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Original article

Electromyographic study of rotator cuff muscle activity during full and empty can tests

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Abstract

The empty can (EC) and full can (FC) tests are used as diagnostic tools for patients with rotator cuff disease. However, recently concerns have been raised that these tests do not selectively activate the muscle. Therefore, the purpose of this study was to evaluate the rotator cuff muscle activation levels during the EC and FC tests in various positions using electromyography. Twelve healthy, right-handed men without shoulder complaints (mean age: 26.1 years, range: 23–35 years) were included. The tests were performed isometrically with the shoulder elevated at 45° and 90° in the sagittal, scapular, and coronal planes, either in the thumb-up (FC test) or thumb-down (EC test) positions. During these positions, the electromyographic signal was recorded simultaneously from the four shoulder muscles using a combination of surface and intramuscular fine-wire electrodes. The average activation of the supraspinatus and subscapularis was greater during the EC test than during the FC test and in the scapular and coronal planes than in the sagittal plane at 90°. For the infraspinatus, there were no significant differences in any positions between the two tests. Thus, the rotator cuff muscles are influenced by arm position and the elevation plane during the EC and FC tests.

Keywords: diagnostic tests; electromyography; muscles; musculoskeletal system; rotator cuff

Introduction

The rotator cuff muscles play an important role in stabilising the humeral head to the glenoid fossa.[1] Patients with rotator cuff tears complain of decreased shoulder strength, limited range of motion and severe pain. In >90% of these patients, the supraspinatus muscle is involved.[2–4] Therefore, most studies focus on the function of the supraspinatus muscle and its role in the pathophysiology of shoulder complaints.[5–7]

The empty can (EC) and full can (FC) test positions are used as diagnostic tools for assessing supraspinatus insufficiency in patients with rotator cuff disease. Jobe and Moynes[5] reported that the supraspinatus function can be isolated and assessed to some degree with the shoulder near 90° of elevation in the scapula plane, at 20° horizontal abduction, and in full internal rotation (EC test).[8,9] Assessing isometric strength in this position is commonly referred to as the supraspinatus test.[1] Kelly et al compared the EC test to a modified version using 45° of external rotation (FC test) using electromyography (EMG).[7] They reported that the supraspinatus activity in the EC and FC tests was similar.[7]

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In contrast, EMG studies have indicated that the EC and FC tests do not selectively activate the supraspinatus.[10] Boettcher et al reported that the EC and FC tests activated the supraspinatus as well as other muscles, including the infraspinatus, subscapularis, deltoid, trapezius, and serratus anterior.[10] Additionally, they mentioned that the activities of the supraspinatus and the surrounding muscles did not differ between the EC and FC tests.[10] However, these studies exclusively examined the activity of the muscles in the scapular plane at 90° of elevation, and not in the sagittal or coronal planes. Yasojima et al reported that the EMG activity of the supraspinatus was significantly higher than that of the other rotator cuff muscles at 45–60° of elevation in the scapular plane according to the FC test.[11] They also suggested that this position (45–60°) was better in both tests for decreasing impingement and compensatory motions.[11]

Therefore, we examined the rotator cuff muscle activity during the EC and FC tests in six elevation positions (i.e., the sagittal, scapular, and coronal plane at 45° and 90°) using EMG. The primary aim of this study was to compare the activation levels of the rotator cuff muscles between the EC and FC tests in the six different elevation positions, and the secondary aim was to compare the muscle activation levels among the three planes.

Materials and methods

Participants

We examined the dominant shoulders of 12 sedentary right-handed male participants. No participant had any history of shoulder pain or injuries before the study. The mean age was 26.1 years (range: 22–31 years), mean height was 171.4 cm (range: 158–182 cm), and mean weight was 63.9 kg (range: 54–76 kg). The Institutional Review Board approved the study protocol (No. 09078), and all the participants provided written informed consent.

EMG recording

EMG signals were recorded simultaneously from four shoulder muscles using a combination of surface and intramuscular fine-wire electrodes. The electromyograms were collected using a sampling of 1000 Hz from the MultiTelemeter System WEB-5000 (Nihon Kohden, Tokyo, Japan). This unit provides a signal amplification of 1000 times, common mode rejection ratio > 54 dB, input impedance > 10 MΩ, and gain of 100 dB. Output from the unit was linked to a 16-bit analog-to-digital converter on a personal computer, and the raw data were monitored and collected in MotionMonitor version 8.43 (Innovative Sports Training, Chicago, IL, USA) for off-line analysis.

The surface electrodes were used to record activity from the infraspinatus muscles. The inter-electrode distance was 10 mm. Beforehand, the skin was cleaned with alcohol pads, and the electrodes were applied parallel to the muscle fibres. Placement of the surface electrodes was selected according to published studies involving EMG data collection from the muscles of interest.[12]

Bipolar intramuscular electrodes (50 μm urethane-coated stainless steel wire; Unique Medical Co., Ltd., Tokyo, Japan) were used for the supraspinatus and upper and lower subscapularis muscles. The intramuscular electrodes were prepared in accordance with the technique described by Basmajian and DeLuca,[13] and they were inserted according to the recommendations of Kelly et al[14] for the supraspinatus and Kadaba et al for the subscapularis.[15] The electrode wires were inserted into a 23-gauge single-use hypodermic needle. The signal quality was checked to ensure adequate signal-to-noise ratios – signals were excluded if they were of poor quality. The ground electrode was affixed to the skin over the flat surface of the acromion. Correct electrode placement was confirmed by observing all the EMG signals on an oscilloscope during resisted contractions of each muscle.

The EMG activity was recorded for the four muscles while the participants performed maximal voluntary contraction (MVCs) against manual resistance, as previously described for shoulder normalization tests: abduction 90° with internal rotation ("empty can"), internal rotation in 90° abduction ("internal rotation 90°"), flexion at 125° with scapula resistance ("flexion 125°"), and horizontal adduction at 90° flexion ("palm press").[16] Strong verbal encouragement was provided during every contraction to promote maximal effort. The EMG data from the MVCs were used to normalise the EMG amplitude (% MVC) during the testing protocol.

Experimental procedures

Each participant was seated upright in a chair. A posture hold bar and cephalic strap were used to minimise trunk compensatory movements during the experiment. The test was performed with the shoulder at 45° and 90° of elevation in the sagittal, scapular, and coronal planes with the thumb-up (FC test) and the thumb-down (EC test) (Fig. 1). The coronal plane was defined as being parallel to the trunk. The sagittal plane was defined as being 90° anterior to the coronal plane. The scapular plane was defined as being 40° anterior to the coronal plane. Shoulder muscular activity was measured while the participants held a dumbbell weighing 3 kg for 5 seconds in the described positions. According to the preliminary research,[17] 3 kg is equivalent to 10–20% of the maximal muscle strength at 90° of arm elevation. Trials in each position were repeated twice and were randomly assigned to the subjects. Each participant was given 30-second rests between each of the trials to eliminate possible muscle fatigue.

Data reduction

The original raw EMG signal was band-pass filtered at 20–450 Hz. The root-mean-square amplitude of the EMG signal was computed using a 600-millisecond window. The first and last second of EMG data were omitted from the analysis. The EMG value of each muscle was then expressed as a percentage of the EMG value during the MVC. The two trials were averaged, and the EMG data for each test position were analysed. The mean EMG values for 3 seconds at each test position were used in the analysis.

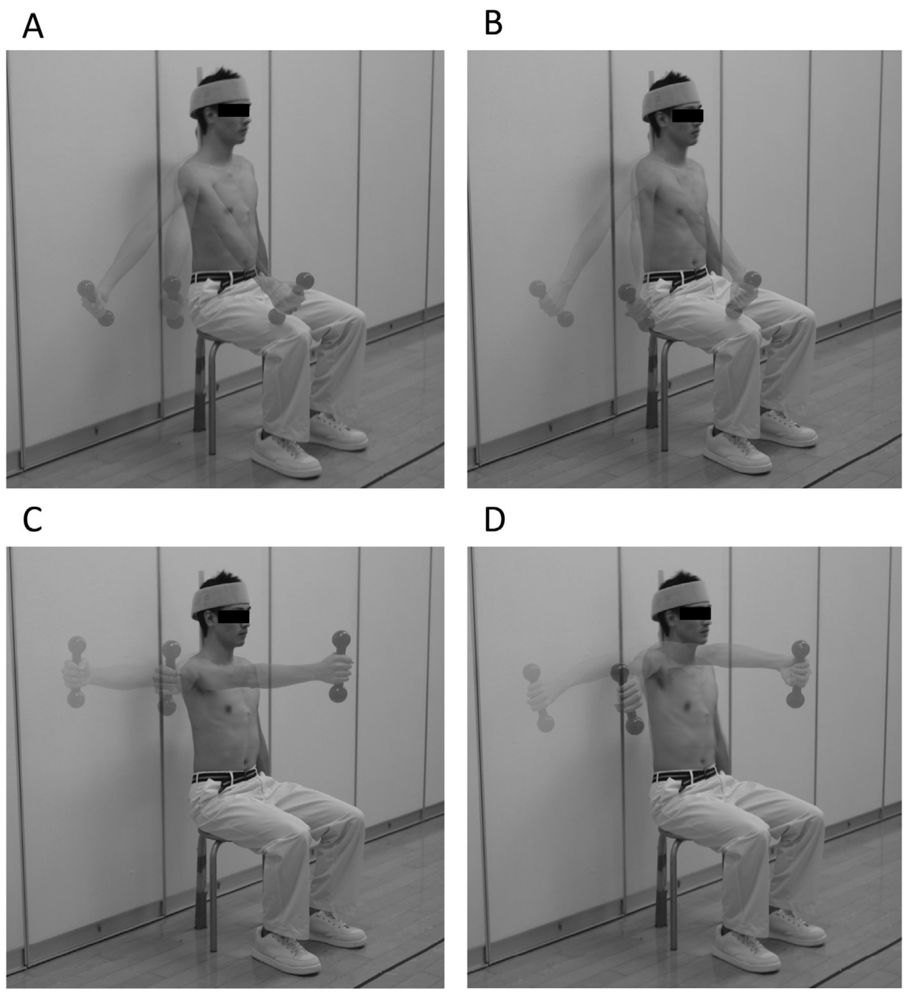

Fig. 1. Full can (A, C) and empty can (B, D) test positions in the sagittal, scapular, and coronal planes with the arm elevated at 45° (A, B) and 90° (C, D).

Statistical analysis

SPSS for Windows version 19.0 (IBM, Armok, NY, USA) was used for the data analysis. The effects of the FC and EC (test position) on the EMG data collected during the three planes of elevation (sagittal, scapular, and coronal planes) were analysed using a two-way repeated measures analysis of variance (test position × plane of elevation). A two-way ANOVA was performed for each muscle (i.e., four times). When a significant interaction between the test positions and the plane of elevation was observed, Fisher's least significant difference (LSD) *post hoc* testing was used to determine significant differences between the test positions and the plane of elevation. The level of statistical significance was set at $p < 0.05$ (two-sided).

Results

The mean %MVC of the rotator cuff muscles during the FC and EC test positions in the six elevation positions are shown in Table 1.

The supraspinatus activity at 45° of elevation had a significant main effect on the FC and EC test positions ($p < 0.01$) and the plane of elevation ($p < 0.05$). There was no significant interaction between the test position and the plane of elevation (Table 1, Fig. 2A). During 90° of elevation, the supraspinatus activity was a significant interaction between the test position and the plane of elevation ($p < 0.01$). *Post hoc* analysis with Fisher's LSD showed that the supraspinatus activity was significantly greater in the EC test position ($p < 0.01$), especially in the scapular and coronal plane than in the sagittal plane ($p < 0.01$) (Table 1, Fig. 3A).

The infraspinatus activity at 45° of elevation had a significant main effect on the plane of elevation ($p < 0.01$), with no significant main effect on the test position. There was no significant interaction between the test position and the plane of elevation (Table 1, Fig. 2B). During 90° of elevation, the infraspinatus activity had a significant interaction between the test position and the plane of elevation ($p < 0.01$). The infraspinatus activity at 90° of elevation was significantly greater in the sagittal plane than in the scapular or coronal planes ($p < 0.01$), but there was no significant difference between the FC and EC tests according to Fisher's LSD *post hoc* analysis (Table 1, Fig. 3B).

The upper subscapularis activity at 45° of elevation had a significant main effect on the test position ($p < 0.01$) with no

Table 1
Changes in the rotator cuff muscle activity during the full can and empty can test positions in each plane of elevation.

		Sagittal plane		Scapular plane		Coronal plane		Main effect		Interaction
		Full can	Empty can	Full can	Empty can	Full can	Empty can	Test position	Plane of elevation	Test position × plane of elevation
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F-value	F-value	F-value
45°	Supraspinatus	25.8 ± 9.9	35.8 ± 11.1	34.11 ± 8.6	42.5 ± 12.2	39.5 ± 12.9	46.2 ± 17.4	33.41**	4.36*	0.61
	Infraspinatus	20.6 ± 8.2	20.5 ± 9.5	15.9 ± 5.3	14.3 ± 5.6	14.4 ± 5.4	11.6 ± 3.4	0.87	21.15**	1.14
	Upper Subscapularis	15.6 ± 7.7	33.4 ± 13.9	22.9 ± 11.9	34.3 ± 18.1	26.3 ± 13.2	34.8 ± 19.1	15.92**	2.41	1.99
	Lower Subscapularis	8.8 ± 4.8	21.9 ± 13.4	17.8 ± 9.4	35.6 ± 16.6	17.6 ± 9.6	25.7 ± 13.8	21.49**	10.86**	2.85
90°	Supraspinatus	30.5 ± 8.4	40.9 ± 15.9	35.4 ± 10.2	62.8 ± 14.2	38.1 ± 9.3	63.6 ± 11.7	99.50**	14.15**	7.50**
	Infraspinatus	32.7 ± 10.2	30.3 ± 10.6	22.2 ± 8.1	24.5 ± 9.2	17.8 ± 6.3	23.4 ± 9.4	0.74	41.78**	14.51**
	Upper Subscapularis	21.1 ± 9.1	30.2 ± 16.2	38.5 ± 14.5	57.5 ± 23.1	43.3 ± 17.4	51.7 ± 25.4	17.39**	17.37**	3.41*
	Lower Subscapularis	10.8 ± 5.2	22.0 ± 15.0	29.1 ± 11.0	53.0 ± 22.7	32.9 ± 18.8	43.2 ± 26.7	16.89**	26.20**	4.23*

* $p < 0.05$; ** $p < 0.01$.
SD = standard deviation.

significant main effect on the plane of elevation. There was no significant interaction between the test position and the plane of elevation (Table 1, Fig. 2C). During 90° of elevation, the upper subscapularis activity had a significant interaction between the test position and the plane of elevation ($p < 0.05$). *Post hoc* analysis with Fisher's LSD showed that the upper subscapularis activity was significantly greater in the EC test position ($p < 0.01$), especially in the scapular and coronal planes than in the sagittal plane ($p < 0.01$) (Table 1, Fig. 3C).

The lower subscapularis activity at 45° of elevation had a significant main effect on the test position ($p < 0.01$) and the plane of elevation ($p < 0.01$). There was no significant interaction between test position and plane of elevation (Table 1, Fig. 2D). During 90° of elevation, the lower subscapularis had a significant interaction between the test position and the plane of elevation ($p < 0.05$) (Fig. 3D). The lower subscapularis activity at 90° of elevation was significantly greater in the EC test position, especially in the scapular or coronal planes than in the sagittal plane ($p < 0.01$) according to Fisher's LSD *post hoc* analysis (Table 1, Fig. 3D).

Discussion

The present study evaluated rotator cuff muscle activity during the FC and EC tests in the sagittal, scapular, and coronal planes with the arm elevated at 45° and 90°. The rotator

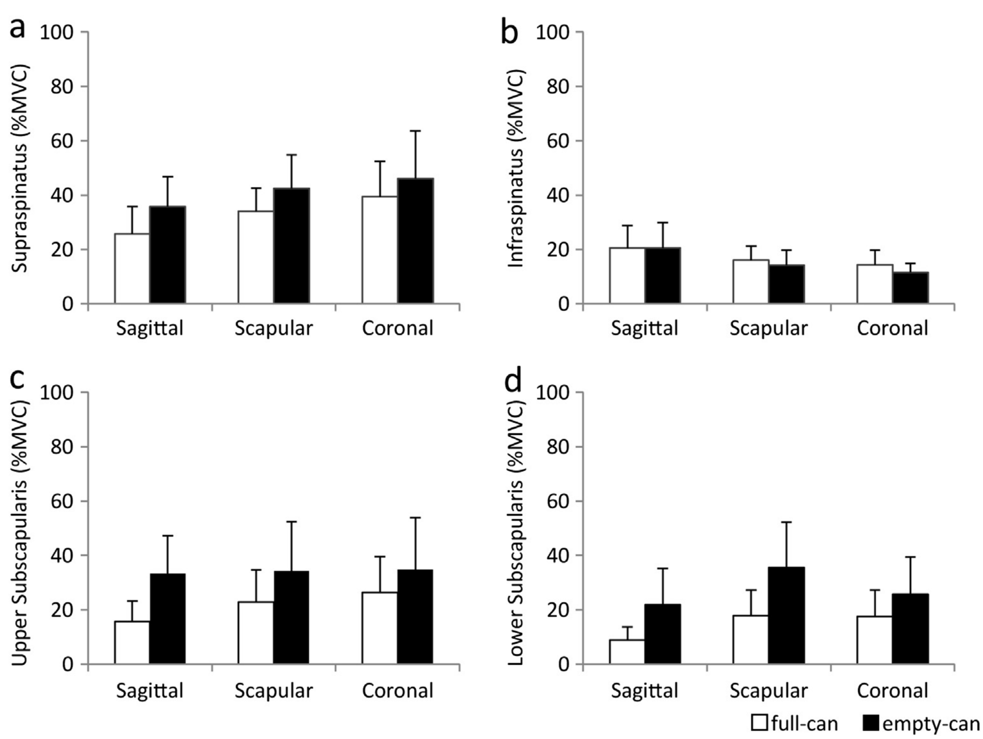

Fig. 2. A comparison of the full can (FC) and empty can (EC) positions for activity of four muscles among three planes of elevation at 45° of shoulder elevation. Error bars indicate the standard deviation.

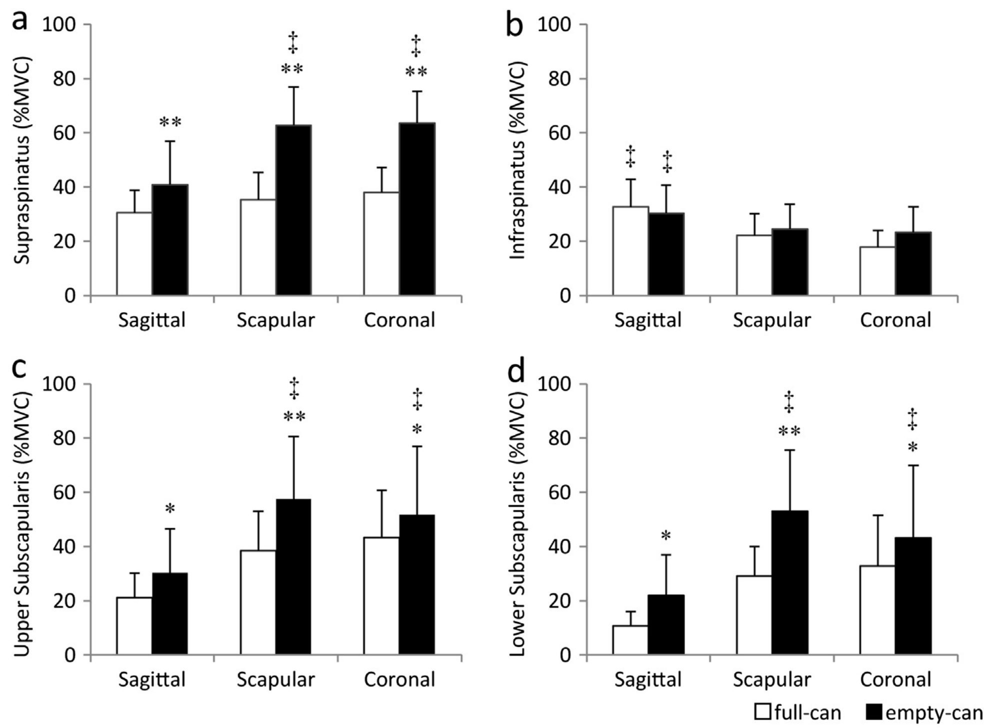

Fig. 3. A comparison of the full can (FC) and empty can (EC) positions for activity of four muscles among three planes of elevation at 90° of shoulder elevation. Asterisks indicates a significant difference between the FC and EC test positions (* $p < 0.05$, ** $p < 0.01$). Dagger indicates a significant difference between each plane of elevation (‡ $p < 0.01$). Error bars indicate the standard deviation.

cuff muscles were activated during both tests, and the muscle activations were unique. The supraspinatus and subscapularis muscle activation levels were increased during the EC test in the scapular and coronal planes with the arm at 90° of elevation. For the infraspinatus, there were no significant differences in any of the positions between the two tests.

Previous studies analysed the FC and EC tests with the arm at 90°of elevation in the scapular plane under maximum isometric resistance.[5,7,10,18,19] Noguchi et al[20] indicated that the muscles surrounding the shoulder were activated when the external resistance was greater than half of the maximum strength exerted compared with the rotator cuff muscles. Pappas et al reported that rotator cuff training under resistance > 2.3 kg did not selectively activate the rotator cuff muscles.[21] To activate selectively the rotator cuff muscles as much as possible, the present study evaluated the EC and FC tests using a low level of external load (3 kg is equivalent to 10–20% MVC).[17]

Arm position is associated with the moment arm of each rotator cuff muscles. The moment arm of the supraspinatus is reduced by internal rotation of the humerus and elevation plane (i.e., the scapular and coronal planes).[22,23] A recent anatomical study demonstrated that the supraspinatus insertion overlapped at the lesser tuberosity with the subscapularis.[24] Taken together, decreased moment arm by the EC positions in the scapular and coronal planes may have increased the supraspinatus and subscapularis activities in these positions. In the present study, the infraspinatus was more activated in the sagittal plane, irrespective of the FC or EC position. Several studies showed that the infraspinatus activity did not differ between the EC and FC test positions.[10,11] In our previous study, there was more infraspinatus activation in the sagittal plane compared to the scapular plane.[17] Consistent with these reports, the present study confirmed the relatively increased infraspinatus activity in the sagittal plane compared with the scapular or coronal planes.

The EC and FC tests are useful diagnostic tools for patients with supraspinatus disease.[25–28] Itoi et al reported that both tests were equivalent for diagnosing a torn supraspinatus in terms of accuracy.[25] Additionally, a recent study observed a cross-sectional analysis change during contraction of the supraspinatus using ultrasound and concluded that both tests contracted the supraspinatus.[29] Overall, the EC and FC tests seem to be associated not only with the activity of the supraspinatus but also with those of the other rotator cuff muscles.

The present study had several limitations. First, the measurements were limited to only an external load level of 3 kg, which is equivalent to 10–20% of the maximum muscle strength. The surrounding shoulder muscles are relatively activated when the external resistance more than half of the maximum strength is exerted compared with the rotator cuff muscles.[20] Therefore, we considered that the external load of 3 kg was the most appropriate for evaluating rotator cuff muscle activity. Second, the measurement position was limited to 45° and 90° of arm elevation. Because the supraspinatus elevation moment arm is increased with the arm at the side (0° position),[22] analysis that included this position may have been needed in the present study. Third, the use of surface electrodes over the infraspinatus may have been invalid because this has been shown in some exercises.[30] Fourth, although the EC/FC tests usually asses the isometric strength,[7,25,31] we did not confirm whether the tests were performed during the isometric movement; this would extend the case in which the rotator cuff muscles fail. Finally, we did not analyse the teres minor in the rotator cuff. Resolving these issues may lead to a better understanding of the rotator cuff muscle activity during the EC and FC tests.

The present study demonstrated that the rotator cuff muscles perform different activities according to the FC and EC test positions and the plane of elevation. For the supraspinatus and lower/upper subscapularis, the muscle activities were influenced by the EC position and the elevation plane; although for the infraspinatus, the activities were associated exclusively with the elevation plane. Thus, the rotator cuff muscles are influenced by arm position and the elevation plane during the EC and FC tests. These data will provide useful information when physicians and therapists perform the EC and FC tests in clinical settings.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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