Original article

Eccentric exercise and muscle fiber conduction velocity: a literature review

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Summary

Introduction: According to the literature, eccentric exercise has been considered a precursor of neuromuscular changes generated by post-exercise damage, mainly causing an alteration in the muscle cell membrane. Muscle fiber conduction velocity (MFCV) has been one of the physiological variables that have allowed to quantify this alteration. Some investigations have shown a decrease in the MFCV after eccentric exercise protocols; however, few studies have confirmed these findings. This review aimed to describe the recent scientific evidence that reports changes in the MFCV after eccentric exercise protocols.
Material and method: From 265 articles, 6 articles were selected from EBSCO and MEDLINE platforms with a temporal filter of 10 years (between 2010 and April 2020), using inclusion/exclusion criteria predetermined. Firstly, the information from eccentric exercise effect on MFCV, and exercise protocols were described. Secondly, the techniques used to record electromyographic signals and some criteria to determine the MFCV were reported.
Results: Modifications of MFCV can be observed after eccentric exercise in almost all selected articles. At the same time, a decrease of this variable was observed in four studies, associated with the biceps brachii and two portions of the quadriceps muscles. However, one article describes an increase of the MFCV in the vastus lateralis quadriceps.
Conclusion: The articles suggest that eccentric contractions could modify the MFCV behavior of some muscles. However, evidence is still lacking to describe the real cause of these changes.

Key words:
Muscle conduction velocity. Electromyography. Eccentric exercise. Musculoskeletal.

Ejercicio excéntrico y velocidad de conducción de la fibra muscular: una revisión bibliográfica

Resumen

Introducción: Según la literatura, el ejercicio excéntrico ha sido considerado como un precursor de cambios neuromusculares generado por el daño post-ejercicio, causando principalmente una alteración en la permeabilidad de la membrana celular muscular. Una de las variables fisiológicas que ha permitido cuantificar esta alteración, es la velocidad de conducción de la fibra muscular (VCFM). Algunas investigaciones han mostrado una disminución de esta variable posterior a protocolos de ejercicio excéntrico; sin embargo, existen pocos estudios que confirmen este hallazgo. Este estudio tuvo como objetivo describir la evidencia científica reciente que reporte cambios en la VCFM después de protocolos de ejercicio excéntrico.
Material y método: De 265 artículos, se seleccionaron 6 artículos de las plataformas EBSCO y MEDLINE con un filtro temporal de 10 años (entre 2010 y abril de 2020), usando criterios de inclusión/exclusión predeterminados. En primer lugar, se describió el efecto del ejercicio excéntrico sobre la VCFM y los protocolos de ejercicios. Secundariamente, se reportaron las técnicas utilizadas para registrar la señal electromiográfica, y algunos criterios para determinar la VCFM.
Resultados: Es posible observar modificaciones de la VCFM luego del ejercicio excéntrico en casi todos los artículos seleccionados. Al mismo tiempo, se observa una disminución de esta variable en cuatro estudios, asociado a los músculos bíceps braquial y dos porciones del cuádriceps. Sin embargo, un artículo describe un incremento de la VCFM en el vasto lateral del cuádriceps.
Conclusión: Los artículos sugieren que las contracciones excéntricas podrían modificar el comportamiento de la VCFM de algunos músculos. Sin embargo, aún falta evidencia para describir la real causa de estos cambios.

Palabras clave:
Velocidad de conducción muscular. Electromiografía. Ejercicio excéntrico. Musculoesquelético.

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Introduction

From the perspective of training and physical rehabilitation, muscular strength contractions have been useful in therapy, given the neuromuscular adaptations post-exercise[1]. However, questions are still raised based on the possible causes of these adaptations, considering concentric, isometric and eccentric contractions[2,3]. In daily life and in sporting practice, these muscular contractions tend to work together4-6. However, there are essential characteristics that classify eccentric contradictions as the most demanding, considering characteristics such as variation in muscular fibre length and damage to the relevant tissue post-exercise[3,7].

From the physiological perspective, eccentric exercise protocols have demonstrated great selective mechanical damage to fast contracting muscular fibres (type II) and, at the same time, acute disruptions in the peripheral tissue[8]. Some studies link the aforementioned effects to greater mechanical stress on the fast fibres during this type of contractions[8,9], also reporting chemical imbalances between the intracellular and extracellular medium of the damaged fibres[10–12], and differences in the neural control strategy centrally[12]. One of the electromyographic variables that has made it possible to describe possible effects generated by eccentric exercise in muscles is the muscle fibre conduction velocity (MFCV), defined as the speed at which an action potential is propagated through the sarcolemma of a musculoskeletal fibre[13]. This variable reflects possible peripheral muscle changes, as the product of exhaustion[13], a pathology associated with the musculoskeletal system[14,15], or the effect of eccentric exercise[16,17]. According to this latter point, some research has reported a modification of the MFCV against its baseline levels after applying a protocol of eccentric contractions, considering different muscles and eccentric exercise protocols[9,11,18]. One example might be the results reported by Nasrabadi *et al*. 2018, who demonstrated a drop in the MFCV magnitude immediately after and then 24 hours post-exercise in two portions of the quadriceps (vastus lateralis (VL) and the vastus medialis obliquis (VMO))[19]. However, an additional finding described by the aforementioned research corresponds to the level of MFCV reduction when comparing both muscles, greater for the VMO[19]. According to the authors, these differences might be justified by the morphological variations of both muscles, considering the high percentage of fast fibres for the VMO, which would be more susceptible to damage generated by eccentric contractions[19].

There is little research that evaluates the MFCV before and after eccentric training protocols, and at the same time, there are no studies that compile the MFCV variation produced by this type of contractions. According to what has been proposed, the aim of this research was to describe recent scientific evidence that reports changes in MFCV produced by eccentric exercise. The results presented in this bibliographic review focus on the description of the two main points considered by the researchers: a) the effect of eccentric exercise on the MFCV and b) eccentric exercise protocols used to induce muscle damage. At a secondary level, and working from the studies compiled, an attempt was made to describe the tools used to register the EMG signal and selection of some criteria that determine the MFCV.

Material and method

Design

Bibliographic review of articles published from 2010 to April 2020.

Inclusion and exclusion criteria

Articles were included with the following criteria: English language; assessment of the motor unit action potentials (MUAP) with surface electromyography on the musculoskeletal system; before-after experimental studies in humans (healthy persons and/or athletes) with application of eccentric exercise protocols at muscle level; estimation of the MFCV from the propagation of the MUAPs registered with surface EMG. Regarding the exclusion criteria used, reviews were ruled out, as they were considered nonexperimental studies, which lack methodological application to measure the MFCV. Additionally, articles that used persons with any type of pathology were also excluded.

Search strategy

The EBSCO and MEDLINE platforms were used to search the literature; the search used thesauruses or free terms. In the case of the thesauruses, the MeSH terms "Humans", "Electromyography" and "Muscle Contraction/physiology" were used. In the case of the free terms, "Muscle fiber conduction velocity" and "eccentric" were used. These terms were combined with the Boolean connector AND, applying a time filter of 10 years between 2010 and April 2020.

Selection of articles

The articles were firstly selected by title and abstract. Subsequently, only before-after experimental studies were considered, selecting any which reflected the following aspects in the complete text reading: a) the effect of eccentric exercise on MFCV, b) eccentric exercise protocols used to induce muscle damage, and c) description of techniques used to register the EMG signal and selection of some criteria to determine the MFCV. These points were used by two reviewers, who initially generated the search independently. Then, along with a third reviewer, articles were selected based on the complete text reading.

Results

Working from the aforementioned strategy, the initial search brought up a total of 265 articles. By eliminating duplicates and considering the reading of the title, abstract, classification as before-after experimental, only 8 articles remained. Of these, only two were excluded, considering their complete reading alongside the selection criteria. Finally, 6 scientific articles were selected to develop this bibliographic review (Table 1).

Effect of eccentric exercise on the MFCV

Two studies calculated the post-exercise eccentric MFCV in the biceps brachii during sub-maximum isometric contractions (10, 20, 30, 40, 50 and 75% of the maximum voluntary contraction (MVC)[9,11], both reported significant drops in the MFCV beyond 40% of the MVC, observed two hours post-exercise (2H). However, only one study reported the average values of the MFCV (during 40% MVC: 4.4 ± 0.3 m/s (prior to the exercise (PRE)) *vs* 4.2 ± 0.3 m/s (2H), $p < 0.05$; 50% MVC: 4.5 ± 0.3 m/s (PRE) *vs* 4.2 ± 0.3 m/s (2H), $p < 0.01$; 75% MVC: 4.4 ± 0.3 m/s (PRE) *vs* 4.2 ± 0.3 m/s (2H), $p < 0.01$)[9]. In addition, studies that assess the

Table 1. General characteristic sample from the selected studies, eccentric exercise protocols and results obtained based on the (before-after) behaviour of the muscle fibre conduction velocity (MFCV).

Authors	Participants (number/ muscle evaluated)	Eccentric exercise protocol	Measuring times	%MVC when registering the EMG signal	Variation in the post-exercise MFCV	Results/ MFCV variation
Piitulainen, *et al.* 2010.	n=9/ Biceps brachii	Fifty repetitions of maximum eccentric contractions on an isokinetic machine (1 rad/s) divided into 2 phases (F1: 65º-120º/F2: 120º-175º). A 3-second rest was determined between phases, with 20 seconds between each repetition.	Before the protocol (PRE) and two hours (2H), two days and four days after the protocol.	10%, 20%, 30%, 40%, 50%, 75% and 100% of the MVC.	↓	100% MVC: 4.1 ± 0.3 m/s (PRE) *vs* 3.8 ± 0.4m/s (2H), $p < 0.01$.
Piitulainen, *et al.* 2011.	n=24/ Biceps brachii	Three series of twenty repetitions of maximum eccentric contractions on an isokinetic machine (60º/s) in a 110º range of movement (65º-175º) with a break of 15 seconds between repetition and 5 minutes between series.	Before the protocol (PRE), immediately afterwards, 2 hours (2H) and 1 day after the protocol.	100% of the MVC	↓	4.16 ± 0.34m/s (PRE) *vs* 3.43 ± 0.44m/s (2H), $p < 0.01$.
Piitulainen, *et al.* 2012	n=16/ Biceps brachii	Fifty repetitions of maximum eccentric contractions on an isokinetic machine (60º/s) divided into 2 phases (F1: 65º-120º/F2: 120º-175º). A 3-second rest was determined between phases, with 20 seconds between each repetition.	Before the protocol (PRE), two hours (2H), two days and four days after the protocol.	10%, 20%, 30%, 40%, 50% and 75% of the MVC.	↓	40% MVC: 4.4 ± 0.3 m/s (PRE), 4.2 ± 0.3m/s (2H), $p < 0.05$. 50% MVC: 4.5 ± 0.3 m/s (PRE), 4.2 ± 0.3m/s (2H), $p < 0.01$. 75% MVC: 4.4 ± 0.3 m/s (PRE), 4.2 ± 0.3m/s (2H), $p < 0.01$.
Cadore *et al*. 2014.	n=22/ Vastus lateralis	Six-week training programme, applying eccentric contractions (cases) and concentric contractions (controls). The training included progressions of eight, ten and twelve repetitions from two to five series, with five-minute breaks between each series. For the contractions, an isokinetic machine (60º/s) was used with a 90º range of movement in the knee joint. (90º-180º).	Before the training (PRE) and after six weeks of training (POST).	100% MVC	↑	4.17 ± 1.62m/s (PRE) *vs* 4.44 ± 1.19m/s (POST), $p < 0.05$.
González *et al.* 2014.	n=16/ Vastus lateralis	Two sessions of 2 MVC were carried out and four series of twenty dynamic contractions (concentric and eccentric) 1 week apart. There was a two-minute break between each series. An isokinetic machine (60º/s) was used with a range of movement of 90º in the knee joint. (90º-180º).	Before the protocol, immediately after (ID) the protocol and 5 minutes (5M) after the protocol.	100% of the MVC	ND	2.1 ± 0.1m/s (PRE); 2.2 ± 0.1m/s (ID); 2.1 ± 0.1m/s (5M); $p>0.05$.
Nasrabadi, *et al*. 2018	n=15/ Vastus lateralis and vastus medialis obliquis	Two sessions of 2 MVC were carried out and four series of twenty dynamic contractions (concentric and eccentric) 1 week apart. There was a two-minute break between each series. An isokinetic machine (60º/s) was used with a range of movement of 90º in the knee joint. (90º-180º).	Prior to the exercise protocol, two hours and twenty-four hours after the protocol.		↓	100% MVC vastus lateralis: 4.9 ± 0.59 m/s (PRE) *vs* 4.5 ± 0.46 m/s (2H), $p < 0.05$, and 4.5 ± 0.44 m/s (24H post-exercise), $p<0.05$ 100% MVC vastus medialis obliquis: 5.3 ± 0.61 m/s (PRE) vs 4.8 ± 0.54 m/s (2H), $p < 0.05$, and 4.9 ± 0.57 m/s (24H), $p<0.05$. 50% MVC: 24H: -26.1% (VMO) *vs* -20.1% (VL), $p<0.05$.

ND: There are no differences; MVC: maximum voluntary contraction.

post-exercise eccentric MFCV in the biceps brachii, during maximum isometric or dynamic contractions reported: (a) significant reductions of the MFCV 2H post-exercise in the group exposed to the eccentric contractions (100% MVC: 4.16 ± 0.34 m/s (PRE) *vs* 3.43 ± 0.44 m/s (2H), p < 0.0118; and 100% MVC: 4.1 ± 0.3 m/s (PRE) *vs* 3.8 ± 0.4 m/s (2H), p < 0.01)[11]. Regarding studies that evaluated the effect of eccentric exercise on the MFCV in the quadriceps, they reported: (a) significant drops in the MFCV during maximum isometric contractions in the vastus lateralis (VL: 4.9 ± 0.59 m/s (PRE) *vs* 4.5 ± 0.46 m/s (2H), p < 0.05, and 4.5 ± 0.44 m/s (twenty four hours post-exercise (24H), p < 0.05), and vastus medialis obliquis (VMO: 5.3 ± 0.61 m/s (PRE) *vs* 4.8 ± 0.54 m/s (2H), p < 0.05, and 4.9 ± 0.57 m/s (24H), p < 0.05)[19]; (b) based on the same study, a greater percentage of decay of the MFCV was seen in the vastus medialis obliquis *vs* vastus lateralis during sustained sub-maximum contractions (50% MVC) (24H: - 26.1% (VMO) *vs* – 20.1% (VL), p < 0.05)(19); and (c) a significant increase in the MFCV during maximum isometric contractions in the group submitted to eccentric training (4.17 ± 1.62 m/s (PRE) *vs* 4.44 ± 1.19 m/s (six weeks post-exercise), p < 0.05)[16].

Protocols for eccentric exercise used to induce muscle damage

Five studies used isokinetic machines to develop eccentric exercise protocols, considering the biceps brachii[9,11,18] and vastus lateralis[16,20] muscles. On the other hand, only one study used the "leg press" machine to induce eccentric muscle damage in the vastus lateralis and vastus medialis obliquis[19]. In relation to the characteristic of the eccentric exercise protocols for biceps brachii, three studies applied different loads to induce muscle damage[9,11,18]. In relation to the applied loads, some research used a series of fifty repetitions with twenty-second rests[9,11], while another study applied three series of twenty repetitions with five-minute breaks between series[18]. Another relevant point is related to the speed of the isokinetic machines used in each study, which were used at 1 rad/s[11] and 60º/s[9,18]. Finally, regarding the characteristics of the developed movement, two studies divided the range of movements into 2 phases (Phase 1: 65º-120º and Phase 2: 120º-175º) three seconds apar[t9,11], while the remaining research maintained the maximum eccentric contraction throughout the entire range of movement (ROM). Regarding the magnitude of the ROM used over the elbow joint, the contractions were made between 65°-175º[9,11,18]. As for the eccentric exercise protocols for the quadriceps (vastus lateralis and medialis), two studies applied different loads to induce muscle damage[16,19] and only one study developed eccentric contractions up to exhaustion[20]. Out of these three studies, one of them applied an eccentric contractions intervention[19], another generated randomised exposures of exhausting dynamic contractions[20], and the last one carried out a training programme with eccentric contractions for six weeks[16]. Two research projects associated with the eccentric exercise of quadriceps used four series, considering twenty[20] and twenty-five contractions[19], with rests of two[20] and three[19] minutes between each series. In the case of the six-week training run by Cadore *et al.,* the progressions included eight, ten and twelve repetitions from two to five series, with five-minute breaks between each series[16]. Studies that applied the eccentric exercise protocol with an isokinetic machine in quadriceps used angular speeds of 60º/s in a range of knee movement between 180º-90º.[16,20] On the other hand, the study that implemented the "leg press" used an external load equal to 150% MVC in a range of knee movements between 180º-60º[19].

Figure 1. Illustrates two types of surface electrode. A) linear arrangement of 16 electrodes (dry array SA16-5 ied 5 mm, OT Bioelettronica, Turin, Italy), and B) grid of 64 electrodes (ELSCH064NM3 ied 10 mm, OT Bioelettronica, Turin, Italy).

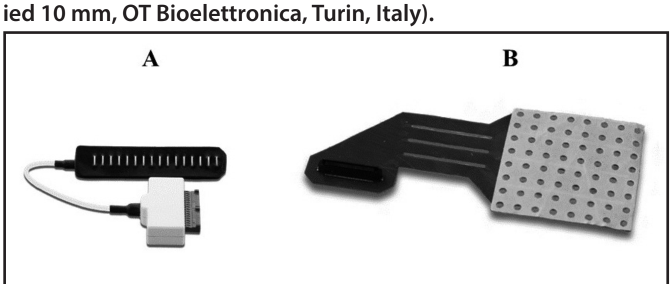
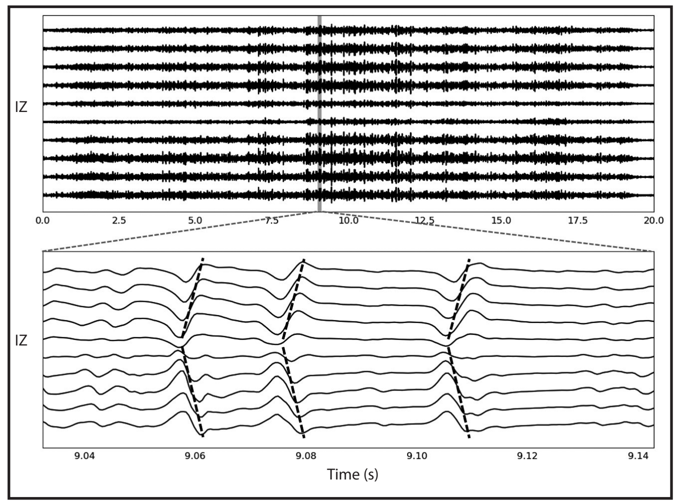


Figure 2. Shows the registry of the motor unit action potentials acquired with high density surface electromyography for 20 seconds from a sub-maximum isometric contraction (60%) of the gastrocnemios medial (top picture). The screen shot was obtained with a linear arrangement of 16 channels (*dry array* SA16-5 ied 5 mm, OT Bioelettronica, Turin, Italy). This shows the registry of 10 channels in a window of 0.1 s (between 9.04 s and 9.14 s, lower picture). The vertical dotted lines describe the orientation of the propagation of the potentials (lower picture). IZ: location of the innervation zone.



Techniques used to record the EMG signal and estimate the MFCV

According to the compiled literature, the electromyographic signals were captured using grids of sixty-four electrodes[9,11], or linear arrangements of eight electrodes[16,18–20]. Considering an inter-electrode distance of eight[9,11] and five[16,18–20] millimetres (Figure 1B). In all cases, the innervation zone was located before placing the electrodes on the skin. This was developed with linear arrangements of sixteen[9,11,16,18,20] or eight[19] surface electrodes (Figure 1A). Additionally, different studies report acquiring EMG signals by amplifying a bandwidth between 10–750 Hz[9,11,18], and 10 - 500 Hz[16,19,20], also considering a band filter between 20–450 Hz[11], 10 - 500 Hz[16], or 10 - 750 Hz[9,18]. All the research projects used a sampling frequency of 2048 Hz, which were digitalised with a 12-bit analogue-digital converter. Relating to the estimation of the MFCV and the selection of the EMG channels, the studies mention different methodologies, highlighting the following points: (a) consider two or three[9,11,18] adjacent channels in the lengthways direction of the muscle; (b) use the maximum number of channels according to the propagation of action potentials with minimum changes in shape without the presence of the innervation zone[19]; and (c) considering the arbitrary selection of some EMG channels[16,20] (see Figure 2). It is important to mention that some studies declare that they exclude channels with the presence of noise, close to the innervation zone and more categorically, rule out MFCV values outside a physiological range (2-6 m/s)[9,11,18].

Discussion

Eccentric contractions in the musculoskeletal system have been a useful tool in physical therapy and sport, given the multiple neuromuscular adaptations that can be induced[21,22]. In the same context, one of the variables used to describe these adaptations was MFCV, which has made it possible to determine possible changes in the permeability of the membrane after muscle damage caused by the exercise[16,21,23]. In relation to sports training and therapeutic exercise, eccentric contractions have taken centre stage, demonstrating a greater adaptive effect compared to other types of muscle contractions[8]. However, it is important to consider that this adaptation might be the result of the selective mechanical damage on a set of muscle fibres, especially type II fibres (fast)[3]. In the same context, high-density EMGs have made it possible to investigate possible neuromuscular changes from recording MUAPs located in surface regions of the muscle being assessed, which would modify their activity after eccentric contractions[24]. Although the quantity of studies is limited, the results based on MFCV behaviour could be determined, to some extent, by the architecture of each muscle, and hypothetically, by their resistance to fatigue. One example of this is demonstrated in the results reported by Nasrabadi *et al.* 2018, who describe a significantly greater percentage drop in the MFCV in the vastus medialis obliquis than in the vastus lateralis, 24 hours after applying an eccentric exercise protocol[19], attributing this finding to the morphological differences of each muscle portion[19]. On the contrary, Piitulainen *et al.* 2013 evaluated the MFCV of both portions of the biceps brachii during maximum eccentric contractions, reporting a significant increase in the MFCV, without finding differences between the two portions[10]. These results might support the hypothesis linked to the muscular architecture and its possible relationship with how the MUAPs work and behave in the light of eccentric exercise. Additionally, histological studies have shown that the magnitude of the muscle damage induced by eccentric exercise might depend on the musculoskeletal architecture[25].

One interesting finding observed in the compiled articles is related to muscle damage and the expected effect on the MFCV. Consequently, despite the inflammatory indicators of the muscle damage reaching a maximum value 24H post-exercise, the MFCV describes its maximum decline in 2H post-exercise, and then it returns to baseline levels after 24H[9,11,18]. However, this research proposes that MFCV behaviour is not associated directly with muscle damage 2H post-exercise, but a chemical imbalance induced by the high eccentric loads[16,19,26]. According to the literature, the above was explained by an ionic imbalance of sodium [Na^+] and potassium [K^+], which would affect the membrane permeability[26]. This generated a hypothesis based on the presence of sodium [Na^+] and calcium [Ca^{+2}] channels which are sensitive to stretching of damaged muscle fibres[3], which would alter both the sarcolemma and the T-tubule complex of the affected region and, as a consequence, would delay the action potential in the membrane[26]. These changes might be more visible at high muscular concentrations, mainly affecting fast contraction fibres[9,11,18]. However, there is not enough evidence to determine whether the proposal described above might affect the whole musculoskeletal system in a similar way[18,19], or if the muscle architecture might play an essential role in MFCV behaviour. Another effect developed by external agents on MFCV was discussed by Bazzucchi *et al.*, who suggested that the use of ergogenic elements, such as oral administration of Quercetin might also modulate the effect of eccentric exercise on the MFCV of the biceps brachii[27].

On the other hand, eccentric exercise protocols varied according to the muscle being evaluated, and the most-studied were the biceps brachii[9,11,18] and portions of the quadriceps[16,19,20]. Additionally, use of isokinetic machines was observed in most of the investigations[9,11,16,18,20], highlighting movement control in the different segments of the body and characterisation of the volume of eccentric exercise used, Regarding the eccentric exercise, the findings reported by Cadore *et al.* suggest that MFCV behaviour does not differ between trainings with eccentric and concentric contractions[16]. However, future research might have to prospectively investigate MFCV behaviour considering different muscle groups, after eccentric and concentric contractions.

According to the articles compiled, high-density EMGs might represent the common denominator to register the different MUAPs, associated with subsequent processing of the MFCV. However, the variation in acquisition of the electromyographic signal is represented by the use of multiple electrodes, highlighting the configuration of linear arrangements[16,19] and grids[11,18]. Furthermore, criteria considered to estimate the MFCV are varied, although essential points can be highlighted such as the location of the innervation zone (prior to calculating the MFCV), selection of the number of adjacent channels, exclusion of channels with noise, and ruling out values outside a physiological range (2-6m/s)[9,11,18].

Within the limitations of this research, it is possible to mention some aspects: i) selection by convenience in all studies, ii) selection of articles only in the English language, iii) the very limitations of a bibliographic review[28].

Conclusion

To sum up, the results suggest that the MFCV behaviour in relation to eccentric exercise could be modulated by a series of intrinsic factors that have been modified. However, there is not enough evidence to prove the variation of the MFCV produced by the eccentric exercise, considering that the most evaluated muscles were the biceps brachii and portions of the quadriceps. This could be a challenge for using high density EMG, a frequently-used technique according to the selected articles.

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Conflict of interests

The authors do not declare any conflict of interests.

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