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Technical note

Application of time-varying analysis to diagnostic needle electromyography

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ABSTRACT

Quantification in clinical, diagnostic electromyography (EMG) currently includes motor unit action potential (MUAP) analysis and interference pattern analysis. Early efforts to examine the frequency/power spectra of the interference pattern showed modest value but the technique was not developed further. This paper re-examines spectral analysis, extending it into the time-varying domain, which has never been studied in diagnostic needle EMG. Time–frequency and time-scale analysis employing wavelet and non-wavelet techniques were applied to short trains of MUAPs. The results show that time-varying analysis produces clear visual representations of the energy content of individual MUAPs within an interference pattern. The time frequency representations allow easy, qualitative distinction between normal and neurogenic MUAPs. Furthermore, the quantified MUAP energy correlates well with the current morphological standard and the quantification process is substantially faster. Time-varying analysis links classical power spectral analysis in the realm of interference patterns with quantitative MUAP analysis. In addition to morphological classification, MUAPs might also be classified by energy content, which more closely reflects the physical and physiological consequences of neuromuscular pathology on the motor unit.

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1. Introduction

In clinical practice, electromyographic (EMG) analysis is usually subjective and performed in real time as the signal is being acquired by observing an oscilloscope-style display, usually on a computer screen. Although modern EMG machines have the ability to record the EMG signals, this is rarely done and even if the recordings are reviewed afterwards, quantification is the exception and the analysis usually remains subjective and visual. The subjectivity and real-time analysis makes learning the technique of diagnostic EMG very difficult and the acquisition of the signal and its interpretation is highly operator-dependent. Thus, there has been long-standing interest in quantification since the early days of clinical EMG.

Quantification of diagnostic electromyographic (EMG) signals currently involves either morphological analysis of individual motor unit action potentials (MUAP), or analysis of the interference pattern (IP) by the turns-amplitude method [1] and the fields are quite separate. Early studies of the interference pattern power spectrum showed some promise but did not garner much clinical or research traction. For example, neurogenic MUAPs were found to have a large amount of low frequency power and myopathic MUAPs had more high frequency power [1]. Clinically, power spectral analysis seemed to have modest discriminatory value for neurogenic muscles [2] and in myopathy [3].

EMG recordings from the skin surface (surface EMG) have been used extensively in studies of kinesiology and related fields [4]. However, surface EMG does not reveal sufficient fine detail about the morphology of the MUAP to be adequate for clinical testing. Using a needle inserted into the muscle allows for selective searching and focusing on specific MUAPs, which can be readily distinguished from each other (c.f. surface EMG), and for analysis of MUAPs in the deeper parts of the muscle, which are not accessible by surface EMG.

The MUAP size reflects the size of a motor unit, especially the number of muscle fibers in the motor unit [5]. In myopathic conditions, the motor unit loses muscle fibers, becomes weaker, and its MUAP becomes smaller. In neurogenic conditions, when a motor unit loses its innervation, adjacent nerves branch out to reinnervate some of the muscle fibers in the denervated motor unit, thereby enlarging their own motor unit size and territory. The resulting MUAPs are therefore larger. Hence, one of the main questions in clinical electromyography is, are the motor units in this muscle normal, or abnormally large (neurogenic) or small (myopathic)? When observing MUAPs, either in real-time or in static images, the

Abbreviations: CWD, Choi–Williams distribution; CWT, continuous wavelet transformation; EEG, electroencephalogram; EKG, electrocardiogram; EMG, electromyography; FFT, fast Fourier transform; MUAP, motor unit action potential; SAPW, smoothed affine pseudo Wigner distribution; SI, size index; TFR, time–frequency representation; TSR, time-scale representation.

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amplitude is the easiest parameter to gauge, but this is not always the best measure of the overall size of the MUAP, especially for neurogenic MUAPs. Sometimes, high-amplitude MUAPs are quite thin and not neurogenic. This led to the development of MUAP thickness and the Size Index [6], which takes into account the area and the amplitude of the MUAP, but this too is difficult to gauge subjectively. Myopathic MUAPs are somewhat easier to identify, since they are usually both low in amplitude and area.

Since we know that the size of a MUAP reflects the size and force generating capacity of a motor unit [7], it seems intuitive that studying the energy content of MUAPs could yield useful clinical information. Advances in digital signal processing and in computing power prompted this re-examination of the potential applicability of spectral analysis of diagnostic EMG. Time-varying displays of EMG energy might allow better visual identification of abnormal MUAPs, especially large, neurogenic MUAPs, and confirmation of these detected outliers through quantification of MUAP energy. This paper presents the results of some preliminary analysis with these techniques to show their potential value in clinical electromyography. However, there is much greater potential beyond subjective visual analysis, in regard to EMG quantification.

2. Methods

This section will briefly address the problems of the first technique used in frequency analysis of needle EMG, followed by a description of time-varying signal analysis and its two main subtypes, and of energy quantification, by way of background. The final segments describe the specific methods used in this study (beginning at 2.6).

2.1. Power spectral analysis

Traditional spectral analysis of EMG consists of a fast Fourier transformation (FFT) of the EMG signal. The output displays the range and amplitude of the component frequencies but does not say anything of the distribution of these frequencies over time. Graphic displays of the FFT shows the energy distribution of the signal but also without localization in time (Fig. 1). Since abnormal MUAPs might be mixed in among many normal MUAPs and may be few in number, traditional spectral analysis of the EMG would be poorly sensitive in detecting abnormal MUAPs. The need for time information in addition to frequency makes the FFT and related techniques unsuitable for analysis of EMG signals, which are non-stationary. In non-stationary signals, the frequency spectrum of the signal changes over time. Analysis of non-stationary signals has progressed substantially since EMG power spectra were last studied.

2.2. Time-varying analysis

The need for both time and frequency based signal analysis led to an elegantly simple solution of breaking up the signal into segments and performing a FFT on each segment, a technique called short-time FFT. However, technical limitations and problems associated with its spectrogram representation prompted development of a new class of techniques, time-varying analysis, which is better able to display the energy distribution of a non-stationary signal according to both time and frequency.

There are two types of time-varying energy representations, time–frequency (TFR) and time-scale (TSR) representations. Both display how a signal changes frequency and energy content over time but they differ mathematically. In TFR, time and frequency shift similarly or in-step when the spectrogram is formed (covariance). In TSR, time shifts covariantly with scale changes. Frequency is comparable to scale and the equivalent of the spectrogram is the

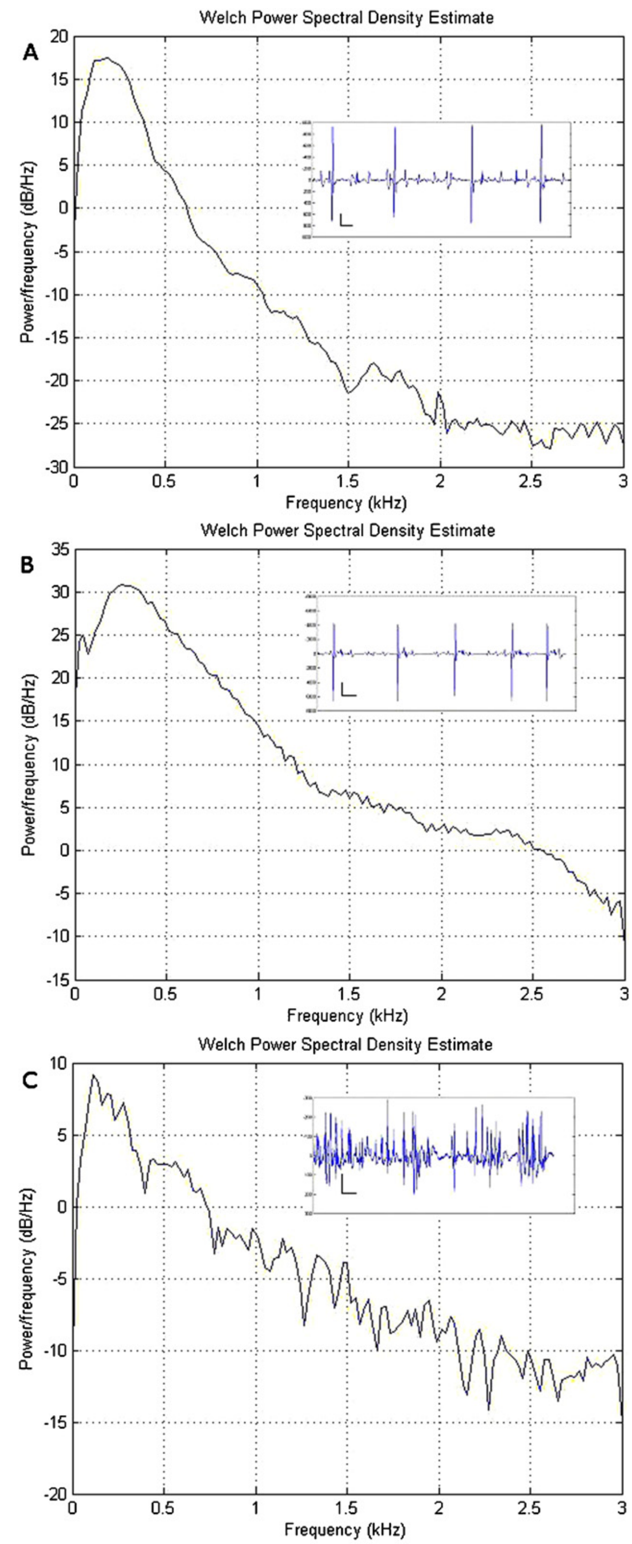

Fig. 1. The power spectral densities (PSD) of normal (A), neurogenic (B), and myopathic (C) interference patterns (embedded). There are small differences in scale and more subtle differences in shape. For example, the neurogenic PSD has more power in the lower frequency ranges than the normal IP, and the myopathic IP has more complexity with a less smooth outline. For the embedded EMG patterns, the scale markers show a time-base of 20 ms and amplitude in μV of 500 (A), 2000 (B), and 200 (C).