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Automatic decomposition electromyography in idiopathic inflammatory myopathies

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Abstract Automatic decomposition electromyography (ADEMG) is a commercially available software package with installed reference values that enables the objective measurement of motor unit action potentials (MUAPs). To assess the diagnostic yield of this package in idiopathic inflammatory myopathies (IIM) we performed biceps brachii ADEMG in 17 patients with polymyositis, dermatomyositis and inclusion body myositis. Results were compared with those in 12 controls, and with the results of conventional EMG of the biceps and other muscles. Decreased mean values for MUAP duration occurred significantly more frequently in IIM patients than in controls; other MUAP characteristics did not differ. In IIM patients, decreased mean amplitude and increased mean number of turns occurred significantly less frequently on ADEMG than did corresponding abnormalities on conventional biceps EMG. Decreased mean values for duration and amplitude, and increased mean values for number of turns were seen significantly less often on ADEMG than corresponding abnormalities on conventional EMG of four different, individually chosen muscles. Overall evaluation of ADEMG resulted in a diagnosis of "possible myopathy" in 1 and "probable myopathy" in 8 patients, whereas overall evaluation of conventional EMG led to a diagnosis "suggestive of IIM" in 13 patients. We conclude that, although measurement of mean MUAP duration might be valuable in IIM diagnosis, our results do not favour the use of biceps brachii ADEMG and the installed reference values for the diagnosis of IIM. We suggest modifications to improve ADEMG's applicability.

Key words Electromyography · Automatic decomposition electromyography · Polymyositis · Dermatomyositis

Introduction

Idiopathic inflammatory myopathies (IIM) are the commonest acquired disorders of muscle to present in adult life [20], with polymyositis, dermatomyositis and inclusion body myositis the major diagnostic entities [3]. Characteristic abnormalities on electromyography (EMG) are an important diagnostic criterion for IIM [3, 17]. The changes consist of fibrillation potentials and sharp positive waves, complex repetitive discharges, and changes in motor unit action potentials (MUAPs) [13]. Typically, abnormalities have a patchy distribution, and the MUAPs are polyphasic with low amplitude and a short duration [13].

IIM are potentially treatable, but in the absence of specific diagnostic tests sometimes difficult to diagnose [3]. Subjective interpretation on conventional EMG may cause MUAP abnormalities to go unnoticed, thus diminishing the chance of detecting IIM. On the other hand,

overdiagnosis might result from the fact that clinical suspicion of IIM could influence the electromyographer. As a consequence, there is a need to further improve electrodiagnosis in IIM.

Objective quantification of MUAP parameters permits a more consistent interpretation of EMG findings [7, 15]. In previous years various automatic quantitative EMG methods have been described, which, however, have not been widely put into clinical practice [9, 10, 16, 18, 19]. More recently, automatic decomposition electromyography (ADEMG) has been developed, a fully automatic method of decomposing EMG patterns into their constituent MUAPs [6, 7, 11, 14]. Potentials from the same motor unit are recognized and averaged, so that duration, amplitude, number of turns and firing rate of the MUAPs are measured. A software package with installed reference values is commercially available as part of the Nicolet Viking electromyographic system. Major advantages of ADEMG are the measurement of large numbers of MUAPs, and the analysis of both low- and higher-threshold MUAPs [7, 15]. Diagnosis of generalized neuromuscular disorders is considered one of its major applications [7]. However, until now there have been few reports studying the clinical usefulness of ADEMG [2, 5, 6]. Therefore, in an attempt to improve EMG diagnosis in IIM, we evaluated the diagnostic yield of ADEMG, by comparing its sensitivity with that of conventional EMG in 17 patients with active IIM.

Subjects and methods

Patients and controls

To validate the data base reference values installed in the ADEMG software package, we performed ADEMG in 12 healthy controls (4 male and 8female) with ages ranging between 22 and 56 years. Then we studied 17 patients with adult-onset IIM (5 male, 12female; age 20–68 years), who attended the Centre for Neuromuscular Diseases of the University of Nijmegen. All patients fulfilled the diagnostic criteria for definite polymyositis (9 patients), definite dermatomyositis (3 patients), or inclusion body myositis (5 patients) [3]. When studied, all patients had signs and symptoms of active disease, including progressive muscle weakness. In 3 patients the research EMG and ADEMG studies were performed prospectively as part of the diagnostic process; in these patients response to subsequent immunosuppressive treatment confirmed the initial diagnosis. Fourteen patients were studied in the course of their IIM disease when clinically worsening after previously successful immunosuppression. Diagnosis, age, sex, duration of symptoms at time of examination, serum creatine kinase concentration, and major findings on muscle biopsy of individual patients are given in Table 1.

All persons gave their informed consent prior to inclusion in the study. All studies were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Automatic decomposition electromyography

ADEMG was performed according to the instructions of the manufacturer. Great care was taken to follow the procedure used by the inventors of the method as described in their original papers [5–7, 14, 15]. Thus, in our opinion the ADEMG examinations were carried out correctly, in that there was no conflict between our performance of ADEMG and the available guidelines. The right biceps brachii muscle was studied in each normal subject and IIM patient. For recording the subject lay supine with the upper arm resting on the examination table, the elbow flexed 90°, and the wrist fully supinated. The subject pulled against variable weights, attached by a cable to a cuff which encircled the distal forearm. Recordings were made using a standard concentric EMG electrode inserted into the midportion of the muscle and adjusted to produce crisp sounds when the amplified signal was fed to a loudspeaker. After measuring the maximal voluntary contraction (MVC), at least 10 sites were sampled, during 10 s per site, at each of three isometric contractile forces: threshold (arm maintained against gravity), 10% of MVC, and 30% of MVC. Feedback of % MVC helped subjects to maintain steady and accurate contractile forces.

Table 1 Diagnosis, age, sex, duration of symptoms, serum creatine kinase (*CK*) concentrations, and major findings on muscle biopsy of the patients with idiopathic inflammatory myopathies (IIM; *PM* polymyositis, *DM* dermatomyositis, *IBM* inclusion body myositis, *Inf* mononuclear cell infiltration, *Necr* muscle fibre necrosis, *SwV* swollen blood vessels, *Peri* perifascicular atrophy, *RBV* rimmed basophilic vacuoles)

Patient	Diagnosis	Age[a]	Sex	Duration[a]	CK U/l[b]	Histology
1	PM[c]	27	M	5 months	1550	Inf, Necr
2	PM	64	F	6 months	1400	Inf, Necr, SwV
3	PM	41	F	3 months	1200	Inf, Necr
4	PM	20	M	1 month	1700	Inf, Necr
5	PM	68	M	2 months	5000	Inf, Necr
6	PM	55	F	15 months	490	Inf, Necr
7	PM	54	F	6 years	260	Inf, Necr, SwV
8	PM	22	F	4 years	990	Inf, Necr
9	PM	65	F	4 years	560	Inf, Necr
10	DM	41	F	4 years	100	Inf, Necr, Peri
11	DM	67	F	4 months	300	Inf, Necr
12	DM	57	F	7 years	2400	Inf, Necr, Peri
13	IBM	68	F	6 months	2200	Inf, Necr, RBV
14	IBM	66	F	7 years	240	Inf, Necr, RBV
15	IBM	52	F	2 years	1900	Inf, Necr, RBV
16	IBM	49	M	6 years	140	Inf, Necr, RBV
17	IBM[d]	53	M	9 years	200	Inf, Necr, RBV

[a] At time of examination
[b] Normative values for CK < 90 U/l
[c] Associated disease: mixed connective tissue disease
[d] Associated disease: rheumatoid arthritis

The processing of the ADEMG signal involves digital prefiltering, high-resolution template matching, interspike-interval analysis, and interference-cancellation averaging [14]. Thus, in each control subject and patient, mean values were calculated from the cumulative MUAP properties for duration, amplitude, number of turns and firing rate. The program automatically compared the individual mean values and intra-individual standard deviations (SD) with the installed data base reference values. Since the reference values have a normal distribution [5, 7, 14, 15], the software package used a two-tailed *t*-test; a *P* value of less than 0.05 was considered significant. In addition, IIM patients having at least two of the three following MUAP abnormalities – decreased mean duration, decreased mean amplitude, or increased number of turns – were classified by us as "probable myopathy". Patients with one of these abnormalities were classified as "possible myopathy".

Conventional EMG

In each patient various muscles were investigated with a concentric needle electrode by an experienced electromyographer (H.V.). The choice of muscles depended on symptoms and signs, as is common practice in EMG diagnosis of IIM [13]. For the group of IIM patients as a whole, the muscles examined were, in decreasing frequency: quadriceps, deltoid, biceps brachii, tibialis anterior, gastrocnemius, triceps brachii, erector trunci, interosseus dorsalis and gluteus maximus. The mean number of muscles examined per patient was four.

MUAPs with short duration, or low amplitude, or polyphasia were detected visually, resulting in a qualitative MUAP assessment: presence or absence of abnormal amounts of short-duration MUAPs, low-amplitude MUAPs, or polyphasic MUAPs. In addition, fibrillation potentials, positive sharp waves and complex repetitive discharges were looked for. Since IIM was clinically suspected ($n = 3$) or known as the previously established diagnosis ($n = 14$), a patchy distribution of abnormalites was anticipated and abnormalities were searched for at various sites within a single muscle.

Finally, in each patient the overall subjective assessment of conventional EMG findings (MUAP abnormalities, fibrillation potentials, positive sharp waves, complex repetitive discharges, patchy distribution) resulted in one of two possible EMG diagnoses: "suggestive of IIM" or "not suggestive of IIM".

Comparisons and statistics

To validate the ADEMG reference values installed in the software package, mean and SD values of MUAP characteristics in healthy controls were compared with the data base reference values. Then, to assess the diagnostic potential of biceps brachii ADEMG in IIM patients, we studied the detection of abnormal mean values in these patients in three different ways: first, we compared the detection of abnormal mean values with that in controls; second, we compared the detection of abnormal mean values with that of corresponding MUAP abnormalities on conventional biceps EMG in the same patient, whereby an increased number of turns was considered to correspond to polyphasia [8]; third, we compared the detection of abnormal mean values with that of corresponding MUAP abnormalities on conventional EMG of multiple muscles in the same patient. Finally, in patients who had ADEMG performed at two or three contraction levels the diagnostic yield of ADEMG was compared with that of conventional EMG, i.e. "probable myopathy" and "possible myopathy" versus "suggestive of IIM".

In the comparison with controls we used the 2×2 Fisher exact test with a one-tailed probability (P), since we expected low-amplitude, short-duration and polyphasic MUAPs to occur in IIM patients, but not in healthy controls. In the comparisons between ADEMG and conventional EMG a two-tailed 2×2 Fisher exact test was used.

Results

Validation of data base reference values for biceps brachii ADEMG

In the 12 control subjects we obtained a total of 144 mean values of MUAP characteristics, 13 of which were classified by the reference data base as abnormal: 3 at threshold, 5 at 10% MVC and 5 at 30% MVC. Abnormal mean values included a decrease of turns ($n = 4$), firing rate ($n = 4$), amplitude ($n = 2$) and duration ($n = 1$), and an increase of duration ($n = 1$) and firing rate ($n = 1$). Of the 144 SD values that were computed, 57 were classified as abnormal: 26 at threshold, 22 at 10% MVC, and 9 at 30% MVC. Decreased SD values concerned firing rate ($n = 23$), number of turns (n=13), duration (n=11) and amplitude ($n = 7$); an increased firing rate SD was recorded 3 times.

From these data we concluded that the installed ADEMG normative data for mean values of MUAP characteristics could be used reliably, in contrast to the SD reference values. Therefore, we only used ADEMG mean values for further analysis.

Table 2 Numbers of IIM patients and controls with abnormal mean values of motor unit action potential (MUAP) characteristics on biceps brachii ADEMG at threshold, at 10% of maximum voluntary contraction (*MVC*) and 30% MVC

Parameter	IIM patients	Controls
Threshold		
Amplitude decrease	1/17	1/12
Duration decrease	7/17	0/12*
Turns decrease	1/17	1/12
Firing rate increase	4/17	1/12
Parameter	**IIM patients**	**Controls**
10% MVC		
Amplitude decrease	1/14	1/12
Duration decrease	3/14	1/12
Turns decrease	4/14	0/12**
Firing rate decrease	3/14	1/12
Firing rate increase	2/12	2/12
Parameter	**IIM patients**	**Controls**
Amplitude decrease	1/13	1/12
Duration decrease	0/13	1/12
Turns decrease	3/13	0/12
Firing rate decrease	2/13	2/12
Firing rate increase	2/13	1/12

* One-tailed probability (Fisher's 2×2 Exact Test) 0.01 compared with IIM patients

** One-tailed probability (Fisher's 2×2 Exact Test) 0.06 compared with IIM patients

Table 3 Comparison of biceps brachii ADEMG and conventional EMG of biceps brachii muscle in eight IIM patients. Numbers of IIM patients with abnormal MUAP characteristics at various contraction levels, and numbers of patients with corresponding abnormalities on conventional EMG

	ADEMG					Conventional EMG
	Threshold	10%	30%	Total		
Decreased mean duration	4/8	3/8	0/8	5/8	8/8	Increase of short-duration MUAPs
Decreased mean amplitude	0/8	0/8	0/8	0/8*	5/8	Increase of low-amplitude MUAPs
Increase of turns	0/8	0/8	0/8	0/8*	6/8	Increase of polyphasic MUAPs

* Two-tailed probability (Fisher's 2 × 2 Exact Test) < 0.01 compared with conventional EMG

Table 4 Comparison of ADEMG of biceps brachii muscle and conventional EMG of various muscles in 17 IIM patients. Numbers of IIM patients with abnormal MUAP characteristics on ADEMG and numbers of patients with corresponding abnormalities on conventional EMG

ADEMG[a]	Conventional EMG
Decreased mean duration 8/17**	Increase of short-duration MUAPs 15/17
Decreased mean amplitude 2/17**	Increase of low-amplitude MUAPs 14/17
Increase of turns 0/17**	Increase of polyphasic MUAPs 15/17

[a] Combined results from threshold, 10% and 30% ADEMG
* $P = 0.03$
** $P < 0.0001$ (two-tailed probability, Fisher's 2 × 2 Exact Test) compared with conventional EMG

Biceps brachii ADEMG in IIM patients and controls

ADEMGs at threshold, 10% MVC and 30% MVC were recorded in 17, 14 and 13 IIM patients, respectively. The numbers of patients with abnormal mean values for MUAP amplitude, duration, number of turns, or firing rate at threshold, 10% MVC and 30% MVC compared with controls are given in Table 2.

Biceps brachii ADEMG and conventional biceps brachii EMG in IIM patients

In 8 patients we compared the MUAP characteristics at threshold, 10% MVC and 30% MVC of the biceps brachii muscle with the results of conventional EMG in the same muscle (Table 3). Significantly more patients had low-amplitude or polyphasic MUAPs on conventional EMG than abnormal mean values for the corresponding parameter on ADEMG, irrespective of contraction level. As shown, there was no difference between ADEMG and conventional EMG as far as MUAP duration is concerned.

Biceps brachii ADEMG and conventional EMG of multiple muscles in IIM patients

In 17 patients the MUAP characteristics on biceps brachii ADEMG were compared with corresponding abnormalities as obtained on conventional EMG of multiple, individually chosen muscles. The results are given in Table 4.

Diagnostic yield of biceps brachii ADEMG and conventional EMG in IIM patients

In 13 of 17 patients overall evaluation of conventional EMG findings in various muscles suggested IIM. The final diagnosis in patients not having an IIM-suggestive EMG was polymyositis ($n = 3$) and inclusion body myositis ($n = 1$). In 16 patients we obtained ADEMG findings at at least two contraction levels, leading to classification as "probable myopathy" in 1 patient with polymyositis, and "possible myopathy" in 8 patients (2 with polymyositis, 2 with dermatomyositis, 4 with inclusion body myositis). One patient with polymyositis had a "probable myopathy" on ADEMG, whereas the conventional EMG was "not suggestive of IIM" (Table 5).

Table 5 Diagnostic yield of biceps brachii ADEMG and conventional EMG of various muscles in IIM patients

Electrodiagnosis		Numbers of patients
ADEMG	Possible myopathy	1/16
ADEMG	Probable myopathy	8/16
EMG	Suggestive of IIM	13/17

Discussion

In this study on the diagnostic usefulness of ADEMG in IIM we made the following observations. On ADEMG only decreased MUAP duration occurred more frequently in IIM patients than in controls, and in IIM patients ADEMG was less sensitive in detecting relevant MUAP abnormalities than conventional EMG. The overall diagnostic yield of ADEMG was not greater than that of conventional EMG. In addition, ADEMG appeared to be rather time consuming, so that in the same amount of time we could examine multiple muscles conventionally. With respect to patient discomfort, ADEMG was not more favourable, since it was as painful as conventional EMG.

There have been few reports on the use of ADEMG in neuromuscular disorders, including IIM [2, 5, 6]. In a minimally symptomatic IIM patient Dorfman et al. [6] found normal mean MUAP amplitudes and number of turns, but an excess of short-duration potentials and increased firing rates; in a treated asymptomatic IIM patient, mean MUAP amplitude, duration and number of turns were all reduced and mean firing rate increased. The authors suggested that findings on ADEMG do not necessarily relate to disease activity [6]. Our observation of only few abnormal mean values in 17 patients with active IIM is in keeping with this suggestion.

We found clear discrepancies in the diagnostic yield of conventional EMG and ADEMG. On evaluation of another automatic method of analysing biceps brachii MUAPs, Fuglsang-Frederiksen [9] found a concordance between automatic analysis and visual assessment in 76% of neuropathy patients, but in only 50% of myopathy patients. As far as our study is concerned, it may be argued that the electromyographer was biased towards IIM diagnosis, since in most patients IIM was suspected on clinical grounds. Although this factor undoubtedly does play a role, it cannot explain the low sensitivity of ADEMG and the resulting low diagnostic yield. Moreover, the percentage of "IIM-suggestive" EMGs in our patients corresponds to that reported in the literature [3, 13].

There are various explanations for the somewhat disappointing results on ADEMG. Firstly, in IIM some muscles may remain electrically normal [13]. For this reason, conventional EMG assessment includes the examination of multiple muscles, with emphasis on those exhibiting moderate weakness [13]. As yet, ADEMG has only been standardized for the biceps brachii muscle, and this muscle is not always affected. Secondly, one of the inherent difficulties with methods automatically analysing MUAPs, including ADEMG, centres on the selection of the signals [13]. On visual analysis of ADEMG recordings, we found that the beginning and the end of a MUAP were not always delineated correctly. Likewise, not all MUAPs were detected. Notably, the program had difficulties in detecting very small MUAPs, and in some patients a substantial

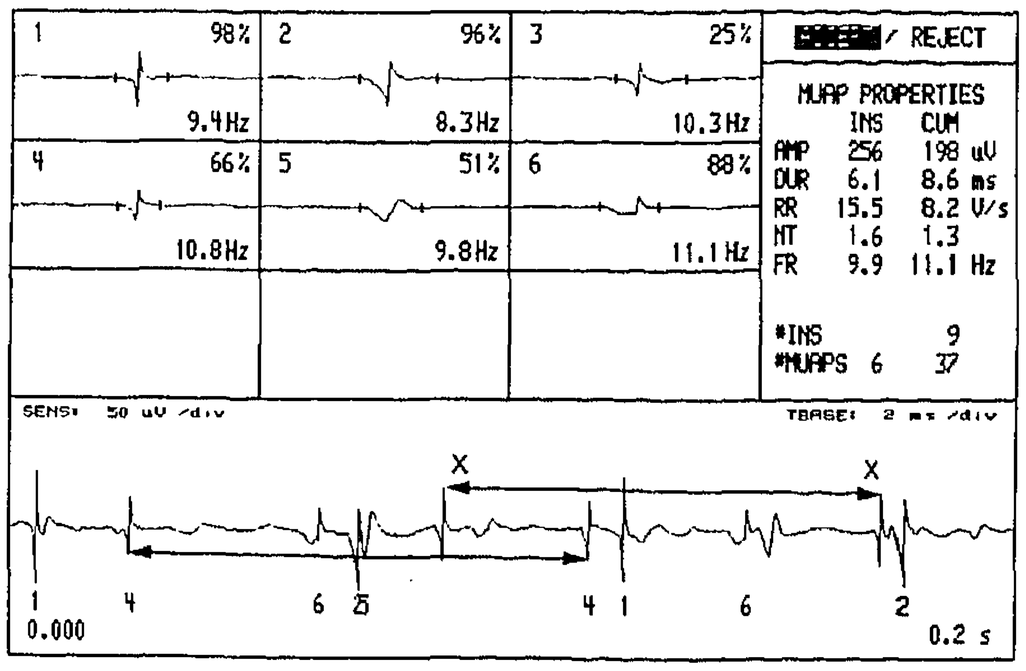

Fig. 1 Motor unit action potentials (MUAPs) from six different motor units (1–6) are represented in the *upper part* (middle and left) of the figure. The *lower part* shows that MUAP X is not identified, and notably not recognized as a MUAP coming from motor unit 4, although the shape and interspike interval of MUAP X are identical to those of MUAP 4 (*X–X* interspike interval of MUAP X, *4–4* interspike interval of MUAP 4)

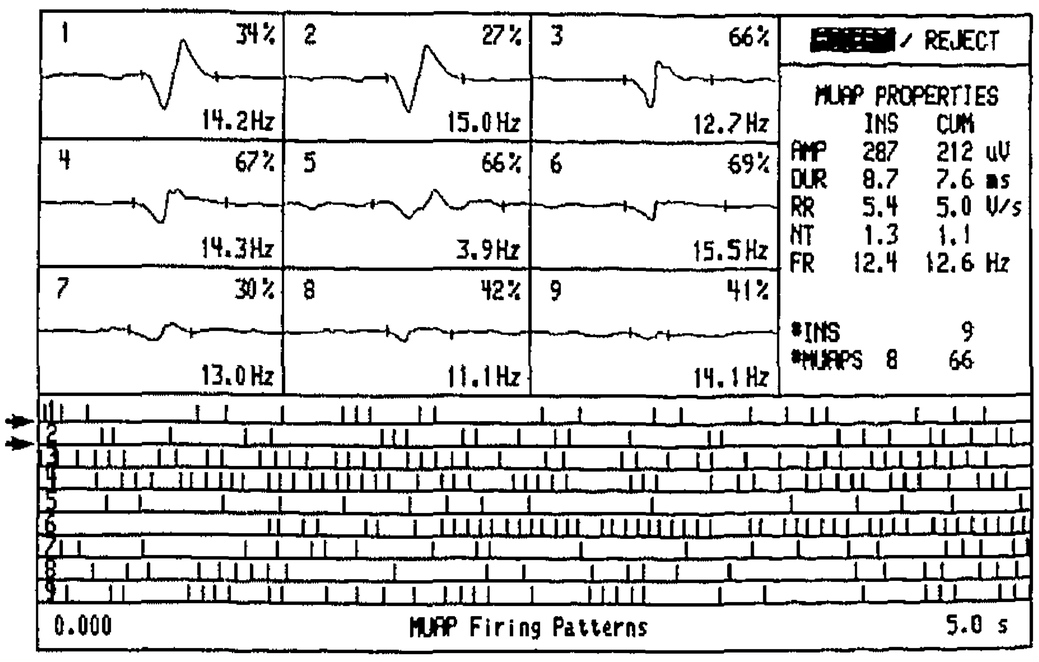

Fig. 2 MUAPs from nine different motor units (1–9) are represented in the *upper part* (middle and left) of the figure. In view of their shapes, MUAP 1 and 2 would be identified by most electromyographers as coming from the same motor unit. The firing patterns of motor units 1 and 2 – indicated by *arrows* in the *lower part* of the figure – confirms this interpretation. The ADEMG program, however, classifies MUAP 1 and 2 as coming from two different motor units

number was missed. Sometimes, MUAPs with very abnormal configuration went undetected (Fig. 1), or a given MUAP was "recognized" as two different ones (Fig. 2). In IIM patients MUAP characteristics may not only differ considerably between motor units [13], but also MUAPs from the same motor unit vary greatly, in that amplitude, duration and configuration fluctuate from one firing instant to another [4]. Therefore, it is likely that MUAPs originating from the same motor unit are not always recognized as such, but instead are interpreted as coming from different units. The resulting low frequency of MUAPs from these "different" motor units causes them not to be accepted by the ADEMG program. As a consequence, precisely motor units with great intra-MUAP

variability run the risk of not contributing to the ADEMG signal.

Thirdly, and perhaps the most important factor, conventional EMG is an interactive process between the investigator and the myographic findings, resulting in an "intelligent search" for abnormal MUAPs. Given the patchy distribution of abnormalities in IIM, detection of low-amplitude, short-duration or polyphasic MUAPs, though constituting a minority in the whole MUAP population, is diagnostically important. In ADEMG, however, the statistical approach prevents abnormal MUAPS from compensating for the prevailing normal ones. In consequence, although many of our patients had mean values in the lower normal range, the values were not abnormal.

Buchthal [1] has extensively measured motor units that were recruited at very slight voluntary contraction, so that MUAPs could be recorded on a smooth baseline. Although we did not compare ADEMG with the Buchthal method, we should like to mention some basic differences between the methods. First, by means of averaging, ADEMG determines the beginning and the end of MUAPs also on a non-smooth baseline. Secondly, MUAP duration and amplitude are related to excitation threshold [13]; at 10% MVC and 30% MVC motor units, with additional information, are recruited other than the units measured by the Buchthal method. Thirdly, ADEMG also measures MUAPs that are not located in the immediate vicinity of the tip of the recording electrode.

It has been suggested that ADEMG will have its most powerful application in those early or borderline cases of neuromuscular disorders in which the electrophysiological abnormalities are relatively slight and which might otherwise elude diagnosis [7]. However, as yet it has not been demonstrated whether automated methods do help in the diagnosis of these patients [13]. Our failure to detect MUAP abnormalities in most IIM patients with active clinical disease argues against a role for biceps brachii ADEMG in the detection of early or borderline cases of IIM.

In conclusion, our results suggest that ADEMG of the biceps brachii muscle with the use of the reference values installed in the software package is not of great diagnostic value in IIM, except possibly for the measurement of mean MUAP duration. However, we expect that the establishment of reference values, especially those for SD, per laboratory or in a multi-centre setting [8] might increase ADEMG's applicability, as will (we believe) the following modifications: firstly, the availability of ADEMG for other muscles, which enables the investigator to choose a clinically involved muscle; secondly, improvement of the program algorithms, both to enhance MUAP detection and to detect outliers, since in myopathies the outliers, particularly of amplitude values, are more often abnormal than the mean value [12]; thirdly, the use of the MUAP area and the area/amplitude ratio as parameters, instead of MUAP duration and amplitude, may circumvent problems of delineation [19]. However, only blinded and prospective comparisons of the diagnostic yield of ADEMG and conventional EMG will establish the usefulness of improved ADEMG techniques.

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