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Exploring lower limb muscle activity and performance variations during instrumented Sit-to-Stand-to-Sit in sedentary individuals: Influence of limb dominance and testing modalities

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A R T I C L E I N F O

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A B S T R A C T

Purpose: to explore lower limb muscle activity concerning limb dominance, as well as variations in force and power during the standing up and sitting down phases of the instrumented sit-to-stand-to-sit test in sedentary individuals, across isokinetic and isotonic modalities.

Methods: 33 sedentary individuals underwent testing using a functional electromechanical dynamometer in both isokinetic and isotonic modes, accompanied by surface electromyography.

Results: In the isokinetic mode, the non-dominant gastrocnemius medialis and vastus medialis exhibited significantly ($p < 0.05$) higher muscle activity values during the standing up and sitting down phase compared to dominant counterparts. In the isotonic mode standing up phase, significant differences in muscle activity were noted for non-dominant gastrocnemius medialis, vastus medialis, and biceps femoris compared to their dominant counterparts. The sitting down phase in isotonic mode showed higher muscle activity for non-dominant vastus medialis compared to dominant vastus medialis. Regard to performance outcomes, significantly lower ($p < 0.0001$) values were observed for standing up (12.7 ± 5.1 N/kg) compared to sitting down (15.9 ± 6.1 N/kg) peak force, as well as for standing up (18.7 ± 7.8 W/kg) compared to sitting down (25.9 ± 9.7 W/kg) peak power in isokinetic mode. In isotonic mode, lower values were found for sitting down (6.5 (6.3–7.1) N/kg) compared to standing up (7.8 (7.3–8.9) N/kg) peak force and for sitting down (18.5 (13.2–21.7) W/kg) compared to standing up (33.7 (22.8–41.6) W/kg) peak power.

Conclusions: Limb dominance influences lower-limb muscle activity during the instrumented sit-to-stand-to-sit test, and the choice of testing mode (isokinetic or isotonic) affects muscle engagement and performance outcomes.

1. Introduction

A recent review emphasized that numerous mechanisms responsible for the adverse effects of a sedentary lifestyle on the musculoskeletal system and other bodily functions remain largely unexplored [1]. In the lower extremities, a sedentary lifestyle has been associated with a decrease in muscle mass [2], which alters muscular performance (i.e., strength and power). However, muscle loss is not the sole cause of reduced muscle performance, as a study has highlighted that a lack of physical activity causes damage to the neuromuscular junction [3]; in this sense, changes in muscle electrical activity are expected.

Indeed, the relationship between muscle electrical amplitude and muscle performance regarding limb dominance in healthy subjects has been explored recently. This was done through the log-transformed electromyography amplitude power output relationship during an exercise that isolates the quadriceps femoris muscles [4]. The study found no significant difference between the dominant and non-dominant limb, similar to results when comparing the electromyography amplitude

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power output relationship during distinct types of single-leg exercises [5]. However, due to the negative effects of a sedentary lifestyle on muscle health and the changes in muscle activation during non-isolated movements, it is expected that these results may differ in sedentary subjects during functional tasks.

Several studies have emphasized the importance of muscle activation patterns in relation to functional tasks [6,7]. It is established that muscle activity asymmetries can compromise movement efficiency [8,9]. However, research findings vary, and there is inconsistency in the results [10]. Moreover, asymmetrical muscle activation has been associated with altered limits of dynamic stability in sedentary middle-aged adults [11], as well as with altered joint mechanics and dynamic stability, particularly during activities such as walking [12]. Despite the aforementioned findings, there is a scarcity of studies investigating changes in muscle electrical amplitude related to limb dominance, as well as variations in force and power during functional tasks in sedentary subjects. This gap in the literature underscores the importance of our study, which aims to provide a comprehensive understanding of these phenomena in a sedentary population.

It is crucial to acknowledge that muscles may exhibit distinct responses when subjected to isokinetic and isotonic evaluation, because of the inherent characteristics of resistance. Isokinetic assessments involve maintaining a consistent speed, whereas isotonic tests permit muscles to contract at different speeds, replicating natural movements. The subtle variations in muscle behavior that can be revealed by these different testing conditions include differences in muscle activation patterns, force production, and fatigue resistance. For example, during isokinetic testing, muscles may show uniform activation patterns and consistent force output due to the controlled speed [13]. However, during isotonic testing, muscles may exhibit more variable activation patterns and fluctuating force output as they adapt to changing speeds and resistance levels [14]. These variations can be critical for understanding how muscles function in different contexts and how they respond to various types of physical demands.

Moreover, the differences in muscle behavior between isokinetic and isotonic testing can reveal important information about muscle coordination, power generation, and endurance. Isokinetic tests can highlight the peak torque and power output of muscles, while isotonic tests can provide insights into how muscles sustain performance over time and adapt to dynamic conditions [15]. While this observation is valid, it is imperative to underscore the significance of understanding these differences, particularly within the context of functional movements performed ecologically in an isotonic manner, especially among sedentary subjects. Functional movements, such as walking, standing up, and lifting objects, are predominantly isotonic in nature, involving dynamic contractions against varying degrees of resistance. Investigating muscle activations during functional tasks in sedentary individuals provides crucial insights into how muscles adapt and function in real-world scenarios, considering the unique challenges sedentary behavior presents to musculoskeletal health [1]. In this sense, studying muscle electrical amplitude, strength, and power during the standing up (SU) and sitting down (SD) phases [16] of instrumented sit-to-stand-to-sit (iSTS-TS) test may be relevant for identifying functional impairments in sedentary individuals [17]. Moreover, understanding the nuances of muscle activation patterns in both aforementioned iSTS-TS phases during isotonic and isokinetic movements in sedentary populations contributes to enhancing our comprehension of biomechanics, motor control, and injury prevention strategies tailored to address the specific needs of this demographic.

Accordingly, this study aimed to explore lower limb muscle activity concerning limb dominance and variations in force and power during the SU and SD phases of iSTS-TS test in sedentary individuals, in isokinetic and isotonic modalities. Based on the existing literature, it is hypothesized that there will be significant differences in muscle activity between the D and ND lower limbs. Furthermore, significant variations in force, and power, are expected during SU and SD phases concerning testing modalities.

2. Materials and methods

2.1. Experimental design

In a cross-sectional investigation, muscle amplitude, strength, and power levels in the lower limbs of sedentary individuals were evaluated during the iSTS-TS test. Subsequent to anthropometric assessment, participants underwent examination using a functional electromechanical dynamometer in both isokinetic (15 cm/s) and isotonic (60 % of body weight (BW)) modalities, with concurrent utilization of wireless surface electromyography electrodes during the iSTS-TS test. The participants' leg dominance was ascertained through a two-fold approach: initially by direct inquiry, where they were asked to self-report their dominant leg, and subsequently corroborated by observing the consistent use of the identified dominant leg during the execution of a ball-kicking task. To enhance the reliability of the testing procedures, two 30-minute familiarization sessions were administered one week prior to the commencement of the study. During these sessions, participants were briefed on the iSTS-TS test and practice trials for each modality (i.e., isokinetic and isotonic) were executed. Participants were explicitly instructed to abstain from engaging in physical training within the week preceding the testing session.

2.2. Participants

Statistical software (G*Power, v3.1.9.7, Heinrich-Heine-Universität, Germany) was employed for the calculation of the sample size. A medium effect size of 0.7, derived from a previous study [18], was utilized. Taking into account the aforementioned effect size, and aiming for a desired power (1-ß error) of 0.95 with an alpha error less than 0.05, the determined total sample size was 25 participants. Considering potential attrition, the minimum initial sample size was set at 30 participants. The following eligibility criteria were applied: (i) free of musculoskeletal injuries for the past two months prior to the start of the study, (ii) could not have undergone lower-extremity surgery in the previous year, (iii) had to be classified as sedentary, as determined by the International Physical Activity Questionnaire [19], and (iv) should not have any musculoskeletal issues that would limit their ability to perform at maximum effort during the testing procedures. A total of 33 sedentary individuals (41 % female; age: 24.7 ± 5.6 years; body mass: 76.5 ± 15.5 kg; height: 1.7 ± 0.1 m; and body mass index: 26.6 ± 4.4 kg/m2) participated in the study. All experimental methods were conducted according to the recommendations of the latest version of the Declaration of Helsinki. Informed consent was obtained from all the participant before their participation, and the study design was approved by the ethics board of the Universidad de Granada, n°:2294/CEIH/2021.

2.3. Data recordings

2.3.1. Anthropometric evaluation

Body mass was quantified using a calibrated mechanical scale (SECA model 711, Germany) with a precision of 0.1 kg. The standing height was determined using a telescopic scale (SECA, model 220, Hamburg, Germany) with an accuracy of 0.1 cm. The evaluation was conducted on subjects attired in lightweight clothing with the footwear removed.

2.3.2. Dynamometric evaluation

Lower limb strength and power assessments were conducted using a functional electromechanical dynamometer (DynaSystem®; Model Research, Spain) with a precision of 3 mm for displacement, 100 g for detected loads, a sampling frequency of 1000 Hz, and a speed range between 0.05 m/s and 2.80 m/s [20]. Throughout the evaluation, the participants assumed a seated position with their hip and knee joints flexed at approximately 90° The iSTS-TS protocol was evaluated using an isokinetic mode at speeds of 5 cm/s (to elicit maximum voluntary contraction) and 15 cm/s, in addition to an isotonic mode at 60 % of BW. These modalities were selected from the software designed for the functional electromechanical dynamometer, which also has the capability to detect the initiation and completion of movement directions. The selection of modalities was based on established evidence that supports their high reliability [21]. Throughout the testing procedure, the participants designated a comfortable foot distance on the platform to ensure consistency in the repetitions. The subjects were attired in a vest securely anchored to the xiphoid process, to which the dynamometer was affixed. Participants completed one set of three attempts with a 3-minute rest interval between sets for each mode in the iSTS-TS maneuver. The testing mode order was randomly assigned using the paper-in-the-bag method. Participants were instructed to cross their hands against their chest and perform the SU and SD phases of the iSTS-TS task, as depicted in Fig. 1. The primary performance measures for the lower limbs were the higher peak force and peak power, both directly obtained from the dynamometric software. Subsequently, both variables were normalized to the subjects' body mass using Microsoft Excel®. Therefore, normalized peak force (N/kg) and normalized peak power (W/kg) where analyzed.

Fig. 1. Measurement of force, power, and sEMG during dynamometric evaluation of iSTS-TS in a representative male participant.

2.3.3. *Surface electromyography (EMG)*

Considering their relevance to knee and ankle movement during sit-to-stand, the sEMG activity of the biceps femoris (BF), gastrocnemius medial head (GM), and vastus medialis (VM) [22] was evaluated using the Trigno Wireless System (Delsys, Natick, MA, USA). Before the test, the skin was prepared by shaving, abrading, and cleaning with alcohol, followed by the application of a Trigno-flex sensor, which had a sample rate of 1950 Hz for the sEMG signal and 148 Hz for the accelerometer. The electrodes were placed on the D and ND leg following the "Surface Electromyography for the Non-Invasive Assessment of Muscles" (SENIAM) recommendations (http://www.seniam.org), and secured with adhesive tape (3 M, Canada). The sEMG signals were amplified (input impedance 120 kΩ, signal-to-noise ratio 750, inter-electrode distance 10 mm) with a gain range of 500–5000 and transmitted wirelessly to a computer through the Trigno Base Station and an analog-to-digital converter (G-42 HP notebook computer, USA). Using EMGworks® software (Delsys, Natick, MA, USA), the sEMG data were filtered with a 10 Hz high-pass and 500 Hz low-pass second-order infinite impulse response Butterworth filter.

The filtered sEMG data were analyzed using the root mean square (RMS) method. A 60 ms moving window was applied to calculate the normalized RMS values. The RMS sEMG data were normalized using the highest sEMG recorded during the iSTS-TS trials at 5 cm/s and expressed as a percentage of the maximum voluntary contraction (MVC%) [23].

During iSTS-TS, the sEMG of the muscles was recorded, along with the acceleration detected by one of the sensors located on the femur greater trochanter. A pilot session was conducted to examine acceleration signals during the test. The results of this session led to the identification of an initial peak that corresponded to the standing phase of the iSTS-TS task. This peak was visually determined by the increase in the acceleration amplitude above the baseline. The peak gradually decreased until it returned to baseline, marking the end of the standing up phase and the start of the sitting down phase. Another peak was observed at the end of the sitting-down phase, which marked the end of the task.

2.4. *Statistical analyses*

The normality of the data was confirmed using the Shapiro-Wilk test ($p > 0.05$), and the equality of variances was assessed using Levene's test ($p > 0.05$). As the majority of the data were non-normally distributed, they are presented as medians and interquartile ranges. However, since peak force and power in isokinetic mode were normally distributed, these data are presented as means ± standard deviations. The differences between the D and ND legs and between the SU and SD phases were analyzed using a paired *t*-test for parametric data and Wilcoxon matched-pairs test for non-parametric data. Statistical significance was set at $p \leq 0.05$, and all statistical analyses were performed using GraphPad Prism 8 (version 8.0.1).

3. Results

Fig. 2 illustrates a comparison of the normalized RMS values expressed as MVC% between the D and ND legs during the SU and SD phases of the iSTS-TS movements in both isokinetic and isotonic modes. There were significantly greater RMS values observed in the ND GM (59 %, range: 27.5–81.7) compared to the D GM (46.5 %, range: 26.0–62.2) ($p = 0.038$), and in the ND VM (95.5 %, range: 63.2–134.5) compared to the D VM (70.5 %, range: 50.0–84.2) ($p = 0.007$) during the SU phase in the isokinetic mode (Fig. 2A). Moreover, a significantly higher RMS was found in the ND VM (92 %, range: 71.0–180.0) compared to the D VM (72.5 %, range: 60.5–96.7) ($p = 0.021$) during the sit-down (SD) phase (Fig. 2A).

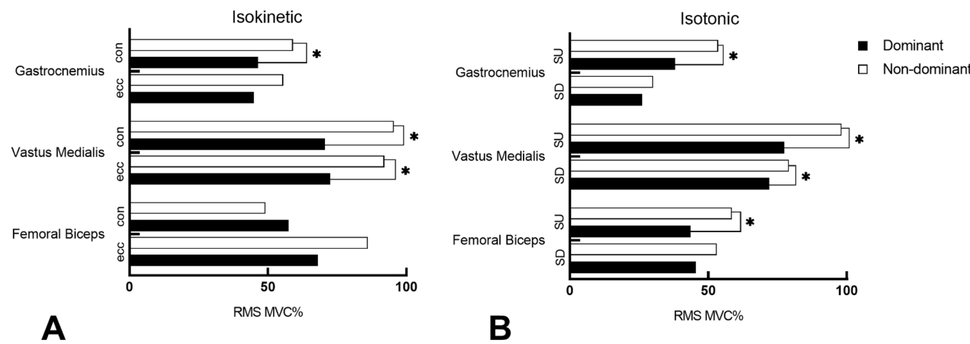

Fig. 2. Comparison of normalized RMS levels between dominant vs non-dominant legs. (A) result from isokinetic mode, and (B) result from isotonic mode. *= Statistically significant ($p \leq 0{,}05$); SU= standing up; SD= sitting down; RMS= root mean square; MVC= maximum voluntary contraction.

Significantly greater RMS values ($p < 0.05$) were observed between the ND GM (53.5 %, range: 29.2–111.3) compared to the D GM (26.0 %, range: 15.0–45.0) ($p = 0.010$), ND VM (98.0 %, range: 70.0–152.0) and D VM (77.5 %, range: 62.0–89.7) ($p = 0.004$), and ND BF (58.5 %, range: 33.7–91.2) and D BF (43.5 %, range: 24.5–83.0) ($p = 0.013$) during the SU phase in isotonic mode (Fig. 2B). The VM of the ND leg was the only muscle that showed a significantly greater RMS of 79.0 % (range: 49.0–151.0) compared to the D VM (72.0 %, range: 49.0–83.0) ($p = 0.028$) during the SD phase in isotonic mode (Fig. 2B).

A comparison of the normalized peak force and normalized peak power during the SU and SD phases of the iSTS-TS in the isokinetic and isotonic modes is shown in Fig. 3. Significantly lower values were observed for SU (12.7 ± 5.1 N/kg) compared to SD (15.9 ± 6.1 N/kg) peak force (Fig. 3A), as well as for SU (18.7 ± 7.8 W/kg) compared to SD (25.9 ± 9.7 W/kg) peak power in isokinetic mode (Fig. 3B). Additionally, in isotonic mode, lower values were found for SD (6.5 (6.3–7.1) N/kg) than for SU (7.8 (7.3–8.9) N/kg) peak force (Fig. 3A) and SD (18.5 (13.2–21.7) W/kg) compared to SU (33.7 (22.8–41.6) W/kg) peak power (Fig. 3B).

4. Discussion

This study aimed to explore lower limb muscle activity concerning limb dominance, as well as variations in force and power during the SU and SD phases of the iSTS-TS test in sedentary individuals, across both isokinetic and isotonic modalities. The study demonstrates that ND leg shows higher normalized RMS values for the GM and VM during the SU phase across both modalities, and for the BF specifically during the isotonic mode. This level of detail in muscle activation patterns provides a nuanced understanding of how different muscles contribute under varying testing conditions, extending beyond the general knowledge of muscle contraction differences. Additionally, the results reveal that during SD phase, the VM is the only muscle exhibiting significant differences, emphasizing that not all muscles respond similarly to the testing modalities during different phases of the task. This phase-specific insight is critical for designing targeted interventions and assessments, highlighting the relevance of selecting appropriate modalities based on the specific phase of the task being evaluated. Furthermore, the finding that the SD phase in isokinetic mode and the SU phase in isotonic mode recorded the highest peak force and power values underscores the importance of modality selection in achieving peak performance metrics. This suggests that certain modalities may be more effective for evaluating or training specific aspects of muscle performance, offering practical implications for rehabilitation and training.

By showing that the GM and VM of the ND leg may play a more prominent role in sedentary individuals, this study suggests potential targets for intervention to improve functional performance in this population. Understanding the modality-specific muscle activity provides a basis for developing customized training and rehabilitation programs that can more effectively enhance muscle performance and balance. The findings underscore the importance of testing modalities by revealing significant differences in muscle activity, force, and power production between isokinetic and isotonic conditions, which are not immediately apparent from a general understanding of muscle contraction principles. Although it is intuitive that different muscle contraction conditions (isokinetic vs. isotonic) lead to variations in force and power output, this study provides specific evidence of how these modalities impact muscle performance during the iSTS-TS test phases in sedentary individuals. This detailed understanding emphasizes the critical role of selecting appropriate testing modalities to accurately assess and enhance lower limb muscle performance.

This investigation presents a statistical measurement for assessing asymmetry in muscle activity. Although there is no consensus on the most appropriate method [24], our findings indicate that the muscle amplitude showed higher levels of asymmetry during the iSTS-TS phases. This result adds to the current understanding of the effect of limb dominance on muscle activity during functional tasks. Specifically, our study found increased muscle amplitude in the ND leg, which is

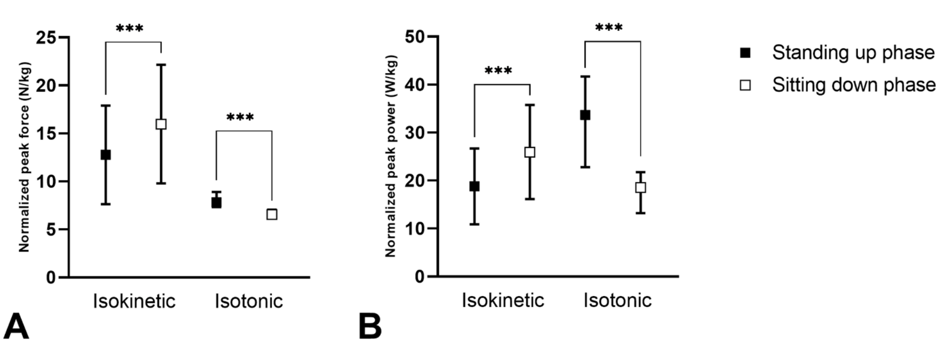

Fig. 3. Comparison of peak force and peak power levels between SU and SD phase of iSTS-TS. (A) Peak force and (B) peak power at both tested modalities. Isokinetic data are expressed as mean ± standard deviation, and isotonic data are expressed as the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively, *** = Statistically significant ($p \leq 0.001$).

consistent with a recent study [25] that reported a correlation between muscle activity in the ND leg and achieving unipodal equilibrium. However, Bond, Cook [18] found no between-leg differences during a chair rise task in healthy subjects with asymmetrical knee extension power, suggesting that less asymmetry during bilateral functional tasks than during unilateral dynamometry is expected. The difference between these findings and the present study can be attributed to the non-resisted chair rise task implemented in the study by Bond, Cook [18], as it has been demonstrated that parameters obtained from an instrumented sit-to-stand task can potentially enhance the detection of strength-related conditions compared to a standard sit-to-stand assessment [26]. These suggest that the ND leg holds particular significance in functional tasks requiring greater muscle demand or control, particularly when external resistance is involved. This observation may elucidate the variations in study outcomes, with some reporting between-leg differences and others not. In alignment with this perspective, a review by Paillard and Noé [27] established that the influence of limb dominance is likely context-dependent. In certain contexts, if the center of pressure shifts towards the dominant (D) leg during the task, heightened muscle activity in the ND leg may function as a control mechanism to avert stability loss through compensatory postural adjustment [28]. This potential explanation aligns with the findings of the present study. However, as this aspect was not evaluated in the current study, additional research is warranted to comprehensively elucidate the underlying mechanisms by which the central nervous system induces such changes in the ND leg compared to the D leg during resisted functional tasks. The acquisition of such knowledge may find practical applications in the development of targeted rehabilitation programs or training interventions tailored for individuals seeking to improve muscle control and stability. This is especially pertinent in activities where limb dominance exerts a pivotal influence.

Regarding the higher levels of SU force and power found in the isotonic modality, previous research has already established that training under the isotonic modality tends to generate higher levels of concentric strength [29], in the present study this will be at SU phase. This phenomenon occurs because the maximal force production capacity of skeletal muscles is higher during eccentric contraction than concentric contraction [30]. Thus, using the same load for both the SU (concentric action) and SD (eccentric action) phases results in the muscle working at a lower percentage of its maximal capacity during the SD phase than during the SU phase. Therefore, a greater SU muscle force is expected during evaluation under the isotonic modality. On the other hand, given that eccentric muscle actions have the potential to generate greater force production, the elevated levels of strength and power found in the isokinetic may be attributed to the device's automatic adjustment of resistance throughout the entire range of motion [31], a feature deemed essential for aligning with the individual's force output in this mode. As a result, elevated force and power levels can be achieved during eccentric muscle actions in the isokinetic mode.

However, the literature suggests that isokinetic training can significantly enhance concentric peak torque to a greater extent than eccentric peak torque [32]. In this sense, a higher concentric force output would typically be expected during isokinetic testing, contrary to the present findings, which show elevated eccentric force and power levels. This discrepancy could be due to the specific protocols or the unique demands associated with this study's approach using an instrumented functional task test. Since it has been established that an instrumented sit-to-stand task enhances the ability to detect functional impairments [26], these results might reflect task-specific muscle performance. Therefore, while isokinetic training generally enhances concentric strength, the current results highlight the importance of context and task-specific factors in muscle performance outcomes when functional tests are performed against resistance.

From a practical perspective, it is recommended to use the isokinetic mode when evaluating SD (eccentric) muscle performance and the isotonic mode when focusing on SU (concentric) performance.

In the present study the evaluation of force and power was bilateral, hindering the comparative analysis between limbs, to address this limitation, future research could consider including measures that differentiate between unilateral and bilateral force and power. This would provide a more comprehensive understanding of the impact of force and power on the iSTS-TS task performance.

5. Conclusions

This study demonstrates that sedentary individuals present differences in muscle amplitude between the D and ND legs and differences in peak force and power during the SU and SD phases of the iSTS-TS task, depending on the modality evaluated (isokinetic or isotonic). These findings provide important insights into muscle imbalances and performance differences in sedentary individuals during resisted functional tests. The novel device used in this study may also have potential for future research on muscle imbalances and rehabilitation.

CRediT authorship contribution statement

Maximiliano Torres-Banduc: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Daniel Jerez-Mayorga:** Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Luis Chirosa-Ríos:** Writing – review & editing, Visualization, Validation, Supervision, Project administration. **Ignacio Chirosa-Ríos:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare no conflict of interest.

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