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# Reference values for amplitudes and conduction velocities obtained from a cohort of middle-aged and retired workers

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Many workers are exposed on the job to chemicals or physical agents which put them at risk for peripheral neuropathies. Currently, electrophysiologic tests are one method of assessing peripheral nerve damage. Reference values for tests of amplitude, latency, and nerve conduction velocity among healthy individuals have been reported by other researchers. Many of these data are limited, however, because mean values are presented for large age ranges, they are based on a small number of observations, or they are not controlled for variables known to affect nerve function. This paper describes the construction of reference values for selected nerve amplitudes and conduction velocities obtained from healthy white male workers. These data improve on previous work by presenting values for a large occupational cohort while controlling for variables related to peripheral nerve function.

## *Subjects and methods*

*Study population.* The data used to construct the reference values were collected as part of a cross-sectional medical study of 281 workers exposed to chemicals contaminated with 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and 260 unexposed individuals. Although the chemical workers had been highly exposed to TCDD, previous research showed that the two study groups were similar with respect to measures of peripheral nerve function (1). Hence the data from the exposed and unexposed groups were combined for the construction of the reference values.

Nonwhites and women were excluded from the present data set because they were few in number (N = 90). Moreover, individuals who had medical conditions which would affect nerve function were excluded from further evaluation. Specifically, individuals were excluded if they reported a history of diabetes (N = 33), stroke (N = 13), neurotoxic drug use (N = 7) (ie, dilantin, hydralazine, dapsone, and phenytoin), or traumatic injuries to the spine, head or limbs or refused to participate in the electrophysiologic tests (N = 4). The final number of individuals in the reference sample included 394 white males for the evaluation of upper-limb nerve function and 392 white males for the evaluation of lower-limb nerve function.

*Electrophysiologic measurements.* In the cross-sectional study, the electrophysiologic tests were conducted by trained technicians on the dominant arm or leg (unless contraindicated by localized pathology, ie, loss of limb or severe trauma to the limb) using a standard protocol described by Kimura (2) and Sweeney (1). The following three measures of nerve function were made: (i) onset latency — the amount of time from stimulation to the onset of principal depolarization (reflects the integrity of the myelin sheath and the mean cross-sectional diameter of the responding axons); (ii) peak amplitude — the size of the maximal response of the compound action potential for sensory studies or the M-wave for motor studies (reflects the number and synchrony of the responding units); and (iii) conduction velocity — a calculated measure of distance or latency (reflects the speed of neural transmission).

All of the tests were performed with the use of surface electrodes. Stimulation consisted of 100—200 μs square pulses presented at fixed locations overlying the median and ulnar nerves in the forearm, as well as the peroneal and sural nerves in the calf and foot. Motor responses were assessed with the use of orthodromic procedures, while the sensory tests were antidromic. Prior to testing, the surface temperature of the limb was measured. A heating pad was used, when needed, to adjust the temperature as near to 33.0°C for the upper limb or 32.0°C for the lower limb as possible.

*Construction of reference values.* Multiple linear regression models were used to compute predicted mean age-adjusted reference values for the amplitude and conduction velocity of each nerve controlling for covariates known to effect measures of nerve function. The initial covariates included in each model were finger or toe temperature (3), lifetime alcohol (4), and

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cigarette consumption, height, weight and age group (30—39, 40—49, 50—59, 60—69, 70—79). Covariates were retained in the models if they achieved statistical significance ($P < 0.05$) and they were not confounders.

Linear regression models were obtained for each electrophysiologic test with the use of the observations from each individual. Residuals were generally distributed normally; therefore, no transformations were used. Mean predicted values and 95% confidence intervals for each age group were computed using the coefficients for each linear regression model while setting covariate values to the mean of the age group (30—39, 40—49, 50—59, 60—69, 70—79).

After review of the full models, several variables were dropped. Lifetime alcohol and cigarette consumption, although they consistently decreased the mean value of nerve function, had small coefficients indicating a marginal contribution to the predicted mean and generally were not statistically significant. Height and weight had inconsistent effects; in some models height or weight or both reduced the mean nerve function value, while in others it increased the mean value. Increasing age group and decreasing limb temperature each significantly and consistently decreased the mean nerve function. Thus the predicted values for healthy white males were recalculated from the final models which included only age group and temperature.

## *Results*

The mean and median age of the reference group was 55.5 and 55.3 years, respectively, with a range of 31 to 77 years. For the age groups 30—39, 40—49, 50—59, 60—69, and 70—79 years, the number of subjects was 27, 102, 119, 110 and 36, respectively. The results of the predicted mean amplitude and conduction velocity obtained from the multiple regression models for each nerve are summarized for each age group in tables 1 and 2. The predicted values in tables 1 and 2 have been based on fixed temperatures of 33°C for the upper limb and 32°C for the lower limb. The number of individuals included in each model varies slightly because a few participants were excluded due to site-specific limb injuries and missing values for a particular test. As expected, the conduction velocities were slower in the legs than in the arms. Moreover, the amplitudes and conduction velocities generally decreased as age increased. The most precipitous reduction or increase was consistently noticed in the two oldest age groups.

## *Discussion*

This paper presents reference values for standard measures of amplitude and conduction velocity for the median, ulnar, sural, and peroneal nerves in a large occupational cohort. The advantages of these reference values are that they were obtained from a population exceeding 390 individuals and were calculated after controlling for variables known to affect the peripheral nerve function. In addition, because of the large number of subjects, the mean values are also presented by 10-year age categories from ages 30 to 70 years and over.

It is interesting to note that, with the exception of age and temperature, the variables which were considered a priori to cause significant diminution of nerve function generally had small or inconsistent influence on the mean predicted value for any test parameter. Thus data for age and limb temperature are minimal requirements for measurements of amplitude and conduction velocities.

**Table 1.** Predicted mean[a] for the normal motor and sensory distal amplitudes (mV) of selected nerves by decade of life. (95% CI = 95% confidence interval)

| Nerve[b] | Age (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30—39 | | 40—49 | | 50—59 | | 60—69 | | ≥70 | |
| | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI |
| Median | | | | | | | | | | |
| Motor | 10.7 | 9.4—12.0 | 10.8 | 10.0—11.5 | 9.3 | 8.7—10.0 | 8.7 | 8.0—9.5 | 7.9 | 6.7—9.1 |
| Sensory | 22.7 | 19.6—25.8 | 20.2 | 18.4—22.0 | 15.5 | 13.9—17.0 | 15.3 | 13.6—17.1 | 11.8 | 9.0—14.6 |
| Ulnar | | | | | | | | | | |
| Sensory | 20.1 | 17.0—23.2 | 19.7 | 17.9—21.4 | 15.9 | 14.3—17.5 | 15.1 | 13.3—16.9 | 11.1 | 8.3—13.9 |
| Peroneal | | | | | | | | | | |
| Motor | 5.6 | 4.5—6.6 | 6.1 | 5.5—6.7 | 5.1 | 4.5—5.7 | 4.9 | 4.3—5.5 | 4.3 | 3.3—5.3 |
| Sural[c] | | | | | | | | | | |
| Sensory | 15.0 | 11.6—18.3 | 17.1 | 15.2—19.0 | 14.1 | 12.2—16.0 | 13.1 | 11.0—15.1 | 11.1 | 7.9—14.3 |

[a] Setting finger temperature to 33°C for upper limb nerves and 32°C for lower limb nerves.

[b] The following equations were used to compute the predicted means: median motor = 12.34 + −1.35 (temp) + 2.80 (30—39) + 2.87 (40—49) + 1.45 (50—59) + 0.83 (60—69); median sensory = 26.36 + −0.44 (temp) + 10.88 (30—39) + 8.40 (40—49) + 3.68 (50—59) + 3.53 (60—69); ulnar sensory = 14.59 + −0.11 (temp) + 8.98 (30—39) + 8.54 (40—49) + 4.79 (50—59) + 3.96 (60—69); peroneal motor = 8.89 + −1.44 (temp) + 1.29 (30—39) + 1.83 (40—49) + 0.84 (50—59) + 0.62 (60—69); and sural sensory = 6.94 + 0.13 (temp) + 3.88 (30—39) + 5.99 (40—49) + 3.01 (50—59) + 2.00 (60—69).

[c] Detectable amplitudes for the sural nerve could not be obtained for the following: 1 (0.5%) age group 40—49; 8 (6.7%) age group 50—59; 11 (10.0%) age group 60—69; and 3 (8.3%) age group 70—79.

**Table 2.** Predicted mean[a] for the normal sensory and motor conduction velocities (m/s) of selected nerves by decade of life. (95% CI = 95% confidence interval)

| Nerve[b] | Age (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30—39 | | 40—49 | | 50—59 | | 60—69 | | 70—79 | |
| | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI |
| Median | | | | | | | | | | |
| Motor | 56.6 | 54.7—58.5 | 56.7 | 55.6—57.7 | 55.1 | 54.1—56.1 | 54.8 | 53.7—55.9 | 54.3 | 52.6—56.1 |
| Sensory | | | | | | | | | | |
| Distal | 49.7 | 46.9—52.4 | 50.8 | 49.2—52.3 | 49.0 | 47.6—50.4 | 49.8 | 48.3—50.4 | 46.6 | 44.1—49.0 |
| Proximal | 59.9 | 57.8—62.0 | 59.6 | 58.3—60.8 | 57.4 | 56.3—58.5 | 56.3 | 55.1—57.5 | 55.7 | 53.7—57.7 |
| Ulnar | | | | | | | | | | |
| Sensory | 54.3 | 51.9—56.7 | 54.7 | 53.3—56.0 | 52.4 | 51.2—53.6 | 52.2 | 50.8—53.5 | 49.0 | 46.8—51.1 |
| Peroneal | | | | | | | | | | |
| Motor | 46.1 | 44.0—48.2 | 45.9 | 44.7—47.0 | 44.7 | 43.6—45.8 | 43.7 | 42.4—44.9 | 43.2 | 41.2—45.1 |
| Sural[c] | | | | | | | | | | |
| Sensory | 44.3 | 42.3—46.4 | 44.0 | 42.8—45.1 | 43.7 | 42.6—44.9 | 42.8 | 41.6—44.0 | 41.9 | 39.9—43.8 |

[a] Setting finger temperature to 33°C for upper limb nerves and 32°C for lower limb nerves.
[b] The following equations were used to compute the predicted means: median motor = 46.58 + 0.24 (temp) + 2.25 (ages 30—39) + 2.31 (40—49) + 0.74 (50—59) + 0.47 (60—69); median sensory distal = 28.82 + 0.54 (temp) + 3.11 (30—39) + 4.21 (40—49) + 2.44 (50—59) + 3.26 (60—69); median sensory proximal = 50.51 + 0.16 (temp) + 4.19 (30—39) + 3.84 (40—49) + 1.70 (50—59) + 0.61 (60—69); ulnar sensory = 26.14 + 0.69 (temp) + 5.33 (30—39) + 5.72 (40—49) + 3.40 (50—59) + 3.24 (60—69); peroneal motor = 44.19 + −0.03 (temp) + 2.93 (30—39) + 2.29 (40—49) + 1.56 (50—59) + 0.50 (60—69); and sural sensory = 32.20 + 0.30 (temp) + 2.49 (30—39) + 2.13 (40—49) + 1.86 (50—59) + 0.94 (60—69).
[c] Detectable latencies for the sural nerve could not be obtained for the following: 1 (0.5%) age group 40—49; 8 (6.7%) age group 50—59; 11 (10.0%) age group 60—69; and 3 (8.3%) age group 70—79.

A subset of the present findings are comparable with the results of a study which examined the health status of American Army veterans (5). The test protocols for the two studies were the same, as were the neurophysiological technicians and the testing environment. The mean nerve function values were computed for veterans with the use of similar age groups (30—39 and 40—48) controlling for several covariates (race, age, body mass index, marital status, income, education, smoking status, alcohol consumption, current illicit drug use, and occupational exposure to herbicides). In all cases, the mean nerve function values for our study corresponded, within normal limits, to those of the veterans for the ages examined.

Data from other studies may be used for reference amplitude and conduction velocity values. One major publication summarizes the results of many previous electrophysiologic studies of the major nerves (6). Direct comparison of our results with those summarized by Kimura is difficult because of variation in the testing procedures and techniques (eg, electrode types, orthodromic versus antidromic stimulation, test environments, etc) and due to the unconventional age groups in which the various authors present their respective data.

One limitation of previous studies is the relatively small number of subjects included in each study. Mean values from these smaller studies may be less reliable as reference data, as suggested by their relatively large confidence intervals. Given the large number of subjects in our study, we were able to refine the age categories into decades, thereby enhancing comparability for future studies.

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