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Research Report

Long-Term Efficacy of Treatment Effects After a Kyphosis Exercise and Posture Training Intervention in Older Community-Dwelling Adults: A Cohort Study

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ABSTRACT

Background and Purpose: Treatments that prevent worsening kyphosis are important due to the progressive nature of kyphosis with aging. We assessed long-term efficacy of treatment effects after a short-term kyphosis exercise and posture training intervention in a cohort study among older adults with hyperkyphosis, and investigated whether long-term treatment effects differ among males and females.

Methods: In the original kyphosis intervention, 112 older adults enrolled in a waitlist design randomized controlled trial. One hundred three participants, mean age 70.0 (5.7) years and kyphosis 52.0° (7.4°), completed a twice weekly, 3-month, group exercise and posture training intervention, and were eligible to enroll in the follow-up study. We compared (1) change in outcomes pre-/postintervention to change postintervention over the follow-up period, (2) change in outcomes pre-/postintervention and postintervention to follow-up, stratified by sex, and (3) long-term change postintervention to follow-up in males and females. Primary outcome was change in kyphometer-measured thoracic kyphosis. Secondary outcomes were change in lumbar lordosis, objective measures of physical function, self-reported measures of physical activity, and health-related quality of life (HRQoL).

Results and Discussion: Forty-three participants, 42% of the eligible cohort, returned for follow-up, a mean 3.0 (0.7) years after completing the original intervention. Participants (27 females and 16 males) were 73.8 (6.1) years old, with mean kyphosis 48.9° (11.9°) at follow-up. Kyphosis declined −1.5° (95% confidence interval [CI]: −3.9° to 1.0°) postintervention to follow-up and this was no different than change pre-/postintervention, $P = .173$. Lordosis improved 8.9° (95% CI: 6.2° to 11.6°), more than change pre-/postintervention, $P < .001$. Gait speed measure of physical function increased 0.08 (95% CI: 0.02 to 0.14) m/s, Physical Activity Scale for the Elderly (PASE) measure of physical activity increased 4 (95% CI: −16 to 24) points, and Patient-Reported Outcomes Measurement Information System (PROMIS) mental health T-score measure of HRQoL increased 1.1 (95% CI: −1.0 to 3.1) points, but these improvements were not significantly more than change pre-/postintervention, $P > .050$. Other measures of physical function (modified Physical Performance Test [PPT], Timed Up and Go, and 6-minute walk) and HRQoL (Scoliosis Research Society [SRS-30] self-image and PROMIS physical function and physical health) declined at follow-up, significantly more than change pre/postintervention, $P \leq .050$. Comparing change in outcomes pre-/postintervention and postintervention to follow-up, stratified by sex, both males and females increased lordosis, and decreased modified PPT and 6-minute walk measures of physical function, $P < .050$. Males and females differed in long-term change postintervention to follow-up. Time loaded standing and PASE improved in females compared with males, $P = .008$ and $P = .092$, respectively, and PROMIS mental health, physical health, and physical function declined in females compared with males, $P = .073$, $P = .025$, and $P = .005$, respectively.

Conclusions: In our follow-up study, a mean of 3.0 (0.07) years after a 3-month kyphosis exercise and posture training intervention, kyphosis maintained and did not progress as expected with age. There was long-term improvement in lordosis. Compared with treatment effects from the short-term intervention, gait speed maintained equally well in males and females, while trunk endurance improved in females. Further investigation of long-term benefits of a short-term kyphosis exercise and posture training intervention is warranted.

Key Words: aging, health-related quality of life, hyperkyphosis, kyphosis, lordosis, sex differences

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The authors declare no conflicts of interest.

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INTRODUCTION

Hyperkyphosis, defined by a thoracic kyphosis angle greater than 40°,[1-5] is common among 40% of older adults, and progresses with age.[6,7] While a small amount of anterior curvature of the thoracic spine is normal due to the shape of the vertebral bodies and intervertebral discs, once kyphosis exceeds 50°, it is associated with reduced quality of life, impaired physical function, falls, and elevated fracture risk.[8-11] To date, there is no standard of care to inform providers how to treat or reduce the rate of age-related kyphosis progression. We recently completed a randomized controlled trial of older males and females, mean age 70.0 (5.7) years, with a mean kyphometer-derived kyphosis of 52.0° (7.4)°, and demonstrated a statistically significant improvement in this clinical measurement of kyphosis after a 3-month kyphosis exercise and postural training program in a controlled research environment.[12] Thus, while the efficacy of a short-term kyphosis exercise and postural training program to reduce kyphosis is now established, the long-term effects and maintenance of treatment effects of the intervention on kyphosis progression are not known.

It is estimated that kyphosis progresses approximately 5° every decade among females age 55 to 80 years[6,7,13] but progression has not been well-investigated among older males. One prior study reported the absolute short-term progression of kyphosis in females as 2.4° (5.0°) over 3.7 years, compared with 1.3° (5.5°) over 4.6 years in males.[14] Factors that influence the degree of kyphosis and its progression, such as low bone mineral density (BMD),[15] low spine muscle strength,[16] quality,[17] and volume,[18] vertebral fractures,[13] and presence of diffuse idiopathic skeletal hyperostosis (DISH),[19] often differ among females and males.[20] Females tend to have lower BMD and paraspinal muscle quality,[21] more vertebral fractures, and less DISH,[3,17,22-26] which may influence response to a kyphosis intervention. However, in the original kyphosis intervention,[14] there were sex differences in baseline degree of kyphosis, BMD, spine strength, fractures, and DISH, but no difference in treatment response according to sex.

To our knowledge, no studies have investigated the long-term efficacy and maintenance of a short-term kyphosis intervention, and whether sex affects long-term treatment effects. This study investigated the long-term efficacy and maintenance of the treatment effects following a 3-month kyphosis exercise and posture training program, and whether long-term treatment effects differ according to sex.

METHODS

Participants

Participants were initially recruited in January 2013 through June 2015 from local senior centers and outpatient medical clinics at 2 large urban medical centers (a university-based center and an integrated managed care center), and 112 participants were enrolled in the original kyphosis trial.[12] Of these, 9 dropped within the first week. After the original study was completed, we obtained additional funding to follow up with the 103 study participants who had completed the original kyphosis intervention to investigate long-term effects of the original kyphosis intervention. Of these, 43 participants agreed to follow-up testing (Figure 1). Follow-up time varied from 2 to 4 years—mean 3.0 (0.7)—after the original intervention.

The original kyphosis intervention was a waitlist randomized controlled trial to determine the effects of a twice a week, 3-month kyphosis intervention on radiographic and kyphometer-derived kyphosis, and to investigate sex differences in response to the intervention.[12] The intervention was a multimodal group-based kyphosis-specific exercise and posture training program, led by a licensed physical therapist and trained research assistant, that targeted spinal extensor muscle strength, spinal mobility, and postural alignment. Exercises were progressed in intensity throughout the study with light weights (0-5 lb), Theraband, and foam rollers to maintain a Borg Scale intensity of 4 to 5, based upon 70% to 80% of perceived exertion, while maintaining good quality movement and neutral spinal alignment. Participants were also given a study manual of pictures depicting neutral spinal alignment during activities of daily living and were instructed to practice good posture at least 3 times a day independently. Inclusion criteria included proficiency in English, 60 years or older, kyphosis angle 40° or higher (measured with a kyphometer at the screening visit), ability to walk one block without an assistive device, able to climb one flight of stairs independently, and rise from a chair without the use of one's arms. Participants were excluded if they were unable to actively reduce their kyphosis measurement by at least 5°, had cognitive impairment on the Mini-Cog,[27] unable to pass safety tests in the screening examination (gait speed $<$0.6 m/s, inability to stand with feet together for 30 seconds, inability to actively flex shoulders to 90°, inability to move from standing to supine on a mat and return to standing independently or with the use of a nearby chair), or had any disorder or disease likely to prevent or interfere with safe participation in a group-based exercise program. This included painful vertebral fractures in the past 3 months, unexplained weight loss ($>$10 lb in the past year), 3 or more falls in the past year, advanced disability or end-stage disease, major psychiatric illness, alcohol or drug abuse (diagnosed by the primary care provider), narcotic pain medications, diagnosed vestibular or progressive neurologic disorder, total hip or knee replacement or hip fracture within the previous 6 months, or oral glucocorticoid medications for 3 months or more in the past year.

The study protocols were approved by the University of California San Francisco and Kaiser Permanente Northern California Institutional Review Boards. All participants signed informed consent to participate in the original and follow-up studies.

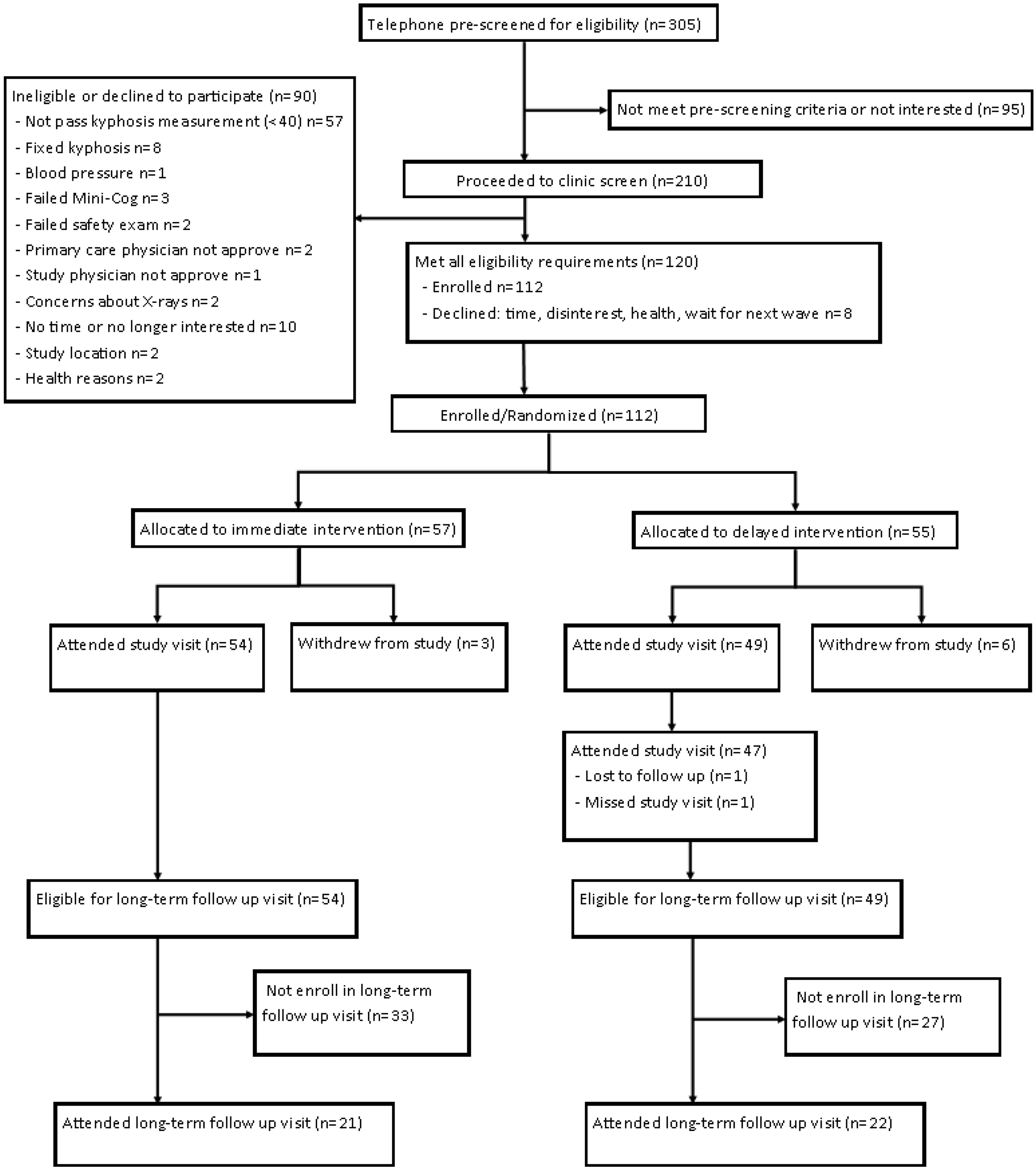

Figure 1. Disposition of study participants for original kyphosis trial and long-term follow-up study.

Study Outcomes

Outcomes that were assessed at baseline and after the original 3-month intervention[12] were reassessed at the long-term follow-up visit. However, due to funding limitations, radiographs were not obtained at the long-term follow-up visit and radiographic Cobb angle of kyphosis was not measured. Change in outcome measurements was compared between pre-/postintervention and postintervention to long-term follow-up. The primary outcome was change in kyphometer-derived kyphosis, and secondary outcomes were change in lumbar lordosis, physical function, physical activity, and health-related quality of life (HRQoL). Clinical measurements were made by a trained staff member at the UCSF Clinical and Translational Science Institute blinded to prior measurements.

Kyphosis

Kyphosis, a measure of the anterior curvature in the thoracic spine, was measured in degrees using a standardized protocol for clinically measured kyphosis (T3-T12)[28] with the Debrunner kyphometer (Techmedica Inc, Camarillo, California). The participants stood in their usual posture, and the angle of kyphosis was measured after placing the feet of the kyphometer over the T2/T3 spinous process interspace superiorly and T11/T12 spinous process interspace inferiorly. Greater degree of kyphosis indicates more kyphosis. The intraclass correlation coefficient (ICC) for repeated intra- and interobserver analysis for kyphosis measurements using the Debrunner kyphometer has been previously reported as 0.98.[29] The validity of the kyphometer measurement of kyphosis compared with the gold standard standing radiographic Cobb angle is ICC = 0.76.[29] The minimal detectable change (MDC) for thoracic kyphosis measured by dual inclinometer has been previously reported as 2.51°.[30]

Lordosis

Lordosis, a measure of the posterior curvature of the lumbar spine, was measured in degrees using a standardized protocol for clinically measured lordosis (T12-S1).[28] The angle of lordosis was measured after placing the feet of the kyphometer over the T11/T12 spinous process interspace superiorly and S1/S2 spinous process interspace inferiorly. Greater degree of lordosis indicates more lordosis. The interrater reliability for radiographic Cobb angle of lordosis has been previously reported as 0.98,[5] and the intra- and interrater reliability for the kyphometer measured lordosis is 0.96.[31] The MDC based on measurements between raters was 3.90° for radiographic Cobb angle.[5]

Physical function

The *modified Physical Performance Test (PPT),* a direct observation test that assesses multiple dimensions of physical function (basic and complex activities of daily living), includes 7 timed standardized functional tasks. A maximum score is 36 and higher scores indicate better performance.[32] Test-retest reliability for the modified PPT score in community-dwelling older adult population has been previously reported as 0.96.[33] A strong correlation was observed with the Berg Balance Scale, $r = 0.71$, and low scores on the modified PPT predicted physical frailty.[34] For this measurement MDC has not been reported. *Gait speed* (meters/second) was calculated over a 4-m marked course while walking at a usual pace.[35] A higher score indicates better performance. Slow gait speed has been shown in several different populations to be the single best predictor of functional decline and disability.[19,35,36] Test-retest reliability has been previously reported as 0.90.[37] Perera et al[38] reported a minimally clinically important difference of 0.05 m/s as small meaningful change and 0.13 m/s as substantial among older adults with a mean age of 77.6 (SD = 7.6) years. The MDC for older adults has been deemed dependent upon baseline gait speed. For intermediate speed (0.85 m/s) and fast (1.30 m/s) walkers, MDC was 0.108 and 0.144, respectively.[39] The *Timed Up and Go test*[40] assesses mobility, balance walking ability, and fall risk in older adults, and is measured as the time in seconds to rise from a 41-cm height armchair, walk 3 m at a usual pace, turn, and return to a fully seated position in the chair. Lower scores indicate better performance. This test has excellent reliability (ICC 0.91-0.96) and sensitivity and specificity for identifying elderly individuals at risk for mobility impairments and falls.[41,42] Lin et al[43] reported responsiveness with moderate effect size for activities of daily life decline as 0.42 seconds, and small effect for activities of daily life improvement at 0.05 seconds in community-dwelling older adults. Minimal detectable changes reported for adults aged 45 to 70 years with knee osteoarthritis ranged from 1.10 and 1.14 seconds.[44] *Timed loading standing* test,[45] a measure of combined trunk and upper extremity endurance, calculates the time in seconds a participant is able to stand while holding a 2-lb dumbbell in each hand with the arms at 90° of shoulder flexion and the elbows extended. Higher score indicates better performance. The ICC for same day and 6- to 10-day test-retest reliability has been previously reported as 0.89.[45] Moderately high correlations were found between timed loaded standing and 16 measures of physical impairment and function,[45] and the total test time was associated with back fatigue supporting the concurrent validity of the time loaded standing test.[46] Minimal detectable change has not been reported. The *6-minute walk* test[47] is an assessment of aerobic capacity/endurance, which measures the distance in meters covered while walking at a usual pace in a long hallway for 6 minutes. Greater distance indicates better performance. One week test-retest reliability is 0.95 and compares with cycle ergometry $r = 0.58$.[48] The MDC has been previously reported as 58.2 m.[38]. *Isometric spinal extension and flexion muscle strength* was assessed using a standardized protocol with the Biodex 3 (Biodex Medical Systems Inc, Shirley, New York) computerized dynamometer and the spine attachment (RSI Systems, Boulder, Colorado). Peak torque (pounds) normalized to body weight was used to quantify strength, and greater peak torque to body weight indicates better performance. The ICC for 1-week test-retest reliability is 0.84 (95% confidence interval [CI] = 0.71, 0.96).[49] Minimal detectable change has not been reported.

Physical activity

The *Physical Activity Scale for the Elderly (PASE)* physical activity questionnaire is a brief survey designed specifically to assess frequency, duration, and intensity level of physical activity over the previous week in persons 65 years and older. Scores range from 0 to 793, with higher scores indicating greater physical activity.[50] The PASE has excellent test-retest reliability (ICC = 0.75) in elderly adults,[50] and excellent correlation ($r = 0.68$) with the 6-minute walk.[48] An MDC of 87 points has been reported in a small sample of older adults with hip osteoarthritis (n = 33).[51]

HRQoL

The modified *Scoliosis Research Society (SRS-30)* is a self-reported spine-specific quality-of-life instrument that includes 4 domains scored separately 1 to 5 (1-worst, 5-best). We scored the self-image/appearance domain, and higher scores indicate better self-image.[52] The self-image domain score of the SRS-30 has significant correlation with Cobb angle of kyphosis in untreated scoliosis.[53] Internal consistency, Cronbach α, has been previously reported as 0.81 for self-image/appearance domain. Validity, determined by Pearson correlation coefficients was, 0.70 or more for relevant domains between 36-Item Short Form Health Survey and the modified SRS-30 instrument.[52] Minimal detectable change has not been reported. The *Patient-Reported Outcomes Measurement Information System (PROMIS)*[54] *Scale v.1.0-Global Health* is a quality-of-life questionnaire with mental and physical health components. This health survey measures patient-reported outcomes such as pain, fatigue, physical functioning, emotional distress, and social role participation that have a major impact on quality of life across a variety of chronic diseases. The PROMIS measures are scored as 0 to 100 T-scores, with a mean T-score of 50 for the general population, and higher scores indicating better self-reported HRQoL.[54] The PROMIS short-form v.1.0-Physical Function instrument measures self-reported capability rather than actual performance of physical activities. It is sensitive to change in intervention studies where physical function is expected to change, and able to distinguish between different clinical samples,[55] but MDC has not been reported.

Statistical Methods

We used descriptive statistics to define the follow-up participants at baseline, after the 3-month intervention, and at long-term follow-up (Table 1). We compared the mean change after the original 3-month treatment (pre-post) intervention in the sample that returned for long-term follow-up versus those who did not return for follow-up; then restricted our analyses to those participants who returned for and completed the long-term follow-up visit, a mean of 3 years after intervention. We used a nonparametric Wilcoxon test to compare the mean change pre-/postintervention and mean change postintervention to long-term follow-up in all participants, and stratified by

Table 1. Means of Measures at Preintervention, Postintervention, and Follow-up

	Preintervention (n = 43)	Postintervention (n = 43)	Follow-up (n = 43)	*P* Value
	Mean (Standard Deviation)			
Kyphosis, °	53.8 (8.1)	50.2 (9.7)	48.9 (11.9)	.077
Lordosis, °	31.2 (12.5)	29.8 (12.2)	38.7 (11.5)	.002
Modified PPT (0-36 points)	33.2 (1.9)	33.7 (2.4)	30.1 (2.1)	<.001
4-m, m/s	1.29 (0.28)	1.31 (0.22)	1.40 (0.25)	.051
Timed Up and Go, s	7.26 (1.23)	7.21 (1.28)	7.70 (1.61)	.596
Time loaded standing, s	120.5 (46.1)	126.6 (52.0)	145.7 (46.7)	.017
6-min walk, m	512.6 (81.4)	524.3 (77.1)	432.9 (93.7)	<.001
PASE (0-400 points)	118 (59)	115 (57)	120 (57)	.842
SRS-30 self-image (0-5 points)	3.54 (0.62)	3.81 (0.55)	3.77 (0.67)	.147
PROMIS mental health T-score	53.2 (7.6)	53.4 (7.9)	54.7 (9.4)	.676
PROMIS physical health T-score	52.5 (5.7)	53.8 (6.6)	52.2 (7.0)	.476
PROMIS physical function T-score	49.2 (7.4)	52.0 (9.7)	51.5 (8.0)	.284
	Median (Interquartile Range, Q1 to Q3)			
Spinal flexion (peak torque/body weight)	29.5 (22.7 to 36.8)	31.75 (23.6 to 35.8)	29 (23.0 to 38.4)	.916
Spinal extension (peak torque/body weight)	70.6 (55.7 to 81.0)	74.7 (60.3 to 82.9)	68 (55.9 to 79.2)	.662
	n (%)			
In general, how do you rate your health?				.668
2: Fair	2 (4.65)	2 (4.65)	2 (4.76)	
3: Good	18 (41.86)	11 (25.58)	14 (33.33)	
4: Very Good	15 (34.88)	24 (55.81)	19 (45.24)	
5: Excellent	8 (18.60)	6 (13.95)	7 (16.67)	

Abbreviations: PASE, Physical Activity Scale for the Elderly; PPT, Physical Performance Test; PROMIS, Patient-Reported Outcomes Measurement Information System; SRS, Scoliosis Research Society.

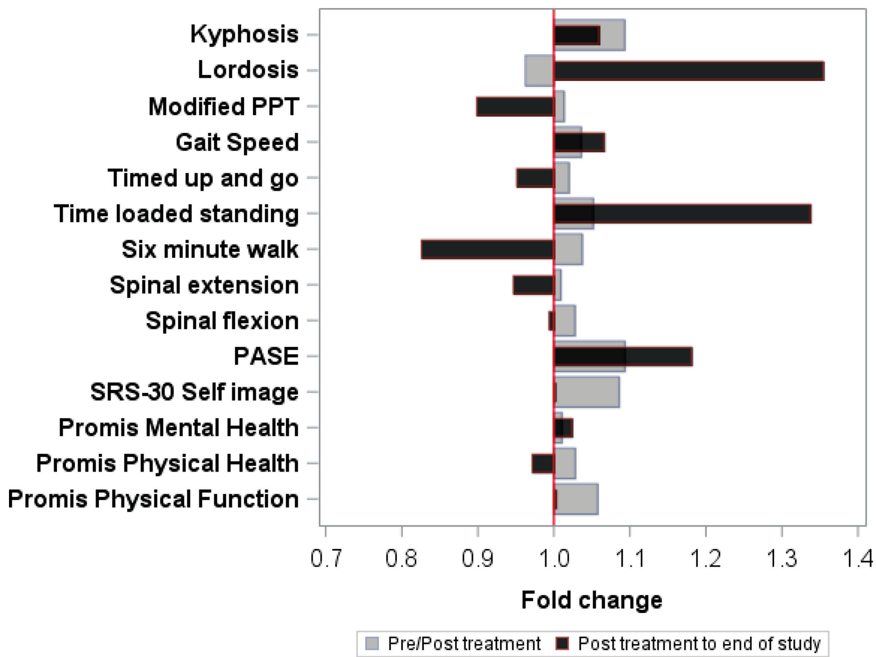

Figure 2. Fold change comparing pre-/postintervention to postintervention to follow-up. Significant difference in change in lordosis, modified PPT, 6-minute walk, SRS-30 self-image, PROMIS physical health, and PROMIS physical function outcomes pre-/postintervention compared with postintervention to follow-up over 3 years, $P \leq .050$. PPT indicates Physical Performance Test; PROMIS, Patient-Reported Outcomes Measurement Information System; SRS, Scoliosis Research Society.

sex. We compared the long-term change postintervention to follow-up in males and females. Mean change was calculated as the difference in units pre-/postintervention and postintervention to long-term follow-up. These changes are represented in the tables. We also standardized the units of all outcomes by calculating the fold change pre-/postintervention and postintervention to long-term follow-up as a ratio, where 1 represented no change, greater than 1 represented improvement, and less than 1 represented a decline. This is illustrated in Figure 2.

For the original randomized trial, we determined that a sample size of 100 participants would have 80% power in 2-sided tests with a type-I error rate of 5%, allowing for within-subject correlation of the baseline and 3-month outcomes, and loss to follow-up of 20% of participants, to detect a clinically meaningful change of 2° (or more) in the primary outcome Cobb angle of kyphosis. Additionally, we determined a priori that a sample including 40% men would have 84% power to detect a 2° difference between men and women in mean change in the primary radiographic-measured kyphosis outcome.

RESULTS

Forty-two percent (n = 43) of the 103 participants who completed the original kyphosis trial returned for long-term follow-up testing (Figure 1). In the original trial, a 3-month targeted spine strengthening exercise and posture training program reduced kyphometer-measured, but not radiographic-measured kyphosis.[12] Despite sex differences in baseline kyphosis, BMD, spine strength, fractures, and DISH, sex did not affect treatment response. The participants in the long-term cohort study (27 females and 16 males) were 73.8 (6.1) years of age, with a mean kyphosis of 48.9° (11.9°) at follow-up (Table 1). Those who returned for follow-up were lower functioning on the time loaded standing test before the intervention compared with those who did not return (120.5 ± 46.1 seconds vs 139.2 ± 50.6 seconds, $P < .024$), but there were no significant differences in change in outcomes pre-/postintervention among those who returned compared with those who did not return for long-term follow-up ($P > .050$). Ninety-five percent of the cohort who returned rated their health as good to excellent (Table 1). Comparing the fold change pre-/postintervention to change postintervention to follow-up, kyphosis, lordosis, gait speed, time loaded standing, PASE physical activity, and PROMIS mental health improved (Figure 2). The modified PPT, Timed Up and Go, 6-minute walk test, spinal extensor and flexor strength, and PROMIS physical health scores declined (Figure 2).

Comparing change in outcomes pre-/postintervention and postintervention to follow-up over 3.0 (0.7 years), kyphosis decreased −1.5° (95% CI: −3.9° to 1.0°), indicating improvement, although the magnitude of change at follow-up was not statistically different than the −3.8° (95% CI: −5.6° to −2.0°) change pre-/postintervention, $P = .173$ (Table 2). Lordosis increased 8.9° (95% CI: 6.2° to 11.6°), more than the −1.1° (95% CI: −2.9° to 0.7°) change pre-/postintervention, $P < .001$. Gait

Table 2. Comparing Change in Outcomes at 2 Time Points (Baseline to Postintervention and Postintervention to Follow-up Over 3 Years)

	Pre/postintervention	Postintervention to Follow-up	
	Mean (95% CI) n = 43	Mean (95% CI) n = 43	*P* Value
Kyphosis, °	−3.8 (−5.6 to −2.0)	−1.5 (−3.9 to 1.0)	.173
Lordosis, °	−1.1 (−2.9 to 0.7)	8.9 (6.2 to 11.6)	<.001
Modified PPT (0-36 points)	0.4 (−0.2 to 1.0)	−3.6 (−4.4 to −2.7)	<.001
4-m, m/s	0.02 (−0.03 to 0.08)	0.08 (0.02 to 0.14)	.105
Timed Up and Go, s	−0.06 (−0.36 to 0.23)	0.49 (0.10 to 0.88)	.031
Time loaded standing, s	5.4 (−4.3 to 15.2)	17.7 (1.8 to 33.8)	.053
6-min walk test, m	14.4 (−6.9 to 35.8)	−93.1 (−119.2 to −67.0)	<.001
PASE (0-400 points)	−4 (−19 to 10)	4 (−16 to 24)	.393
SRS-30 self-image (0-5 points)	0.24 (0.11 to 0.38)	−0.03 (−0.22 to 0.16)	.025
PROMIS mental health T-score	0.3 (−1.4 to 2.0)	1.1 (−1.0 to 3.1)	.635
PROMIS physical health T-score	1.4 (0.0 to 2.8)	−1.7 (−3.3 to −0.1)	.006
PROMIS physical function T-score	2.9 (1.3 to 4.5)	−0.5 (−2.5 to 1.5)	.009
	Median (Interquartile Range, Q1 to Q3)		
Spinal flexion (peak torque/body weight)	0.2 (−1.9 to 2.3)	2.4 (−2.2 to 7.1)	.872
Spinal extension (peak torque/body weight)	1.4 (−6.1 to 8.9)	−1.0 (−10.3 to 8.2)	.361

Abbreviations: CI, confidence interval; PASE, Physical Activity Scale for the Elderly; PPT, Physical Performance Test; PROMIS, Patient-Reported Outcomes Measurement Information System.

speed increased 0.08 (95% CI: 0.02 to 0.14) m/s, PASE physical activity score increased 4 (95% CI: −16 to 24) points, and PROMIS mental health increased 1.1 (95% CI: −1.0 to 3.1) points at follow-up, although compared with change pre-/postintervention, these changes were not statistically significant, $P > .050$ (Table 2). Modified PPT, Timed Up and Go, 6-minute walk, PROMIS physical function and physical health, and the SRS-30 self-image worsened at follow-up, significantly more than the change pre-/postintervention, $P \leq .031$ (Table 2).

In sex-stratified analyses comparing change in outcomes pre-/postintervention and long-term postintervention to follow-up in males and females, lordosis increased and the modified PPT and 6-minute walk decreased. Females only declined in SRS-30 self-image, PROMIS physical health, and PROMIS physical function, $P < .050$ (Table 3). Females improved 33.2 (95% CI: 16.8 to 49.6) seconds in time loaded standing, $P < .001$, and males declined −14.6 (95% CI: 46.7 to 17.6) seconds, $P = .060$. On the PASE physical activity questionnaire, females increased 18 (95% CI: −12 to 47), $P = .184$, and men decreased −15 (95% CI: −38 to 7) points, $P = .940$; thus, the overall 4-point increase in PASE scores resulted from the large 18-point improvement in females. SRS-30 self-image increased 0.19 (95% CI: −0.09 to 0.47) points in males, $P = .835$, and decreased −0.16 (95% CI: −0.42 to 0.10) points in females, $P = .007$.

Comparing the long-term change postintervention to follow-up in males and females, there were differences between them in time loaded standing ($P = .008$), PROMIS physical health ($P = .025$), and physical function ($P < .001$) (Table 4). There were differences between males and females in long-term change in PASE physical activity ($P = .092$), SRS-30 ($P = .069$), and PROMIS mental health ($P = .073$), but these differences were not statistically significant (Table 4).

DISCUSSION

In this long-term follow-up study among 43 participants, a mean of 3.0 (0.7) years after exposure to a 3-month kyphosis exercise and posture training intervention, kyphosis did not progress as expected with aging. Kyphosis improved an additional −1.5° (95% CI: −3.9° to 1.0°) over the 3-year follow-up period, and the magnitude of the change was not statistically different from the change during the 3-month intervention. Comparing the change in outcomes after the 3-month intervention to the long-term change postintervention to follow-up, lordosis, gait speed, PASE physical activity, time loaded standing, and mental HRQoL improved, and except for lordosis, the magnitude of change was not significantly greater than the change during the intervention, highlighting the long-term benefits and sustainability of a short-term kyphosis intervention. Other measures of physical function including 6-minute walk, modified PPT, spinal extension and flexion strength and Timed Up and Go, and HRQoL including PROMIS physical health worsened, as expected with aging.

Table 3. Comparing Change in Outcomes at 2 Time Points (Baseline to Postintervention and Postintervention to Follow-up Over 3 Years), Stratified by Sex

	Pre-/Postintervention	Postintervention to Follow-up	*P* Value
	Males (n = 16), Mean (95% CI)		
Kyphosis, °	−3.9 (−7.4 to −0.4)	−1.7 (−5.4 to 2.0)	.395
Lordosis, °	−1.8 (−5.4 to 1.8)	10.0 (3.9 to 16.2)	.002
Modified PPT (0-36 points)	0.03 (−1.0 to 1.1)	−2.8 (−4.6 to −1.0)	.014
4-m, m/s	0.02 (−0.08 to 0.13)	0.08 (−0.06 to 0.22)	.255
Timed Up and Go, s	0.13 (−0.60 to 0.87)	0.95 (0.16 to 1.75)	.135
Time loaded standing, s	16.3 (0.8 to 31.7)	−14.6 (−46.7 to 17.6)	.060
6-min walk, m	16.8 (−8.1 to 41.7)	−88.7 (−122.2 to −55.2)	<.001
PASE (0-400 points)	−5 (−34 to 25)	−15 (−38 to 7)	.940
SRS-30 self-image (0-5 points)	0.19 (−0.03 to 0.41)	0.19 (−0.09 to 0.47)	.835
PROMIS mental health T-score	0.3 (−3.0 to 3.6)	3.3 (0.6 to 6.1)	.141
PROMIS physical health T-score	1.2 (−1.8 to 4.1)	0.6 (−1.9 to 3.1)	.597
PROMIS physical function T-score	3.2 (0.7 to 5.7)	1.1 (−1.9 to 4.1)	.168
	Median (Interquartile Range, Q1 to Q3)		
Spinal flexion (peak torque/body weight)	−0.4 (−4.3 to 3.6)	6.0 (−6.6 to 18.7)	.644
Spinal extension (peak torque/body weight)	−5.3 (−24.6 to 14.0)	5.7 (−19.3 to 30.8)	.644
	Females (n = 27), Mean (95% CI)		
Kyphosis, °	−3.7 (−5.9 to −1.6)	−1.3 (−4.8 to 2.1)	.264
Lordosis, °	−0.7 (−2.9 to 1.5)	8.2 (5.6 to 10.9)	<.001
Modified PPT (0-36 points)	0.6 (−0.2 to 1.4)	−4.0 (−4.9 to −3.0)	<.001
4-m, m/s	0.02 (−0.05 to 0.09)	0.08 (0.01 to 0.15)	.307
Timed Up and Go, s	−0.18 (−0.42 to 0.07)	0.22 (−0.2 to 0.64)	.131
Time loaded standing, s	0.2 (−12.3 to 12.7)	33.2 (16.8 to 49.6)	<.001
6-min walk, m	13.1 (−18.7 to 44.9)	−95.7 (−133.7 to −57.6)	<.001
PASE (0-400 points)	−4 (−20 to 12)	18 (−12 to 47)	.184
SRS-30 self-image (0-5 points)	0.28 (0.10 to 0.46)	−0.16 (−0.42 to 0.10)	.007
PROMIS mental health T-score	0.3 (−1.7 to 2.4)	−0.3 (−3.2 to 2.6)	.614
PROMIS physical health T-score	1.5 (0.0 to 3.0)	−3.2 (−5.8 to −1.2)	<.001
PROMIS physical function T-score	2.8 (0.6 to 4.9)	−1.5 (−4.2 to 1.3)	.041
	Median (Interquartile Range, Q1 to Q3)		
Spinal flexion (peak torque/body weight)	0.5 (−2.2 to 3.2)	0.8 (−3.5 to 5.1)	.898
Spinal extension (peak torque/body weight)	4.4 (−2.9 to 11.8)	−4.2 (−12.9 to 4.5)	.103

Abbreviations: CI, confidence interval; PASE, Physical Activity Scale for the Elderly; PPT, Physical Performance Test; PROMIS, Patient-Reported Outcomes Measurement Information System; SRS, Scoliosis Research Society.

We found that after exposure to the original intervention, kyphosis treatment effects were maintained and lordosis improved in our cohort during the follow-up period. In the original kyphosis trial, there was a −3.8° (95% CI: −5.6° to −2.0°) decrease (improvement) in kyphosis after the 3-month intervention, and an additional mean −1.5° (95% CI: −3.9° to 1.0°) decrease in kyphosis at long-term follow-up, rather than an expected progression of kyphosis reported in previous longitudinal cohort studies among older adults.[6,7,56] For example, in the Study of Osteoporotic Fractures, females experienced a 7° increase in kyphosis over 15 years, an approximate 0.5° progression

Table 4. Comparing Long-Term Change Postintervention to Follow-up Differences Between Males and Females

	Males (n = 16)	Females (n = 27)	
	Mean (95% CI)		*P* Value
Kyphosis, °	−1.7 (−5.4 to 2.0)	−1.3 (−4.8 to 2.1)	.882
Lordosis, °	10.0 (3.9 to 16.2)	8.2 (5.6 to 10.9)	.839
Modified PPT (0-36 points)	−2.8 (−4.6 to −1.0)	−4.0 (−4.9 to −3.0)	.293
4-m, m/s	0.08 (−0.06 to 0.22)	0.08 (0.01 to 0.15)	.599
Timed Up and Go, s	0.95 (0.16 to 1.75)	0.22 (−0.20 to 0.64)	.144
Time loaded standing, s	−14.6 (−46.7 to 17.6)	33.2 (16.8 to 49.6)	.008
6-min walk, m	−88.7 (−122.2 to −55.2)	−95.7 (−133.7 to −57.6)	.766
PASE (0-400 points)	−15 (−38 to 7)	18 (−12 to 47)	.092
SRS-30 self-image (0-5 points)	0.19 (−0.09 to 0.47)	−0.16 (−0.42 to 0.1)	.069
PROMIS mental health T-score	3.3 (0.6 to 6.1)	−0.2 (−3.2 to 2.6)	.073
PROMIS physical health T-score	0.6 (−1.9 to 3.1)	−3.2 (−5.3 to −1.2)	.025
PROMIS physical function T-score	1.3 (−1.9 to 4.1)	−1.5 (−4.2 to 1.3)	.005
	Median (Interquartile Range, Q1 to Q3)		
Spinal flexion (peak torque/body weight)	6.0 (−6.6 to 18.7)	0.8 (−3.5 to 5.1)	.778
Spinal extension (peak torque/body weight)	5.7 (−19.3 to 30.8)	−4.2 (−12.9 to 4.5)	.572

Abbreviations: CI, confidence interval; PASE, Physical Activity Scale for the Elderly; PPT, Physical Performance Test; PROMIS, Patient-Reported Outcomes Measurement Information System; SRS, Scoliosis Research Society.

annually, whereas our follow-up cohort reduced kyphosis after the original intervention, but without any ongoing treatment.[7] We recognize that the change in kyphosis was smaller than the change pre-/postintervention, and did not exceed the 2.51° MDC previously reported by Jang et al,[30] but it was not statistically different from the treatment effect from the original intervention $P = .173$. We can say with certainty that kyphosis did not progress as expected. Moreover, lordosis, which usually declines with aging,[57,58] did not change significantly after the original intervention, yet significantly improved 8.9° at long-term follow-up, exceeding the MDC of 3.9° for radiographic Cobb angle measure of lordosis reported by Hicks et al.[5] Greater lumbar lordosis has been positively associated with paraspinal extensor muscle strength[16]; however, in our study, there was no significant change in spinal muscle flexion and extension strength, yet both sexes saw a large increase in lordosis at long-term follow-up. Furthermore, in a similar aged cohort of females, time loaded standing was modestly correlated with lumbar lordosis,[45] although we found it improved by 33.2 seconds in females but declined 14.6 seconds in males even though lordosis improved comparably in both groups. It is possible that unmeasured changes in motor control, specifically improved activation patterns between the deep and superficial trunk musculature derived from the postural training during the original intervention, may explain the additional improvements in lordosis.[59-61] Regardless, these long-term changes suggest that a 3-month kyphosis-specific exercise and posture training intervention may prevent age-related kyphosis progression and improve lumbar lordosis, which may have long-term beneficial effects on overall sagittal spine alignment. Future study is warranted that includes measures of motor control to better understand mechanisms for maintaining or improving postural alignment with aging.

Despite studies that report gait speed as a vital sign indicative of overall physical function, and the single best predictor of functional decline and disability,[19,35,36] we found that gait speed was maintained at follow-up, but other broader physical function measures, except time loaded standing, declined at long-term. Our cohort had a mean gait speed of 1.40 (0.25) m/s at long-term follow-up (Table 1), which is faster than age-matched norms,[62] and we observed an increase of 0.08 (95% CI: 0.02 to 1.4) m/s at long-term follow-up. This exceeds a small meaningful change in gait speed of 0.05 m/s reported by Kwon et al,[63] although does not approach the 0.14 m/s change deemed to exceed measurement error for fast walkers.[39] It is possible that preventing kyphosis progression prevented a decline in gait speed, and contributed to the maintenance of gait speed observed in our study. This is generally consistent with findings from other studies that report greater kyphosis is associated with slower gait speed,[64-66] and that worsening kyphosis is an independent predictor of decline in gait speed over time.[67] Furthermore, the other physical performance measure that improved was time loaded standing, a measure of trunk and upper extremity endurance[45] that has been associated with kyphosis in older women.[68] However, it improved in females only despite maintenance of kyphosis in both males and females. Further study investigating the causal association between changes in kyphosis and physical function are needed.

We observed an improvement in PROMIS mental health, but a decline in PROMIS physical health and physical function measures of HRQoL at long-term follow-up. Interestingly, the direction of these outcomes is the same as has been reported previously in the PROMIS reference population with aging.[69] Reference populations tested for PROMIS mental health improved 0.3 points from T-scores of 53.1 in the 65- to 74-year age group to 53.4 in the +75-year group and declined between 1 and 2 points on PROMIS physical function and physical health scales. The PROMIS physical function and physical health HRQoL scores declined, which is consistent with the decline in physical function expected with aging, and that was observed in the objective measures of physical function including the modified PPT, Timed Up and Go, and the 6-minute walk tests. However, the magnitude of change in these HRQoL and physical function scores is small, and the only changes approaching clinical significance are the 3.2-point (95% CI: −5.3 to −1.2) decline in PROMIS physical health in females and the overall −93.1-m (95% CI: −119.2 to −67.0) decline in the 6-minute walk. For the PROMIS, a half standard deviation (5 points on a T-score metric) has been proposed as a minimal important difference (MID) in instances when there is no empirical literature on which to base an MID estimate.[70] For the 6-minute walk, the decline exceeded the 87-m MDC for measurement error. Further research to better understand the physical, mental, and psychosocial experience associated with living with hyperkyphosis and patient-centered benefits associated with improving hyperkyphosis in older adults is needed.

Comparing change in outcomes pre-/postintervention and postintervention to follow-up, the changes were fairly consistent in males and females, except in time loaded standing, PASE physical activity, and SRS-30 self-image. Both males and females significantly increased lordosis, and decreased modified PPT and 6-minute walk over the follow-up period compared with the intervention period. However, the time loaded standing score improved 33.2 (95% CI: 16.8 to 49.6) seconds in females, compared with a decline of −14.6 (95% CI: −46.7 to 17.6) seconds in males, and the difference in the magnitude of change between males and females in the long-term follow-up period was significant. Time loaded standing is a measure of trunk and upper extremity endurance, and trunk muscle endurance has been associated with the degree of kyphosis in older females.[68] However, the difference between males and females that we observed in time loaded standing occurred even though there was no significant difference between males and females in long-term change in kyphosis. Moreover, the PASE physical activity score decreased by −15 (95% CI: −38 to 7) points in males and increased 18 (95% CI: 12 to 47) points in females, although the long-term difference between them was not statistically significant, $P = .092$. The MDC for PASE has been reported as 87 points in a small sample of adults age 40 to 80 years with hip osteoarthritis, so it is difficult to estimate clinical relevance of this magnitude of change. Moreover, while it is generally accepted that an increase in physical activity is associated with an improvement in physical self-image,[71] in our study, the females increased their physical activity but the SRS-30 self-image score declined by −0.16 (95% CI: −0.42 to −0.1) points. However, this decline in self-image may be of questionable clinical significance, given the minimum clinically important difference (MCID) for the related SRS-20 has been reported as 0.5 points.[72] Regardless, other unmeasured factors likely affected the long-term change in physical activity and time loaded standing outcomes in our male and female participants, and warrants further study.

The strength of this study is that we investigated long-term treatment effects of a short-term kyphosis exercise and posture training intervention. However, there are several limitations. First, only 42% of the eligible cohort returned for follow-up, which may be because the follow-up study was not planned a priori and many participants did not respond when they were contacted again. However, changes in kyphosis and other treatment outcomes after the intervention were no different in this group compared with those who did not return for long-term follow-up, suggesting that the sample population that returned for follow-up were not appreciably different from those who did not return. Second, the follow-up visit was added once additional funding was obtained, and we did not have funding to include radiographs for Cobb angle measurements of kyphosis, which would have been useful to assess the long-term changes in radiographic measures of kyphosis. The kyphometer measure, but not the radiographic measure of kyphosis, improved in the original trial, and we had hypothesized that a longer period may be needed before radiographic changes were established. However, given the correlation between the kyphometer measurement of kyphosis and the gold standard standing radiographic Cobb angle is ICC = 0.76, it is possible these 2 measurements of kyphosis may capture somewhat different aspects of thoracic spine curvature because they use slightly different bony landmarks. Third, the follow-up time was not consistent among all participants; therefore, we standardized the change in outcomes and presented the change pre-/postintervention compared with the change postintervention to long-term follow-up as a fold change, or ratio, in order to make it more clinically relevant (Figure 2). Fourth, we relied on the self-reported PASE questionnaire to measure physical activity and change in physical activity after the original intervention could have affected long-term outcomes. However, we reported no significant difference in the PASE physical activity measure at follow-up compared with postintervention, $P = .393$, which suggests that physical activity did not change substantially over the mean 3-year (0.7) follow-up period. Furthermore, while we did not measure daily physical activity objectively with actigraphy, the questionnaire has been validated as a measure of physical activity in numerous populations of older adults.[55] Future study is warranted to follow up our participants with actigraphy measures over time. Finally, 95% of our cohort rated their health as good to excellent, making it difficult to generalize the results to less healthy individuals.

CONCLUSIONS

Thoracic kyphosis usually progresses with aging, yet there is no standard of care to inform providers how to treat or reduce the rate of age-related kyphosis progression. In our follow-up study, a mean 3.0 (0.07) years after a 3-month kyphosis exercise and posture training intervention, kyphosis was maintained and did not progress as expected. There was long-term improvement in lordosis in both males and females. Compared with the treatment effects from the short-term intervention, gait speed was maintained equally well in males and females, while trunk endurance improved in females. Given the significance of worsening kyphosis with age, further study of the long-term benefits of a kyphosis exercise and posture training intervention is warranted.

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