

– Abstract –

Decomposition of Sensory Nerve Action Potential and Motor Unit Action Potential in Patients with Diabetic Neuropathy using Wavelet Transform and Fast Fourier Transform

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Objectives : To evaluate the characteristics of nerve conduction abnormalities and activities of different types of muscle fibers in diabetic neuropathy with comparison to clinical and electrophysiological features, using analysis of power spectral density and relative energy ratio.

Methods : For analysis of sensory nerve action potentials (SNAPs) we used the distribution of conduction velocity (DCV) based upon power spectral analysis, power spectral density (PSD) by fast fourier transformation, and relative energy ratio of the low frequency versus high frequency by wavelet transform method. For investigation of electromyography (EMG), PSD was determined during minimal and maximal volitions.

Results : DCV demonstrated reduction of slow fibers (<40 m/sec) in small or large fiber dysfunction and attenuation of fast fibers (40~60 m/sec) in severe mixed fiber lesions. PSD of SNAPs showed reduction of low frequencies with increase of high and intermediate frequencies. PSD of EMG signals on maximal volition was significantly decreased in diabetics. PSD of SNAPs and EMG revealed a correlation with electrodiagnostic severity.

Conclusion : Attenuation of slower nerve fibers and reduction of lower frequencies of SNAPs could be early findings of diabetic neuropathy. In addition, dysfunction of type II myofibers would be highly suggestive. Power spectral analysis could be utilized for early diagnosis.

Key Words : Diabetic neuropathy, Action potentials, Electromyography, Spectrum analysis, Transformation

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* 1998

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(49.4 ± 15.5)
28 65
32 (22 , 10 , 46.9 ± 14.8)

Na⁺-K⁺ ATPase

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가

2.

HbA1c

2,3

II , Klueber 가⁴

가

가

3

)가

가

가

가

10,11

5-7

가¹² , 8

4

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가

가

22~24

8,9

Counterpoint MK II (Dantec, Denmark)

(Fast Fourier Transform)

(Wavelet Transform)

10mm
malleolus)

(lateral

4cm

10cm

20cm

0.2msec,

10Hz~10KHz

20

20

Data Acquisition (DAQ) 1200 (National Instrument,
U.S.A.) A/D II

1.

1~2

가

가

가

3

69

25 ,

17

31

10Hz~10KHz

42

DAQ 1200 A/D

10KHz

U.S.A.) Visual C++ 5.0 (Microsoft, U.S.A.)

Matlab 4.0 (MathWork, U.S.A.)

2) (1) (FFT)

1) FFT

20KHz 20msec (512 point) (discrete) A/D

(Fig. 1). (PSD)

3). PSD 1.2KHz 1.2KHz 4.3KHz 4.3KHz PSD

(Fig. 2, (2) (WT) FFT (stationary) (nonstationary) FFT (Short Time FFT, STFFT) (window) (masking)

(1~300Hz), (300Hz~2000Hz) f(x)

(Fig. 4). SPSS for Windows (Release 7.5.2K,) Mann-Whitney Kruskal-Wal-

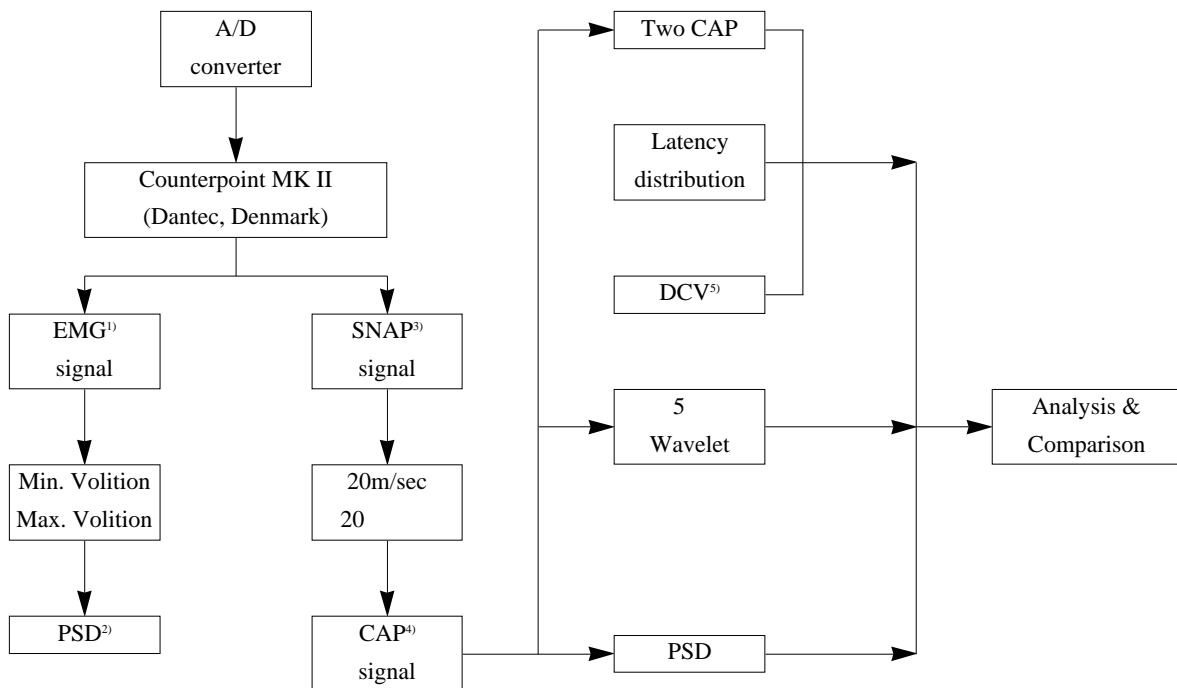
$$W_{j,k}f(x) = 2^{-j/2} \int f(x) (2^{j/2}x-k)dx$$


Fig. 1. Diagram of the system for the analysis of sensory nerve action potential and electromyography in normal and diabetic groups.
 1. EMG: Electromyography, 2. PSD: Power spectrum density, 3. SNAP: Sensory nerve action potential, 4. CAP: Compound action potential, 5. DCV: Distribution of conduction velocity

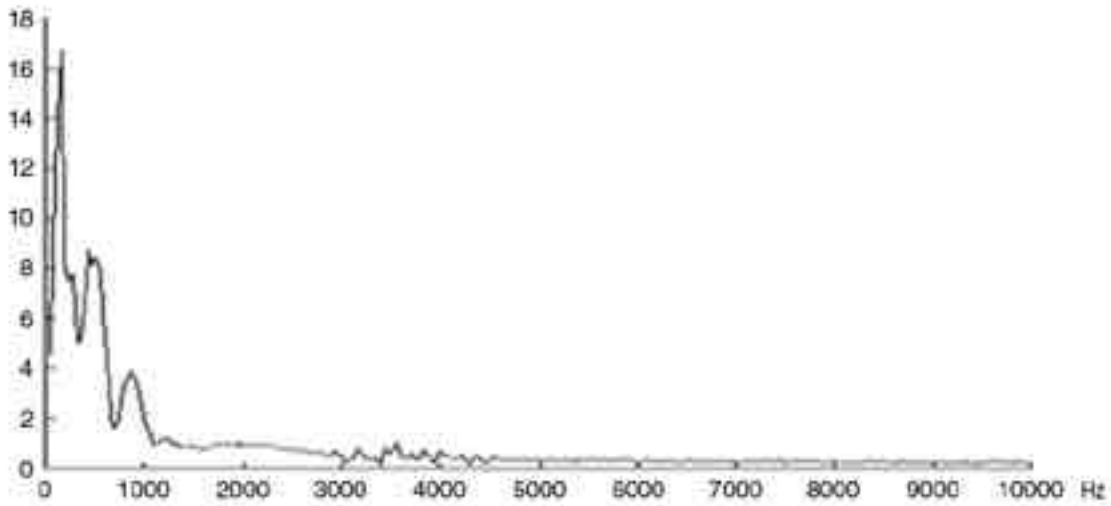


Fig. 2. Example of the power spectrum density for compound action potential.

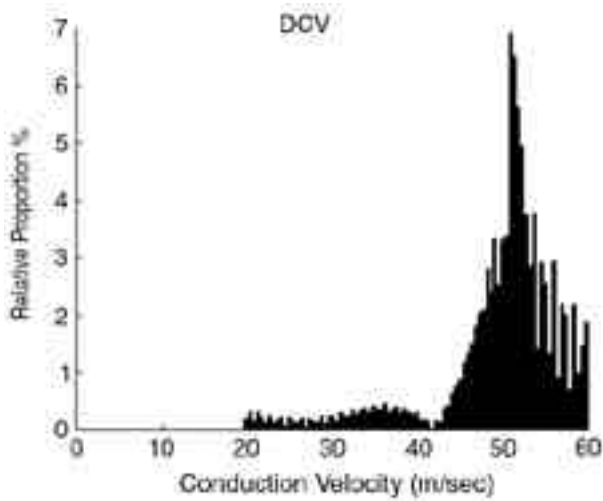


Fig. 3. Example of the distribution of conduction velocity (DCV).

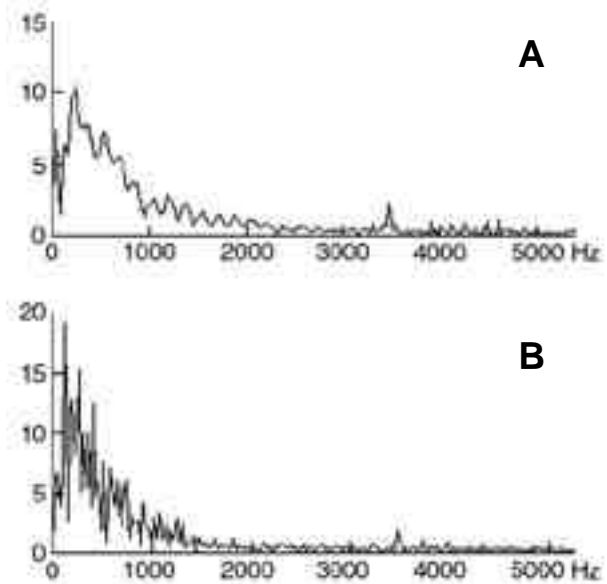


Fig. 4. Example of the power spectrum density of electromyography on minimal (A) and maximal (B) volitions.

(filtering) approximation detail

Daubechies 4

(3) (DCV) 가

(1)~(18)

$$g_{11}(t) = \sum_{i=1}^M a_i n_i d_i(t - \tau_i)$$

(1)

$$g_{11}(t) = \sum_{i=1}^M p_{11}(\tau_i) \cdot d(t - \tau_i) \quad (2)$$

$$g_{11}(t) = \sum_{i=1}^M p_{11}(\tau_i) \cdot d(t - \tau_i) = p_{11}(t) * d(t) \quad (3)$$

$$g_{12}(t) = \sum_{i=1}^M p_{12}(\tau_i) \cdot d(t - \tau_i) = p_{12}(t) * d(t) \quad (4)$$

$$v_1 = l_1 / \tau_{11} = l_2 / \tau_{12} \quad (5)$$

$$p_{11}(\tau_1) \cdot \tau_1 = p_{12}(\tau_2) \cdot \tau_2 \quad (6)$$

$$\frac{l_1}{\tau_1} p_{11}(\tau_1) = p_{12}(\tau_2) \quad (7)$$

$$g_{11} = p_{11} * d(t) \tag{8}$$

$$g_{12} = p_{12} * d(t) \tag{9}$$

$$G_{11}(k) = P_{11}(k) \cdot D(k) \tag{10}$$

$$G_{12}(k) = P_{12}(k) \cdot D(k) \tag{11}$$

$$G_{11}(k) / G_{12}(k) = P_{11}(k) / P_{12}(k) \tag{12}$$

$$P_{12}\left(\frac{1}{I_1} k\right) = (G_{11}(k) / G_{12}(k)) P_{12}(k) \tag{13}$$

$$P_{12}(k) = G(k/a) \cdot P_{12}(k/a) \tag{14}$$

$$|P_{12}(k)| = A(k) \cdot \{ |P_{12}([k/a+1])| - |P_{12}([k/a])| \} \cdot (k/a - [k/a]) + |P_{12}([k/a])| \tag{15}$$

$$\arg\{P_{12}(k)\} = B(k) + [\arg\{P_{12}([k/a+1])\} - \arg\{P_{12}([k/a])\}] \cdot (k/a - [k/a]) + \arg\{P_{12}([k/a])\} \tag{16}$$

$$D(k) = \frac{G_{12}(k)}{P_{12}(k)} \tag{17}$$

$$P_{11}(k) = \frac{G_{11}(k)}{D(k)} \tag{18}$$

가 (Table 1).
 HbA1c
 HbA1c (p>0.05),
 17.3 ± 4.1 9.4
 ± 6.1
 1. (Table 2, 3)
 ,
 20~30m/sec , 40~50m/sec
 가 (p<0.05).
 20~40m/sec 가
 , 50~60m/sec 가
 가 (p<0.05).
 20~40m/sec 가 가 , 40~60m/sec
 가 (p<0.05).
 20~40m/sec 가 가 40~60m/sec
 가 (p<0.05).

Table 1. Distribution of EDX¹⁾ Severity and Clinical Classification

| Clinical | EDX | | Diabetics | | Total |
|----------|--------|--|-----------|--------|-------|
| | Normal | | Mild | Severe | |
| Small | 8 | | 3 | - | 11 |
| Large | - | | 10 | - | 10 |
| Mixed | - | | 13 | 8 | 21 |
| Total | 8 | | 26 | 8 | 42 |

1. EDX: Electrodiagnosis

42
 11 ,
 21 (Table 1).
 가 8 ,
 26 8 .

Table 2. Comparison of DCV¹⁾ by Clinical Classification

| Velocity (m/sec) | Group | Normal (%) | Diabetics (%) | | |
|------------------|-------|------------|---------------|-----------|-----------|
| | | | Small | Large | Mixed |
| 20~30 | | 5.1±1.2 | 3.7±2.5* | 4.0±2.0* | 15.2±3.4* |
| 30~40 | | 8.9±1.8 | 7.5±9.3 | 6.3±7.2* | 16.5±6.7* |
| 40~50 | | 30.0±3.2 | 34.0±7.9* | 31.7±6.0 | 26.4±4.5* |
| 50~60 | | 56.0±3.9 | 54.9±6.5 | 57.2±5.9* | 43.6±3.1* |

Values are mean±S.D.

1. DCV: Distribution of conduction velocity

*p<0.05 by Kruskal-Wallis test compared to the value of normal group

2. (PSD)(Table 4, 5)

3. (PSD)(Table 6, 7)

(p<0.05). PSD
(p>0.05).
가 (p<0.05).
PSD
가 1 5 2
(Fig. 5).
가
48.7 ±
5.3% 58.0 ± 7.4%

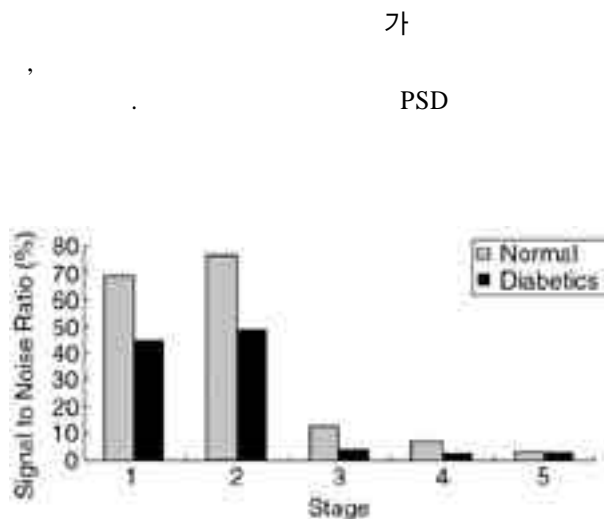


Fig. 5. Characteristics of wavelet distribution at 5 stages.

Table 3. Comparison of DCV¹⁾ by EDX²⁾ Severity

| Velocity (m/sec) | Group | Diabetics (%) | | |
|------------------|-------|---------------|-----------|------------|
| | | Normal (%) | Mild | Severe |
| 20~30 | | 5.1±1.2 | 10.5±3.3* | 21.6±2.1*† |
| 30~40 | | 8.9±1.8 | 12.2±5.8* | 21.0±2.4*† |
| 40~50 | | 30.0±3.2 | 27.9±7.0* | 23.1±2.7*† |
| 50~60 | | 56.0±3.9 | 49.4±4.9* | 34.4±3.3*† |

Values are mean±S.D.

1. DCV: Distribution of conduction velocity

2. EDX: Electrodiagnosis

* p<0.05 by Kruskal-Wallis test compared to the value of normal group

† p<0.05 by Mann-Whitney test compared to the value of mild group

Table 5. Comparison of PSD¹⁾ of SNAP²⁾ by EDX³⁾ Severity

| Frequency | Group | Diabetics (%) | | |
|--------------|-------|---------------|-----------|------------|
| | | Normal (%) | Mild | Severe |
| Low | | 73.8±11.0 | 65.0±5.4* | 57.2±1.4*† |
| Intermediate | | 16.7± 3.3 | 19.5±3.3* | 29.1±7.0*† |
| High | | 15.9±12.1 | 24.0±9.5* | 23.0±9.2* |

Values are mean±S.D.

1. PSD: Power spectrum density

2. SNAP: Sensory nerve action potential

3. EDX: Electrodiagnosis

* p<0.05 by Kruskal-Wallis test compared to the value of normal group

† p<0.05 by Mann-Whitney test compared to the value of mild group

Table 4. Comparison of PSD¹⁾ of SNAP²⁾ by Clinical Classification

| Frequency | Group | Normal (%) | Diabetics (%) | | |
|--------------|-------|------------|---------------|------------|-----------|
| | | | Small | Large | Mixed |
| Low | | 73.8±11.0 | 62.7±4.7* | 65.1±19.3* | 63.0±9.5* |
| Intermediate | | 16.7±3.3 | 24.1±4.6* | 22.2±11.0* | 24.4±4.5* |
| High | | 15.9±12.1 | 23.2±8.0* | 21.6±5.5* | 22.0±6.0* |

Values are mean±S.D.

1. PSD: Power spectrum density

2. SNAP: Sensory nerve action potential

*p<0.05 by Kruskal-Wallis test compared to the value of normal group

5

II

가

I
가 1~2

I

1

II

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19-21

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II

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Daubechies 4

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II

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4

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II

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1)

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22,23

20~40m/sec

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가

가

20~40m/sec

Henneman

(size principle)²⁴

가

40~60m/sec

가

2)

I

가

가

II

가

가

가

3)

40m/sec

25

가

가

가

가

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