The phrenic nerve may be impaired during thoracic surgery such as lung transplantation, and the diagnosis of a phrenic nerve injury may then be necessary. Phrenic nerve conduction studies can be invaluable in establishing the diagnosis of a phrenic nerve injury, determining its severity, and following the disease progression. However, phrenic nerve conduction studies are still not widely used, as they are often perceived as technically difficult, inaccurate, time-consuming, and uncomfortable for the patient [1,2]. We conducted the present study to (1) determine the normal data of the phrenic nerve diaphragmatic compound muscle action potential (CMAP), and (2) investigate the difference between the right and left phrenic nerve CMAPs in healthy adult males.

Subjects and Methods

Subjects. We studied 45 healthy male volunteers aged 20–40 (mean 25.0) years. None of the subjects had neurological or respiratory dysfunction. Their mean (± standard deviation) height was 170.8 ± 4.8 cm, and they weighed 62.6 ± 6.2 kg. The subjects were recruited mainly from hospital personnel. Informed consent was obtained from each subject after they received a thorough explanation of the purpose and procedure of the study. The protocol was approved by the Okayama University Ethics Committee (no. 1702-028).

Phrenic nerve conduction studies. The phrenic
nerve conduction studies were performed on Keypoint®
EMG equipment (Medtronic Dantec, Copenhagen,
Denmark). For the examination, the subject was in the
supine position in a warm room. The phrenic nerve was
stimulated using bipolar surface electrodes placed at the
posterior border of the sternomastoid muscle in the
supraclavicular fossa immediately above the clavicle.
For recording purposes, positive and negative elec-
trodes were placed on the xiphoid process and at the
eighth intercostal bone cartilage transition, respectively
(Fig. 1).

A constant current stimulator delivered square-wave pulses of 0.1-msec duration. Filters were set at 5 Hz to
5 kHz (−3dB down). Three measurements of the dia-
aphragmatic CMAP were made: (1) the onset latency (msec) was determined from the onset of the negative peak; (2) the peak latency (msec) was determined from the negative peak; and (3) the amplitude from the baseline to the negative peak. Both the right and left sides were studied for the identification of any differences between the 2 sides.

Data analysis. The paired t-test was used to detect right-left differences. Differences were considered sig-
nificant when \( p < 0.05 \).

Results

Both phrenic nerves could be stimulated easily and
without intolerable discomfort in all 45 subjects. The
intensity required for supramaximal stimulation was always <50 mA with rectangular pulses of 0.2 msec. As shown in Table 1, the mean onset latency (±SD) of the right CMAPs (5.99 ± 0.39 msec) was significantly shorter than that of the left CMAPs (6.45 ± 0.50 msec) \( p < 0.01 \). The mean peak latency was significantly shorter in the right CMAPs (10.22 ± 1.33 msec) than the left CMAPs (12.48 ± 2.02 msec) \( p < 0.01 \) (Fig. 2). The mean (±SD) amplitude was significantly lower in the left CMAPs (0.42 ± 0.11 mV) than the right CMAPs (0.49 ± 0.10 mV; \( p < 0.01 \)) (Fig. 3).

The distance between the cathode and the anode of the recording electrodes was 13.11 ± 1.42 cm. The distance between the recording electrode and the stimulation electrode was 23.78 ± 2.01 cm.

Discussion

The diaphragm plays an important role in sustaining
the body’s breathing, and it is thus very important to
understand and carry out techniques for testing the dia-
aphragm. The diaphragm is responsible for > 70% of the
body’s respiratory muscle function, and the phrenic
nerve controls the diaphragm. The CMAP onset latency has a well-established role in studies of phrenic nerve conduction, and it is very useful for the detection of demyelination of the phrenic nerve [3]. Phrenic nerve

![Fig. 1 Method of phrenic nerve conduction studies. A, Positions of the stimulation and recording electrodes for phrenic nerve conduction studies; B, Conduction in the phrenic nerve showing the uniform shape and amplitudes of the compound muscle action potential (CMAP) for stimulation at the posterior border of the sternomastoid muscle.](image)

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Conduction studies have been applied to amyotrophic lateral sclerosis (ALS) and Guillain-Barre syndrome, both of which are life-threatening due to respiratory muscle dysfunction; the results indicated a decrease in the amplitude and distal latency prolongation of the CMAP [4, 5].

Komori reported that, as ALS progresses, one indication that respiratory support (such as noninvasive positive pressure respiratory support) for a patient should be started is when M waves become polymorphic or both the right and left phrenic nerve amplitudes become ≤0.2 mV [6]. In the present study, the right-to-left differences in onset and peak latencies were significant. However, previous studies reported different results. Imai et al. stated that the mean latency was almost the same for the left and right diaphragmatic action potentials in 132 nerves of all subjects, and he noted that a left-right difference may be useful in diagnosing a unilateral phrenic lesion [7]. Swenson et al. studied 20 normal subjects and reported the ease of application and good side-to-side agreement for distal compound motor action potential (DCMAP) latencies [8] (Table 1).

In a phrenic nerve conduction study, Komori set the onset latency and amplitude of phrenic nerve as measurement parameters [6]. In healthy individuals, differences in amplitude between the left and right phrenic nerve action potentials are usually not significant, and both sides of the diaphragm function together as the

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Table 1: Latency and amplitude differences between the right and left phrenic nerves

<table>
<thead>
<tr>
<th></th>
<th>Right</th>
<th>Left</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>Onset latency, msec</td>
<td>5.99 ± 0.39</td>
<td>6.45 ± 0.50</td>
</tr>
<tr>
<td></td>
<td>Peak latency, msec</td>
<td>10.22 ± 1.33</td>
<td>12.48 ± 2.02</td>
</tr>
<tr>
<td></td>
<td>Amplitude, mV</td>
<td>0.49 ± 0.10</td>
<td>0.42 ± 0.11</td>
</tr>
<tr>
<td>Imai et al. [7]</td>
<td>Latency, msec</td>
<td>6.80 ± 0.72</td>
<td>6.82 ± 0.80</td>
</tr>
<tr>
<td></td>
<td>Amplitude, mV</td>
<td>0.44 ± 0.18</td>
<td>0.37 ± 0.17</td>
</tr>
<tr>
<td>Swenson et al. [8]</td>
<td>Latency, msec</td>
<td>6.28 ± 0.55</td>
<td>6.30 ± 0.48</td>
</tr>
<tr>
<td></td>
<td>Amplitude, mV</td>
<td>0.35 ± 0.12</td>
<td>0.35 ± 0.19</td>
</tr>
</tbody>
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Fig. 2: The differences in latency between the right and left phrenic nerves.

Fig. 3: The differences in amplitude between the right and left phrenic nerves.
nerves might have affected the difference between the 

The difference between the lengths of the right and left 

phrenic nerve is longer than the right phrenic nerve. 

phragm on the outside of the vena cava hole. The left 

explained by the two-intercostal-space elevation of the 

lengths of the phrenic nerve on the right side could be 

respectively [10]. In both cases mentioned above, the 

observed that the full length of the phrenic nerve was 

24.6 ± 1.7 and 30.6 ± 1.8 cm on the right and left sides, 

Jiang et al. dissected ten fresh adult cadavers and 

observed that the full length of the phrenic nerve was 

24.6 ± 1.7 and 30.6 ± 1.8 cm on the right and left sides, 

respectively [10]. In both cases mentioned above, the 

lengths of the phrenic nerve on the right side could be 

explained by the two-intercostal-space elevation of the 

diaphragm due to the liver on the right side of the body 

[10, 11]. 

The best approach will vary among subject populations 

and may vary between the 2 sides of an individual 

subject due to asymmetry of the phrenic nerves [11]. Su 

Jiang et al. dissected ten fresh adult cadavers and 

observed that the full length of the phrenic nerve was 

24.6 ± 1.7 and 30.6 ± 1.8 cm on the right and left sides, 

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[10, 11]. 

The phrenic nerves arise from C4 with accessory 

branches from C3 and C5. It lies on the anterior scalene 

muscle and then passes anterior to the hilum of the lung 

to the diaphragm, with some fibers continuing into the 

peritoneum. The paths of the left and right phrenic 

nerves are not exactly the same. The left phrenic nerve 

is bent around the rear of the apex of the heart, but 

reaches the diaphragm to draw a concave bow to the 

front. In contrast, the right phrenic nerve is on the 

outer surface of the right arm's head vein, and then 

runs in contact with the outer surface of the superior 

vena cava, reaching forward and arriving at the dia-

phragm on the outside of the vena cava hole. The left 

phrenic nerve is longer than the right phrenic nerve. 

The difference between the lengths of the right and left 

nerves might have affected the difference between the 

latencies of the right and left sides. The onset latencies 

obtained in our study (5.99 ± 0.39 and 6.45 ± 0.50; 

Table 1) were considerably shorter than those reported 

by Chen (6.54 msec) and Resman-Gaspersc (6.55 msec). 

We speculate that the differences in the onset latencies 

might be affected by the physique of each subject and 

the inspection methods used. 

The subjects in this study were limited to healthy 

males aged 20–40 years old. In future investigations we 

will include subjects from several age groups and female 

subjects in order to further elucidate differences 

between the left and right phrenic nerves.

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