

The Eccentric Torque Production Capacity of the Ankle, Knee, and Hip Muscle Groups in Patients with Unilateral Chronic Ankle Instability

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Abstract

Purpose: The aim of this study was to investigate eccentric torque production capacity of the ankle, knee and hip muscle groups in patients with unilateral chronic ankle instability (CAI) as compared to healthy matched controls.

Methods: In this case-control study, 40 participants (20 with CAI and 20 controls) were recruited based on convenient non-probability sampling. The average peak torque to body weight (APT/BW) ratio of reciprocal eccentric contraction of ankle dorsi flexor/plantar flexor, ankle evtor/invertor, knee flexor/extensor, hip flexor/extensor and hip abductor/adductor was determined using an isokinetic dynamometer. All subjects participated in two separate sessions with a rest interval of 48 to 72 hours. In each testing session, the torque production capacity of the ankle, knee, and hip muscle groups of only one lower limb was measured. At first, 3 repetitions of maximal eccentric-eccentric contraction were performed for the reciprocal muscles of a joint in a given movement direction. Then, the same procedure of practice and testing trials was repeated for the next randomly-ordered muscle group or joint of the same limb.

Results: There was no significant interaction of group (CAI and healthy controls) by limb (injured and non-injured) for any muscle groups. Main effect of limb was not significant. Main effect of group was only significant for eccentric torque production capacity of ankle dorsi flexor and hip flexor muscle groups. The APT/BW ratio of these muscles was significantly lower in the CAI group than the healthy controls ($P<0.05$).

Conclusion: CAI is associated with eccentric strength deficit of ankle dorsi flexor and hip flexor muscles as indicated by reduction in torque production capacity of these muscles compared to healthy controls. This strength deficit appeared to exist in both the injured and non-injured limbs of the patients.

Key Words: Eccentric Strength; Lower Limb; Chronic Ankle Instability

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INTRODUCTION

Lateral ankle sprain is the most common type of ankle injury among both general and athlete populations [1]. Ankle injuries account for 10-30% of all sports injuries and it has been reported that approximately 80% of ankle sprains lead to injury recurrence and instability [1,2]. Ankle injuries have caused more participation restriction than any other single sport injuries [2].

Chronic ankle instability (CAI) is attributed to the contribution of mechanical and functional instability in the development of residual pain, giving way, and disability of patients suffering from the initial acute ankle sprain [3-6]. The high prevalence [7] and rate of recurrence and instability followed by ankle sprain [5] has motivated the researchers and clinicians to identify some relevant factors associated with CAI. Factors such as ligamentous laxity, proprioceptive impairment, balance instability, and strength deficit (especially

ankle evertors) have been hypothesized as potential causes of CAI [6,8-13], among them ankle muscle weakness is the most questionable factor [11]. Identifying the potential contribution of these factors is important for the patients' return to pre-injury daily/sports activity and also to prevent recurrence and instability associated with the CAI [5].

Muscle strength evaluation and training are important parts of rehabilitation of individuals with musculoskeletal disorders [6,8,11]. Ankle muscle strength has been studied extensively in patients suffering from CAI. Most of these studies have focused on the strength of evtor and invertor muscle groups [7,10-14] and some have tested strength of dorsi flexors and plantar flexors [5,9,15]. However the results are inconclusive: while some studies reported isokinetic strength deficit for the evtor [7,10,13], invertor [7,10], dorsi flexor [9, 15], and plantar flexor [5] in CAI; others failed to find any significant muscle weakness between the two study groups [11,12,14].

In addition to the above case-control studies in which healthy participants served as a control group, other studies that used the non-injured ankles as the control [16-19] have also reported inconclusive results. The reason for these conflicting results is not clear. Variations in contraction mode (concentric vs. eccentric), velocity of the tests (slow vs. fast), and methodological limitations (e.g. small sample size) have been addressed as possible reasons [8].

Optimal function of the lower limb during weight bearing and closed chain activities requires both concentric and eccentric contraction of the involved muscles in order to minimize ground reaction forces imposed on the ankle-foot complex [6,11]. For example, lateral ankle sprain occurs when the ankle is forced into plantar flexion/inversion; therefore eccentric activity of ankle dorsiflexor and evtor muscle groups is necessary to prevent this injury [10,12-14]. For this reason, clinicians and researchers should focus on evaluation and training of eccentric as well as concentric contractions [7,9] in musculoskeletal disorders including CAI.

Moreover, synergistic muscle activity of the hip, knee and ankle joints is necessary for appropriate gait mechanics and foot positions during heel strike [20,21]. Therefore, from a biomechanical perspective,

dysfunction of a single joint could influence the others in the kinetic chain [6,22,23]. Despite this relationship, to our knowledge, there are only two studies investigating the strength of the muscles acting on knee and hip joints in patients with CAI [5,21]. In these studies, only isometric strength of the hip abductor/extensor [21] and concentric strength of the knee and hip flexor/extensor [5] were investigated using hand-held and isokinetic dynamometers, respectively. Observation of isometric strength weakness of hip abductor and concentric strength deficit of knee flexor/extensor in the CAI could support the notion of inter-joint interaction of the lower limb kinetic chain secondary to a single joint injury.

Given the conflicting results on the ankle strength deficit and limited research on muscle weakness of the knee and hip muscles in CAI, it is necessary to conduct a more comprehensive study to evaluate torque production capacity of all muscle groups acting on hip, knee and ankle. Moreover, eccentric torque of the knee and hip muscle groups has not yet been investigated in the CAI. Therefore, the purpose of this study was to investigate eccentric torque production capacity of the ankle, knee, and hip muscle groups in patients suffering from CAI as compared to healthy matched controls. Research on this topic may provide important insight on designing an appropriate rehabilitative intervention to restore functional performance and prevent injury and instability followed by lateral ankle sprain.

METHODS AND SUBJECTS

Subjects:

The sample consisted of 40 participants (20 with CAI and 20 controls) between the age of 18 and 35. All participants provided a written informed consent prior for participation in this investigation.

Sample size determination in the current research was done based on the approach suggested by Campbell et al for repeated measure designs [24]. For this purpose, we focused on the findings of Gribble and Robinson for concentric strength data of the ankle,

knee and hip muscle groups in patients with CAI [5]. A sample of 33 participants (16.5 per group) was required to provide 90% power ($\beta = 0.10$) with a significance level of 0.05 for detecting effect size equal to 1.1 for each variable based on a repeated measure design with one between-group factor. The planned total study size was finally considered as 40 subjects (20 per group).

Subject recruitment from orthopedic and physiotherapy clinics was based on the medical records of patients who had been seeking medical care for “acute ankle sprain” in the past year. Inclusion criteria were: (1) experience of at least one unilateral acute ankle sprain without fracture which resulted in pain, swelling, and temporary use of crutches (but not in the past 3 months) [5,21]; (2) at least two episodes of the ankle “giving way” in the past 6 months [5,11]; (3) no participation in the rehabilitation program at the time of study [5,7,11,21]; and (4) no evidence of mechanical instability [25] as evaluated by an orthopaedist using anterior drawer test [11] or talar tilt test [3]. All patients were pain free and were able to perform full weight bearing on both legs at the time of assessment [7,11,14,21]. Patients were also excluded if they reported history of lower limb injury other than the unilateral CAI.

To evaluate functional limitation, all patients completed the foot and ankle ability measure (FAAM) questionnaire [26]. The FAAM is a 29-item self-reported instrument with two main subscales: activity of daily living (ADL) with 21 items and sport with 8 items. Total scores of ADL and sports were transformed to percentage for which higher scores represent higher level of functional status. An Iranian version of FAAM has been validated for use in our country [26]. To match the activity level of two study groups, the ankle activity score (AAS) [27] was completed by all participants. The AAS is an adapted version of Tegner activity rating scale [28] which has been originally developed for knee ligament injuries. Similar to the Tegner activity rating scale, AAS has 11 items with a scoring range of 0-10; higher scores indicating higher level of physical activity. The Persian version of the Tegner has acceptable psychometric properties for use in patients with anterior cruciate ligament injury [28].

Both patients and healthy participants were excluded if they had (self-report) any history of vestibular dysfunction or head injury in the previous 6

months [5], back pain, discopathy, radicular pain, prior surgery in the back or lower limbs [21], recent pregnancy for the female participants and history of neurological disorders [21]. Two groups of CAI and controls were matched according to gender (15 female, 5 male), age, height, body mass index, and activity level.

Procedures:

This study was approved by Institutional Review Board (ETH-073) of Ahvaz Jundishapur University of Medical Sciences. The Biodex System IV isokinetic dynamometer and Biodex Software Package (Biodex Inc., Shirley, NY, USA) was used to determine the average peak torque to body weight (APT/BW) ratio of reciprocal eccentric strength of ankle dorsi flexor/plantar flexor, ankle evertor/invertor, knee flexor/extensor, hip flexor/extensor, and hip abductor/adductor muscles. Normalizing APT to BW allows for comparing the participants despite body-weight differences [6,13]. Reliability of isokinetic variables for assessing muscle strength of ankle dorsi flexor (intra-class correlation coefficient of 0.77 to 0.93) and ankle plantar flexor (intra-class correlation coefficient of 0.78 to 0.95) has been reported in the literature [29]. Furthermore, the recent data available on muscle strength studies of CAI patients reveal that APT/BW ratio is the most commonly used isokinetic parameter [5,9]. Therefore, to increase the comparability of the current study, the authors decided to report the results of APT/BW.

All subjects participated in two separate sessions with a rest interval of 48 to 72 hours. In each testing session, the torque production capacity of the ankle, knee, and hip muscle groups of only one randomly-ordered lower limb was assessed. The order of joints and their motion direction were also randomized for each participant. The injured limb of the patient group was matched with the corresponding dominant/non-dominant limb of healthy controls [9]. Dominant limb was defined as a limb used to kick a ball.

At first, 3 practice repetitions of sub-maximal and 3 practice trials of maximal contractions were performed to familiarize each participant with the equipment and procedure [11]. After a two minute rest, three repetitions of maximal eccentric-eccentric contraction (reactive



Fig. 1: Isokinetic testing of ankle dorsi flexor-plantar flexor

eccentric mode) with no rest were performed by the reciprocal muscles of a joint in a given movement direction. A two minute rest was considered between the practice and test trials to avoid potential fatigue [5]. The highest peak torque value was recorded for each of the 3 repetitions and the average of these values was considered as APT [5]. After a five minute rest period, the same procedure was repeated for the next randomly-ordered muscle group or joint of the same limb. Participants were given verbal encouragement throughout the isokinetic muscle testing procedure [7, 11, 13]. All practice and testing trials were performed at the angular velocity of $60^{\circ} \cdot s^{-1}$ [5]. The literature suggests that strength testing must be performed in a velocity between $30^{\circ} \cdot s^{-1}$ and $240^{\circ} \cdot s^{-1}$ [8]. Moreover, choosing a slower velocity within this range would increase the chance of detecting possible differences in torque production capacity [8]. Angular velocity of $60^{\circ} \cdot s^{-1}$ has been used in some literature aiming to assess lower limb strength of patients suffering from CAI [5, 18].

Patients were positioned based on the manufacturer guidelines for assessing strength testing of the hip, knee, and ankle in various directions. Eccentric-eccentric contraction of ankle dorsi flexor/plantar flexor was performed in a sitting position in which the

isokinetic chair was in a semi-recumbent position and the knee of the ipsilateral limb was in 20° - 30° flexion (Fig. 1). Ankle evor/invertor strength was assessed in a similar way in which the subject was seated in a semi-recumbent position [11, 13] while the knee of the ipsilateral limb was in 30° - 45° flexion. The movements were performed within the active range of motion, i.e. about 0-30 degree of dorsi flexion, 0-50 degree of plantar flexion, 0-40 degree of eversion and 0-55 degree of inversion. Eccentric strength of knee flexor/extensor was assessed as participants moved their knee from 90° flexion in to near full extension in the sitting position, while the hip joints were in 90° flexion [20]. For testing the hip flexor/extensor and hip abductor/adductor, participants were placed in the supine and side position, respectively (Fig. 2). The test was performed within the available active range of motion from the neutral position of the hip joint, i.e. about 0-120 degrees of flexion and 0-45 degrees of abduction.

Statistical Analyses:

Data were analyzed using Statistical Package for the Social Sciences (SPSS version 16) and the level of statistical significance was set at $p < 0.05$. For each joint

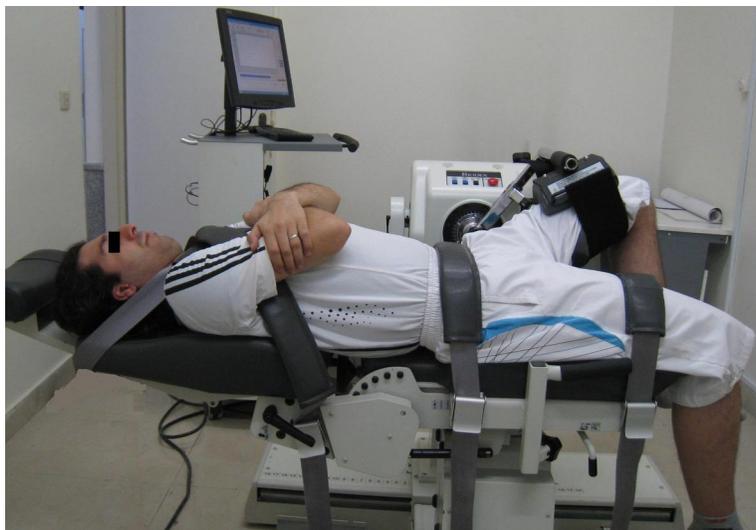


Fig. 2: Isokinetic testing of hip flexor-extensor

direction, a separate 2×2 (2 groups by 2 limbs) mixed model of analysis of variance (ANOVA) test was used to determine main effects and interactions of group and limb factors for each APT/BW ratio.

RESULTS

Table 1 shows that there were no significant differences between the two study groups regarding the age, height, body mass index and activity level. Table 2 shows the mean and standard deviation (SD)

for the APT/BW ratio of the ankle, knee and hip muscle groups in the CAI and healthy participants. A summary of ANOVA results is shown in Table 3.

There was no significant interaction of group (CAI and healthy controls) by limb (injured and non-injured) for any muscle groups. Main effect of limb was not significant, meaning that the eccentric APT/BW ratio of the injured limb muscles was not different from that of a non-injured limb. Similar finding was obtained when comparing dominant and non-dominant limbs of the healthy control group.

Main effect of group was only significant for eccentric torque production capacity of ankle dorsi flexor and hip flexor muscle groups. APT/BW ratio of

Table 1: Demographic and functional characteristics of CAI and healthy groups

Demographic data	CAI group (n = 20)	Healthy group (n = 20)	P. value (Mean difference)
	Mean (SD)	Mean (SD)	
Age (yr)	25.1 (4.52)	24.7 (4.57)	0.78
Height (m)	1.68 (0.75)	1.68 (0.62)	0.98
Body mass index(kg/m ²)	22.5 (2.79)	22.6 (2.12)	0.91
Time since last lateral ankle sprain (month)	6.65 (3.43)	not applicable	-
Frequency of giving way (in the past 6 month)	7.50 (5.85)	not applicable	-
Ankle activity score*	7.05 (2.16)	6.35 (1.95)	0.29
foot and ankle ability measure [†]			
Activity of daily living	91.4 (6.33)	not applicable	-
Sports	80.4 (13.5)	not applicable	-

* Range of scores is from 0-10; †Range of scores is from 0-100
CAI: chronic ankle instability; SD: Standard deviation;

Table 2: Mean (SD) of average peak torque to body weight ratio ($N.m^{-1}.kg^{-1}$) for the ankle, knee and hip muscle groups in both of the CAI and healthy participants

Parameter	Average Torque to Body Weight Ratio		
	CAI	Healthy	
Isokinetic testing the injured limb (and its matched limb in the control group)	Ankle Dorsi-flexor	0.51 (0.08)	0.59 (0.11)
	Ankle Plantar-flexor	1.17 (0.39)	1.40 (0.39)
	Ankle Evertor	0.33 (0.09)	0.38 (0.11)
	Ankle Invertor	0.36 (0.11)	0.40 (0.09)
	Knee Flexor	1.23 (0.27)	1.36 (0.38)
	Knee Extensor	2.40 (0.48)	2.58 (0.75)
	Hip Flexor	1.41 (0.59)	1.94 (0.93)
	Hip Extensor	2.24 (0.73)	2.51 (0.64)
	Hip Abductor	1.21 (0.50)	1.33 (0.50)
	Hip Adductor	1.78 (0.55)	1.74 (0.37)
	Isokinetic testing the non-injured limb (and its matched limb in the control group)	Ankle Dorsi-flexor	0.53 (0.15)
Ankle Plantar-flexor		1.14 (0.47)	1.39 (0.40)
Ankle Evertor		0.33 (0.11)	0.36 (0.08)
Ankle Invertor		0.37 (0.13)	0.40 (0.08)
Knee Flexor		1.29 (0.34)	1.33 (0.37)
Knee Extensor		2.55 (0.65)	2.53 (0.78)
Hip Flexor		1.41 (0.54)	1.96 (0.98)
Hip Extensor		2.25 (0.69)	2.49 (0.74)
Hip Abductor		1.16 (0.44)	1.28 (0.45)
Hip Adductor		1.69 (0.52)	1.76 (0.41)

CAI: chronic ankle instability; SD: Standard deviation

these muscles was significantly lower in the CAI group than the healthy controls. The effect size for this main finding was calculated and based on Cohen's suggestion^[30], large and medium effect sizes were detected for the between-group differences of ankle dorsi-flexor (effect size= 0.81) and hip flexor (effect size= 0.67) muscle groups, respectively.

DISCUSSION

The results of this study showed that CAI is associated with eccentric strength deficit of ankle dorsi flexors and hip flexors as indicated by reduction in torque production capacity of these muscle groups in patients with CAI compared with healthy matched controls.

Table 3: Summary of analysis of variance for the average peak torque to body weight ratio of the ankle, knee and hip muscle groups: F-ratios and P-values by variable

Parameter	Main effect				Interaction	
	Limb		Group		Limb×Group	
	F	P	F	P	F	P
Ankle dorsi-flexor	1.16	0.3	5.46	0.02	0.00	1
Ankle plantar-flexor	0.18	0.7	3.61	0.06	0.10	0.7
Ankle evertor	0.22	0.6	1.88	0.2	0.38	0.5
Ankle invertor	0.04	0.8	1.25	0.3	0.31	0.6
Knee flexor	0.16	0.7	0.75	0.4	0.89	0.3
Knee extensor	0.56	0.4	0.16	0.7	2.51	0.1
Hip flexor	0.01	0.9	5.04	0.03	0.05	0.8
Hip extensor	≤0.01	0.95	1.42	0.24	0.02	0.86
Hip abductor	1.17	0.28	0.65	0.42	0.00	0.98
Hip adductor	0.58	0.45	≤0.01	0.93	1.22	0.27

This strength deficit appeared to exist in both the injured and non-injured limbs of the patients. Similar findings were seen in the literature focusing on strength evaluation of CAI when compared with healthy matched controls [9,14,31]. This finding could be attributed to “cross-training” or “cross-over” phenomena in which strength change of one limb could affect the strength of the contra-lateral limb [9]. The likelihood of a bilateral deficit of eccentric torque production preceded or followed by the ankle injury addresses an important limitation for the findings of those studies that use the non-injured limb as healthy control limb in their study [14,31,32]. This may lead to misinterpretation of the results obtained in these studies.

Eccentric torque of ankle muscle groups:

Because there are a few studies that assessed eccentric torque of ankle dorsi flexor/plantar flexor [9], comparability of our findings is limited. Fox et al (2008) in a recent investigation on 20 patients with functional ankle instability found lower eccentric torque value of ankle plantar flexor in the patients as compared to healthy controls [9]. It is necessary to note that they found eccentric torque reduction in ankle “plantar flexion movement” of the injured limb and this would be related to eccentric torque deficit of ankle “dorsi flexor muscles”. However, the authors discussed about the finding of eccentric torque deficit of ankle “plantar flexor muscles”. If we assume eccentric torque deficit of ankle dorsi flexor in the Fox et al study, one may conclude that this deficit is associated with recurrent ankle sprain in the CAI patients. Considering the fact that most ankle sprains occur during the forced movement of ankle plantar flexion/inversion, adequate eccentric strength of ankle dorsi flexor and evtor is necessary to prevent this injury [15]. Therefore, eccentric strength deficit of these muscles is believed to predispose individuals with CAI to injury or recurrent sprains. Alternatively, several mechanisms such as muscle atrophy and muscle reflex inhibition secondary to initial ankle injury [9,12] could explain the eccentric strength deficit of the ankle dorsi flexor in this patient population.

Based on the injury mechanism described for the ankle sprain, it was expected to observe eccentric

strength deficit of ankle evtor in CAI. However, we did not find any significant differences between two study groups. Some investigators have focused on examination of eccentric torque values of ankle evtor/invertor in CAI [7,9-11,13,14]. Similar to the results of the current study, some have found no eccentric strength deficit in CAI [9,11,14] while the others have reported a significant decrement in eccentric torque production capacity of patients compared to healthy controls [7,10,13]. The reason for these inconsistencies is not clear. However, several factors such as heterogeneity of sample sizes, differences in movement velocity and selection of patients with different disability levels could partially explain these inconsistencies. None of the studies that have considered non-injured ankles as controls for comparison, have found a deficit in eccentric torque production of ankle evertors of the injured compared to non-injured ankles [16-19]. On the other hand, concentric and/or eccentric torque production capacity of ankle invertors was lower in the injured compared to non-injured ankles. Consistent with the later findings, a recent systematic review demonstrated concentric invertor torque deficit in patients with recurrent ankle sprain [33]. These authors acknowledged that this finding was not expected. However, several mechanisms such as selective reflex inhibition of the ankle invertors and deep peroneal nerve stretching secondary to forced inversion movement have been theorized by some investigators to explain this finding [18,19].

Eccentric torque of knee and hip muscle groups:

Only a limited number of researches have focused on the knee and hip torque production capacity in individuals suffering from ankle sprain [5, 21]. Gribble and Robinson (2009) examined the concentric torque of ankle, knee and hip muscle groups in the sagittal plane and found a strength deficit in knee flexor/extensors in addition to ankle plantar flexors [5]. In another study, Friel et al (2006) in an attempt to find a relationship between CAI and hip muscle strength (hip extensor and abductor) using a hand-held dynamometer, reported lower strength in the hip abductor muscle of the injured limb relative to the non-injured limb [21]. They had no healthy control group in

their study and comparisons were made between the injured and non-injured limbs of the CAI group [21].

Eccentric torque examination of hip and knee muscle groups in the CAI patients has not been studied yet, so it was not possible for us to compare our results with other studies. However, other functions of proximal muscles such as muscle activation pattern have been investigated in previous studies on patients with inversion ankle sprain [34, 35]. The authors have observed a delay in activation of hip extensor muscles during hip extension in the patients compared to healthy controls. It has been hypothesized that failure in mechanoreceptor afferent inputs (dys-afferentation) from the distal injured joint could affect the efferent motor outputs (dys-efferentation) of the proximal limb muscles [5, 34]. Deficit in eccentric torque production capacity of hip flexor in patients with CAI might be attributed to the role of this muscle during inversion ankle sprain. We hypothesized that the ankle sprain occurs when the lower limb is in the position of slight hip extension and at the same time the ankle forced into the plantar flexion/inversion. Therefore, adequate eccentric strength of hip flexor is necessary to prevent this injury. Based on this hypothesis, we searched for the position of the proximal joints of the lower limb (especially hip position) during ankle sprain and found no study to explain this issue. This issue could be considered as a possible topic to investigate in future projects.

Limitations and recommendations:

Due to the cross-sectional design of the present study, it is not clear whether the observed deficit in eccentric torque of ankle dorsi flexor and hip flexor muscle groups is a preexistent and a possible causal factor, or a

consequence of the ankle sprain. The design of the present study did not also allow determining the clinimetric properties of isokinetic dynamometry. To overcome the above limitations, future studies should focus on exploring the cause and effect relationship. Furthermore, as the assessment of peak torque by isokinetic system is subjected to human error, future studies should determine the reliability of these measures.

CONCLUSION

The findings showed that CAI is associated with eccentric strength deficit of ankle dorsi flexor and hip flexor muscles as indicated by reduction in torque production capacity of these muscles compared to healthy controls. This strength deficit appeared to exist in both the injured and non-injured limbs of the patients. Therefore, we suggest that the clinicians and researchers focus not only on the strength evaluation of the injured joint (i.e. ankle dorsi flexor), but also on other joints of the kinetic chain (i.e. hip flexor) when faced with CAI.

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Conflict of interests: None

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