

Comparison of the Electromyographic Activity of Different Zones of the *Abductor digiti minimi manus* Muscle in Search of a Functional Compartmentalisation

Comparación de la Actividad Electromiográfica de Diferentes Zonas del Músculo *Abductor Digiti Minimi manus* en Busca de una Compartimentación Funcional

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SUMMARY: There is evidence demonstrating the presence of functional compartmentalisation (FC) in some skeletal muscles. This means that the motor units (MU), grouped in certain areas of the muscle, show different levels of activation in comparison to those located in other zones. This has only been described in large muscles whose morphology proves the existence of a FC. However, there is no background information about small muscles, such as the *Abductor digiti minimi manus* (ADM). The objective of this study was to compare the activation of the MU in different zones of the ADM to support the hypothesis of the existence of a FC in the ADM. By using a cross-sectional, analytical, observational study, the activity of the MUs in the ADM was assessed in 12 volunteers (age 21 ± 1.6 years old; weight 75.3 ± 8 kg; height 176.2 ± 7.3 cm; average \pm standard deviation). The activity of MUs was evaluated using high-density surface electromyography (HD-sEMG) with an array of 64 electrodes arranged two-dimensionally. This allowed us to record the activity of the MUs in three zones of the ADM (Z1: dorsal zone; Z2: dorsal-palmar zone and Z3: palmar zone). Electromyographic recordings were obtained during voluntary isometric contractions of the ADM at 20, 40, 60 and 80 % of the maximum voluntary contraction (MVC). The comparison of the activation levels of MUs between the three zones was carried out using a mixed model analysis of covariance. The results showed a significant difference between the dorsal and palmar zones at 40 % of the MVC ($p= 0.03$), and between the dorsal and dorsal-palmar zone at 80 % of the MVC ($p= 0.03$). The results obtained in the evaluated sample support the hypothesis of the existence of FC in the ADM. However, further research is needed to determine with greater certainty the presence of this compartmentalisation in the ADM.

KEY WORDS: functional compartmentalisation, neuromuscular compartmentalisation; *Abductor digiti minimi manus*, high-density surface electromyography.

INTRODUCTION

The *Abductor digiti minimi* of hand (ADM) is the most superficial of the muscles of the hypothenar eminence. Its origin is found in the pisiform bone, in the pisohamate and pisometacarpal ligaments, as well as in the tendon of flexor carpi ulnaris (Palastanga *et al.*, 2002), some authors include the hamulus process of the hamatum and the palmar carpal ligament to this insertion (Gudemez *et al.*, 2002). It is distally inserted in the ulnar region of the first phalanx of the little finger and in the dorsal digital expansion (Palastanga *et al.*), as well as in the dorsal expansion of the extensor digiti minimi muscle, the distal digital fascia and the skin at

the level of the proximal interphalangeal joint (Soldado-Carrera *et al.*, 2000; Gudemez *et al.*).

The ADM is innervated by the deep motor branch of the ulnar nerve, which passes across the muscle at an average distance of 31mm, distal to the proximal edge of the pisiform. From a morphological point of view, it has been recognised that the ADM consists of a single fusiform belly (Testut & Latarjet, 1959; Murata *et al.*, 2004). However, more recent studies have more frequently shown the presence of two bellies, one medial and other lateral (Santo Neto *et*

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al., 1984; Buarque de Gusmão *et al.*, 2005), the latter being the most superficial (Gudemez *et al.*).

The action of the ADM involves abduction of the little finger and flexion of the metacarpophalangeal joint. Due to its proximity to the dorsal digital expansion, the ADM is a synergist muscle in the extension of the interphalangeal joint. In addition, this muscle plays an important role in grasping large objects when the fingers are extended (Palastanga *et al.*).

The action of the ADM, as a whole muscle, lies in the activation of its motor units (MUs). In this context, there are electromyographic (EMG) studies that demonstrate the existence of heterogeneity in the recruitment of MUs, which is dependent on their specific location within the muscle and on the characteristics of the motor task performed. This heterogeneity in activation has led to the hypothesis that certain muscles could be organised neuromuscularly as functional compartments (FC), beyond the existence that is demonstrable at a morphological level. This would imply that the MUs grouped in certain muscle regions would show different activation levels that differ from the MUs located in other zones of the same muscle (Brown *et al.*, 2007). In this sense, several studies have demonstrated the existence of this neuromuscular compartmentalisation (NMC). Staudenmann *et al.* (2009) recorded the differential activation of the different regions of the triceps surae, in relation to foot movements and the direction of the ground reaction force (GRF). Moreside *et al.* (2008) demonstrated the existence of differential recruitment of the upper and lower portions of the rectus abdominis muscle in different low intensity-exercises. While studying the recruitment of different regions of the rectus femoris in exercises combining hip flexion and knee extension, Watanabe *et al.* (2012) demonstrated the presence of at least two regions with differential recruitment, so that two NMC were identified. Later, Guzmán-Venegas *et al.* (2015) demonstrated the existence of three FCs in the superficial masseter muscle during submaximal bite-force magnitudes.

The relatively large size, and the association with gross motor tasks are characteristic of the muscles that have been the subject of study in the search for their NMC. On the contrary, the intrinsic muscles of the hands have not been subject of studies in the search of possible NMCs, as these muscles are seen to be small and associated with quite fine tasks, implying that their motor units are relatively small (Santo Neto *et al.*, 1998). For this reason, it is of interest to test the hypothesis of the existence of possible FC in muscles with these characteristics. The objective of this study was to compare the activation of the MUs in different zones of the ADM in order to support the hypothesis of the existence of a FC in this muscle.

MATERIAL AND METHOD

By using a cross-sectional, analytical, observational study (Hernández Sampieri *et al.*, 2014), a sample of 12 healthy volunteers (age 21 ± 1.6 years old; weight 75.3 ± 9.8 kg; height 176.2 ± 7.3 cm; average \pm standard deviation) was evaluated. The following exclusion criteria were applied in the recruitment of volunteers: i.- history of musculoskeletal injuries to the upper limbs in the past 6 months (for example, fracture, muscle tear, sprain, etc.); ii.- history of both central and peripheral neurological conditions or diseases; iii.- consumption of substances such as alcohol and/or drugs in the previous 24 hours; iv.- habitual practice of sports that involve the use of the muscles of the hand (for example, climbing, judo, etc.); v.- use of psychotropic drugs in the past 6 months (e.g. olanzapine, risperidone, quetiapine, droperidol, clonazepam, sertraline, etc.). All volunteers gave written consent by signing an informed consent document. All procedures in this study were in accordance with the criteria of the Declaration of Helsinki and were approved by the local ethics committee (Date of approval: 2018-15-05 code: SCEC201824).

Procedure. All assessments were performed in a laboratory environment. Each volunteer was asked to sit in a chair in front of a table, on which a specially designed device was placed to place the hand and part of his/her forearm (Fig. 1A). Throughout the assessment, the elbow was kept in a 90° flexion position. In the device, a force sensor (3E151/014, Kinetecnics, Santiago de Chile, Chile) was installed to assess the isometric force developed by the ADM (Fig. 1B). Likewise, the device allowed for the installation of a matrix of 64 surface EMG electrodes (ELSCH064NM5, OT Bioelettronica, Torino, Italy) which was arranged in 4 rows of 13 electrodes each, and one row of 12 electrodes (Fig. 1C). This allowed us to record the electrical activity of the MUs in the different zones of the ADM. The electrode array was placed on the ADM, in a way that its rows were arranged parallel to the muscle fibres. In the first instance, the maximum voluntary isometric contraction (MVIC) of the ADM was assessed using the force sensor. Each volunteer was asked to perform three maximal contractions of the ADM, lasting four seconds, with one minute of rest between them. From these three recordings the maximum value was determined, and that was considered the MVC (Guzmán-Venegas *et al.*).

Prior to EMG recordings, the skin on the ADM was cleaned with an abrasive paste (Everei, Spes Medica, Battipaglia, Italy), in order to reduce the skin impedance. The recorded tests consisted of performing submaximal voluntary isometric contractions of the ADM, equivalent to

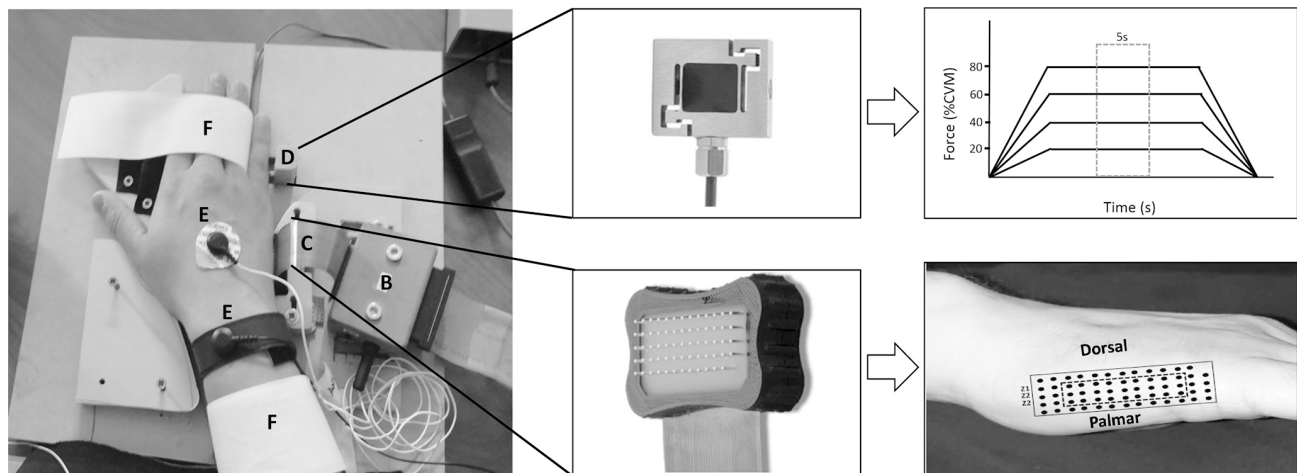


Fig. 1. Mounting details for electromyographic records of *abductor digiti minimi manus*(ADM). General view of set-up for measuring the activity of the motor units (MU) of ADM (1A), components of set-up: High-density electromyographic signal preamplifier(B). 64-electrode surface electromyography (sEMG) matrix (C). Force sensor(D). Reference electrode and cuff for electromyographic amplification(E). Velcro fastening for wrist and fingers (F).

Mounting sensors: force sensor used to measure the isometric force of the ADM(1B). Recording electrode matrix, (1C) detail of the arrangement of the 64s EMG electrodes. Graph used to control the force of the ADM, (1D) force paradigms performed by the volunteers at levels of 20, 40, 60 and 80 % of maximum voluntary contraction (MVC). Location of the electrode array on the ADM(1E). The zone has been highlighted with the red dashed line, and the electrodes that were used in the analysis of the MUs activity. The designation of recording zones are Z1: dorsal zone; Z2: dorsal-palmar zone and Z3: palmar zone.

20, 40, 60 and 80 % of the MVC, which were conducted following a pre-established paradigm (Fig. 1D). The magnitude of the contractions was controlled by visual feedback from the ADM force record, which was superimposed over the paradigms, and both were graphed in real time on a screen located in front of the volunteer. There was a break of five minutes between each test, and their order of execution was randomly determined. Before the final recording, testing samples were carried out at 50 % of the MVC in order to familiarise the volunteer with the procedure. The EMG signals were recorded using high-density EMG equipment (EMG-USB2, OT-Bioelettronica, Torino, Italy), and they were amplified in a monopolar manner with a gain factor of 500 units. The signals were digitised with a sampling frequency of 2048 hz in a bandwidth from 10 to 500 hz (Guzmán-Venegas *et al.*). A synchronised capture of both EMG and force sensor signals was made, which were stored using data collection software (OtBiolab version 2.6, OP Bioelettronica, Torino, Italy).

EMG signal processing. EMG data, corresponding to the central 5 seconds of each test (Fig. 1D), were processed in order to consider data in a stable state. For the analysis of the signals, the outermost rows of the matrix were not considered in the analysis. Similarly, the most proximal and distal channels were not considered in the analysis. The foregoing was decided in order that the processed signals were found with greater certainty within the anatomical

territory of the ADM. The 27 monopolar signals considered in the analysis were differentiated in the direction of the matrix rows (Z1, Z2 and Z3), thus, each row had 8 differential EMG signals (24 in total). Then, the amplitude of the signals was assessed calculated using the root mean square (RMS), using a 250 milliseconds window. Thus, for each signal, 20 RMS amplitude values were obtained corresponding to the 5 seconds of analysis. Therefore, for each row, a total of 160 RMS values were obtained. To represent the activity of the MUs of each row, and thus of the different regions of the ADM, the median of the 160 values was considered. The rows were assigned according to their location in the ADM, as follows: Z1: dorsal zone; Z2: dorsal-palmar zone, and Z3: palmar zone, as shown in Figure 1E.

Statistical analysis. Initially, a descriptive statistics analysis of the activation levels of the different zones of the ADM was carried out. The comparison of the activation levels of the MUs recorded in the different dorsal, dorsal-palmar and palmar zones (Z1, Z2 and Z3, respectively) was carried out through a mixed model analysis of covariance (Littell *et al.*, 2006). All statistical analyses were carried out in two tails and with a statistical significance level of 95 %. Statistically significant differences were those associated with a p-value <0.05. All analyses were performed using statistical analysis software (STATA/SE 12.1. Stata Corp. College Station, USA).

RESULTS

The EMG amplitudes recorded in the three zones of the ADM (Z1, Z2 and Z3) at the different contraction levels are shown as averages and standard deviation in Table I. At the contraction levels of 20 and 60 % MVC, no significant differences between the three zones were observed. At 40 % MVC, the dorsal zone (Z1) showed greater activity than the palmar zone (Z3) ($p = 0.039$). Similarly, at 80 % MVC, the

dorsal zone showed greater activity than the dorsal-palmar zone ($p = 0.037$) and there was a tendency for the dorsal zone to have greater activity than the palmar zone ($p = 0.053$). P-values of all comparisons are presented in Table II.

Table I. Comparison of the normalised electromyographic amplitude between three zones (Z1, Z2 and Z3) of the *abductor digiti minimi* (ADM) muscle, during contractions at different levels. The amplitudes are shown as averages (standard deviation) of the EMG amplitude adjusted to the MVC.

%MV	(Z1)	(Z2)	(Z3)	Inter-regional
20%	27.1 (20.8)	24.4 (12.5)	23.0 (9.4)	None
40%	54.9 (31.7)	52.4 (30.6)	48.7 (22.0)	Z1>Z3†
60%	66.0 (22.7)	68.2 (25.9)	64.5 (15.9)	None
80%	94.6 (37.6)	78.3 (21.7)	79.5 (22.7)	Z1>Z2†

MVC: Maximum voluntary contraction.

† P-value < 0.05 in mixed model analysis.

Z1: dorsal zone; Z2: dorsal-palmar zone and Z3: palmar zone.

Table II. P-values calculated from the comparison made using the mixed model analysis of covariance.

% MVC		(Z1)	(Z3)
20	(Z1)	--	0.224
	(Z2)	0.427	0.673
40	(Z1)	--	0.039 †
	(Z2)	0.407	0.216
60	(Z1)	--	0.791
	(Z2)	0.716	0.530
80	(Z1)	--	0.053
	(Z2)	0.037 †	0.881

MVC: Maximum voluntary contraction.

† P-value < 0.05 in mixed model analysis.

Z1: dorsal zone; Z2: dorsal-palmar zone and Z3: palmar zone.

DISCUSSION

The results of this research show that at certain levels of muscle contraction (40 and 80 % MVC) the dorsal, dorsal-palmar and palmar zones of the ADM show differences in the recruitment of the MUs located in these zones, which could support the hypothesis of the existence of a functional or neuromuscular compartmentalisation of the ADM.

While it is true that the ADM has been the subject of previous electrophysiological studies (Farina *et al.*, 2008; Bouillard *et al.*, 2012), to date, these studies have not focused on examining the heterogeneity in the recruitment of the MUs. The results of the present study bring to light the possible existence of a FC; however, the results are not categorical, since at certain levels of contraction (20 and 60 % MVC), differences in the recruitment of MUs are not demonstrated. In this study, the activity of the MUs was examined, considering three zones: dorsal, dorsal-palmar and palmar (Z1, Z2 and Z3, respectively), which were divided according to the fusiform morphology of the ADM. From a mechanical perspective, it is difficult to justify the presence of differential activation of the MUs in different zones of a muscle whose fibres fusiformly converge to a single tendon. In comparison with another type of morphology—such as that of the masseter muscle—this turns out to be more justifiable, given that it

has multiple insertion sites in the jaw, which suggests functional differences between the MUs of its different portions. Indeed, the existence of a FC has been evidenced in this muscle, using a fundamentally mechanical rationale (Guzmán-Venegas *et al.*). However, there is background information about muscles with a single tendon in which the behaviour of their MUs describes the existence of a FC. Blanksma *et al.* (1997) demonstrated the heterogeneous recruitment of MUs from the temporalis muscle in humans during different chewing tasks. Furthermore, Wickham & Brown (2012) showed the existence of a FC in the pectoralis major and latissimus dorsi muscles, in relation to different movements of the shoulder. Likewise, Méndez *et al.* (2013) reported the existence of three functional compartments in the fibularis longus muscle.

The presence of the differential recruitment pattern between the three zones recorded in the ADM could have a morphological substrate related to the three motor branches emerging from the motor branch of the ulnar nerve that innervate the ADM (Gudemez *et al.*). Possibly, each of these motor branches could innervate the muscle fibres located in the areas studied; however, the corroboration of this assumption should be done with histochemical and/or stereoscopic studies.

The differential recruitment of the MUs could be attributed to their different properties. It is well known that MUs have different metabolic and mechanical properties, which differentiate them in terms of size, rate of force production, resistance to fatigue and activation threshold, classifying them into fast, fast-slow and slow motor units (Burke *et al.*, 1971; McDonagh *et al.*, 1980). In general, the fast MUs turn out to be large with a high activation threshold and low resistance to fatigue, while the slow ones are smaller in diameter with a low activation threshold, and they are more resistant to fatigue (Henneman *et al.*, 1965). On the other hand, it has been described that the distribution of the different types of MUs within a muscle proves to be heterogeneous, in which a greater amount of MU of a certain type is concentrated in certain regions (Korfage & Van Eijden, 1999; Rainoldi *et al.*, 2000). For this reason, the differences in the activation levels of the MU of the three zones studied could be attributed to the heterogeneous distribution of the MU type within the ADM. The results indicate that the MUs located in the dorsal zone of the ADM showed greater activation than the MUs of the dorsal-palmar and palmar zones, being significant at 40 and 80 % of the MVC. The foregoing could be interpreted as a higher concentration of slow MUs in this area, since this type of MU shows a lower activation threshold; however, this needs to be analysed by histochemical studies.

Within the limitations of this study is the fact of studying the activity of MUs of the ADM only in the main motor function of the ADM. Future research should consider, in addition to the abduction, the flexion component of the metacarpophalangeal joint, as well as functional tasks such as grasping.

CONCLUSION

The results obtained in the evaluated sample support the hypothesis of the existence of functional compartmentalisation in the ADM. However, further research is needed to determine with greater certainty the topographic behaviour of the MUs of the ADM.

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RESUMEN: Existe evidencia que demuestra la presencia de una compartimentalización funcional (CF) en algunos músculos esqueléticos. Aquello se traduce en que las unidades motoras (UM) agrupadas en ciertas zonas del músculo, presentan diferentes niveles de activación a las ubicadas en otras regiones. Esto solo ha sido descrito en músculos grandes, cuya morfología justifica la existencia de una CF. Sin embargo, no existen antecedentes de aquello en músculos pequeños, tales como el *abductor digiti minimi manus* (ADM). El objetivo de este estudio fue comparar la activación de las UM en distintas zonas del ADM, con la finalidad sostener la hipótesis de la existencia de una CF en el ADM. Mediante un estudio observacional analítico transversal se evaluó la actividad de las UM del ADM en 12 voluntarios (edad $21 \pm 1,6$ años; peso $75,3 \pm 8$ kg; altura $176,2 \pm 7,3$ cm; promedio \pm desviación estándar). La actividad de las UM, se evaluó mediante electromiografía de superficie alta densidad usando una matriz de 64 electrodos dispuestos bidimensionalmente. Esta permitió registrar la actividad de las UM en tres zonas del ADM (Z1: zona dorsal; Z2: zona dorso-palmar y Z3: zona palmar). Los registros electromiográficos fueron obtenidos durante contracciones isométricas voluntarias del ADM al 20, 40, 60 y 80 % de la contracción voluntaria máxima (CVM). La comparación de los niveles de activación de las UM entre las tres zonas fue realizada mediante un análisis de modelos mixtos de covarianza. Los resultados indicaron que existió diferencia significativa entre la zona dorsal y palmar al 40 % de la CVM ($p=0,03$), y entre la zona dorsal y dorso-palmar al 80 % de la CVM ($p=0,03$). Los resultados obtenidos en la muestra evaluada sostienen la hipótesis de la existencia de una CF en el ADM. Sin embargo, son necesarias más investigaciones para establecer con mayor certeza la presencia de esta compartimentalización en el ADM.

PALABRAS CLAVE: Compartimentalización funcional; Compartimentalización neuromuscular; *Abductor digiti minimi*; Electromiografía de alta densidad.

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