Sensors & Transducers
Published by IFSA Publishing, S. L., 2024
http://www.sensorsportal.com

Evaluation of the Force Generated in the Biceps Brachii Muscle by Simulating the Forearm Bending Movement during Dynamic Movement

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Received: 5 April 2024 / Accepted: 6 May 2024 / Published: 30 May 2024

Abstract: Gripping is an important hand function required for successful daily living activities. Grip strength measurements are one of the regional strength assessment methods and are used as the basic element in the evaluation of arm function. The scope of this study is to analyze biceps brachii muscle strength levels by taking noninvasive muscle strength measurements from individuals. The biceps brachii muscle plays an important role in upper body movements. There are various studies in the literature on measuring the EMG signal and muscle strength of the Biceps Brachii muscle during arm wrestling movement, but no study has been found on measuring biceps muscle strength during a movement similar to arm wrestling movement, in other words, during dynamic movement, with a hand dynamometer. In this context, an EMG device (EMG) was used to examine muscle electrical signals and measure the electrical currents produced during muscle contraction. By taking into account the force values obtained from the EMG signal in line with the analyzes performed at the end of the study, it was possible to determine whether individuals' cumulative trauma disorders (CTD) and various muscle diseases (paralysis, multiple sclerosis, etc.) are a risky situation for the biceps brachii muscle. This framework reveals a promising potential in the design of prosthetics and orthoses, in the evaluation of rehabilitation processes, and in improving the quality of life of individuals struggling with movement and coordination disorders in the studied muscle.

Keywords: Biomechanics, Muscle strength, Biceps brachii, Cumulative trauma disorders (CTD), Electromyography (EMG), Muscle diseases.

1. Introduction

Biomechanics is a field that uses engineering tools to analyze the kinetics (i.e. loads) and kinematics (i.e. movements) experienced by the musculoskeletal system. These analyzes focus on different loads and movements that occur during activities of daily living, disease conditions, or injury events. Biomechanics can be divided into five or more subfields, such as sports, transportation, rehabilitation, and orthopedic biomechanics [1].

These subfields use engineering analysis tools to understand the mechanical properties of bones, joints, muscles and soft tissues and develop new implants and biomaterials for artificial joint replacement, muscle and soft tissue repair, and bone fracture detection [2]. From a biomechanical perspective, the movement of body connections is regulated by the complex interaction of skeletal muscles, nervous system, bones and joints. In this interaction, the forces produced by skeletal muscles during movement are important. Force production occurs as a result of contractions controlled by the interaction of actin and myosin fibers in the muscle structure. Grip strength is one of the regional strength assessment methods and is a basic measurement in the evaluation of arm function [2].

In the literature research, there are many studies conducted with the Biceps Brachii muscle during arm wrestling movement [3-6]. Daniela et al. In the study conducted by et al., EMG signals and muscle strength data in the biceps brachii muscle were measured by performing both dynamic tests and static tests during the arm wrestling movement [3]. Zixiang et al. In another study conducted by et al., the contraction force occurring in the biceps brachii muscle and the resulting moment provided by the biceps were determined in order to analyze the most appropriate forearm angle during the arm wrestling movement [4]. In another study, EMG signals were measured and analyzed from three different points of the biceps brachii muscle during the arm wrestling movement [5]. A hand dyno monitor was not used in any of these three studies [3-5]. Nizam et al. In the study conducted by et al., electrodes were placed at three different points of the biceps brachii muscle during isometric contraction, in other words, during the contraction in which no joint movement occurs, EMG signals (average amplitude – average EMG signal) and muscle activity of the biceps brachii (BB) muscle were measured and analyzed using a hand dynamometer [6]. Considering the literature studies researched, there are various studies on measuring the EMG signal and muscle strength of the biceps brachii muscle during arm wrestling movement [3-6] but no study has been found on measuring biceps muscle strength during a movement similar to arm wrestling movement, in other words, during dynamic movement, with a hand dynamometer.

Noninvasive measurements were made on individuals and biceps brachii muscle strength levels were analyzed. EMG measurements for the upper arm regions of the individuals were performed according to the determined measurement procedure [6] and the results were interpreted. During the measurements, individuals were made to perform a movement similar to an arm wrestling movement. Accordingly, it was planned to measure the biceps brachii muscle strength levels of the volunteers with an electromyography (EMG) device to determine whether there is a risky situation for the biceps brachii muscle in terms of cumulative trauma disorders (CTD) and various muscle diseases such as stroke and multiple sclerosis. To achieve this goal, measurements were collected via the EMG device and analyzed using the BioPac application. By taking into account the force values obtained from the EMG signal in line with the analyzes performed at the end of the study, it will be possible to understand whether individuals carry the risk of cumulative trauma disorder and muscle disease in terms of the relevant muscle.

This framework reveals promising potential in the design of prosthetics and orthoses, in the evaluation of rehabilitation processes, and in improving the quality of life of individuals struggling with movement and coordination disorders in the studied muscle.

2. Material and Method

2.1. Devices Used and Consumables

While taking measurements for the study, the BioPac measuring device, disposable electrodes, intermediate cables and hand dynometer (Clench force) were used.

2.1.1. BioPac Measuring Device

BioPac device is a type of data acquisition system used to measure, record and analyze biological signals. Biological signals can result from electrical activity, physiological changes, or other biological processes produced by the human body or other living organisms. BioPac systems allow researchers to study biological signals in neuroscience, psychophysiology, medicine, sports science and many other fields. In this thesis study, the BioPac device was used to measure and measure muscle forces on volunteers, as shown in Fig. 1.

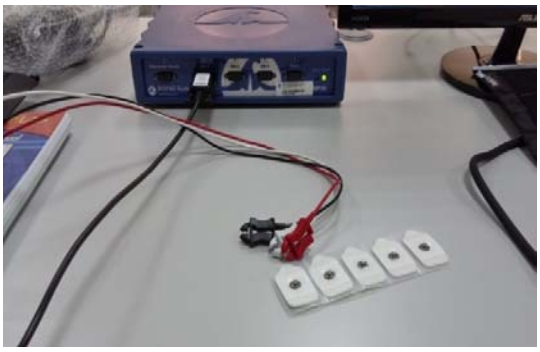

Fig. 1. BioPac measuring device

2.1.2. Disposable Electrodes

Electrodes used in EMG measurements; There are 3 types: Vin+, Vin- and GND. Vin+ represents the positive electrode, Vin- represents the negative electrode, and GND represents the ground electrode. As shown in the literature [6]; Vin+ (red electrode) was placed on the upper part of the biceps brachii muscle, Vin- (white electrode) was placed on the lower part of the muscle, and finally GND (black electrode) was placed on the elbow bone. Electrodes must be placed in the correct position in order to take accurate measurements according to the muscle group to be measured. Fig. 2 shows the correct positions of the electrodes placed on the individuals on the biceps brachii muscle while measuring EMG during the study, according to similar literature studies.

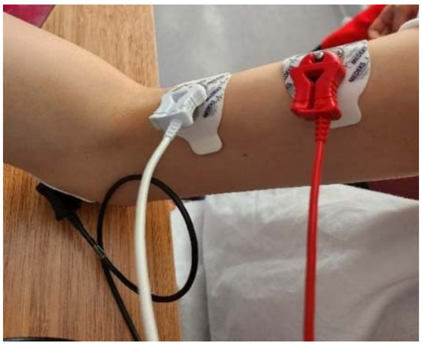

Fig. 2. Correct positions of the electrodes placed on individuals on the biceps brachii.

2.1.3. Clench force (Hand Dynamometer)

A hand dynamometer was used to in-depth examine muscle work, muscle strength, and therefore muscle deformation levels and fatigue in the measured individuals. The handheld dynometer displays force measurements (calibrated in pounds or kilograms) as well as raw and integrated EMG data. The hand dynamometer is squeezed and released repeatedly during measurement. Fig. 3 shows the hand dynamometer used during measurement.

Fig. 3. Clench force used during measurement.

2.2. Measurement Group

Individuals were selected with almost similar physical characteristics (height, age, weight, gender) [7]. Participants in the study are a total of 5 female students (ages between 22-28 years old; average weight about 53 kg and average height is 165 cm) who are engineers and work at desk jobs all day long. The individual does not have any muscle disease or pathological condition that will affect the muscles, and there is no sports history that affects the biceps brachii muscle.

2.3. Preparations and Measurements for Measuring Grip Strength

Individuals participating in the study were asked to perform a movement similar to arm wrestling during the measurement. Data were recorded three consecutive times for each individual for 10 seconds over the biceps muscle, with a five-minute break between each contraction to prevent muscle fatigue. A portable hand dynometer (clench force) was used to measure the grip force during movement. Electrode placements given in the literature for measuring EMG signals of the biceps brachii muscle during a movement similar to arm wrestling were taken as reference in our study [6, 8]. In this study, the forearm was lifted into the air during contraction for measurement and the position of the elbow angle was determined as 80° [6]. For measurements, individuals were placed so that only their elbows were in direct contact with the table. A 180-degree protractor was used to measure elbow pain between the forearm and upper arm. Only after placing the elbow in full contact with the table, the angles were measured between the table surface and forearm and the table surface and upper arm using a protractor, and the elbow angle was kept constant at 80° throughout the entire experiment (Fig. 4). The schematic representation of the elbow angle is shown in Fig. 5.

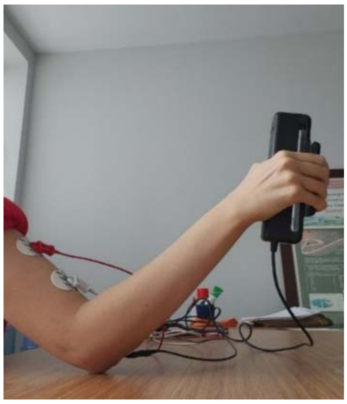

Fig. 4. Display of the 80° position of the elbow angle during measurement.

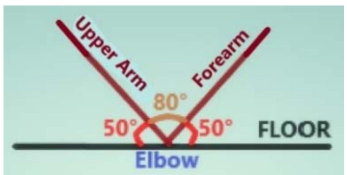

Fig. 5. Schematic representation of elbow angle.

While maintaining the upper arm position, the angle of the forearm with the table was changed to 90° (Fig. 6), 45° (Fig. 7), and 0º (Fig. 8) positions, respectively, and these positions continued in a cycle. Measurements were started with the 90º position (Fig. 6). In each position, individuals were allowed to squeeze the hand dynometer with their dominant arm and with all their strength for 2-3 seconds intermittently and then release it immediately, and this frequent-release cycle was repeated an average of 10-20 times in a row. The same measurement procedure was applied for each individual. All measurements were taken while the individuals were sitting in a comfortable and upright position on a chair. During the measurements, the accuracy of the position of the individuals' hand dynamometer was monitored and, when necessary, the individuals were warned to take the correct position. Before starting the measurements, each individual was explained how and at what intervals the hand dynometer would be tightened, and trial measurements were made before the actual measurements.

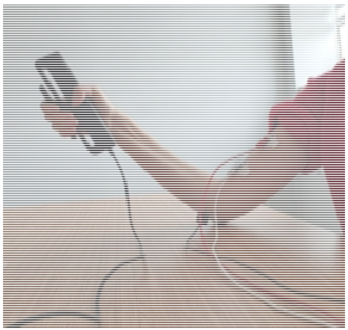

Fig. 6. Photo of the forearm in the 90º position (Starting position).

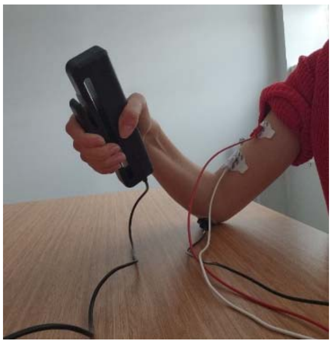

Fig. 7. Photo of the forearm in the 45º position (Intermediate position).

Fig. 8. Photo of the forearm in the 0º position (Final position).

3. Experimental Studies

3.1. Starting, Intermediate and Final Positions

In the initial state, the surface of the table was considered as the 'x' axis, and the forearm, including the radius and ulna bones from the elbow, was considered as the 'y' axis, and the forearm was oriented perpendicular to the table surface. As it is shown in Fig. 9 and Fig. 10, this position is accepted as 90°. For the starting position, anatomically, only the elbow joint was placed in contact with the surface, and the radius and ulna bones were positioned at an 80° angle with the humerus bone.

Fig. 9. Side view of starting position.

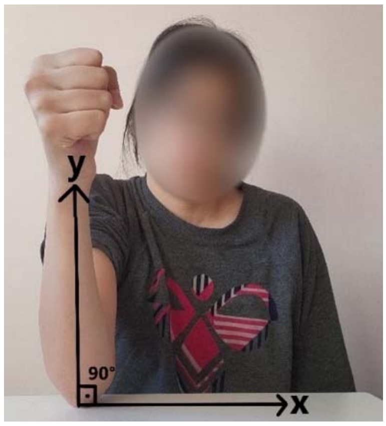

Fig. 10. Front view of starting position.

Individuals are given the position shown in Fig. 8, and Fig. 9, as well as Fig. 11 and were instructed to make the positions related to the intermediate and final positions shown in Fig. 13. The aim here is to distinguish the angles formed by the different postures that occur at various stages of the movement. Fig. 10, Fig. 12 and the photographs in Fig. 14 are adapted from a similar arm wrestling movement literature study [3].

In Fig. 10, the angle is 90° at the beginning, then it is 45° during movement in Fig. 12, and finally it stops at 0° in Fig. 14. This means that the angles formed throughout the movement vary between 0° and 90°.

(0° < ϕ < 90°)

Fig. 11. Side view of intermediate position.

Fig. 12. Front view of intermediate position.

Fig. 13. Side view of final position.

Fig. 14. Front view of final position.

3.2. Measuring Grip Forces with the BioPac Device

The grip forces measured while the individuals squeezed the hand dynometer with their dominant arm were recorded with the BioPac device. Afterwards, the maximum and average force values were measured in kg via the BioPac application, while the maximum and average EMG signals were measured in mV (Fig. 15-16 and Table 1). Finally, the maximum and average force values, measured three times in a row, and the maximum and average EMG signals were tabulated separately for each individual.

First measurement

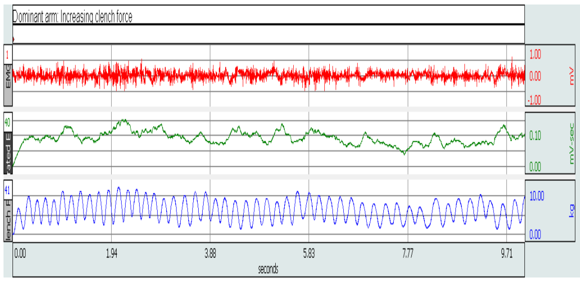

Fig. 15. Example EMG recordings in the force range for measurement 1.

Second measurement

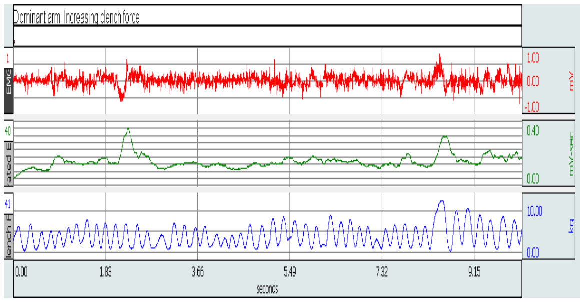

Fig. 16. Example EMG recordings in the force range for measurement 2.

Third measurement

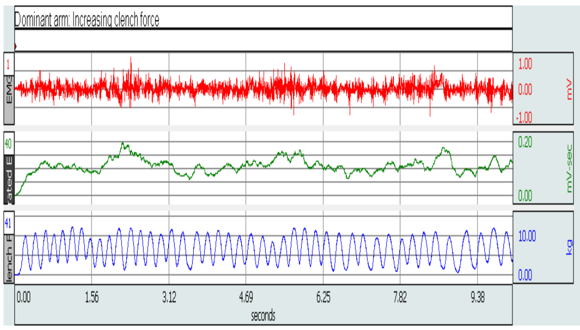

Fig. 17. Example EMG recordings in the force range for measurement 3.

Table 1. Maximum and average values measured for the sample individual.

	Maximum Force Value (kg)	Average Force Value (kg)	Maximum EMG Signal (mV-sec)	Average EMG Signal (mV-sec)
Measurement 1	12.957154	6.392436	0.162843	0.093525
Measurement 2	13.672568	4.453621	0.451288	0.127583
Measurement 3	12.086533	6.798265	0.185169	0.128626

4. Results and Discussion

The Table 2 contains summary tables for the calculated averages of the maximum and average force values measured 3 consecutive times for the dominant arms of individuals, respectively. While the average forces in kilograms (kg) were converted into Newtons (N), the gravitational acceleration was assumed to be approximately 10 m/s^2.

Table 2. Average values of maximum and average forces calculated for a total of 5 individuals.

Dominant Arm	Average of Maximum Force Values (kg) / (N)	Average of Average Force Values (kg) / (N)
Individual 1	12.9 / 129	5.9 / 59
Individual 2	11.0 / 110	4.6 / 46
Individual 3	13.4 / 134	5.0 / 50
Individual 4	12.5 / 125	6.3 / 63
Individual 5	16.0 / 160	6.9 / 69

The graphs below show the average values of maximum forces for individuals (Fig. 18) and the average values of average forces for individuals (Fig. 19). Numbers from 1 to 5 on the horizontal axis represent each individual, respectively, while the vertical axis represents the average values of the maximum and average forces for the biceps brachii muscle for each individual, respectively.

Since the average force values were averaged over a period of approximately 10 seconds, the average force values were lower than the maximum force values.

The graphs were taken from female individuals working in the same environment and under the same conditions and having similar physical characteristics (height, age, weight), and show that the force signals are at close levels.

The average of the maximum forces of a total of 5 individuals is approximately 132 N and the average of the average forces is approximately 58 N. Average force values were calculated with the following formula:

$$\bar{x} = (x1+x2+x3+x4+x5)\ /5) \tag{1}$$

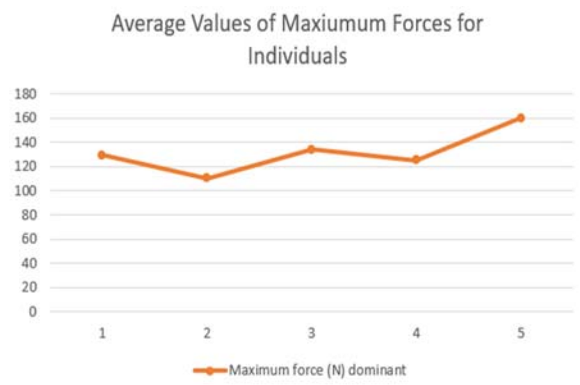

Fig. 18. Average values of maximum forces for individuals.

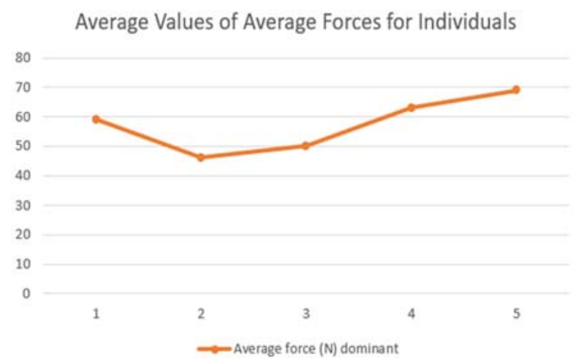

Fig. 19. Average values of average forces for individuals.

The average deviation for a total of 5 individuals is approximately 12 N for maximum forces and approximately 7 N for average forces. Average deviation values were calculated with the following formulas, respectively:

$$di| = |xi - \bar{x}| \text{ ve } \bar{d} = = (|d1|+|d2|+(|d3|+(|d4|+|d5|)\ /\ 5 \tag{2}$$

Accordingly, the calculated values are expressed as 132 ± 12 N for the average of the total maximum forces and 58 ± 7 N for the average of the total average forces.

It was calculated with the following formula:

$$x = \bar{x} \pm |d| \tag{3}$$

In their literature research, María et al. In a study conducted by 36 women with multiple sclerosis, it was measured with a dynamometer from the biceps brachii muscle on both the right and left arms. And the average force values measured are in Newton (N); Average force value taken from the biceps muscle on the right arm (Din BB-R (N)); 7.28±2.44, The average force value obtained from the biceps muscle on the left arm is (Din BB-L (N)); It was measured as 8.05 ± 2.7 [9].

Considering the force values calculated above based on the values in literature study and examining all force values, it cannot be said that individuals carry any risk in terms of cumulative trauma disorder and various muscle diseases for the biceps brachii muscle. Because, according to the calculated average and maximum force values, no force values were observed in the biceps brachii muscle strength values of individuals that were lower than the forces in the literature study [9], indicating cumulative trauma disorder and various muscle diseases. As seen in the summary tables and graphs above, the reason why the average values of maximum and average muscle forces differ among individuals can be considered as the number of fibers and muscle mass in the muscles of individuals.

5. Conclusion

It is of great importance to be able to accurately detect muscle forces in biomechanics studies. As a result, strength measurements for the biceps brachii muscle in the upper arm region of the individuals were carried out according to the determined measurement procedure. Accordingly, the electrodes were placed in the biceps muscle according to similar studies in the literature. The elbow angle was calculated by measuring the angles of the upper arm and forearm with the table, and the forearm bending exercise was simulated. While measuring muscle strength, the elbow angle was preserved and the measurements were made in this way. Then, experimental measurements were made on individuals with the aim of determining the risk potential of cumulative trauma disorders and various muscle diseases in individuals who do their daily activities regularly. During the measurements, individuals were made to perform a movement similar to arm wrestling. In other words, the maximum and average forces occurring in the Biceps brachii muscle during dynamic movement were measured. Measurements were collected via the BioPac device. During the measurement, the maximum and average force values in the biceps brachii muscle of the individuals were measured. In line with the analyzes carried out at the end of the study, analyzes were made by taking into account the maximum and average force values obtained from the EMG signal, and it was possible to understand whether the individuals' biceps brachii muscle was at risk for cumulative trauma disorders and various muscle diseases (paralysis, multiple sclerosis, etc.). However, the average force value obtained from measurements during dynamic movement of the Biceps Brachii muscle in this study, (58 ± 7) N, indicates that there is no risk of cumulative trauma disorder or various muscle diseases for healthy female individuals aged between 22-28 years. This value can be considered as one of the acceptable indicators.

References

[1]. R. Zdero, et al., Quasi-static stiffness and strength testing of whole bones and implants, Chapter 2, in Experimental Methods in Orthopaedic Biomechanics, *Academic Press*, 2017, pp. 19-32.

[2]. H. A. Dereshgi, K. Serbest, S. N. Sahin, B. Balik, Skeletal Muscle Mechanics from Hill-Based Muscle Model to Computer Applications: State of the Art Review, http://biyak.subu.edu.tr

[3]. D. C. de O. Silva, et al., Electromyographic evaluation of upper limb muscles involved in arm wrestling sport simulation during dynamic and static conditions, *Journal of Electromyography and Kinesiology*, Vol. 19, Issue 6, Dec. 2009.

[4]. Z. Tong, X. Shao, Z. Chen, X. He, Optimization of the forearm angle for arm wrestling using multi-camera stereo digital image correlation: A preliminary study, *Theoretical and Applied Mechanics Letters*, Vol. 11, Issue 6, Nov. 2021, 100287.

[5]. N. Uddin Ahamed, K. Sundaraj, R. Badlisha Ahmad, M. Rahman, M. Anamul Islam, M. Asraf Ali, Coherence in muscle activity of the biceps brachii at middle, proximal and distal tendon region among the arm wrestling contestants, *Biomedical Research*, Vol. 24, Issue 2, 2013.

[6]. N. U. Ahamed, K. Sundaraj, R. B. Ahmad, M. Rahman, M. A. Islam, Analysis of right arm biceps brachii muscle activity with varying the electrode placement on three male age groups during isometric contractions using a wireless EMG sensor, *Procedia Engineering*, Vol. 41, 2012, pp. 61-67.

[7]. M. C. Akarca, U. Bunyatova, M. Dogan, Advanced modeling approach for arm muscle deformation kinetics, in *Proceedings of the 4th IFSA Winter Conference on Automation, Robotics & Communications for Industry 4.0 / 5.0 (ARCI'2024)*, 7-9 February 2024, Innsbruck, Austria, pp. 291-294.

[8]. K. H. Whitmer, A Mixed Course Based Research Approach to Human Physiology, https://LibreTexts.org

[9]. M. Cuerda-Ballester, et al., Influencia del sexo en la capacidad funcional, y fuerza muscular y motricidad fina de miembros superiores en pacientes con esclerosis múltiple (Influence of sex on functional capacity, and muscle strength and fine motor skills of upper limbs in patients with multiple sclerosis), *Revista Científica de la Sociedad Española de Enfermería Neurológica*, Vol. 58, 2023, pp. 31-38 (in Spanish)