Title: RADIAL NERVE F-WAVE REFERENCE VALUES WITH SURFACE ELECTRODES FROM THE ANCONEUS MUSCLE

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ABSTRACT: Introduction: We sought to obtain normative values for radial nerve F-wave variables, recording with surface electrodes from the anconeus muscle. Methods: We tested 30 healthy participants (17 women, 13 men) and measured the following variables: number of F waves/40 traces (F%); minimum, maximum, and mean F-wave latency (FMIN, FMAX, FMED, respectively); F-wave chronodispersion (FCHR); interside differences of F% and FMIN (DF% and DFMIN, respectively). Results: The mean F % was 41.3%; the normative values of FMIN, FMED, FMAX, and FCHR were < 21.2, <22.1, <23.3, and < 4.0 ms, respectively; and normative values of DF% and DFMIN were < 16.6% and < 1.1 ms, respectively. Height was the sole independent predictor in a regression model of FMIN, FMED, and FMAX; this explained 37%–44% of the variability. Discussion: We identified a feasible and useful technique to record radial nerve F waves from the anconeus muscle and obtained normative values of F-wave variables. Muscle Nerve: XX: 000–000, 2018.

The F wave is a late motor response that occurs after the compound muscle action potential (M wave), when motor or mixed nerves are stimulated supramaximally.1 The F study is particularly useful for assessing proximal nerve segments and nerve roots, although F waves are routinely recorded only from C8- and T1-innervated muscles in cervical segments. These roots are infrequently affected by the most common causes of radiculopathy (disc herniation or spondylosis), which involve mainly the C5, C6, and C7 roots.2 The anconeus muscle,3 a radial-innervated muscle located on the posterior aspect of the elbow, seems particularly suitable for overcoming this limitation because it has a very selective C7 innervation, with only a minor C8 contribution.4 In this study, we investigate F responses, stimulating the radial nerve and recording from the anconeus muscles in a population of healthy volunteers in order to establish normative values.

MATERIAL AND METHODS

Recording and Stimulation Technique.

The recording and stimulation technique that we used is detailed in Supporting Information FIGURE 1A. As has been previously described,[3] the anconeus was identi[fi]ed between the olecranon process (4 cm distally) and the humeral lateral epicondyle (1 cm laterally) by asking the participants to extend their forearm against resistance. Twenty stimuli were delivered in each of 2 separate series for each arm (40 stimuli per arm). All studies were evaluated for recording quality and were repeated when <20 sweeps were artefact free. Data from only 1 side were used for statistical analyses after participants' randomization between left and right side; both sides were considered for the calculation of the interside differences.

Definition of F Waves.

F waves (Supp. Info. FIG. 1B) were defined as potentials with amplitude >20 μV (peak-to-peak); the onset cursor was placed on the [fi]rst de[fl]ection from the baseline. We measured the following variables: (1) M-wave amplitude (peak-to-peak); (2) distal motor latency; (3) the percentage of traces with F responses (i.e., F-wave persistence [F%]); (4) the shortest and longest F-wave latency (FMIN and FMAX, respectively); (5) the mean latency of all traces with F waves (FMED); and (6) the difference between FMAX and FMIN (i.e., F chronodispersion [FCHR]). We calculated the interside differences of F% (DF%) and FMIN (DFMIN), which were expressed as absolute values.

Study Population.

The study population included 30 volunteers who were recruited through an advertising campaign at the University of Parma. The eligibility criteria were age ≥ 18 years, negative past medical history (including a history of peripheral neuropathy), and normal neurological examination results. On the basis of an FMIN SD of 1.8 ms reported in published studies on upper limb nerves,[5–10] a sample size of 30 participants predicts an FMIN margin of error of 0.68 ms with 95% confidence interval. Informed consent was obtained from all study participants. The ethics committee approved the study protocol.

Statistical Analysis.

A t test for independent samples was used to compare the mean age by sex. We verified whether F and M variables were normally distributed with the Kolmogorov–Smirnov test with Lilliefors correction and the Shapiro–Wilk test. The normative values were expressed as mean +/- 2 SD for variables with normal distribution; for non-normal variables, the reference limits were calculated as the value of the 95% percentile. The Pearson correlation coef^{fi}cient was used to de^{fi}ne the relation between age and height and the electrophysiological variables. The t test for independent samples was used to define the effect of sex. Finally, a stepwise multiple linear regression was performed to study the influence of height, sex, and age (independent variable) on normally distributed electrophysiological variables (dependent variable). The collected data were analysed in SPSS version 20.0 for Windows (IBM, Armonk, New York). We calculated two-tailed P-values and set statistical signi^{fi}cance at $P < 0.05$.

RESULTS

There were 17 women (aged 18–65 years, mean 34.2 +/- 13.6) and 13 men (aged 25–68 years, mean 45.1 +/- 13.4). The mean age was not statistically different between the 2 groups ($P = 0.085$). The mean height was 163.9 cm (range, 154–176) for women and 173.1 +/- 3.9 cm (range, 164–178 cm) for men. The test was well tolerated, and F waves were recordable in all patients. All considered F and M variables had normal distributions except DF% and DFMIN. The descriptive statistics of these variables are given in Table 1. In Supporting Information Tables 1 and 2, we present the correlation between height and age and F and M variables and analyse the effect of sex. The multiple regression analysis results for FMIN showed that height was the sole independent variable to enter the model ($P < 0.001$), with a coefficient of determination of 0.407, meaning that height explains 40.7% of FMIN variability; however, age and sex did not enter into the final model, meaning that they do not independently contribute to FMIN variability. The regression models for FMED and FMAX were quite similar to FMIN (Table 2). These models define

a regression equation that correlates height to each dependent variable as follows: y = constant + β × height (cm), where β is the unstandardized regression coefficient. For FMIN (FIG. 1), the equation is y = 0.138x − 5.480, meaning that for each 10-cm increase of height, there is a 1.38-ms increase of FMIN. By contrast, FCHR was not influenced by age, sex, or height.

DISCUSSION

The anconeus muscle seems to be particularly suitable for F studies for different reasons, including that (1) it is delimited by bones, which reduce volume conduction artefacts and prevent the coactivation of adjacent muscles; (2) for this reason, the onset of the M and F wave from the isoelectric line is clear cut; (3) it is easily accessible; (4) it is a selectively C7-innervated muscle, whereas other F studies are routinely recorded from the C8–T1 muscles.

F waves of other radial innervated muscles have been previously described. Zappia et al.[6] measured F waves by recording with needle electrodes from the extensor digitorum communis, whereas Papathanasiou et al.[7] obtained normative values by recording with surface electrodes from the extensor indicis muscle. The main limitation of these studies is that either needle recordings, which are more invasive or technically demanding than the surface recordings, were used or that the coactivation of adjacent muscles or volume conduction artefacts may have occurred. F-wave latencies in our study were lower than the reported normative data for median, ulnar,[5] and the previously mentioned radial nerve, which is consistent with a more proximal location of the anconeus.

F chronodisperison[11] was comparable to published values for ulnar and median nerves[9]; similarly to previous studies,[9,12] it was not in[fl]uenced by height, age, or sex. F-wave persistence in the upper limb ranges between 60% and 100% for the median, 70% and 100% for the ulnar,[1,8,10] and 75% for the radial nerve[7]; in our study, we found a lower persistence (41%), which is in agreement with a lower F%[13] of upper limb extensors compared with muscles involved in standing or holding. Our normative value of DFMIN (1.08 ms) was comparable to 1.5 ms for median and ulnar nerves[9] and to 1.7 ms for the radial nerve.[7]

We were able to correlate F-wave latencies with height by using a regression model. Puksa et al.[9] have shown that, with every 10-cm height increase, F latencies in the arms increase by 1.6 ms, which is comparable to our result (1.38 ms). In contrast to previous reports, in our study, age did not influence F-wave latencies, probably because of the relatively small size and the composition of our study population, with a low representation of the extreme age groups.

As has been reported by others,[8,9] women as agroup had shorter F-wave latencies compared with men. This is explained by the influence of height, as suggested by the regression analysis in which height was the only predictive factor. A task force formed by the American Association of

Neuromuscular & Electrodiagnostic Medicine has recently proposed a set of quality criteria that must be met by researchers who conduct studies investigating nerve conduction study normative values.[14] A major limitation of our study is the small sample (n = 30), which is smaller than that suggested (n > 100). A larger sample is recommended to ensure a proper representation of the distribution extremes and to increase precision[14]; mean square errors[15] are reduced by 66% as sample size increases from 20 to 50 participants and by 80% with a sample size of 100. However, on the basis of the mean SD reported in published FMIN studies,[5–10] a sample of 100 participants predicts a 0.35-ms margin of error, which is comparable to the 0.68 ms for our sample. Furthermore, the published literature on F studies provides limited direction regarding proper sample sizes.

In conclusion, we established normative values for radial nerve F waves from the anconeus muscle using surface recording and stimulation, therefore allowing the investigation of the C7 nerve root. Through a multiple linear regression analysis, the established model also accounts for the effect of height.

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Table 2. Regression model of FMIN, FMED, and FMAX in relation to height.

	Constant	r2	β	SD
FMIN	−5.480	0.407	0.138	1.62
FMED	−6.230	0.441	0.149	1.63
FMAX	−5.453	0.366	0.151	1.71

β, unstandardized regression coefficient; FMAX, longest F latency; FMED, mean F latency; FMIN, shortest F latency; r2, coefficient of determination.

Table 1. Descriptive statistics of F- and M-wave variables and corresponding normative values.

	Mean SD	95% CI	Range	Median	Normative
DML, ms	3.15 0.49	2.97–3.33	2.20–4.20	3.05	<4.1
M, mV	6.34 2.62	5.36–7.32	1.40–12.40	6.40	>1.1
F%, %	41.25 21.22	33.33–49.17	7.50–85	37.50	*
FMIN, ms	17.92 1.62	17.31–18.52	15.30–22.90	18.20	<21.2
FMED, ms	18.82 1.63	18.21–19.42	16.10–23.40	18.95	<22.1
FMAX, ms	19.91 1.71	19.27–20.55	17.40–24.30	19.90	<23.3
FCHR, ms	2.16 0.92	1.82–2.49	0.40–4.70	2.00	<4.0
DF%, %	12.91 9.81	9.25–16.58	0–40	11.25	<16.6
DFMIN, ms	0.81 0.73	0.53–1.08	0–2.80	0.70	<1.1

CI, confidence interval; DML, distal motor latency; DF%, interside difference of F%; DFMIN, interside difference of FMIN; F%, F-wave persistence; FCHR, F-wave chronodispersion; FMAX, longest F latency; FMED, mean F latency; FMIN, shortest F-latency; M wave, compound muscle action potential amplitude.

*The normative value cannot be defined (negative value).

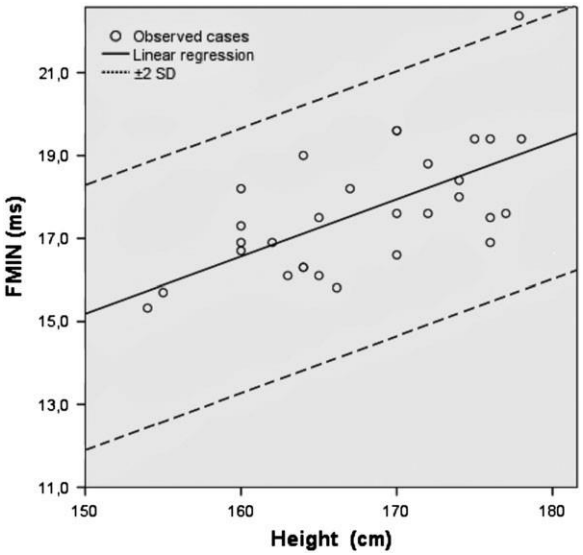

FIGURE 1. Graphical representation of the linear regression equation that correlates height (independent variable) to shortest F latency (FMIN; dependent variable). Dashed lines represent the estimated values 2 SD above and below the regression line.