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Strength Training with Same Ranges of Motion at Different Muscle Lengths does not Change Muscle Activation among Synergist Muscles

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SUMMARY

Objective. Strength training adaptations involve the synergistic activation of different muscles during training and rehabilitation. The aim of this study was to verify changes in electromyographic activity and the synergism of Vastus Medialis and Vastus Lateralis after 12 weeks of knee extension training.

Methods. Eighteen untrained young women were divided into 2 groups, performing training with matched duration of muscle actions, volume, frequency, rest between sets, and intensity. Both protocols used the same range of motion of 35°, but in different positions: initial range of motion between 100°-65° and final between 65°-30° of knee flexion, resulting in different muscle lengths. We analyzed the electromyographic signal amplitude, activation ratio between muscles, and cross-correlation.

Results. The results demonstrated that in both groups the VM and VL decreased their EMG activity ($p = 0.001$ and $p = 0.017$, respectively). There was an increase in the mean value of the VM/VL activation ratio from 0.97 to 1.092 ($p = 0.001$) in both protocols and decreased cross-correlation value when comparing pre- and post-training ($p = 0.001$). However, there were no significant differences between the two positions for any of the analyzed parameters.

Conclusions. The restricted degrees of freedom in the exercise, the matching of training load components, as well as its submaximal magnitude, and the adoption of the same range of motion for both protocols seemed to have prevailed in these results, overshadowing the differences in quadriceps muscle lengths between the protocols.

KEY WORDS

Electromyography; quadriceps; range of motion; synergism; vastus lateralis; vastus medialis.

INTRODUCTION

Coaches, therapists, athletes, and strength training enthusiasts in general seek to manipulate the variables of strength training in order to achieve better results in specific sports performances, as well as in physical rehabilitation and changes in body aesthetics. Investigations in this regard have been conducted with different manipulations of training load (1), body segment positions (2), different exercises (3, 4), and ranges of motion (ROM) (5-7).

Performing an exercise in different positions throughout ROM can interfere with neuromechanical aspects, as changes in muscle length, joint torques, and applied torque by external resistance along ROM (2, 6-8). Different muscle responses such as cross-sectional area and force production, have been observed when comparing protocols performed in different positions along ROM in knee extension exercises (8). In addition to these responses, electromyographic (EMG) activity and synergistic activation between muscles in various positions along ROM should also be considered, as different muscles may exhibit different variations in length throughout the ROM. Several studies are available regarding EMG responses to knee extension training protocols (1, 2, 5, 7), as well as the synergism between the vastus medialis (VM) and lateralis (VL) during this exercise (1, 9). However, the understanding of the acute and chronic impact of training at different muscle lengths along the range of motion (ROM) on the synergism between VM and VL still represents a gap in the available knowledge. Additionally, in different positions along the trajectory of an exercise, the same partial ROM can be performed (*e.g.*, 35°) both at the initial and final positions of the concentric action; these positions have different muscle lengths, as well as different capacities for producing joint torque. Understanding muscle synergism under these conditions could provide relevant information for more specific strength training prescription, as well as for other contexts such as rehabilitation.

The VM and VL muscles have different lengths, insertion angles, and fiber orientations in the muscle belly. Consequently, they would be acting to produce force to perform a specific exercise in different positions along the length-tension curve. These differences may undergo non-similar alterations between them along the same ROM. It is reasonable to suggest that muscle activation could be altered, as well as the synergistic activations, as the training occurs at different muscle lengths along a specific ROM.

Therefore, considering that knee extension force production is the result of the synergistic action of these muscles and that this synergism could be altered due to changes in the exercise position along the ROM caused by alterations in muscle lengths and present torques, the aim of this study was to analyze the amplitude of the EMG signal and the synergism between the VM an VL after 12 weeks of knee extension training, performed at similar ROMs but with different quadriceps muscle lengths. In this study, ROM was quantified by the angular displacement during knee extension.

The hypothesis of this study considers that the changes in EMG responses of these muscles will be different from each other after the training period, resulting in an alteration of the synergism between them.

MATERIALS AND METHODS

Twenty women between the ages of 18 and 30 years, with no strength training experience six months prior to the start of the study, and with no history of knee, spine, and hip injuries (**table I**) participated in the research. To determine the sample size, Beck's recommendations (10) were used, and the sample size calculation was performed using G.Power software (version 3.1.7). Additionally, an alpha error of 0.05, a power of 0.80, a correlation between repeated measures of 0.80, a correction for non-sphericity of 1, considering two study groups and two measurements (pre- and post-training) were applied.

The project has been approved by the Ethics Committee of the Federal University of Minas Gerais in Brazil (No.: 1758518.1.0000.5149 – date of approval: November 07, 2018).

The sample was divided into two groups that performed 12 weeks of training with protocols differentiated by the position along ROM. In this study, the ROM was determined by a 35° angular displacement. The initial position (IP) ranged between 100° and 65° of knee flexion, and the Final Position (FP) ranged between 65° and 30° of knee flexion on the equipment (0° = knee fully extended) (**figure 1**). In this regard, although the ROM was similar between the protocols, the muscle lengths were different.

Table I. Sample characterization by group: IP and FP.

Variable	Group	Average ± SD	Min-Max
Age (years)	IP	23.33 ± 2.58	20-27
	FP	23.00 ± 2.91	21-30
Body mass (kg)	IP	60.38 ± 10.75	42.00-73.9
	FP	60.28 ± 7.90	46.00-67.80
Height (cm)	IP	162.00 ± 5.00	152.00-172.00
	FP	160 ± 40	151.00-166.00
Body fat (%)	IP	23.58 ± 4.66	15.90-32.00
	FP	26.25 ± 4.00	17.70-32.60

SD: standard deviation; IP: initial position; FP: final position.

Participants performed 3 sets of 7 repetitions at 60% of one-repetition maximum (1RM), with each muscle action lasting 2 seconds and a 2-minute rest between sets. Training sessions were conducted three times a week, with at least 48-72 hours of rest between each session. Exclusion criteria for the study included: a) absence from three consecutive training sessions; b) failure to complete at least 90% of the total training sessions; c) inability to perform the tests within the specified intervals; d) engaging in incompatible activities with the training condition.

The equipment used was designed exclusively for research purposes (MASTER®, BRAZIL), with an eccentric axis cam, where the resistance torque remained constant throughout the range of motion (except in the last 10° of knee extension), and it was instrumented to allow recording of the ROM over time. A linear potentiometer of 10 kΩ with a linearity error of 2% and a voltage range between +10V to -10V was attached to the rotation axis, enabling the monitoring and recording of the range of motion. A four-point safety belt was adjusted on the volunteer with a buckle system to minimize accessory movements in the trunk and hip.

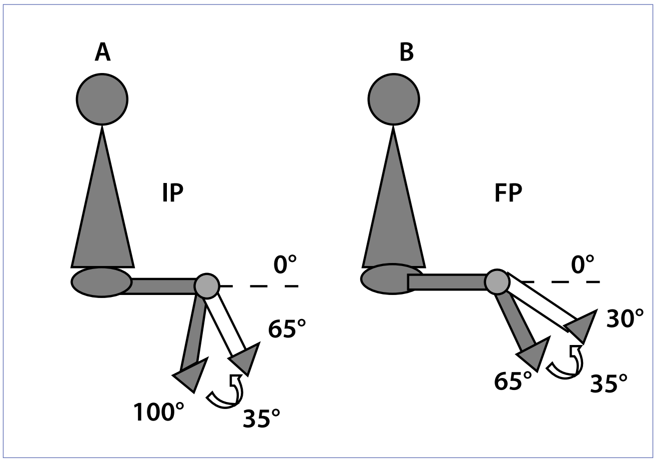

Figure 1. Positions performed in the exercise
(A) IP protocol; **(B)** FP protocol.

For FP position a manual lifting system (hydraulic jack) was used, which allowed raising the weight support to the height corresponding to the desired initial angle. Additionally, a mirror was installed next to equipment, enabling the volunteer to have visual access to ROM.

In the first session, a 1RM test familiarization was conducted with the volunteers positioned on the bench at an angle of 110° with the backrest, and the lateral femoral epicondyle was aligned with the potentiometer installed on the rotation axis. The pad in contact with the lower limb was positioned approximately three centimeters above the medial malleolus. The weight on the equipment was progressively increased until it was not possible to achieve the predetermined ROM for the concentric action. On the 3rd session, the 1RM test was performed again. After this session, familiarization with the ROM and the proposed duration of muscle actions was carried out, consisting of 10 repetitions without additional resistance on the equipment. Each group performed the 1RM test in the same position they performed their training sessions (IP or FP).

In the first two weeks, the volunteers performed three sets, with an additional set added every two weeks, resulting in six sets at the end of the study. In order to adjust the weight used in the sessions, the 1RM test was repeated every two weeks.

Electromyography

Electromyographic data from the VL and VM were collected during the three series of the fourth and the first three series of the 31st training session. For this purpose, surface electrodes of the Ag/AgCl type (3M-2223, Brazil) with a capturing area of 1 cm were used. Prior to placement, the skin was shaved, and the area was cleaned with an alcohol-based solution (11, 12). The electrodes were fixed in pairs with a distance of 2 cm between their centers. The electromyographic and potentiometer signals were synchronized and converted using an A/D board (Biovision, Wehrheim, Germany) and sampled at a frequency of 4,000 Hz. Appropriate software (DasyLab 11.0; Measurement Computing Corporation, Massachusetts, USA) was used to record and treat the data. The electromyographic data acquisition was amplified 500 times and filtered (4th-order Butterworth band-pass filter of 20-500 Hz) tocalculate the EMG amplitude as the root mean square (EMG_{RMS}).

The parameters for electrode placement in each muscle followed the recommendations of Hermens *et al.* (13), and the sensors were located at the following percentages of the total length of the thigh (the distance from the lateral femoral epicondyle to the greater trochanter), above the upper edge of the patella on the VM (30%) and VL (55%).

For acquisition, the EMG data were amplified 500 times and then stored. Subsequently, they were filtered through a second-order Butterworth band-pass filter (20-500 Hz) and rectified to calculate the signal amplitude using the root mean square (RMS) method, considering both concentric and eccentric muscle actions for the analysis.

For normalization of the EMG data, the mean RMS of 2 maximum voluntary isometric actions (MVIC) lasting 5 seconds each was used, with a 30-second interval between each action, at an angle of 65° as measured by the electrogoniometer attached to the equipment.

Activation ratio

The activation ratio allows verifying the relative activation of each quadriceps muscle during knee extension (6, 14, 15). The analysis of the VM/VL ratio was performed by considering the average of the EMG_{RMS} amplitude of each series for each muscle, dividing the normalized EMG_{RMS} value of VM by the value of VL. This measure has been used in other studies (1, 16, 17).

Cross-correlation

Cross-correlation analysis is capable of quantifying the association between measurements through spatial and temporal investigations, measuring, for example, the similarity between two EMG signals, resulting in a scale between -1 and 1. This analysis allows verifying the similarity between two EMG signals and represents a spatial and temporal comparison of the EMG signals, assessing an activation pattern through correlation, independently of their amplitudes (18). For the present study, the analysis involved correlating two time-variable signals with each other.

Statistical analysis

The three series from the 4th session and the first three series of the 31st session were analyzed. Initially, a descriptive analysis of the data was performed. Normality and homogeneity were checked using the Shapiro-Wilk and Levene tests respectively, and all study variables were presented as mean and standard deviation. The analysis of the VM and VL EMG signal amplitude values was performed using a three-way mixed ANOVA with repeated measures (Factor 1 - muscle (VM and VL); Factor 2 - time (pre- and post-training); Factor 3 - protocol (FP and IP). For the activation ratio, a simple mathematical ratio was calculated by dividing the normalized RMS_{EMG} of one signal by the other, *i.e.*, VM/VL, and the result was analyzed using a two-way mixed ANOVA with repeated measures (time and protocol). The same analysis was performed for the cross-correlation data. In the presence of a significant F-value, the Bonferroni *post-hoc* test was applied. The effect size classification adopted according to Cohen (19) was $\eta^2 = 0.14$ for a large effect size, $\eta^2 = 0.06$ for a medium effect size, and $\eta^2 = 0.01$ for a small effect size. The statistical procedures were conducted using SPSS version 22.0. The significance level adopted for all analyses was $\alpha < 0.05$.

RESULTS

The results were analyzed as a percentage response from the 4th to the 31st training session and three variables were considered: EMG signal amplitude (VM and VL), activation ratio (VM/VL), and cross-correlation.

EMG signal amplitude

The analysis of the normalized EMG_{RMS} amplitude values of the protocols are shown in **figure 2**. Initially, a two-way ANOVA (muscle and protocol factors) was performed to compare the mean values of the pre-training condition. There was no double interaction (F = 0.574; p = 0.452), nor main effect of muscle (F = 3.597; p = 0.077), and protocol (F = 1.077; p = 0.304).

The three-way mixed ANOVA with repeated measures did not find a significant triple interaction between muscle, time, and protocol factors (F = 0.17; p = 0.898; $\eta^2 = 0.021$), nor significant double interactions between time and protocol factors (F = 0.580; p = 0.450; $\eta^2 = 0.011$), and muscle and protocol factors (F = 2.483; p = 0.121; $\eta^2 = 0.001$). There was only a significant double interaction between time and muscle factors (F = 12.532; p = 0.01; $\eta^2 = 0.27$). The *post-hoc* analysis using Bonferroni showed that both VM and VL decreased their EMG activity (p = 0.001 and p = 0.017, respectively) after 12 weeks compared to the pretest. Additionally, when analyzing the main effects, a significant effect of time was observed (F = 17.021; p = 0.001; $\eta^2 = 0.075$), indicating a reduction in electromyographic activity for both muscles, regardless of the protocol.

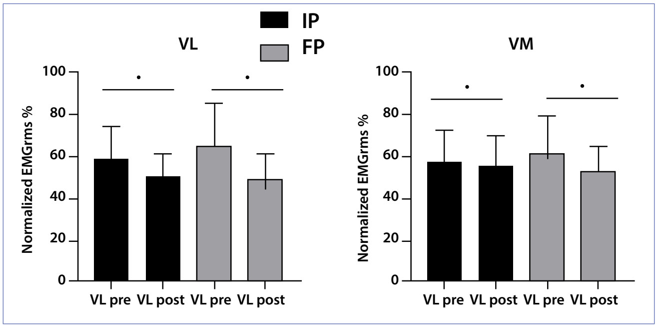

Figure 2. Comparison of normalized EMG_{RMS} of VL and VM between the IP and FP training protocols under pre- and post-training conditions.

*Values significantly different from each other after 12 weeks of training (p < 0.05); VL: Vastus Lateralis; VM: Vastus Medialis; there was no significant alteration for the muscle (F = 0.204; p = 0.653; $\eta^2 = 0.001$) and protocol (F = 0.202; p = 0.655; $\eta^2 = 0.002$) factors.

Activation ratio

No significant difference was found in the interaction between time and protocol factor (F = 0.14; p = 0.905; $\eta^2 = 0.004$) nor in the protocol factor (F = 0.198; p = 0.658; $\eta^2 = 0.002$). A significant difference in the activation ratio was observed after 12 weeks for both protocols (**figure 3**). The two-way ANOVA showed a significant effect of time (F = 14.315; p = 0.001; $\eta^2 = 0.085$), meaning that there was an increase in the mean value of the VM/VL activation ratio from 0.97 to 1.092 in both protocols, without significant difference between them.

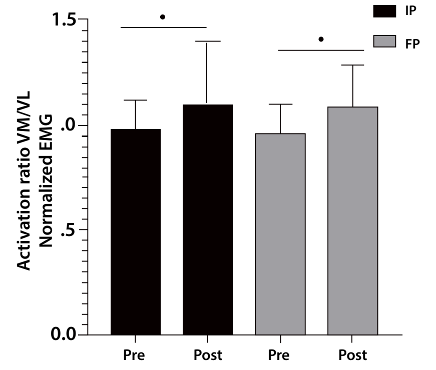

Figure 3. Comparison of VM/VL activation ratio between the IP and FP training protocols under pre- and post-training conditions.

*Significant difference in the time factor: post values > pre ($p < 0.05$).

Cross-correlation

Mean values for cross-correlation between the protocols were as follows: IP pre-training 0.76 (SD = 0.09) and 0.65 (SD = 0.11) post-training, and FP 0.76 (SD = 0.08) pre-training and 0.69 (SD = 0.05) post-training. A two-way ANOVA was performed with time and protocol factors and no significant interaction was found ($F = 1.192$; $p = 0.28$; $\eta^2 = 0.005$). When analyzing the main effects, there was no significant difference for the protocol ($F = 0.903$; $p = 0.346$; $\eta^2 = 0.01$); however, there was a significant difference for time ($F = 46.923$; $p = 0.001$; $\eta^2 = 0.202$) (**figure 4**). Bonferroni *post-hoc* analysis showed that the pre-training mean values were higher than the post-training values for both protocols, with no significant difference between them.

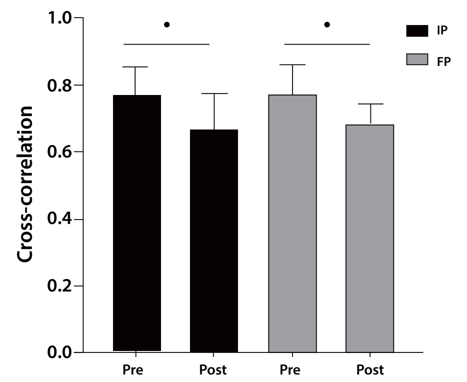

Figure 4. Comparison of cross-correlation between IP and FP training protocols under pre- and post-training conditions.

*Values different from each other after 12 weeks of training ($p < 0.05$).

DISCUSSION

The present study aimed to investigate the EMG activity of VM and VL after 12 weeks of knee extension training in protocols matched for training load and ROM but performed in two different positions along the exercise (initial and final), resulting in different muscle lengths. Considering the distinct changes between VM and VL lengths and the changes in joint torque in both protocols, different activation patterns between the groups might be expected. However, this expectation was not confirmed, as the changes occurred similarly in both groups. Additionally, VM and VL showed a decrease in EMG activity after the training period, but the reduction in VM was smaller than VL, with no significant differences between the groups; in other words, no different muscle activation responses were observed between the two positions performed at different muscle lengths.

Other studies that reported differences in EMG activity analyzed different ROMs in isometric actions (5), combinations of dynamic and isometric actions (6), different intensities from the present study (6), or protocols until concentric muscular failure (2, 14). Moreover, the use of multi-joint exercises such as the leg press (14) and the squat (6) may lead to different outcomes compared to knee extension exercise. Both involve movement in more than one joint to overcome external resistance and, consequently, different strategies to produce performance. The squat exercise has more degrees of freedom, which could result in changes in the execution dynamics, altering the torques in a non-similar manner to the knee extension exercise. Additionally, in the squat, small adjustments in the position of body segments or even the bar trajectory along the initial and final ROMs may affect the obtained results. These variabilities in this exercise can be seen in the different results obtained by Jaberzadeh *et al.* (6), who found a difference in activation ratio between two ROMs and the results obtained by Jarbas da Silva *et al.* (20), where no difference was found in the activation of VM and VL; however, unlike the present study, the first use only body mass without additional external resistance and the latter compared two different angular displacements in the squat exercise in a 10RM set.

The present study used protocols where only each specific position was performed (IP and FP), unlike Signorille *et al.* (2) and Gorostiaga *et al.* (14), which evaluated partial ROMs in the exercise performed with complete ROM. This may lead to differences in instantaneous force values along each ROM (21), which could potentially lead to different muscle activation responses.

It may be suggested that the results of the present study be attributed to the training load used. The intensity was maintained at 60% 1RM, and despite the increase in the number of sets during the experiment, only the first three sets were analyzed in the post-test, similarly to the pre-test analysis, where only three sets were performed. Given that there was no difference between the experimental groups, as well as a decrease in EMG activity, it can be speculated that the demand imposed on the volunteers for the three sets in the 31st session may have been lower compared to the three sets in the 4th training session, as training adaptations allow for a higher number of repetitions for the same relative intensity and/or a higher intensity for the same volume. This reasoning is supported by Braith *et al.* (22), who analyzed the intensity (in % 1RM) for performing a single set of 7-10RM in the knee extension exercise after 18 weeks of training. An increase in the percentage of 1RM used to perform 7-10RM was observed (from 68.4% 1RM to 79.1% 1RM). In the present study, the intensity was kept the same, but the number of sets and repetitions evaluated was not increased, representing a lower task demand after 12 weeks of intervention, as participants gained performance with training. This factor may have counterbalanced possible influences of different torques and muscle lengths along the tested positions, justifying the decrease in EMG signal and the absence of differences between the two groups.

A change in synergism was observed through an increase in the VM/VL activation ratio when comparing pre- and post-training periods, but with no difference between the two positions. Compared to pre-training condition, the VM showed a smaller reduction in EMG amplitude than the VL after the training period. Similar results were verified by Wong and Ng (1), but comparing two different training loads. After 8 weeks of training, these authors found an increase in VM activation and consequent increases in the activation ratio, similar between two groups performing protocols for hypertrophy or maximum strength. According to the authors, this suggests that regardless of the training protocol, the CNS response was an increase in VM activation compared to VL when exercises involving knee extension were used. Our results suggest that changes in activation ratio can occur regardless of changes in muscle lengths present in each protocol for this training load stipulated in the present study. Although not effectively measured, the changes in muscle lengths and joint torques did not represent factors that led to different EMG responses, as hypothesized in the study.

It has been observed that the presence of patellofemoral syndrome can occur with a VM/VL ratio less than 1 in healthy individuals (23). An increase in this ratio would imply a possible increase in patella medialization (15), leading to a better distribution of compressive forces acting on the patellofemoral joint during activities involving this joint.

Considering that the knee extension is an exercise with few degrees of freedom, meaning it does not allow changes in the equipment trajectory or in body segment positions during ROM, it can be speculated that only the differentiation in the execution positions and consequently different muscle lengths, may not have been sufficient to produce different effects between IP and FP. In this case, other parameters of movement were kept constant, such as trajectory, repetition duration, and the use of the same values for the components of the load.

Another parameter used for synergism that provides temporal information on relation between two or more EMG signals is cross-correlation (17, 18). In the present study, the results showed a significant decrease in this cross-correlation value between pre- and post-training, again with no difference between IP and FP groups. It can be expected that individuals not familiar with strength training tend to present less efficient activation patterns than trained individuals (24) and that the CNS develops more efficient strategies for performance production over training sessions. However, the results of the present study suggest adaptations in the sense that these temporal variations differed in the pre and post-training comparison but without differences between the two positions. The significance of this change seems to demonstrate that the timing of activation adjustments over repetitions may be different for each muscle, according to their neuromechanical and morphological characteristics, aiming to establish appropriate synergism for the task. It should be understood that synergism can be verified by activation magnitudes, as measured by the activation ratio, as well as by the timing of these activations between the muscles involved in cross-correlation analysis.

Another important factor concerns the equipment used in the investigations. Depending on the pulley structure and cam shape, different joint torques exist along the ROM, and in isokinetic equipment where velocity is kept constant throughout the ROM, different force-angle relationships occur when compared to conventional equipment, regardless of the produced joint torque. In the present study, the equipment had almost constant resistance torque along the ROM with approximately 10% increase at the end of knee extension, which was not used in the experimental protocols. It can be said that a limitation of the present study is that the presented results are exclusively for the training loads and range of motions stipulated in the present study. Different angles throughout the range of motion can produce different results depending on the variables being analyzed (25).

CONCLUSIONS

The results showed that similar knee extension exercise ROM performed in two different positions, with muscles producing force at different lengths, may not yield different EMG responses after a training period in protocols matched for volume and intensity. This was observed in the EMG signal amplitude and in the synergism between VM and VL, assessed by the activation ratio and cross-correlation. The results also indicated that the groups exhibited reductions in EMG after the training period, but there were no significant differences between the groups for any of the analyzed parameters, indicating no alteration in neural strategies for muscle activation.

As a suggestion for further studies, it is recommended to investigate other equipment with different configurations of external resistance application. Additionally, the use of different protocol configurations, with diverse progressions in training load throughout the period, is recommended.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

FVL: methodology, supervision, writing – original draft, writing- review & editing. MRP: methodology, investigation, formal analysis. GFP: conceptualization, methodology, investigation. RCRB: conceptualization, methodology, supervision, formal analysis. MRV: formal analysis. MHC: conceptualization, methodology, supervision, writing- review & editing. AGPA: formal analysis, writing- review & editing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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