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ELECTROMYOGRAPHY IN CASES OF CONGENITAL AND TRAUMATIC ARM AMPUTATIONS

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Battye, Nightingale & Whillis (1955), were the first to recommend the use of myo-electric potentials for the control of powered prostheses. A model of a prosthesis, in which signals transmitted by skin electrodes has been described by *Kobrinski* (1960) and is subject to further exposition by *McKenzie* (1965). The use of myo-signals has also been discussed in works by *Bottomley* (1962), *Bottomley, Kinnier Wilsen & Nightingale* (1963). Recently, (1965) Bottomley discussed the matching of amplifiers to electrodes showing a resistance up to 200 KOhms. The suitability of the myo-signals is far as their composition of frequency is concerned, has been discussed by *Battye et al.* (1955) and by *Horn* (1963), and more particularly by *Hirsch, Kaiser & Petersén* (1965).

Considerably more searching information than up to the present is however required regarding the characteristics of the muscular action potentials from muscles in the region of amputation and proximal muscles. The present work refers to such an investigation of arm-amputated subjects, in which cases conventional EMG, frequency analysis of the EMG-signals, and determination of the muscle temperature have been performed.

MATERIAL AND METHODS

The material consists of 50 patients from the department of orthopaedics, who have previously been subject to arm amputation. As will be seen from Figure 1, there were 42 cases of traumatic arm amputations, 35 men and 7 women, of ages ranging from 20 to 72 years. Amputation of the arm had been performed from 5 to 68 years previously, with the exception of two cases where it had been carried out 4 months and 12 months earlier, respectively. There were eight cases of congenital amputations

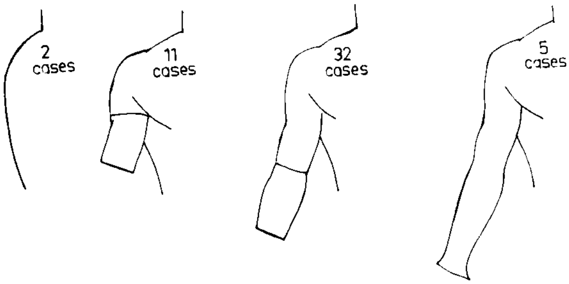


Figure 1.

	50 cases		
Traumatic amputation	42:	35 ♂	7 ♀
Congenital amputation	8:	2 ♂	6 ♀
Right side	31		
Left side	19		

—2 men and 6 women of the ages 10 to 47 years. In 31 cases the amputation was on the right side and in 19 cases, on the left. In 2 cases a complete exarticulation was performed, in 11 cases the amputation was performed on the brachium, in 32 cases on the forearm, and in 5 cases, below the wrist.

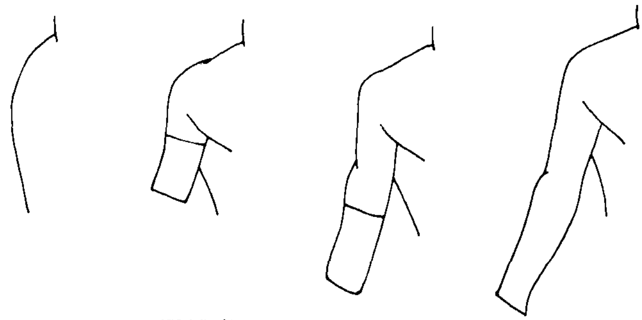
In all the cases, an EMG test of routine type was made on the remaining muscles belonging to the extensor and flexor group of the forearm, M. brachioradialis, M. biceps brachii and M. triceps brachii, M. deltoideus and M. trapezius. Coaxial needle electrodes with an outer diameter of .65 mm. (Disa) were used. The action potentials were recorded by a Disa machine. In 26 cases, a frequency analysis of the EMG signals was carried out by means of a method described by *Kaiser & Petersén* (1965). In this method the signals are filtered by means of octave filters, the output of which is used to express the spectral frequency distribution of the muscle action potentials. The center frequencies of the octave filters were 50 Hz, 200 Hz, 800 Hz and 1600 Hz, and the spectral distribution expressed as the logarithm of the ratio of the different filter outputs as compared to the 200 Hz output.

In 19 cases the temperature of a muscle in the stump remaining after the amputation was determined for comparison with that of the corresponding muscle on the other side. The temperature recordings were made by means of a thermo-element type of instrument from ELLAB, Copenhagen.

RESULTS

The Results of Electromyographic Investigation

The result of the routine EMG test can be seen in Figure 2, which shows the distribution of normal EMG findings, as well as findings of EMG-signs of lower motoneuron lesion. The distribution of these findings appear to be more or less as anticipated, namely, that the majority of the lower motoneuron lesions have been diagnosed in



EMG-findings

	Small signals	Normal	Lower motoneuron lesion	Normal	Lower motoneuron lesion	Normal	Lower motoneuron lesion
Trapezius	2	10		24		2	
Deltoideus		9	1	22		2	
Biceps		4	2	29	1	3	
Triceps		1		22	1	2	
Forearm							
Extensors				17	10	5	
Flexors				20	8	5	
Brachioradialis				18	7	4	

Figure 2.

muscles directly associated with the region of amputation. In some solitary cases, the nature of the injury caused signs of lower motoneuron lesions to appear in more proximal muscles also.

Figure 3 shows some examples of EMG findings. *B.* shows the typical EMG sign of voluntary contraction in cases of lower motoneuron lesion; in this case, amputated on the brachium, the EMG has been recorded from M. biceps brachii. For the sake of comparison, *A* shows the normal "interference" activity from M. biceps brachii on the opposite arm. *C* also shows a somewhat reduced activity. The potentials show here to a great extent a polyphasic form, as illustrated in the separate picture to the extreme right. This surplus of polyphasic potentials may constitute an expression of a reinnervation process, and was noted in this material in six different muscles. Fibrillary action potentials were observed in three muscles only. *D* shows the amazingly favourable activity from islands of trapezius muscle left behind in one of the

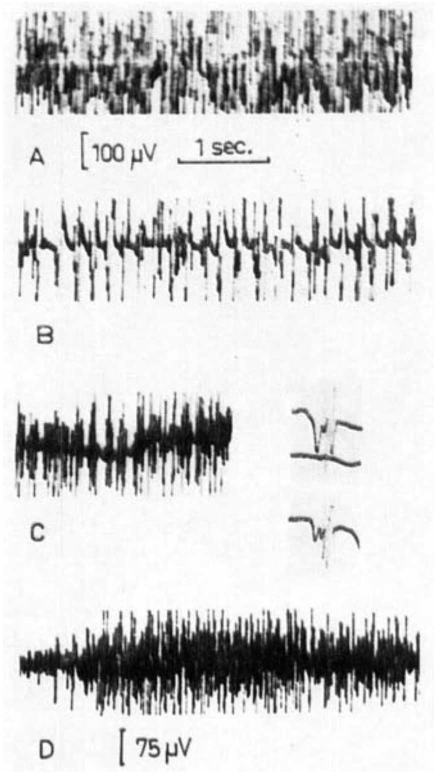


Figure 3. A) normal motor unit activity from M. biceps brachii on the non-amputated side, B) M. biceps brachii on the amputated side in the same patient as in A). Reduced number of potentials on voluntary contraction as in the case of lower motoneuron lesion, C) diminution of motor unit activity on voluntary contraction of muscles in the region of amputation. To the extreme right: polyphasic potentials. A surplus quantity of polyphasic potentials in this case may be a sign of reinnervation, D) activity from a small residue of a muscle corresponding to the position of M. trapezius in an exarticulated patient.

exarticulated cases. In neither of these two cases could these islands of muscle be activated in response to a call for voluntary contraction. When, on the other hand, the patient on request contracted the trapezius on the uninjured side, a simultaneous activation of the muscle islands on the exarticulated side could be observed.

In one particular case the patient had a certain amount of trouble in mobilizing the muscles left behind to perform a contraction, although the muscles in the stump region were in a good state of preservation. The case referred to a forearm amputation at the age of three in a patient now 71 years old.

Apart from these EMG findings, a certain increase in duration of the observed muscle potentials was noted as the only divergent finding in 20 muscles. In order to determine the significance of such an increased duration of potential it would be necessary to collect a number of potentials from different needle position in muscles on the side of amputation for statistical evaluation and comparison with corresponding muscles

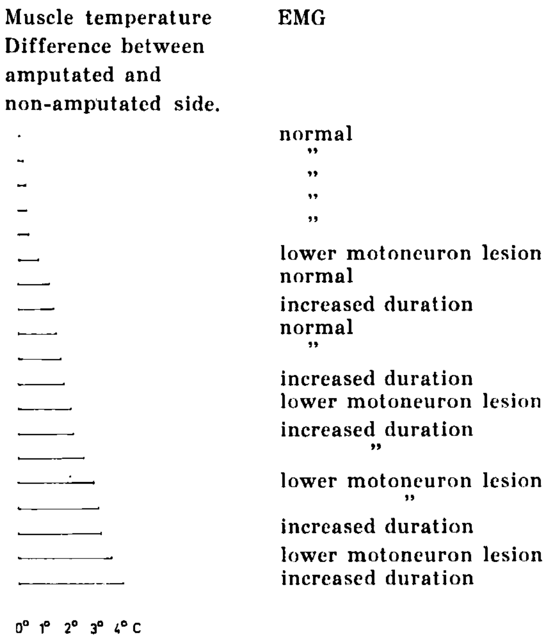


Figure 4. Difference in muscle temperature between amputated and non-amputated sides in collation with EMG findings in the muscles on the amputated side where the temperature of the muscle has been measured.

in the other arm, or with known normal material published. Since, however, parts of muscles left behind often are of insiginificant size, and in view of the fact that the patients as a rule are rather sensitive to needle pricks in the stump region, it has not been possible to assemble a sufficient amount of material of muscle action potentials to accomplish such a statistical analysis.

Result of the Determination of the Muscle Temperature

In 19 of the cases investigated, the muscle temperature was measured in a muscle located within the stump region, as well as in the corresponding muscle of the other arm. The result is shown in Figure 4. The difference in temperature between the two compared muscles is shown to the left. Only in the topmost case is there no difference. In all the other cases the muscle temperature is lower on the amputated side. In 13 of the cases the temperature difference is found to be more than 1 degree Centigrade. When collating the temperature differences with the electromyographic findings to the right, it will be seen that the normal EMG findings are all located in the half section showing slight temperature differences between the amputated and not-amputated sides, whereas all except two cases with lower motoneuron lesion and increased duration of potentials are to be found in the half section displaying the widest differences in temperature.

The Result of Frequency Analysis of the EMG Signals

As already mentioned in the section headed "Materials and method", the frequency analysis is accomplished with the aid of a method described by *Kaiser & Petersén* (1965), in which the passband activity of each one of the 50, 800 and 1600 Hz filters is related to the activity of the 200 Hz filters. This analysis showed that there was no certain difference between right and left sides when muscles on the amputated side of the type which showed normal EMG images on routine EMG were compared with corresponding muscles on the other side. In the same way, no deviations were traced on comparison of such muscles on the amputated side which, on routine EMG, showed somewhat increased duration of muscle action potentials with the corresponding muscles on the other side. In the matter of frequency spectrum from muscles showing electromyographic signs of lower motoneuron lesions, however, the reduction in amplitude of the 800 and 1600 Hz signals was considerably greater than in the control material, and on the basis of these facts it was possible to decide that the myo-signals from muscles showing EMG signs of lower motoneuron lesion are less useful for the purpose of controlling a prosthesis. The section headed "Material and method" also mentions the spectral distribution of signals revealed via the output of the various filters expressed as the logarithm of ratio of the different filter outputs as compared with the 200 Hz filter output. The decibel scale (dB) is used to indicate the observed differences between the output levels. Thus 20 dB, corresponding to a ratio of 10, is indicated by an output voltage of 2 volts, corresponding to .1 v. per dB. On evaluating of the results of the analysis I have taken the mean value ratios (expressed in dB) of log. 800 Hz output: 200 Hz output, and log. 1600 Hz output: 200 Hz output. We then consider 15 dB as the upper determinant of acceptability for control of a servo prosthesis. The reason for this approximate limit is that a poor representation of signals in the 800–1600 range (great dB values) would demand a high amplification of the EMG, which in its turn would decrease the signal to noise level.Figure 5 shows a divisioning of muscles on the am-

	Forearm						
	Extensor	Flexors	Brachio-radialis	Biceps	Triceps	Deltoideus	Trapezius
				—		—	—
						—	—
						+	+
				—	—	+	+
				+		—	+
	—	—	—	+	—	—	—
	—	—	—	—	—	—	+
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Figure 5. Mapping out of the portion of the material where conventional EMG or frequency analysis of EMG could furnish information as to the suitability (+) or non-suitability (—) of the muscles for producing signals for control of powered prosthesis. See text for further details.

putated side examined in the manner stated above, where the symbol— means either that the stated dB figure is higher than 15 or that routine EMG test shows signs of lower motoneuron lesion, or both, whereas the symbol + indicates that the dB value is 15 or less in a muscle which on routine EMG shows no sign of lower motoneuron lesion. The most fruitful section of our material deals with patients who have been amputated below the elbow. From the sketches it can be seen that six of these have no muscle in the forearm stump which is able to produce suitable signals according to our criteria. In all, five patients show suitable signals from at least two muscles in the forearm stump. On the other hand, not less than 13 of the 19 cases have at least three muscles on the amputated side which can produce suitable signals. Obviously, the number of suitable muscles indicated in the illustration constitutes a minimum number, since in each individual case only certain muscles of the flexor and extensor group of the forearm have been subject to investigation.

DISCUSSION

The present investigation has produced evidence to support the fact that it is possible with the aid of electromyography and frequency analysis of the myopotentials to effect a mapping out of the muscles which might be of use in producing signals for control of a powered prosthesis. Certain data from the present investigation may be subject to modification as some of the amputations were performed a long time age. In the present work, therefore, there is no doubt that a smaller number of findings of so-called denervation potentials, as well as a reduced quantity of polyphasic potentials as expressions for reinnervation, exist than would be the case in the course of an examination closely associated with the amputation. I also plan to extend the investigation by adding a suitable number of cases of more immediate association with the amputation.

Of special interest is the 71-year old patient who had his forearm amputated at three years of age. During the examination he had difficulty in effecting a reasonable voluntary contraction, although the muscles in the stump region were in a good state of preservation. It is possible that disturbances in the central innervation were of significance in this case, possibly due to the early date of the amputation. Similar innervation disturbances have been stated to be much more common in material of leg amputations. (*Blom, Hagbarth, Lemperg & Ottoson* 1965).

On comparison with corresponding muscles on the non-amputated side, the temperature of muscles located within the amputation region was found to be lower. This may possibly explain the comparatively common finding of muscle action potentials of extended duration. It could, for example, be assumed that the lower muscle temperature has a special influence on the most peripheral nerve branches, resulting in the spreading of the time taken for the nerve transmission, which in turn may result in an extension of the duration of muscle potentials. Such an extended duration of the muscle action potentials due to a lowering of the muscle temperature, has previously been proved by *Buchthal, Pinelli & Rosenfalck* (1954).

SUMMARY

Fifty cases of arm-amputated patients have been subject to investigation; traumatic arm amputation in 42 cases, 35 men and seven women, congenital arm amputation in eight cases, two men and six women. In 31 cases, amputation had taken place on the right arm, and in 19 cases, on the left. In two cases, it was a matter of complete exarticulation, in 11 cases, amputation somewhere above the elbow, in 32 cases, somewhere below the elbow, and in 5 cases, below the wrist.

In all the cases a routine EMG test was carried out. Signs of lower motoneuron lesion appeared in a number of examined muscles, principally within the region of the stump. Frequency analysis of the EMG signals was also carried out according to the method described by *Kaiser & Petersén* (1965). On the basis of the result of the conventional EMG test and frequency analysis an attempt was made to map out the muscles on the amputation side which will be suitable or unsuitable for producing signals for control of powered prosthesis.

RESUME

50 cas de malades amputés du bras ont fait l'objet d'un examen: amputation traumatique du bras dans 42 cas, 35 hommes et 7 femmes, amputation congénitale du bras dans 8 cas, deux hommes et six femmes Dans 31 cas, il était question de l'amputation du bras droit et dans 19 cas du bras gauche. Dans deux cas, il s'aggissait d'une exarticulation compléte, dans 11 cas l'amputation avait eu lieu quelque part au-dessus du coude, dans 32 cas, quelque part au-dessous du coude et dans 5 cas au-dessous du poignet.

Dans tous les cas examen routinier par électromyographie (EMG) a été pratiqué. Des signes de lésion de neurone moteur inférieur sont apparus dans un certain nombre de muscles examinés, principalement

dans la région du moignon. Une analyse de la fréquence des signaux EMG a aussi été pratiquée selon la méthode décrite par *Kaiser & Petersén* (1965). Sur la base du résultat du test conventionnel EMG et de l'analyse de la fréquence, on a tenté de voir si les muscles du côte de l'amputation sont aptes ou non à produire les signaux de contrôle des prothèses.

ZUSAMMENFASSUNG

Fünfzig Fälle von Arm-amputierten Patienten wurden untersucht, traumatische Armamputation in 42 Fällen, 35 Männer und sieben Frauen, angeborene Armamputationen in acht Fällen, zwei Männer und sechs Frauen. In 31 Fällen hatte die Amputation am rechten und in 19 Fällen am linken Arm stattgefunden. In zwei Fällen handelte es sich um vollständige Exartikulation, in 11 Fällen um Amputation oberhalb des Ellbogens, in 32 Fullen distal vom Ellbogen und in 5 Fällen distal des Handgelenkes.

In allen Fällen wurde eine routinemässige EMG ausgeführt. Zeichen von Beschädigung des distalen Motorneuron zeigten sich in einer Anzahl der untersuchten Muskeln, Hauptsählich in der Stumpfregion. Frequenzanalyse der EMG Signale nach der von *Kaiser & Petersén* (1965) beschriebenen Methode wurde ebenfalls vorgenommen. Auf der Basis von konvetionellen EMG Prüfungen und der Frequenzanalyse wurde der Versuch unternommen die Muskeln der amputierten Seite herauszufinden, die geeignet oder ungeeignet sein würden Signale zur Kontrolle einer aufgeladenen Prothese hervorzubringen.

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