Anterior magnetic phrenic nerve stimulation: laboratory and clinical evaluation

Abstract  Objective: Anterior magnetic stimulation (aMS) of the phrenic nerves is a new method for the assessment of diaphragm contractility that might have particular applications for the clinical assessment of critically ill patients who are commonly supine.

Design: We compared aMS with existing techniques for measurement of diaphragm weakness and fatigue in 10 normal subjects, 27 ambulant patients with suspected diaphragm weakness and 10 critically ill patients.

Setting: Laboratory and intensive care unit of two university hospitals.

Results: Although aMS was not demonstrably supramaximal in normal subjects, the mean value of twitch transdiaphragmatic pressure (Tw Pdi) obtained at 100% of stimulator output, 23.7 cmH₂O, did not differ significantly from that obtained with bilateral supramaximal electrical stimulation (ES), 24.9 cmH₂O, or bilateral anterior magnetic phrenic nerve stimulation (BAMPS), 27.3 cmH₂O. A fatiguing protocol produced a 20% fall in aMS-Tw Pdi and a 19% fall in BAMPS-Tw Pdi; the fall in aMS-Tw Pdi correlated with the fall in BAMPS-Tw Pdi ($r^2 = 0.84, p = 0.03$) indicating that aMS can detect diaphragm fatigue. In ambulant patients aMS agreed closely with existing measures of diaphragm strength. The maximal sniff Pdi correlated with both the aMS-Tw Pdi ($r^2 = 0.60, p < 0.0001$) and the BAMPS-Tw Pdi ($r^2 = 0.65, p < 0.0001$) and the aMS-Tw Pdi was a mean (SD) 2.2 (4.3) cmH₂O less than BAMPS-Tw Pdi. In addition, aMS correctly identified diaphragm dysfunction in patients studied on the ICU.

Conclusions: We conclude that aMS is of clinical value for the investigation of suspected diaphragm weakness.

Key words  Magnetic stimulation · Phrenic nerves · Diaphragm · Fatigue

Introduction

The diaphragm is normally the most important inspiratory muscle in man [1]. Diaphragm dysfunction, in the form of weakness [2] or fatigue [3, 4], may lead to ventilator dependence. Indeed in patients whose cardiac and respiratory problems have resolved, acquired abnormalities of neuromuscular function contribute to weaning difficulties in a majority of patients [5]. Critically ill patients are unable to make a maximal voluntary effort and therefore traditional measures of respiratory muscle function, for example the upper airway pressure during a maximal voluntary effort, are not valid measures of respiratory muscle strength in the intensive care unit (ICU) [6].

Techniques to assess diaphragm function in ventilator-dependent patients, who are generally supine, are therefore of clinical interest to physicians caring for the critically ill. Measurement of transdiaphragmatic [7, 8]
or mouth pressure [9, 10] following cervical magnetic stimulation (CMS) of the phrenic nerves is an established technique for the assessment of diaphragm function in ambulant patients. Unfortunately this technique is impractical in the supine patient since it requires the coil to be positioned behind the cervical spines. An alternative approach, bilateral anterior magnetic phrenic nerve stimulation (BAMPS), requires the positioning of two coils (each driven by their own magnet) anteriorly over each phrenic nerve [11]. Although this technique is attractive in many respects, a limitation is the financial disadvantage associated with the need for two magnets (US$12,900 in 1998) as well as the practical difficulties if the technique is attempted by a single operator. Magnetic stimulators are increasingly used both in respiratory medicine and also in neurophysiology. Consequently, while many centres might have access to a single stimulator, few currently have the two stimulators and 2.45 mm coils required for BAMPS. As with ambulant patients, the clinician may measure transdiaphragmatic pressure or endotracheal or tracheostomy tube pressure. A brief airway occlusion is required for all twitch measurements and we have recently described a rapidly responsive valve suitable for use in the ICU [12].

Recently Similowski et al. noted that an action potential could be recorded from electrodes placed over the surface markings of the diaphragm if a single circular coil was discharged over the anterior chest wall [13]. This observation was of potential practical importance, for if a supramaximal stimulation of the diaphragm could be obtained in this manner then diaphragm contractility could be assessed in the supine subject with a single stimulator. Moreover, even if a near-maximal response could be obtained, the technique could be clinically useful for the confirmation (or refutation) of the possibility of diaphragm weakness. The aim of the present study, therefore, was an electrophysiological, mechanical and clinical evaluation of the technique of anterior magnetic stimulation (aMS).

Methods

The protocols were approved by our ethics committee and all subjects gave informed consent to participate. The subjects for Study 1 were normal healthy volunteers (eight men and two women) who were free of neurological and respiratory disease. These subjects had a mean age of 35 years, mean height 1.79 m and mean weight 80 kg. In Study 2 we studied 27 patients referred to our laboratories for assessment of diaphragm function and 10 patients in ICU with suspected diaphragm dysfunction.

Measurements

Gastric, oesophageal and transdiaphragmatic pressures

Gastric, oesophageal and transdiaphragmatic pressures (Pga, Poes, Pdi) were obtained using a pair of commercially available latex balloon catheters (PK Morgan, Rainham, Kent, UK) 110 cm in length placed in the stomach and oesophagus in the conventional manner. The catheters were connected to differential pressure transducers (Validyne MP45–1, Validyne, Northridge, Calif., USA), carrier amplifiers (PK Morgan, Rainham, Kent, UK), a 12-bit NB-MIO-16 analogue–digital board (National Instruments, Austin, Tex., USA) and a Macintosh Quadra Centris 650 personal computer (Apple Computer, Cupertino, Calif., USA) running LabView software (National Instruments, Austin, Tex., USA). Transdiaphragmatic pressure (Pdi) was obtained on-line, by subtraction of Poes from Pga. A minimum sampling frequency of 100 Hz was used.

Compound diaphragm action potential

The compound diaphragm action potential was obtained via a custom-built oesophageal electrode [14]. This electrode was passed peranally and swallowed until the centre was positioned at the electrically active centre of the diaphragm (EARDi) as judged by reversal of the polarity of the signal elicited by bilateral electrical phrenic nerve stimulation. These signals were passed via short leads to a Neurosign 100 amplifier (Magstim, Whitland, Dyfed, Wales) and displayed using LabView software with a recording frequency of 2 kHz or greater. The signals underwent bandpass filtering in the amplifier to exclude signals outside the range 10 Hz and 10 kHz, but were not subsequently altered.

Stimulation techniques

All stimuli were performed with the subject seated at relaxed end-expiration (usually judged by on-line display of Poes) wearing a noseclip. In order to minimise twitch potentiation [15] a 20-min rest period preceded all experimental sessions. Where appropriate, an independent measure of diaphragm strength was obtained by measuring the Pdi during a maximal voluntary sniff [16]. Sniffs were performed from FRC in the seated position; the subjects were helped to maximise their effort by being able to view their effort in real time [17].

Electrical stimulation (ES)

Bilateral and unilateral supramaximal ES of the phrenic nerves was performed using hand-held felt-tipped bipolar electrodes (Medelec, Old Woking, UK) powered by a constant voltage stimulator (Digitimer 3072, Digitimer, Welwyn Garden City, UK) producing square waves 100 μs in duration. The electrodes were sited at the posterior border of sternomastoid at the level of the cricoid cartilage. In the present study a supramaximal stimulation intensity is defined as one 30% or 50% greater than that which produces no further increase in twitch Pdi (Tw Pdi) or action potential (CMAP).

Anterior magnetic stimulation (aMS)

Anterior magnetic stimulation was performed using a 90 mm circular coil (P/N 8443), powered by a Magstim DEM stimulator [18] (Magstim, Whitland, Dyfed, UK), firmly placed centrally over the upper sternum such that the upper border of the coil touched the cricoid cartilage, with the handle vertically downwards. Great care was taken to angle the coil in a way to obtain maximal apposition to the portion of the sternum cranial to the angle of Louis