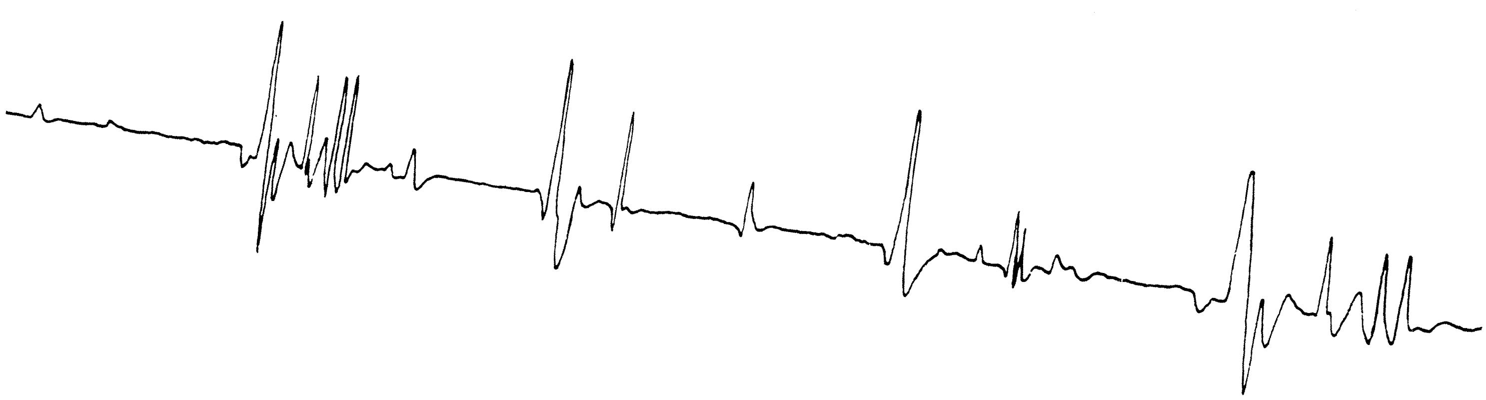

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Combined ultrasonographic and neurographic examination: a new technique to evaluate phrenic nerve function

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Abstract

In this report a new technique for simultaneous assessment of the electrical and mechanical properties of the diaphragm is presented. The phrenic nerve of 9 healthy persons was stimulated at the neck using magnetic stimulation. Electrical activity was recorded using chest surface electrodes. The mechanical function of the diaphragm was evaluated by performing combined B- and M-mode ultrasonographic examination. The data show that this method helps to distinguish the diaphragm muscle compound action potential from electrical activity derived from neighboring muscles activated by the brachial plexus. Furthermore, it provides a non-invasive tool which can easily be used in clinical practice to study the mechanical properties of the diaphragm.

Introduction

Attaining reliable data about the function of the phrenic nerve and the diaphragm is necessary for an increasing number of patients with restrictive respiratory dysfunction. In patients with neuromuscular diseases (15, 19), primary pulmonary disorders (5) and following thoracotomy (9) neurophysiological examination of the phrenic nerve can provide important diagnostic and prognostic information. Phrenic nerve conduction tests are used for monitoring patients before and after the implantation of a phrenic pacemaker (14).

Phrenic nerve conduction studies were described quite a long time ago (4) and in spite of their usefulness this test is only seldom used in clinical practice. The main reason behind this fact is that percutaneous nerve stimulation requires electrical shocks of high intensity, which are not tolerated well by patients. Exact localization of the nerve can take up to 30 minutes (12) and sometimes exact localization of the nerve is not possible (13). Stimulation using needle electrodes, as suggested by other authors, may be harmful and is quite uncomfortable.

The new technique of magnetic stimulation of peripheral nerves, which is less painful, facilitates a less invasive examination of the phrenic nerve (16). The two main problems with using magnetic stimulation are the submaximal stimulation (3) and the difficulty in focusing the magnetic impulse field on a single nerve (7).

The purpose of this study was to find a simple and non-invasive technique of gathering information about the electrical properties of the phrenic nerve and about the mechanical function of the diaphragm.

Subjects and methods

The data are based on examinations of 9 healthy informed volunteers aged between 26 and 37 (median 31 years). All subjects were male members of the staff of the University of Munich.

Compound muscle action potentials (CMAP) of the diaphragm were registered

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using silver chloride electrodes with a diameter of 5 mm. The active electrodes were placed in the sixth and seventh intercostal space at the midclavicular line, the reference electrode was located at the xyphoid processus (4, 17), the ground electrode was attached to the right arm.

Registration of the electrical signal was performed employing a Counterpoint System (Dantec electronics, Danmark), which was externally triggered by the magnetic stimulator. The time base was 3 msec/div, the amplitude gain was 50 Microvolt/div. The filters were set at 0.8 Hertz to 16 kHertz.

The magnetic stimulation was performed using a Novametrix Magstim 200 stimulator (Magstim Comp. Ltd., UK). The coil had an outer diameter of 62 millimeters.

The peak magnetic field at the center of the coil was 4.0 Tesla, the rise time of the stimulus 0.1 msec, the duration 1 msec. Stimulation was performed with the A-side of the coil up (clockwise direction). Stimulation began at 10 % of maximal magnetic output, if no contraction of the diaphragm occurred intensity was increased in steps of 5 % to a maximum of 100 %. If no stimulation occured the stimulus position was changed.

The subjects were examined in a supine position. In order to define the best point for stimulation they were first examined with their head in the midline position and then with their head turned contralateral to the site of the stimulation. The center of the coil was placed about 3 centimeters behind the sternocleidomastoid muscle at the level of C4 (Fig. 1). If no contraction of the diaphragm could be seen in the B-mode ultrasonogram inspite of increases of stimulus intensity, the coil was moved at steps of 0.5 cm medially until a diaphragmatic contraction was seen.

If activation of the phrenic nerve was not successful, this procedure was repeated after having moved the coil 0.5 cm up or down.

After reaching a stable position, at which a constant movement of the diaphragm was seen, the minimum magnetic output necessary to elicit maximal contraction of the muscle and a stable CMAP was measured.

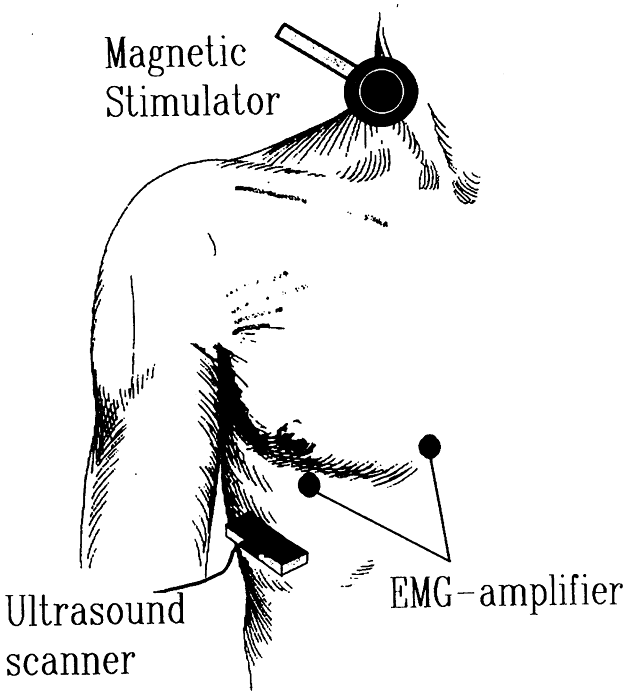


Fig. 1. — Setup for simultaneous ultrasonographic and electroneurographic examination.

For ultrasonographic examination an electronic real time sector scanner with a 3.75 MHz transducer that allows for the simultaneous registration of B- and M-mode (Toshiba Tosbie SSA-240 A, Japan) was employed. The signal of the M-mode analysis was triggered by the magnetic stimulator. Examination of the diaphragm was performed using a standardized

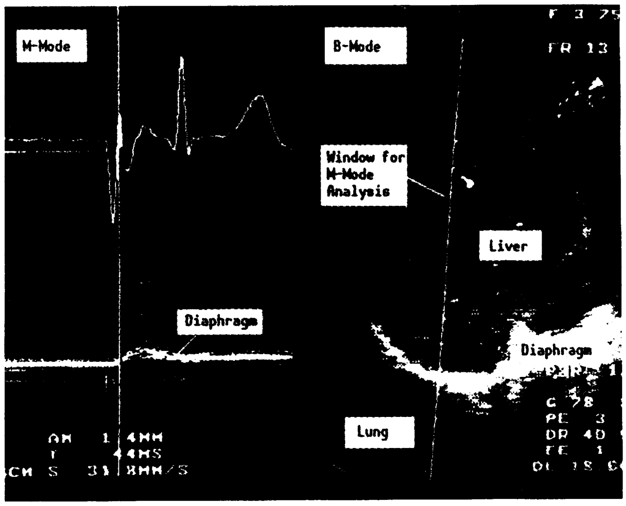


Fig. 2. — Simultaneous B- and M-mode ultrasound examination. (The line indicates the section at which M-mode analysis is performed).

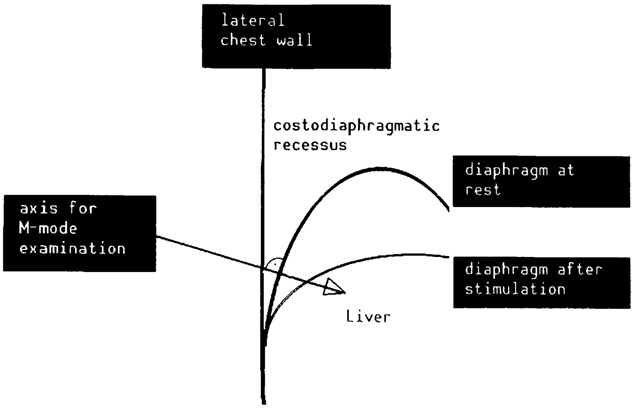


Fig. 3. — Axis for M-mode ultrasonographic examination.

intercostal approach in the midaxillary line (Fig. 1). The liver and the spleen were used as acoustic windows on the right and left sides, respectively. After having focused the diaphragm in the B-mode, M-mode examination was performed (Fig. 2). The movement of the diaphragm was measured using M-mode analysis in an axis as perpendicular as possible to the lateral part of the diaphragm in the costophrenic recessus (Fig. 3).

The amplitude and the duration of the diaphragmatic movement were measured.

Results

With the head in a midline position it was not always possible to sufficiently stimulate the phrenic nerve. In this position increase of stimulus intensity up to 100 % of maximal stimulus output in 3 subjects resulted in painful activation of the brachial plexus without movement of the diaphragm. The best position to examine the phrenic nerve was with the head turned to the contralateral side. In this position, stimulation of the phrenic nerve was possible in all subjects.

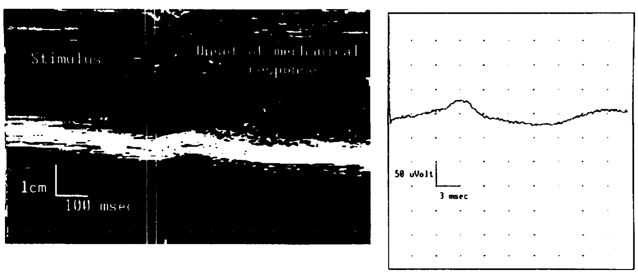
The nerve could be best stimulated, when the center of the coil was localized over the sternocleidomastoid muscle between the middle and cranial third of the muscle. In this position slight changes of the angle, at which the coil was placed on the skin, sufficed to elicit stimulation of the phrenic nerve.

The time to find the optimal position varied from 30 seconds to 10 minutes. Maximum contraction of the diaphragm was observed between 17 and 26 % of maximal magnetic output. Using this stimulus intensity, coactivation of the brachial plexus could be avoided in only 2 of 9 subjects. As is shown in figure 4a/b ultrasonographic examination helped to define the adequate stimulus intensity.

Further increase of magnetic energy did not increase the movement of the diaphragm or its duration. The shape, amplitude, duration and latency of the compound muscle action potential did not change after a stable amplitude of the contraction was reached.

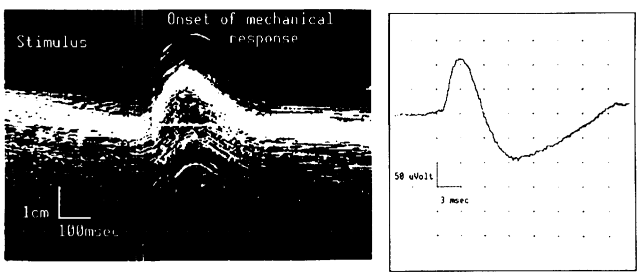
An increase of stimulus intensity beyond 40 % of maximal magnetic output lead to painful sensations in all subjects. As a general rule, when stimulation was not possible, the localization of the stimulus was changed as opposed to increasing stimulus intensity.

When the intensity of the magnetic field was increased, muscle action potentials could be



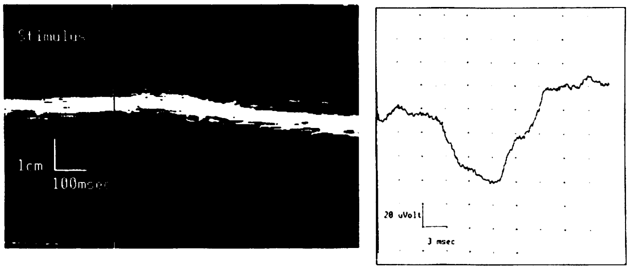
M-mode EMG

Fig. 4a. — Submaximal contraction of the diaphragm using a stimulus intensity of 14 % of maximal stimulus output.



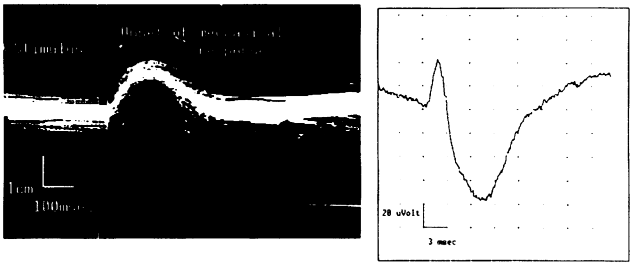
M-mode EMG

Fig. 4b. — Same volunteer. Maximal mechanical and electrical response using 24 % of maximal stimulus output.



M-mode **EMG**

Fig. 5a. — Electrical activity despite absence of mechanical response (Stimulus intensity 21 % of maximal output).



M-mode **EMG**

Fig. 5b. — Same patient as in figure 2a. After change of stimulus position appearance of motor response. Change of configuration and amplitude of the CAMP.

registered without any measurable movement of the diaphragm (Fig. 5a).

Individual CMAPs without activation of the diaphragm differ intraindividually from those evoked by the diaphragm with regards to the shape and latency. There was no consistent difference of polarity between these CMAPs (Fig. 5b). Nevertheless, due to a marked interindividual variation the origin of CMAPs could not be defined by shape, duration or amplitude.

The mean latency of the diaphragmatic CMAP was 8 msec, the duration 5.9 msec and the amplitude 0.2 millivolt (Table 1).

The mean movement evoked by a single magnetic impulse of the diaphragm was 11 millimeters. The mean duration of the mechanical response to the stimulus was 320 msec, the rise time from offset of the mechanical response from the baseline to the maximum was 90 msec. A summary of this data is presented in table 1.

Table 1. — *Parameters in response to magnetic stimulation of the phrenic nerve*

	Median	Range
Electrical response (CMAP)		
Latency	8.2 msec	6.5-9.8
Duration	6.9 msec	5.4-8.9
Amplitude	150 µVolt	100-240
Mechanical response		
Latency	40 msec	36-48
Duration	290 msec	260-350
Rise-time	90 msec	80-110
Amplitude	11 mm	8-14

Discussion

This study shows in accordance with Similowski (16) that magnetic stimulation is a simple and painless procedure for the functional assessment of the phrenic nerve. The latency of the CMAPs is similar to the values obtained by other authors (10, 11, 17) with electrical stimulation.

As it could be suspected from the anatomical localization of the phrenic nerve electrical potentials can be registered by surface electrodes without stimulation of the phrenic nerve. This makes control of the mechanical effect of diaphragmatic activation mandatory, especially when using a magnetic stimulator.

Different procedures have been proposed to overcome the problem of coactivation and registration of surrounding muscles. The simplest, but not necessarily the most reliable method is to observe an audible "hiccup" (17). Particularly in patients with neuromuscular diseases, excursion of the diaphragm may not suffice to produce an audible effect.

Averaging techniques can only eliminate chest wall EMG during respiration, but not signals from the mm. pectoralis, serratus anterior or latissimus dorsi. Mapping of CMAPs (17) helps to differentiate phrenic nerve action potential from those registered from neighboring muscles. Unfortunately this procedure takes a lot of time. At the anterior axillary line, CMAPs of the serratus anterior muscle cannot always be distinguished from diaphragmatic CMAPs.

Using needle electrodes inserted through the chest wall (18) or oesophageal electrodes (6, 11) is a cumbersome procedure. Controling phrenic nerve stimulation using ultrasound monitoring is the most comfortable for the patient.

Another application for this method is the study of mechanical properties of the diaphragm. The registration of the electrical potential is of limited use in quite a number of clinical situations for a variety of reasons. First, there is a marked variability of the CMAP due to subcutaneous fat tissue, localization of the diaphragm, impedance of the skin etcetera (17). Mier was not able to elicit action potentials in 2 of 110 subjects with severe weakness of the diaphragm (12). Though we did not observe this in our small series of healthy persons this may be true in obese patients with malfunction of the phrenic nerve.

The second reason is that CMAP does not provide information about the mechanical function of the diaphragm. Though there is a clear intraindividual correlation between twitch tension of the diaphragm and amplitude of the CMAP (2), both parameters are not correlated interindividually. By use of a motion transducer (10) only indirect information about the diaphragm by way of registration of chest wall movement can be attained. This has not been used clinically. Another method of measuring mechanical function of the diaphragm is to register the transdiaphragmatic pressure. This has been used to assess diaphragmatic fatigue (1) and twitch characteristics of the diaphragm (11). The main problem with this method is that registration of transdiaphragmatic pressure requires the use of an esophageal balloon catheter system. In most studies the examination was done in a seated position, which is not always possible in clinical circumstances.

In order to attain reliable data using M-mode examination a combination of B-mode and M-mode is necessary for the exact positioning of the axis for analysis. The data of this study show that there is only a small interindividual variability of the mechanical response in healthy subjects using a standardized position of the ultrasound scanner.

The values for mechanical twitch time recorded using combined electroneurographic and ultrasonographic method are similar to those obtained by measurement of transdiaphragmatic pressure. The mean rise time of the observed mechanical contraction in our study was 90 msec. This value is similar to the mean contraction times of 90 msec (8) for maximal twitches reported in other studies. Thus we believe that the non-invasive method of stimulated M-mode-examination may give satisfactory information about diaphragmatic function.

In conclusion simultaneous ultrasound examination of the diaphragm and phrenic nerve conduction study is likely to be a valuable tool in patients with restrictive ventilatory disease. It is a non-invasive method with minimal discomfort for the patient. It may be useful in the study of diaphragmatic fatigue during withdrawal from ventilatory support. The combined method improves the reliability of phrenic nerve conduction studies in the follow-up of patients with phrenic pacemakers.

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