Journal of Electromyography and Kinesiology 23 (2013) 1057–1064

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Multichannel surface electrodes increase the sensitivity of diagnosis of neuropathy in diabetic patients

Yong Seo Koo [a], Ki-Young Jung [a], Sang-Hoon Lee [b], Charles S. Cho [c], Kyung-Sook Yang [d], Jae Hong Jang [a], Byung-Jo Kim [a,*]

[a] Department of Neurology, Korea University Medical Center, Seoul, Republic of Korea
[b] Department of Biomedical Engineering, Korea University College of Health Science, Seoul, Republic of Korea
[c] Department of Neurology and Neuroscience, Stanford University Medical Center, CA, USA
[d] Department of Biostatistics, Korea University College of Medicine, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 26 February 2013
Received in revised form 1 July 2013
Accepted 9 July 2013

Keywords:
Multichannel electrode
Diabetic neuropathies
Early diagnosis
Compound muscle action potentials
Nerve conduction study
Neural conduction

ABSTRACT

This prospective study investigated the diagnostic sensitivity of a novel multichannel surface electrode for detecting electrophysiologic changes in symptomatic diabetic neuropathy. We recruited healthy subjects without neuropathic complaints and diabetic patients with distal symmetric sensory symptoms who had normal nerve conduction studies (NCS). Eight compound muscle action potentials (CMAPs) were recorded using a multichannel electrode from each subject's abductor pollicis brevis muscle by stimulating the median nerve at the wrist. Latency- and amplitude-related variables were obtained and analyzed to compare the two groups. We used the Classification and Regression Tree (CART) algorithm to determine the cut-off values for selected predictors of diabetic neuropathy. All of the variables related to CMAP latency showed statistically significant differences between the median values for the diabetic group and the healthy control group. For example, the median value of the maximum latency and standard deviation of the eight CMAP onset latencies in diabetic patients (3.82 ms and 0.15 ms, respectively) were significantly larger than those in controls (3.26 ms and $p < 0.001$; 0.09 ms and $p < 0.001$, respectively). The CART analysis revealed that these variables were the most sensitive and specific variables for discriminating between patients with diabetic neuropathy and normal subjects. The multichannel surface electrode demonstrated both high sensitivity and specificity in detecting neurophysiologic abnormality of diabetic neuropathy, even when conventional NCS did not detect the abnormality.

1. Introduction

Diabetic neuropathies can be classified into typical and atypical polyneuropathies (Tesfaye et al., 2010). The most common phenotype is distal symmetric polyneuropathy (DSPN) (Dyck et al., 1993). DSPN, in particular, increases the risk of other diabetes-related complications (Greene et al., 1999; Thomas, 1999), including foot ulcers, infection, peripheral vascular disease and amputations, leading to a severely impaired quality of life. DSPN is diagnosed by medical history and examination, along with electrodiagnostic studies (England et al., 2005). Some diabetic patients, however, have normal results in nerve conduction studies (NCS), despite clear signs or symptoms suggestive of polyneuropathy (Dyck et al., 2011). These cases are described as atypical diabetic polyneuropathy and are often ascribed to small fiber neuropathy, which cannot be detected by conventional NCS. The small fiber pathology, however, does not describe all diabetic patients who have distal dominant symmetric sensory symptoms with normal conventional NCS. The low sensitivity and other problems associated with conventional techniques of diagnosis could explain some of these cases of normal NCS (Koo et al., 2012).

The low sensitivity of conventional NCS in early stages of the disease, partial neural fiber injury, or in the presence of sampling errors has prompted efforts to improve the sensitivity of electrodiagnosis (de Haro et al., 2002). Various diagnostic criteria have been established (Killian and Foreman, 2001; Kim et al., 2010; Rutkove et al., 1997; Tan and Tan, 2003; Turgut et al., 2006), and new equipment including better electrodes have been developed. We developed a multichannel surface electrode which has eight small electrodes in a single platform to detect eight compound muscle action potentials (CMAPs) at different points of a designated muscle (Lee et al., 2009). Conventional disposable 1-cm-diameter single surface electrodes record a summed CMAP of motor unit potentials in a muscle. The CMAP recorded using the conventional

* Corresponding author. Address: Department of Neurology, Korea University Medical Center, Korea University College of Medicine, #73, Inchon-ro (Anam-dong 5 ga), Seongbuk-gu, Seoul 136-705, Republic of Korea. Tel.: +82 2 920 6619; fax: +82 2 925 2472.
E-mail address: nukbj@korea.ac.kr (B.J. Kim).

1050-6411/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jelekin.2013.07.003

single surface electrode reflects the summation of multiple near-simultaneous action potentials, producing a latency value and an amplitude measurement. Therefore, sensitivity is diminished in asynchronous summations or in cases with partial lesions, where only a subset of multiple motor units is represented. These values represent only a small portion of the compounded potential, thereby diluting the pathological signal of interest. The multichannel electrode with eight small-size electrodes may improve this limitation.

Our previous study (Lee et al., 2009), which tested a multichannel electrode in three patients with DSPN and three normal subjects, found significant differences in latency between patients and control subjects. Furthermore, conduction disturbances produced by pathologic lesions in some motor units led to a large variance of latencies of CMAPs compared to a relatively small variance of latencies in normal subjects as recorded by multiple small electrodes. The number of subjects in the previous study, however, was too small to detect significant efficacy or to determine the clinical applicability of this new electrode. The present study investigated the sensitivity and the reliability of the newly developed multichannel (eight electrodes) surface electrode in detecting neuropathy in diabetic patients who have typical distal symmetric sensory symptoms, but no evidence of neuropathy in NCS when using the conventional single electrode.

Table 1
Baseline characteristics of Patients with DM.

	Normal (n = 56)	DM (n = 24)	p
Age (years)	62.5 (30.0, 83.0)	63.0 (38.0, 75.0)	0.789
Sex (male%)	42.9	50.0	0.556
Height (cm)	161.1 ± 9.3	158.4 ± 7.2	0.162
Duration of DM (years)		7.0 (1.0, 30.0)	
BMI (kg/m^2)		25.7 (16.7, 32.0)	
FPG (mg/dL)		113.0 (80.8, 224.0)	
Postprandial glucose (2 h) (mg/dL)		193.42 ± 75.73	
$HbA1_C$ (%)		6.8 (6.1, 12.0)	
Total Cholesterol (mg/dL)		166.5 (108.0, 238.0)	
HDL (mg/dL)		43.0 ± 10.4	
LDL (mg/dL)		93.0 (60.0, 177.0)	
TG (mg/dL)		189.0 (64.0, 507.0)	
MNSI A		1.5 (0.0, 5.0)	
MNSI B		1.0 (0.0, 6.0)	
MDNS		2.0 (0.0, 20.0)	

Data were presented as mean ± SD or median (min, max) based on their distributions. DM, diabetes mellitus; BMI, body mass index; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TG, triglyceride; MNSI, Michigan neuropathy screening instrument; MDNS, Michigan diabetes neuropathy score.

2. Research design and methods

2.1. Subjects

The inclusion criteria was a confirmed diagnosis of type 2 diabetes mellitus (American Diabetes Association, 2006) and distal symmetric sensory signs/symptoms, evaluated at a neurology clinic in a university-affiliated hospital. Patients were excluded if they had a previous history of specific peripheral nerve or muscle disease, a neuromuscular junction disorder, spine surgery for radiculopathy, or medical conditions associated with peripheral neuropathy, such as alcohol abuse, metabolic disorders, malignancy, or long-term drug use. Fifty-six normal healthy volunteers for the control group were recruited from those who visited our health promotion center for general check-up. The subjects were consecutively recruited until the age and sex of the control group statistically matched the patient group. All of the participants received conventional NCS according to the recommended protocol for DSPN (England et al., 2005), and those with abnormal results or anomalous innervations were excluded. Needle electromyography (EMG) was also performed, and those with abnormal findings were excluded from the study. Written informed consent, approved by our Institutional Review Board, was obtained from all participants.

A total of 24 diabetic patients (12 men, 12 women; median age, 63 years) and 56 controls (24 men, 32 women; median age, 62.5 years) were recruited. There were no statistically significant differences in age, sex, or height between the two groups. Clinical characteristics are documented in Table 1.

2.2. Clinical evaluation of diabetic patients

An examiner evaluated all diabetic patients using the Michigan Neuropathy Screening Instrument (MNSI) (Feldman et al., 1994) and the Michigan Diabetic Neuropathy Score (MDNS) (Feldman et al., 1994). MNSI and MDNS were measured only in diabetic patients, since these questionnaires apply only to the diabetic patients. Clinical indicators related to metabolic status such as duration of diabetes, body mass index (BMI), and HbA1c were recorded on the same day the NCS was performed using the multichannel surface electrode.

2.3. Conventional NCS and EMG

Prior to NCS, skin temperature was confirmed at or above 32 °C, by recording at the thenar eminence. Room temperature was maintained at or above 25 °C. While performing NCS and EMG, skin temperature is a well-known factor which can greatly affect CMAP (Koo et al., 2012). Therefore, all research related to electrodiagnostic medicine recommends controlling skin temperature. We strictly followed this guideline to exclude confounding factors related to body temperature. NCSs were performed by an expert electromyographer using standard techniques of supramaximal percutaneous stimulation, and were administered at approximately 20–33% above the stimulation current which did not produce a further increase in response. A constant current stimulator and a 10-mm-diameter, single surface electrode were used for recording. Subjects lay in the supine position on the examination couch and were instructed to keep their hands relaxed. Motor NCSs were conducted on the right-side median (recorded at the abductor pollicis brevis), ulnar (recorded at the abductor digiti minimi), peroneal (recorded at the extensor digitorum brevis), and tibial (recorded at the abductor hallucis) nerves. A stimulus duration of 0.1 ms, a sensitivity setting of 5 mV, a sweep speed of 2 ms/division, and a filter setting range of 5–5,000 Hz were maintained throughout all measurements. All the stimuli applied were square waves through the study. Sensory NCSs were performed on the right-side median and ulnar nerves using orthodromic measurements and on the right-side peroneal and sural nerves using antidromic measurements. A sensitivity setting of 10 μV, a sweep speed of 1 ms/division, and a filter setting range of 20–3,000 Hz were maintained throughout all measurements. F-waves were measured from all of the investigated motor nerves, and H-reflexes were obtained for both posterior tibial nerves using stimulation at the popliteal fossa. EMG was performed on the right side of the biceps brachii, brachioradialis, flexor carpi radialis, first dorsal interossei, abductor pollicis brevis, vastus medialis, tibialis anterior,