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Publication Date

2020-12-02

DOI

10.21203/rs.3.rs-111481/v1

Preliminary Estimates of Change in Physical Function After Targeted Kyphosis Exercise Intervention in Older Adults With Low Function: A Secondary Analysis of The SCOR Trial

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Research Article

Keywords: hyperkyphosis, physical function, older adults, health related quality of life

Posted Date: December 2nd, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-111481/v1>

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Version of Record: A version of this preprint was published on February 22nd, 2021. See the published version at <https://doi.org/10.1186/s12877-021-02062-8>.

Abstract

Background: Hyperkyphosis is common in older adults and associated with low physical function and reduced health related quality of life (HrQoL). Improved kyphosis has been previously established in kyphosis-targeted interventions in randomized controlled trials in older adults with hyperkyphosis however evidence for improved physical function is conflicting. Few studies have investigated change in physical function after a targeted kyphosis intervention in older adults with low physical function. The primary aim in this descriptive study was to explore change in physical function after a progressive high intensity 3-month targeted kyphosis exercise and posture training intervention in older adults with low physical function and hyperkyphosis. Secondary aims were to explore change in HrQoL, spinal strength and spinal curvature, and adherence and safety of the intervention in older adults with low physical function and hyperkyphosis.

Methods: In this secondary analysis of the Specialized Center of Research (SCOR) Kyphosis randomized trial, 101 community dwelling older men and women with hyperkyphosis who completed the intervention were divided into a low function group (LFG) and high function group (HFG). Baseline characteristics were compared between LFG and HFG. Physical function, HrQoL, spinal strength and spinal curvature (kyphosis and lordosis) pre/post intervention change scores were explored within and between groups. Adherence and adverse events were examined in the LFG and HFG.

Results: Twenty-six (26%) older adults were LFG, mean SPPB 9.62 (SD=1.17) points. At baseline, the LFG was older than HFG ($p=0.005$), endorsed more pain, ($p=0.060$), had worse physical function and HrQoL ($p\leq 0.001$), and comparable kyphosis ($p=0.640$). SPPB increased 0.62 (95% CI: -0.20 to 1.44) points in the LFG and decreased 0.04 (95%CI: -0.28 to 0.19) points in the HFG, $p=0.020$. Gait speed improved 0.04 (95%CI: -0.02 to 0.10) m/s in the LFG. Kyphosis improved equally in both groups. Adherence was similar and there were no adverse events in the LFG or HFG.

Conclusions: Older adults with low physical function and hyperkyphosis may improve physical function after a kyphosis targeted intervention. Older adults with low physical function may safely participate in targeted high-intensity kyphosis exercise and posture training. This observation needs to be confirmed in larger adequately powered studies. Clinicaltrials.gov identifier: NCT01766674

Introduction

Age-related hyperkyphosis, commonly defined by a thoracic spine Cobb angle curvature of 40 degrees or greater, progresses with age and affects up to 40% of older adults.¹ Hyperkyphosis in older adults has been associated with impaired physical function and reduced health-related quality of life (HrQoL).¹⁻⁶ Numerous cross-sectional and longitudinal studies have demonstrated hyperkyphosis is associated with slowed gait speed cross-sectionally and is predictive of worsening chair-stand time and Timed Up and Go (time to rise from chair, walk 10-meters turn and return to sit) performance longitudinally in adjusted

models.²⁻⁷ Furthermore, hyperkyphosis has been identified as a 'new' geriatric syndrome, thus targeting hyperkyphosis as an impairment may contribute to slowing the progression to physical frailty.⁸

It is theorized that hyperkyphosis causes an anterior displacement of the center of gravity, which affects physical function characteristics and balance, and in turn negatively impacts physical function.⁹ Therefore, it has been hypothesized that interventions that reduce kyphosis may also improve physical function; however few randomized controlled trials targeting improvement of kyphosis have reported a significant increase in physical function despite successfully reducing kyphosis.¹⁰⁻¹⁴ Previous trial results could be explained by a ceiling effect in high functioning cohorts of individuals who were already functioning above age-matched normative values for physical function. For example, two randomized clinical trials assessing 6-month targeted kyphosis exercise interventions in older men and women with hyperkyphosis demonstrated improvements in kyphosis but no change in physical function.^{11,12} Both trials enrolled older adults who were high functioning at baseline and had gait speeds greater than age-stratified norms for healthy adults.¹⁵ In one trial, 72% of the cohort was categorized as 'not frail' on the modified Physical Performance Test, (modified PPT), a physical performance measure of upper and lower extremity standardized tasks, and baseline Timed Up and Go speed was faster than age-matched norms which may have affected the physical function results.^{11,16} In contrast, in an uncontrolled study investigating effects of a 3-month targeted kyphosis intervention in 21 older women with hyperkyphosis who were characterized as mildly frail on the modified PPT at baseline (mean 30.6 ± 2.6 points out of possible 36 points), there was an improvement in both kyphosis and physical function.^{17,18} However, the study participants were not randomized, and the study was not powered to detect change in physical function, thus the effect of the kyphosis intervention on physical function cannot be concluded. Further investigation of the effects of a targeted kyphosis intervention on physical function in older adults with low function and hyperkyphosis may inform future treatment for older adults at risk for physical function decline.

Given it is unknown if adults with hyperkyphosis and low physical function who undergo a targeted kyphosis intervention will also improve physical function, we performed a secondary analysis using data from the Specialized Center of Research (SCOR) randomized controlled trial that investigated change in kyphosis, physical function and HrQoL in older adults with hyperkyphosis after a 3-month targeted high-intensity kyphosis exercise and posture training intervention.¹⁰ We categorized participants post-hoc into low and high physical function groups according to baseline physical function scores. We hypothesized that older adults with hyperkyphosis and low physical function would improve physical function after a targeted kyphosis intervention. Our primary aim was to explore change in physical function in older adults with hyperkyphosis and low physical function, and whether they responded differently than adults with higher function. We also explored change in HrQoL, spinal strength and spinal curvature in low versus high function groups. Lastly, we explored the feasibility of conducting a targeted high-intensity kyphosis intervention in older adults with hyperkyphosis and low physical function by comparing adherence to the intervention and safety in both low and high function group. We used change in physical function scores in the low function group to determine a sample size needed to test the hypothesis in a future trial.

Methods

Study design. This secondary data analysis included participants (n=101) who completed the SCOR kyphosis intervention in a randomized controlled waitlist design trial.¹⁰ We calculated a baseline Short Physical Performance Battery (SPPB) score using baseline measurements to divide the SCOR cohort into a low functioning group (LFG) and a high functioning group (HFG). The SPPB is a lower extremity strength, mobility and balance physical performance measure, and a composite measure of gait speed, Five-times Sit to Stand and ability to stand with feet together, feet in half tandem and feet in full tandem for 10 seconds.¹⁹ Each component is scored on an ordinal scale from 0 to 4, where 0 represents lowest ability and 4 represents highest ability, with a maximum score of 12 possible. The SPPB is predictive of future mobility decline and incident activities of daily living disability.¹⁹⁻²¹ The definition of low physical function was operationalized by an established cut-off score of 10 or less on the SPPB that identifies older adults who are at-risk for mobility decline.^{20,22} A score of 10 or less has been identified as the best cut-off point for the determination of the physical frailty process with a likelihood ratio of 1.59.^{20,22} An SPPB score of 11 or 12 was categorized as the HFG. The SPPB has high levels of reliability, good to moderate concurrent validity with quality of life, strength, muscle power and mobility and scores less than 10 are predictive of all-cause mortality.^{23,24}

Study participants. Participants in the original SCOR trial (n=112) were recruited from a university-based medical center and an integrated managed-care center in San Francisco from January 2013 to June 2015 and included community-dwelling adults age 60 or greater with hyperkyphosis > 40 degrees, English language proficient, able to walk 1 block without an assistive device and rise from a chair without their hands.¹⁰ Participants were excluded from the SCOR trial if they were unable to actively extend their thoracic spine by at least 5 degrees or had cognitive impairment.²⁵ Participants were initially randomized to an active (n=57) or waitlist control (n=55) group, however 9 withdrew within the first week due to lack of time or interest, and 2 did not have analyzable baseline radiographs for Cobb angle measurements. Participants (n=101) who completed the trial were included in the secondary analysis. The trial protocol was approved by the Institutional Review Boards at the University of California, San Francisco and Kaiser Permanente Northern California. Written informed consent was obtained from all participants. The study protocol and methods were performed in accordance with the guidelines and regulations of the Declaration of Helsinki.

Intervention groups. The SCOR active intervention was a physical therapist led group targeted kyphosis exercise and posture training program for 1-hour twice weekly for 3 months.¹⁰ The active intervention included progressive high-intensity spinal and lower extremity strengthening exercise, thoracic spine and lower extremity range of motion exercise, and posture training. Participants were asked to practice good posture during activities of daily living outside the intervention and provided with an educational handout with pictures to reinforce good posture during activities of daily living. Details on the exercise and posture training intervention have been previously published.²⁶ A wait-list control group received usual

care during the initial 3-months and received the active intervention after the 3-month waitlist period, thus all participants received the intervention.

Demographic and other measures. Prior to randomization in the original SCOR trial, participants provided demographic and health information via self-report (age, sex, education, co-morbidities). Height and weight were collected using standard measures, and body mass index was calculated. Bone mineral density of the hip and spine was measured using dual-energy X-ray absorptiometry (GE Lunar Prodigy). Baseline standing lateral spine radiographs were obtained and assessed for prevalent vertebral fractures and diffuse idiopathic skeletal hyperostosis by experienced assessors.²⁷⁻²⁹

Outcome Measures. SCOR study outcome measures were performed at baseline, 3-months and 6-months (for the waitlist group only). The waitlist group received the intervention after the 3-month measurement. All measurements were performed by trained examiners blinded to group allocation.

Physical Function. Performance-based physical function was assessed using the modified Physical Performance Test, 4-meter walk test, Timed Up and Go and Six-minute Walk tests.³⁰⁻³² The modified Physical Performance Test included 7 standardized timed tasks: 50-foot floor walk, donning and doffing a lab coat, picking up penny from floor, Five-times Sit to Stand test from a 41cm chair without using upper extremities, lifting a 7-pound book, climbing one flight of stairs, standing balance and two untimed tasks: climb up/down 4 flights of stairs and performing a 360 degree turn.³² Each component is scored 0 to 4 with a maximum score of 36. Scores 25 to 31 indicate mild frailty.¹⁸ The Four-meter walk test (gait-speed) measures time to walk 4-meters (meter/second).³⁰ The Six Minute Walk test measures distance (meters) walked in 6-minutes.³⁰ The Timed Up and Go (TUG) measures time (s) to rise from a chair, walk 10-meters turn and return seated to the chair.³⁰ The four-meter walk test, 6MW and TUG are well described in the literature and have good to excellent reliability among older adults with arthritis.^{30,31} The Patient-Reported Outcome Measurement Information System (PROMIS) Physical Function questionnaire is scored using a t-score metric and is calibrated to have the population mean be a t-score of 50 with the standard deviation set to be 10.³³ Scores range from 0-100 and higher t-scores indicate improved physical function.

Health related quality of life (HrQoL). Participants completed a battery of patient reported HRQoL outcomes including, PROMIS Global Health Scale v.1.0 (both physical and mental health individual scores), the modified Scoliosis Research Society 30, self-image domain and the Physical Activity Scale for the Elderly.³⁴⁻³⁶ For all HrQoL measures, an increase in score indicates an improvement within the specific domain (see table 2 for score ranges). Pain and self-rated general health outcomes were extracted from single questions within the PROMIS Scale v.1.0 - Global Health.³⁷ The pain measurement within the PROMIS Global Health questionnaire utilizes a visual analogue scale and states 'In the past 7 days, how would you rate your pain on average' 0 indicates 'no pain' and 10 indicates 'worst imaginable pain'.

Spinal Strength. Spinal strength was measured using the Biodex 3 (Biodex Medical Systems Inc, Shirley, NY), a computerized dynamometer for spinal flexors and spinal extensors.¹⁷ Spinal endurance was measured with the Timed Loaded Standing test, a combined measure of trunk and arm endurance, and is quantified as the time in seconds able to hold a 2-pound dumbbell in each hand with both shoulders flexed to 90 degrees and elbows extended to neutral.³⁸

Spinal Curvature and Cobb angle kyphosis. Clinical measures of thoracic kyphosis and lumbar lordosis were measured in a usual standing posture with the Debruenner Kyphometer (Techmedica Inc., Camarillo, CA).^{39,40} Cobb angle of kyphosis measurements were made from standing lateral spine radiographs according to standardized protocols by an experienced radiologist.⁴¹

Adherence and Safety. Adherence, adverse events and non-reportable events were monitored by the study coordinator, who administered a standardized questionnaire on a weekly basis during the active intervention. Adverse events are defined as any unfavorable medical occurrence and problems that are possibly related to study participation serious or unexpected. Non-reportable events are expected symptoms that may occur during the intervention and described in the study protocol and disclosed in the consent. Examples of non-reportable events in this study are muscle or joint soreness or exacerbation of previous injuries associated with the intervention and resolved within an expected duration of time.⁴²

Data analysis for secondary analysis. Baseline characteristics were compared between the LFG and HFG using t-tests or Wilcoxon nonparametric tests for continuous variables and the χ^2 statistic for categorical variables. We calculated mean differences and 95% confidence intervals for change pre/post treatment unadjusted for any covariates for all outcome measures in the LFG and HFG. We compared the pre/post change scores in the LFG and HFG using t-tests. P-values < 0.05 were considered statistically significant. Analyses were conducted using SAS Version 9.4 (SAS Inc, Cary, NC). In this post-hoc secondary analysis, we did not have power to detect significant differences within the groups based upon the small sample size in the subgroups. We determined sample sizes needed for a future study to test the hypothesis that older adults with hyperkyphosis and low physical function will improve physical function on the SPPB after a kyphosis exercise and posture training intervention. Sample size calculations were conducted using PASS 15.0.3 software.

Results

Twenty-six adults (26%) had low function, mean SPPB score 9.62 (SD = 1.2) points, and seventy-five (74%) were high functioning, mean SPPB score 11.37 (SD = 0.7) points. (Table 2) There were more men in the LFG vs HFG, 54% vs 36%, $p=0.110$. The LFG was older than the HFG, 72.4 (SD= 6.5) years versus 68.8 (SD = 5.15) years, $p=0.005$, and reported poorer general health ($p=0.006$) and endorsed more pain 3.3 (SD = 2.7) points in the HFG and 2.0 (SD = 1.7) in the LFG ($p=0.060$). (Table 1). At baseline, all physical function and HrQoL scores were lower in the LFG versus the HGF $p0.017$ except physical activity was similar in both groups ($p=0.330$). Trunk endurance was worse in the LFG ($p = 0.017$). There were no differences in baseline levels of kyphosis.(Table 2).

Please insert Table 1 and Table 2

Within group change in physical function in low function group. There were no significant within-group changes in physical function in the LFG (Table 3). SPPB score improved in the LFG by 0.62 (95%CI: -0.2 to 1.44) points. Gait speed improved 0.04 (95%CI: -0.02 to 0.10) m/s. Timed Up and Go improved by 0.2 (95%CI: -0.6 to 0.3) seconds and the Six Minute Walk by 1.8 (95%CI: -14.0 to 17.6) meters.

Between group change in physical function in low function versus high function. Comparing change pre/post intervention in the LFG and HFG, the LFG improved SPPB significantly more than the HFG, $p=0.020$. There was no between group difference in change in gait-speed, $p=0.406$, Timed Up and Go, $p=0.370$ and Six Minute Walk, $p=0.265$. (Table 3).

Other change in health related quality of life (HrQoL), spinal strength and spinal curvature. Self-image, a measure of HrQoL, improved 0.19 (95%CI: 0.02 to 0.4) points in the LFG and 0.24 (95%CI: 0.1 to 0.3) points in the HFG, $p=0.473$. (Table 3) Spinal extensor strength worsened in the LFG by 6.8 (95%CI: -16.12 to 2.56) percent and improved in the HFG 6.0 (95%CI: 1.0 to 11.0) percent, $p=0.018$. Spinal endurance measured by the Timed Loaded Standing worsened in the LFG -8.8 (95%CI: -23.3 to 5.7) seconds and improved in the HFG 5.2 (95%CI: -1.6 to 12), $p=0.080$. Kyphometer measure of kyphosis improved equally in both groups -3.1 (95%CI: -5.2 to -0.9) degrees in the LFG and -3.7 (95%CI: -5.0 to -2.4) degrees in the HFG, $p=0.409$.

Please insert Table 3

Feasibility. Adherence during the 3 month intervention was 83% in the LFG and 79% in the HFG (Table 4). There were no adverse events in either group. Sixty-nine percent (18/26) of the low function participants, and 68% (51/76) of the high function participants had non-reportable events including including pain and stiffness several hours to days after exercise, often from a pre-existing musculoskeletal complaint, which resolved within an expected period of time.⁴² The LFG reported an average 2.83 events per person and the HFG reported 2.35 events per person.

Please insert Table 4

Sample Size Calculation. Based on a 2-by-2 repeated measures design a sample size of $n=138$ (69 in intervention, 69 in control group) achieves 80% power to detect a difference in mean change of 0.6 points on the SPPB at a 0.050 significance level (α) using a two-sided, two-sample t-test (Additional file 1).

Discussion

The primary purpose of this secondary data analysis was to explore the hypothesis that targeting kyphosis will improve physical function in a low functioning cohort of older adults with hyperkyphosis. While there were no statistically significant changes in physical function in the participants with low physical function, there were clinically significant improvements on the SPPB and gait speed after the

targeted kyphosis intervention in the LFG while the HFG declined on the SPPB. There were small improvements in self-image in both groups. Kyphosis improved equally in the LFG and HFG, even though spinal extensor strength and Time Loaded Standing measure of endurance worsened in the LFG and improved in the HFG. Adherence to the intervention, adverse events and non-reportable events were similar in both groups suggesting the intervention is acceptable and safe in a low functioning cohort.

As we hypothesized, SPPB improved a clinically significant amount in the LFG. The 0.62 (SD = 2.00) point improvement in the SPPB in the LFG is similar to 2 previous randomized studies that included lower functioning adults.^{13,14} Benedetti et al.¹³ performed a targeted exercise program among older adults with hyperkyphosis, and both active and control groups improved SPPB while only the control group improvement was significant ($p=0.03$). Baseline score for SPPB in the active group was 10.33 (SD = 1.17) points and improved 0.74 points after the intervention, and the control group baseline score was 9.38 (SD = 1.04) points and improved 1.08 points, consistent with the 0.62 (SD = 2.00) point change in our LFG.

However, both groups in the Benedetti trial received an exercise program. The active group received targeted spinal strengthening while the control group received a global posture training program, which may explain why both groups improved. Jang et al.¹⁴ tested the efficacy of an 8-week kyphosis correction exercise program in a frailer group than our current LFG. The experimental and control group baseline SPPB scores were 8.7 points and 8.9 points respectively. The control group received written instructions on the intervention exercises and performed them independently, and the experimental group received in-clinic training and feedback on the exercises. After the intervention period, SPPB scores improved 1.4 points in the experimental group and did not change in the control group. These results support our hypothesis that a combined kyphosis exercise and posture training program in a low functioning cohort may improve physical function, but a larger study powered to detect a significant change in physical function is needed.

It is possible targeting kyphosis in older adults with low physical function and hyperkyphosis may slow expected age-related decline in physical function. Minimum Clinically Important Difference (MCID) has been reported to be between 0.3 to 0.8 points on the SPPB using a combination of both distribution and anchor-based methods in two different studies evaluating cohorts similar to the current cohort (age range 70-89) of mildly frail older adults. This suggests the 0.62 (95%CI: -0.2 to 1.44) point improvement on the SPPB in the LFG may be clinically relevant.^{43,44} Furthermore older adults in LFG improved from a baseline SPPB of 9.62 (1.2) to a score greater than the cut-off score of 10 suggesting targeting kyphosis may mitigate risk of future disability.²² The LFG improved gait-speed 0.04 (95%CI: -0.02 to 0.11) m/s which may be clinically relevant given MCID has been reported to be between 0.03 to 0.06 m/s utilizing both distribution and anchor-based methods.^{43,44} In fact, on average 3 years after the SCOR intervention, kyphosis was maintained and gait speed improved an additional 0.08m/s, highlighting the potential long-term benefits of a short-term kyphosis intervention. Moreover, Merchant et al.⁴⁵ concluded trunk adaptations including flexed posture precede declines in gait speed in a cross-sectional gait kinematics study of older Chinese men who were mildly frail when compared to fit older men. Our LFG may have

been transitioning to frailty and improving kyphosis may have associated with a small improvement in gait-speed possibly slowing the progression to frailty.

We investigated change in self-image, which is central to psychological well-being and a measure of HRQoL and has been linked to kyphosis.^{1,46} Self-image, a subdomain of self-esteem, is related to exercise self-efficacy, one's belief in one's ability participate in regular exercise.⁴⁷ It is well known older adults who are physically active have better physical function.⁴⁸ We observed a small within-group improvement in self-image in both the LFG 0.19 (95% CI: 0.02 to 0.37) points and the HFG 0.24 (95% CI: 0.14 to 0.34) points after receiving the intervention and both groups responded similarly, $p=0.47$. These changes are less than the 0.43 (95% CI: 0.24 to 0.61) point change reported after a 6-month targeted kyphosis intervention delivered 3 times a week. Improving self-image through a targeted kyphosis intervention may be useful in facilitating maintenance of physical activity in older adults, however neither LFG or HFG group improved physical activity significantly after the intervention, and it is possible that a 3-month intervention was not adequate to facilitate a change.

Spinal extensor strength and endurance decreased in the LFG but increased in the HFG after the intervention (-6.0% vs +6.8%, $p=0.018$) and (-8.8 seconds vs +5.2 seconds, $p=0.080$) respectively. Weakness in the spinal extensors increases risk of kyphosis progression and more recently trunk muscle composition has been linked to increased risk of kyphosis progression and decline in physical function.⁴⁹⁻⁵² The LFG had lower baseline spinal endurance (112 seconds vs 138 seconds) and higher baseline pain scores (3.3 vs 2.0 points) which may have affected their ability to improve during the intervention, and they may have benefited from more time to accommodate to the strengthening intervention provided in the 3 month intervention. There is a dose-response relationship to strength training in older adults and while 12-weeks leads to improved strength, longer duration up to 53 weeks leads to even greater effect sizes on strength (SMD=1.57 at 21.2 weeks and SMD=2.34 at 50-53 weeks).⁵³ While trunk muscle composition may be an important biologic factor in decline in physical function in older adults, it is unknown if improved trunk muscle composition has a mediating effect on improved physical function. Future trials targeting older adults with hyperkyphosis and low physical function should consider assessing trunk muscle composition in future trials to investigate it as a mediating factor for change in physical function.

This analysis suggests that lower functioning adults with hyperkyphosis may improve physical function after a targeted kyphosis intervention, however there were several limitations. This was a post-hoc exploratory analysis of previously reported data from a randomized controlled trial. Causal relationships cannot be established because the number of older adults in the low functioning group was small, and the analysis was not powered to detect significant changes in physical function. Furthermore, we did not adjust for any covariates due to the small sample size in our analyses, therefore it is possible the changes in physical function were attributable to age or other covariates. There were differences in baseline characteristics of age, BMI, self-reported health in the low- and high- functioning groups that may have influenced results. However, the magnitude and direction of changes in SPPB and gait speed

suggest further study is warranted to test the hypothesis that lower functioning older adults with hyperkyphosis who participate in a targeted kyphosis intervention will improve physical function. The strength of this study is that no prior published studies have specifically targeted lower functioning older adults with hyperkyphosis to determine the effects of a kyphosis intervention on physical function. However our results are consistent with other studies that included a range of physical functioning, including lower functioning older adults with hyperkyphosis^{13,14}

Conclusion

The results from this secondary analysis suggest that older adults with low physical function and hyperkyphosis may improve physical function after a targeted kyphosis intervention. Older adults with low physical function in our cohort adhered to and safely participated in a progressive, targeted high-intensity kyphosis exercise and posture training intervention. This observation needs to be confirmed in larger adequately powered studies. Further study is warranted with a large sample of low functioning older adults and hyperkyphosis to confirm these observations and determine if hyperkyphosis is relevant on the causal path towards decline in physical function.

Abbreviations

SCOR - Specialized Center of Research Kyphosis randomized trial

HrQoL- Health-related Quality of Life

modified PPT -modified Physical Performance Test

SPPB- Short Physical Performance Battery

LFG- Low function group

HFG – High function group

MCID - Minimum Clinically Important Difference

TUG- Timed Up and Go

6MW – Six Minute Walk test

PROMIS- Patient-Reported Outcome Measurement Information System

PASE- Physical Activity Scale for the Elderly

SMD- Standardized Mean Difference

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Boards for the University of California at San Francisco and Kaiser Permanente Northern California. The study protocol and methods were performed in accordance with the guidelines and regulations of the Declaration of Helsinki.

Consent for publication

All participants signed a joint-informed consent approved by the Institutional Review Boards for the University of California at San Francisco and Kaiser Permanente Northern California

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

No authors report competing interests.

Funding

The original SCOR trial was supported by grant P50 AR063043 from the Office of Research in Women's Health and the National Institute of Arthritis and Musculoskeletal and Skin Disorders (PI: Lane). This work was supported by grant K24NR015812 from the National Institute of Nursing Research (PI:Fukuoka)

Authors' contributions

AG and WK participated in conception, design, analysis, interpretation and writing the manuscript, YF, NL participated in conception, design, analysis, interpretation and reviewing the manuscript, NP and SW participated in acquisition, analysis and interpretation of the work and reviewing the manuscript.

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Tables

Table 1. Study participant characteristics at baseline in the HFG and LFG

Variable	Category	Low Function Group(LFG)	High Function Group (HFG)	LFG vs. HFG*	Entire Cohort
		n= 26	n= 75	p-value	n= 101
		n(%) or mean (±SD)	n(%) or mean (±SD)		n(%) or mean (±SD)
Age (years)		72.4 (±6.6)	68.8 (±5.2)	0.005	69.7 (±5.7)
Gender	Female	12 (46)	48 (64)	0.110	60 (59)
Vertebral Fracture	none	22 (85)	65 (87)	0.741	87 (86)
	1	2 (8)	7 (9)		9 (9)
	2	2 (8)	3 (4)		5 (4.95)
Diffuse idiopathic hyperostosis (DISH) present (yes)		7 (28)	15 (21)	0.461	22 (23)
Body Mass Index(kilograms/meter ²)		27.7 (±3.9)	25.7 (±4.1)	0.037	26.2 (±4.1)
Bone mineral density total hip t-score		-0.5 (±1.3)	-0.9 (±1)	0.074	-0.85 (±1.1)
Bone mineral density total spine t-score		0.7 (±2.8)	-0.5 (±1.8)	0.064	-0.2 (±2.2)
Race	Caucasian	25 (96)	69 (92)	0.472	94 (93)
Education	High school, some College	2 (8)	11 (15)	0.360	13 (13)
	College, professional degree	24 (92)	64 (85)		88 (87)
Pain Score from PROMIS scale 1.0-Global health, 0-10 (points)		3.3 (±2.7)	2 (±1.7)	0.060	2.3 (±2.1)
Self-rated health from PROMIS scale 1.0-Global Health	Fair	5 (19)	3 (4)	0.006	8 (9)

	Good	12 (46)	19 (25)		31 (31)
	Very Good	7 (27)	41 (55)		48 (48)
	Excellent	2 (8)	12 (16)		14 (14)
Co-morbidities	2 or more	10 (38)	30 (40)	0.890	40 (40)

SD= standard deviation , PROMIS=Patient-Reported Outcome Measurement Information System, LFG= low functioning group ,HFG= high functioning group, *p values for comparison between LFG and HFG

Table 2 Means of measures at baseline stratified by HFG, LFG and entire cohort

Outcome measures	Low Function Group (HFG)	High Function Group (LFG)	LFG vs. HFG*	Entire cohort
	n= 26	n= 75		n= 101
	Mean (\pm SD)	Mean (\pm SD)	P-value	Mean (\pm SD)
Physical Function				
Short Physical Performance Battery (SPPB) (0-12 points)	9.62 (1.2)	11.37 (0.7)	<0.001	10.92 (1.1)
4-meter gait speed (meters/second)	1.14 (0.2)	1.38 (0.34)	<0.001	1.32 (0.3)
Modified PPT (0-36 points)	31.4 (2.7)	33.8 (1.7)	<0.001	33.2 (2.2)
Timed Up and Go (seconds)	8.4 (1.6)	7.1 (1.5)	<0.001	7.4 (1.7)
Six Minute Walk Test (meters)	471.7 (77.2)	524.9 (95.9)	0.008	511.6 (94.1)
PROMIS Physical function t-score (0-100)	44.8 (4.7)	50.1 (7.6)	<0.001	48.7 (7.3)
Health-related Quality of Life				
SRS 30 Self-image (0-5 points)	3.33 (0.49)	3.69 (0.56)	0.016	3.53 (0.55)
PROMIS Global Health Scale (0-100)	35.8 (6.5)	40.7 (4.7)	0.001	39.5 (5.6)
PROMIS Global Health Scale, Mental Health t-score (0-100)	48.8 (8.1)	54.1 (7.5)	0.003	52.8 (7.9)
PROMIS Global Health Scale, Physical Health t-score (0-100)	47.9 (7.5)	53.6 (5.6)	<0.001	52.2 (6.6)
PASE activity level (0-793) points	102.1 (60.5)	111.0 (53.2)	0.330	108.7 (54.9)
Pain Score 0-10 from PROMIS Global Health scale (0-10 points)	3.3 (2.7)	2.0 (1.68)	0.060	3.4 (2.1)
Spinal Strength				
Spinal flexion strength (percent peak torque/body weight)	28.8 (11.4)	32.7 (11.3)	0.119	31.7 (11.4)
Spinal extensor strength (percent peak torque/body weight)	64.2 (16.2)	71.0 (22.0)	0.238	69.2 (20.8)
Timed Loaded Standing (seconds)	112.0 (49.9)	138.4 (49.0)	0.017	131.0 (50.3)

Spinal Curvature				
Cobb angle of kyphosis (degrees)	56.8 (13.3)	55.5 (11.7)	0.640	55.9 (12.2)
Kyphosis derived from kyphometer (degrees)	53.6 (6.2)	51.5 (7.8)	0.216	52.0 (7.4)
Lordosis derived from kyphometer (degrees)	25.9 (12.2)	31.7 (11.4)	0.028	30.2 (11.8)

SD= Standard Deviation, Modified PPT=Physical Performance Test, SRS Scoliosis Research Society, PASE= Physical Activity Scale for the Elderly, PROMIS=Patient-Reported Outcome Measurement Information System, HFG= high functioning group, LFG= low functioning group, group *p values for comparison between LFG and HFG

Table 3 Change scores pre/post intervention in outcome measures in the HFG, LFG and overall cohort with confidence intervals (CI)

	Low - Function group (LFG)	High- Function group (HFG)	LFG vs HFG*	Entire cohort
	Mean difference (95% CI)	Mean difference (95% CI)	p-value	Mean (95% CI)
Physical Function				
Short Physical Performance Battery (SPPB) (0-12 points)	0.62** (-0.20 to 1.44)	-0.04 (-0.28 to 0.19)	0.020	0.13 (-0.14 to 0.40)
4-meter gait speed (m/s)	0.04** (-0.02 to 0.1)	-0.01 (-0.06 to 0.04)	0.406	0 (-0.04 to 0.04)
Modified PPT (0-36 points)	-0.29 (-2.7 to 2.1)	-1.3 (-3.0 to 0.3)	0.166	-1.1 (-2.4 to 0.3)
Time up and go (seconds)	-0.2 (-0.6 to 0.3)	0.04 (-0.2 to 0.3)	0.370	-0.01 (-0.2 to 0.2)
6 Minute walking test (meters)	1.8 (-14.0 to 17.6)	8.8 (-4.6 to 22.1)	0.265	7.0 (-3.6 to 17.6)
PROMIS Physical Function t-score (0-100 points)	0.91 (-5.5 to 2.3)	2.0 (0.5 to 3.5)	0.353	1.7 (0.5 to 2.9)
Health-related Quality of Life				
SRS 30 Self-image (0-5 pts)	0.19 (0.02 to 0.4)	0.24 (0.1 to 0.3)	0.473	0.23 (0.1 to 0.3)
PROMIS Global Health Scale (0-100 points)	1.0 (-0.8 to 2.8)	0.3 (-0.5 to 1.1)	0.820	0.5 (-0.2 to 1.2)
PROMIS Global Health scale, Mental Health t-score (0-100 points)	1.19 (-0.8 to 3.2)	0.3 (-0.9 to 1.5)	0.536	0.52 (-0.5 to 1.6)
PROMIS Global Health scale, Physical Health t-score (0-100 points)	1.8 (-0.3 to 3.9)	0.6 (-0.5 to 1.8)	0.194	0.9 (-0.06 to 1.9)
PASE activity (0-793) points	6.3 (-14.0 to 26.6)	1.7 (-8.2 to 11.6)	0.928	2.9 (-5.9 to 11.7)
Pain Score 0-10 from PROMIS Global Health scale (0-10 points)	-0.2 (-0.9 to 0.5)	-0.3 (-0.6 to 0.06)	0.54	-0.26 (-0.5 to 0.03)
Spinal Strength				

Spinal Flexion (percent peak torque/bodyweight)	-0.09 (-3.4 to 3.2)	1.5 (-0.1 to 3.2)	0.515	1.12 (-0.4 to 2.6)
Spinal extensor (percent peak torque/bodyweight)	-6.8 (-16.1 to 2.6)	6.0 (1.0 to 11.0)	0.018	2.7 (-1.8 to 7.2)
Time loaded standing (seconds)	-8.8 (-23.3 to 5.7)	5.2 (-1.6 to 12)	0.080	1.6 (-4.7 to 7.8)
Spinal Curvature				
Cobb Angle (degrees)	-0.6 (-2.0 to 0.9)	-1.6 (-2.7 to -0.4)	0.390	-1.3 (-2.2 to -0.4)
Kyphosis (degrees)	-3.1 (-5.2 to -0.9)**	-3.7 (-5.0 to -2.4)**	0.409	-3.5 (-4.6 to -2.4)
Lordosis (degrees)	0.4 (-2.0 to 2.9)	-1.5 (-3.0 to 0.03)	0.229	-1.0 (-2.3 to 0.3)

CI= confidence interval, Modified PPT=Physical Performance Test, SRS Scoliosis Research Society, PASE= Physical Activity Scale for the Elderly, HFG= high functioning group, LFG= low functioning group, *p values for comparison between LFG and HFG, ** denotes change scores surpassing minimum clinical change estimates (SPPB .03 to .08 points and gait speed .03 to .06 m/s and kyphosis Minimum Detectable Change 2.51 degrees)^{14,43,44}

Table 4 Adherence and safety/adverse events in the LFG and HFG

	Low-Function group (LFG)	High -Function group (HFG)
	N=26	N=75
Mean adherence to sessions (percent)	20 (83)	19 (79)
Number of people reporting non-reportable events ¹ (percent)	18(69)	51(68)
Number non-reportable events	51	120
Range of non-reportable events per person	1 to 8	1 to 8
Mean number of non-reportable events per person	2.8	2.4
Number of people reporting adverse events ²	0	0

LFG= low functioning group, HFG= high functioning group

¹ Non-reportable events are symptoms that may occur during the intervention and disclosed in the consent, and resolve within an expected duration of time.

² Adverse events are defined as any untoward or unfavorable medical occurrence.

Supplementary Files

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