Title:

Test-retest reliability of a load cell setup, Ito, and timed loaded standing tests for measuring muscle strength and endurance in older adults with and without hyperkyphosis

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ABSTRACT

Background*:* The association of back muscle weakness with greater thoracic kyphosis has been widely documented. Reliable and easy-to-use techniques are needed to monitor changes in muscle function over time and assess the effectiveness of therapeutic interventions. Therefore, the present study aimed to evaluate the test-retest reliability of a designed load-cell setup and two clinical tests, namely Ito and Timed loaded standing (TLS) tests for measuring back muscle function (i.e., strength and endurance) in older adults with and without hyperkyphosis.

Method*:* Fifty-three older people (28 with thoracic hyperkyphosis and 25 normal age-matched controls) completed the present test-retest reliability study. A two-way random model of the Intraclass Correlation Coefficient ($ICC_{2,3}$) was used to estimate relative reliability. Absolute reliability was assessed by calculating Standard Error of the Measurements (SEM) and Minimal Detectable Change (MDC).

Results*:* The findings showed excellent test-retest reliability in all performed tests for this population (ICC= 0.95 - 0.99). In addition, the MDC values for measuring endurance time via load cell, Ito, and TLS tests in the hyperkyphosis group, were 16.5, 28.2, and 35.1 seconds, respectively. These values ranged from 36 to 39 seconds for the control group.

Conclusion*:* The present study suggests high test-retest reliability of the designed load-cell setup, Ito, and TLS for assessing back extensor muscle strength and endurance in older adults with and or without hyperkyphosis.

Keywords: Hyperkyphosis; Psychometric properties; Back extensor muscles; Maximum extensor force

INTRODUCTION

Age-related hyperkyphosis is a geriatric syndrome, affecting up to 40% of older adults as a common disfiguring condition (Kado, et al., 2007; Takahashi et al., 2005). This deformity is progressive and associated with adverse health consequences, such as decreased respiratory function and increased risk of falls (Katzman et al., 2010; Roghani et al., 2017). For years, age-related hyperkyphosis has been primarily attributed to an underlying osteoporotic vertebral compression fracture (OVF), but only one-third of the elderly with hyperkyphosis suffer from OVF (Kado et al., 2013; Kado et al., 2009). Therefore, other factors such as back muscle dysfunction may play a prominent role in the development or progression of this deformity since the back extensor muscles have antigravity functions, and they are the main spinal supportive factor (Mika et al., 2005). The association between back muscle dysfunction (i.e., deficits in trunk extensors strength and/or endurance) and greater thoracic kyphosis has been previously documented. Previous studies have mainly focused on the negative correlation between thoracic kyphosis degree and trunk muscle strength (i.e., ability to generate maximum muscle force against a resistance) (Granito et al., 2012; Hongo et al., 2012; Mika et al., 2005; Sinaki et al., 1993). Previous studies have found that back extensor strength training can significantly affect the degree of kyphosis (Bennell et al., 2010; Wilhelm et al., 2012). It is theoretically plausible that back muscle endurance is more relevant than back muscle strength for maintaining an upright posture (O'Sullivan et al., 2006). However, only a few studies have investigated this aspect of muscle function in age-related hyperkyphosis (Hosseinabadi et al., 2020; Roghani et al., 2019). For example, Roghani et al. (2019) found lower back extensor endurance in older women with hyperkyphosis compared to those without hyperkyphosis (Roghani et al., 2019).

Previous research has described various methods for evaluating back extensor strength and endurance in various populations with different health statuses. Still, there is no consensus on the most appropriate method for assessing back extensor function in research and clinical practice (Newman et al., 2018). Isokinetic dynamometer machine is a standard, reliable and valid tool to measure muscle strength (Garcia-Vaquero et al., 2020). Nevertheless, it is rarely used in clinical settings because of being cumbersome, expensive, and time-consuming (Newman, et al., 2018; Villafane et al., 2016).

A handheld dynamometer (HHD) is a portable measurement device widely used to quantify extremities' muscle strength in clinical practice (Stark et al., 2011). However, using this device to evaluate the strength of large muscle groups, such as trunk muscle, is questionable because if the resistance provided by the examiner is much less or greater than the patient's trunk action, it leads to measurement errors (De Blaiser et al., 2018; Moreland et al., 1997; Roghani et al., 2018). Some researchers have tried to reduce measurement errors of HHD; for example, Park et al. (2017) fixed the force sensor inside the seatback of a chair and reported reduced measurement error and excellent reliability for measuring isometric back extensor strength. However, they recruited healthy young volunteers without back problems (Park et al., 2017), and the reliability of this method has not been tested in older adults with and or without hyperkyphosis. Trunk muscle dysfunction is a potential contributing factor to the development or progression of postural deformities in older adults (Roghani et al., 2017). This is the population where hyperkyphosis is most prevalent, and interventions can slow the progression. Thus, it is essential to have a reliable, simple, and easy-to-use measurement method to identify dysfunction and monitor clinical progress in older adults. Accordingly, Roghani et al. (2018) tested the reliability of a load-cell setup to measure strength and endurance in older women with and without hyperkyphosis.

In addition to HHD and load cell, there are some clinical tests for quantifying back muscle endurance, especially in older adults with spinal musculoskeletal conditions. For example, the Ito test is a prone trunk holding test that imposes less load on the spine than the Biering Sorensen test (Demoulin et al., 2006; Muller et al., 2010) and is more tolerable for the elderly with hyperkyphosis (Ito et al., 1996), while Timed loaded standing (TLS) is a combination of trunk and arm muscle endurance measurement performed in a standing position (Shipp et al. , 2000). Although these tests have been used in previous research (del Pozo-Cruz et al., 2014; Eyskens et al., 2015; Hosseinabadi et al., 2020; Newman et al., 2018), their reliability has not been evaluated in older adults with and or without hyperkyphosis. Therefore, the present study aimed to evaluate the intra-rater test-retest reliability of a designed load-cell setup and two clinical tests, namely Ito and Timed loaded standing (TLS), to measure back muscle strength and endurance in older adults with and without hyperkyphosis.

MATERIALS & METHODS

Participants

The present cross-sectional observational study was conducted between April 2020 to October 2020 at the School of Rehabilitation Sciences, Iran University of Medical Sciences. The sample size was estimated as at least 22 per group based on the guideline presented by Bujang (Bujang and Baharum, 2017), assuming the null hypothesis value of ICC= 0.5, α value of 0.05, and test power of 80% (β= 0.2) for two replicated measurements (intra- rater). Nonetheless, we considered 30 participants per group, considering possible dropouts. A convenience sample of 60 participants (30 older people with hyperkyphosis and 30 normal controls) was recruited through public advertisement. Older adults over the age of 60 who could stand and walk without assistance were included in the study. The inclusion criteria were thoracic kyphosis more than 50 degrees for the hyperkyphosis group and less than 50 degrees for the age-matched control group. Exclusion criteria were history of fractures, surgery or trauma to the spine, inflammatory diseases such as ankylosing spondylitis, rheumatoid arthritis, spinal deformities other than hyperkyphosis, cardiopulmonary disease, severe osteoporosis, Central Nervous System (CNS) disease, neuromuscular disorders, diabetic neuropathy and history of taking drugs affecting the CNS. The participants were clearly explained the study procedure and then signed written informed consent. To assess eligibility criteria, all participants underwent a comprehensive physical examination by an experienced physical therapist. The Ethics Committee at Iran University of Medical Sciences approved the study (IR.IUMS.REC.1398.435). The study has been reported according to the Guidelines for Reporting Reliability and Agreement Studies (GRRAS).

Examiner and outcome assessments

All measurements were performed by the first author (F.K.), who had MSc in Orthotics and Prosthetics with over three years of clinical experience. For the test-retest reliability assessment, the measurements were repeated in a one-week interval in completely homogeneous conditions (assessment time, location, light and ambient temperature, and individual position). The examiner was blinded to her own prior results.

Measurement of the thoracic kyphosis degree

Thoracic kyphosis degree was measured using photogrammetry examination as described in the previous literature (Azadinia et al., 2021; Porto and Okazaki, 2017). Three photographs were taken by a Nikon camera (Nikon D5300, 24.2-megapixel, Nikon, Thailand) from the participants' right side during inhalation (Figure 1). Digital photographic records were imported to AutoCAD software. The angle formed between the intersections of the straight-line extensions drawn from the markers at spinous processes of the seventh cervical (C_7) and twelfth thoracic (T_{12}) vertebrae was calculated as the thoracic kyphosis degree for each photograph, and the average of all three measures was used later.

<Figure 1 about here>

Back muscle strength (maximal voluntary contraction force)

Muscle strength is commonly measured by how much force a person can exert. We measured produced force by a "S" shaped load cell in the sitting position as an indication of back extensor muscle strength (Figure 2). Before the test, participants performed a 2-minute warm-up of the back extensor muscles, and the load cell was calibrated before each session. After positioning the participant on the chair in a neutral, upright posture, the load cell position was adjusted on the vertical bars to align with the spinous process of the T_7 vertebra. Participants were asked to gradually increase their backward force over 1-3 seconds upon hearing a *beep* sound, and then maintain the maximum force for 5 seconds and gradually relax it for 1-3 seconds. A 30-second pause was given between the trials to prevent fatigue. For each trial, peak back extensor force (kg) was recorded. An additional trial would be conducted if the maximum trial was 5% higher than either of the two previous trials. Three successive trials were performed. Participants had a practice trial before testing and received verbal encouragement and visual feedback (displaying force output on the monitor) during testing.

<Figure 2 about here>

Trunk muscle endurance test

Trunk muscle extensor endurance was assessed by three different methods, including the designed load-cell setup, Ito test, and TLS test.

<u>Muscle endurance measured via load cell</u>

After measuring the maximum extensor force, a 30-minute rest was given. Participants then performed a sustained contraction at 50% of their maximum force to assess back muscle endurance. After a single familiarization trial, three endurance trials with 30-second rest between trials were performed, followed by recording maximum endurance time (in seconds). The test would stop when the participants could not maintain more than 40% of their maximum force.

<u>Ito test</u>

This prone trunk holding test modifies the Biering-Sorenson method (Ito et al., 1996). Participants were set in a prone position with a small pillow under their lower abdomen and the arms at their sides. Participants lifted their sternum off the ground upon hearing the *start* command. During the test, they needed to maintain the maximum flexion of the cervical spine and contract the gluteal muscles to stabilize the pelvis. Participants held this position as long as possible, but not more than a 300-second limit. Holding duration was recorded in seconds using a stopwatch.

<u>Timed loaded standing (TLS) test</u>

Shipp et al. designed a reliable and valid measure of the combined trunk and arm endurance called TLS for people with vertebral osteoporosis (Shipp et al., 2000). TLS measures the time (in seconds) a person can stand, holding a 1-kg dumbbell in each hand with shoulders flexed at 90 degrees, elbows extended, and wrists in neutral pronation/supination.

Statistical analysis

SPSS Version 25 was used for the statistical analysis. The data were encoded to prevent bias in data analysis. Normal distribution of the variables was assessed using the Shapiro-Wilk test. Paired t-test and/or Wilcoxon signed-rank test were performed on measurements obtained in test and retest sessions to verify the absence of systematic bias. A two-way random model of the Intraclass Correlation Coefficient ($ICC_{2,3}$) was used to estimate relative reliability. The classification proposed by Koo and Li was used to interpret the relative reliability indices; ICCs less than 0.5 as poor, 0.5< ICC <0.75 as moderate, 0.75< ICC <0.90 as good, and greater than 0.90 as excellent (Koo and Li, 2016). Absolute reliability was assessed by calculating Standard Error of the Measurements (SEM), which is an estimate of the error value associated with the measurement (SEM = $SD \times \sqrt{1 - ICC}$), and it is also used to calculate Minimal Detectable Change (MDC = $\sqrt{2} \times 1.96 \times SEM$). The MDC shows how much change in muscle force and/or endurance time is needed to ensure that the resulting change is not a mere measurement error and that a real change in muscle strength and/or endurance has occurred. The significance level was set at 0.05 for all statistical tests.

RESULTS

Fifty-three older adults (28 with hyperkyphosis and 25 age-matched control) completed both sessions. Table 1 presents the demographic characteristics of the participants. There were no significant differences between muscle force and endurance times between the test and retest sessions, indicating the absence of systematic bias, except maximal extensor force in the control group, which revealed a significant difference between test and retest value indicating a mild learning effect.

Our designed load-cell setup showed excellent relative reliability (ICC= 0.99) for measuring back extensor strength. Also, the MDC values for back extensor strength were 3 and 4.2 Kg in the hyperkyphosis and control groups, respectively. Furthermore, all three measurement methods showed excellent relative reliability for measuring back extensor endurance. The MDC values for endurance time via load cell, Ito, and TLS in the hyperkyphosis group, were 16.5, 28.2, and 35.1 seconds, respectively. These values ranged from 36 to 39 seconds for the control group. Table 2 shows the results of test-retest analysis, including ICC with 95% confidence interval (CI), SEM, and MDC.

<Table 1 about here>

<Table 2 about here>

DISCUSSION

This study evaluated the test-retest reliability of a designed load-cell setup and two clinical tests (i.e., Ito and TLS) assessing back extensor strength and endurance in older adults with and without hyperkyphosis. The findings generally showed excellent test-retest reliability for all performed tests in both groups.

The designed load-cell setup demonstrated excellent test-retest reliability for measuring back extensor strength in the hyperkyphosis and control group. This finding supports previous studies reporting high test-retest reliability for measuring back muscle strength (Park et al., 2017; Roghani et al., 2018). However, Roghani et al. (2018) employed a pulling test to measure back muscle strength in older women with and without hyperkyphosis, but we measured muscle function using a pushing test among both older men and women. The ICC values observed in our study were higher than those reported by Park et al. (2017), who used a similar method (combined force sensor of HHD with a chair) and consistent with that reported by Roghani et al. (2018). This discrepancy with Park's findings (2017) may be attributable to sample and methodological differences. Park et al. (2017) utilized a chair equipped with a portable dynamometer in healthy young volunteers with no back problems. Also, Park et al. did not explicitly state the time interval between the sessions (Park et al., 2017) while we had a 7-day interval between the test and retest sessions.

We also calculated absolute reliability values that are clinically more important than relative reliability. The SEM and MDC values were low in the present study and similar to those reported by Roghani et al. (2018) but better than those observed in two other studies (Harding et al., 2017; Valentin and Maribo, 2014). It may be due to the study sample, testing position, or the extent of external fixation. For example, Valentin and Maribo (2014) assessed back muscle strength in a prone position without pelvic stabilization among women with osteoporotic vertebral fractures. However, the pelvis needs to be stabilized to minimize the involvement of hip extensor muscles during back extensor strength measurements (Kankaanpaa et al., 1998). Accordingly, we stabilized the thigh and pelvis using a seat belt. In this study, the MDC values of measuring back muscle strength with the designed load-cell setup were 3 kg and 4.2 kg for the hyperkyphosis and control group, respectively. However, they differed slightly from the MDC values found by Roghani et al. (2018): 3.9 and 2.7 kg for older women with and without hyperkyphosis, respectively. Therefore, we need a change of > 3 kg in the back muscle force for older adults with hyperkyphosis and > 4.2 kg for control individuals to ensure that the observed changes are real, not measurement errors.

Regarding endurance measurements, we found excellent test-retest reliability (ICCs: ≥95) for all three measurement methods: the designed load-cell setup, TLS, and Ito. The relative reliability was considerably better than that Roghani et al. (2018) reported for their designed setup. The difference might be due to measurement methods; we employed a pushing test, whereas Roghani et al. used a pulling test. Maintaining a sustained isometric contraction in sitting during the pushing test seems to be easier for older adults with and without hyperkyphosis. We had lower endurance time measured by load cell setup compared with Roghani's study (2018). Endurance time was approximately 50 seconds and 100 seconds for the older adults with and without hyperkyphosis versus 153 and 238 seconds reported by Roghani et al. (2018). A possible explanation is older participants in our study. Furthermore, Roghani et al. (2018) included only older women in their study. There is evidence that women have a higher proportion of fatigue-resistant type I muscle fibers in their back extensor muscles than men (Mannion, et al., 1997).

In the present study, the ICC values of measuring back muscle endurance by Ito were consistent with those reported before (del Pozo-Cruz et al., 2014, Ito et al., 1996). However, their absolute reliability was better than the present study, probably because of their younger sample population. Although the Ito test is a prone trunk holding test, it is easier to perform than the Sorensen test, especially for the elderly, because it imposes less load on the spine and avoids back pain (Demoulin et al., 2006).

Regarding the TLS test, we found substantially better relative reliability than Shipp et al. (2000) did, probably due to different demographic characteristics of the participants in the two studies. For instance, their study population was women with osteoporosis and vertebral fracture (Shipp et al., 2000). Depending on the method used to assess back muscle endurance, an increase of greater than 16.5, 28.2, and 35.1 seconds in endurance time measured by load-cell setup, Ito, and TLS, respectively, should be considered a real change in older adults with hyperkyphosis. The hyperkyphosis group had slightly lower SEM and MDC values than the controls. The MDC values of endurance time obtained from load-cell setup and Ito were approximately similar (36.7 and 36 seconds, respectively) and almost close to the endurance time of TLS (39 seconds) for older adults without hyperkyphosis. Since Ito and TLS are rapid and easy-to-perform tests that require neither specific equipment nor trained operator, they are prioritized over load-cell setup in clinical settings. However, unlike the load-cell setup, these two tests can only be used to assess trunk muscle endurance, not muscle strength.

Limitations

Some limitations of this study should be considered while interpreting the findings. First, our sample was a convenience sample that was recruited via public advertisements. Hence, it may not be representative of the clinical population with comorbid conditions. Since pain and pain catastrophizing (Larivière et al., 2010) are identified as confounding factors that affect muscle function, especially capacity to exert maximum force (muscle strength), we, therefore, excluded individuals with acute vertebral fracture and/or back pain. The results of this study cannot be generalized to a patient population with severe osteoporosis and or symptomatic hyperkyphosis. Moreover, we did not assess the concurrent validity of our designed load-cell setup since an isokinetic dynamometer was not available. Furthermore, inter-rater reliability was not assessed. Further research is needed to evaluate the inter-rater reliability of these techniques.

CONCLUSION

The present study suggests high reliability of the designed load-cell setup, Ito, and TLS for measuring back extensor muscle force and endurance in older adults with and without hyperkyphosis. All three measurement techniques have clinical applicability to evaluate and monitor muscle function in the older population. However, because of some benefits of field-based tests (i.e., Ito and TLS), such as rapid and easy-to-perform, they are prioritized over load-cell setup for clinical use.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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FIGURES

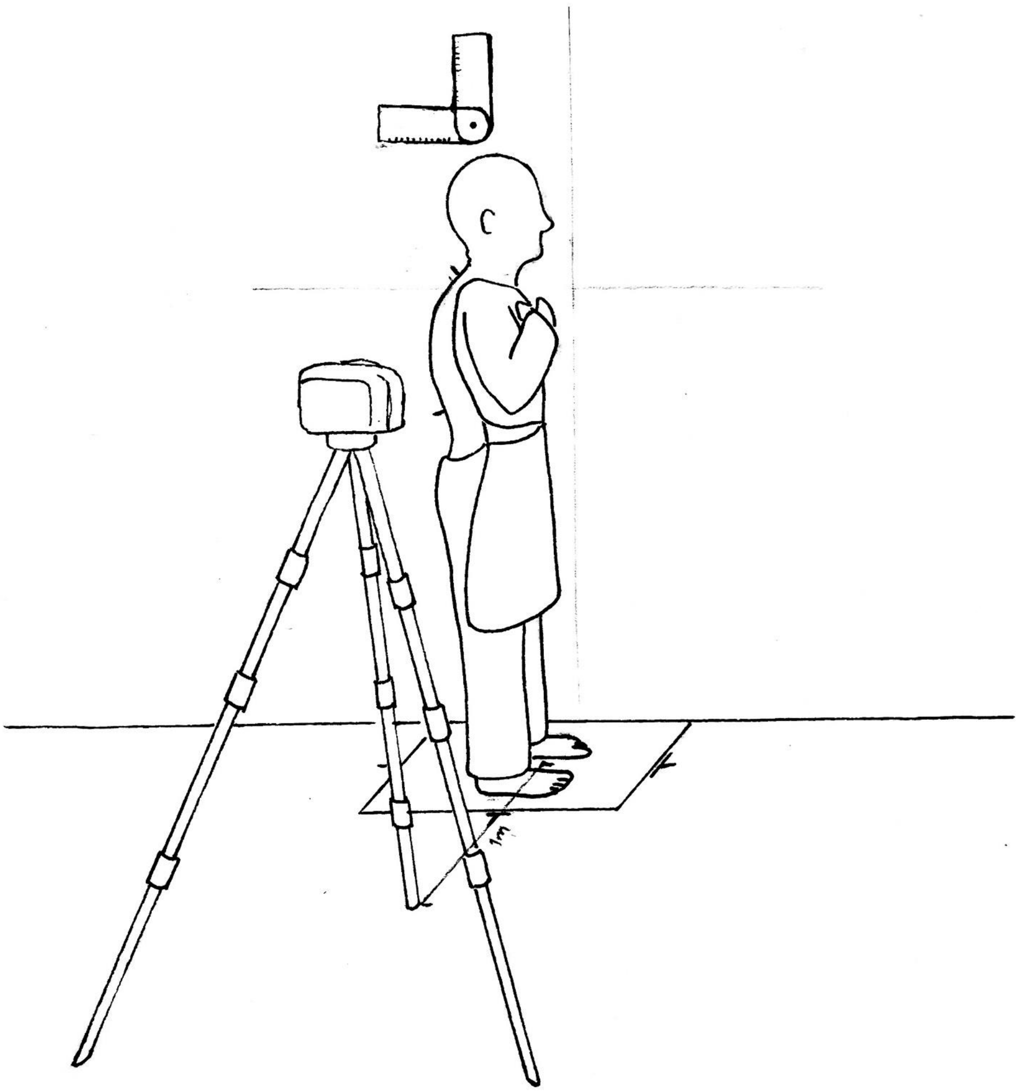

Figure 1. Measuring thoracic kyphosis using Photogrammetry method.

Spinous processes of the seventh cervical (C_7) and twelfth thoracic (T_{12}) vertebrae were detected by palpation. Then custom-made lightweight 3-cm long markers were adhered vertically to the skin by double-sided adhesive tape on the spinous processes of the C_7 and T_{12} vertebrae.

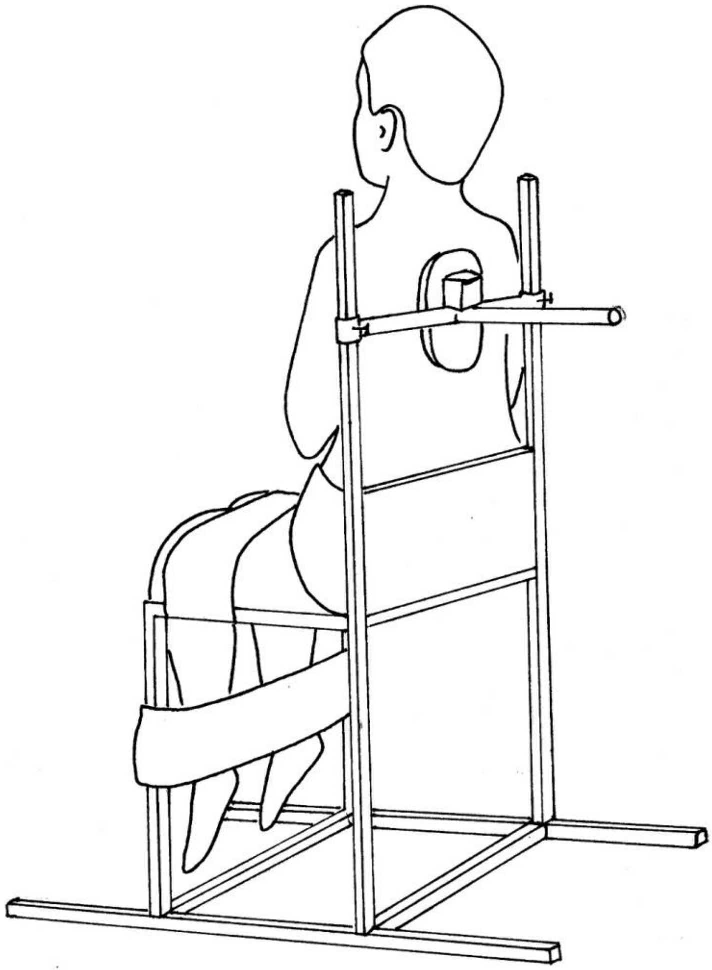

Figure 2. Assessing isometric back extensor strength and endurance using the designed load-cell setup.

Our designed setup consists of a chair with a 25 cm high backrest, with two vertical bars firmly attached to the backrest, a board with a hole in the center to hold the load cell was mounted on the vertical bars, with the height of the board and the load cell adjusted to the vertical bars according to the height of the participants via a rail bar. For the convenience of the participants and to minimize the local bony pressure, the load cell was covered with a pad of high-density foam. The participants sat on the chair, their hips and knees flexed 90 degrees, and their thighs parallel to the seat. The arms were crossed on the abdomen, and the chair's height was set so that the participants' feet were off the ground. The leg, thigh, and pelvis were tightened with inelastic belts and straps to restrain movement.

Table 1. Demographic characteristics of participants.

Variable	Hyperkyphosis group (n=28)	Control group (n=25)
Sex (Male/Female)	8/20	11/14
Age (year)	69.6 ± 5.6	67.2 ± 4.5
Height (cm)	160 ± 6.5	163.8 ± 7.2
Weight (kg)	66 ± 9.8	70.32 ± 9.6
Thoracic kyphosis angle (degree)	72 ± 7.3	40.07 ± 5.2

Note. Values are shown in mean ± standard deviation.

Table 2. Descriptive statistics for back muscle strength and endurance on test and retest sessions.

	Hyperkyphosis group (n = 28)			Control group (n = 25)		
	Session 1	**Session 2**	***p*-value**	**Session 1**	**Session 2**	***p*-value**
Maximal extensor force / strength (kg)	24.5 ± 11	25.1 ± 10.8	0.07	36.4 ± 15.1	37.1 ± 15	0.04*
Back endurance measured via load cell (sec)	49.3 ± 35	52.1 ± 38.2	0.05	101.6 ± 94.1	95.9 ± 87	0.37
Endurance time of Ito test (sec)	126.1 ± 102.1	126.8 ± 97.8	0.93	186.8 ± 93.2	191.4 ± 95.4	0.26
Endurance time of TLS test (sec)	89.3 ± 57.1	94.1 ± 58.8	0.6	189.3 ± 101.3	194.7 ± 100.8	0.21

Note. Values are shown in mean ± standard deviation.

Table 3. Test-retest reliability of back muscle strength and endurance measurements.

	Hyperkyphosis group (n=28)			Control group (n = 25)		
	ICC (95% CI)	**SEM**	**MDC**	**ICC (95% CI)**	**SEM**	**MDC**
Maximal extensor force / strength (kg)	0.99 (0.98 – 0.99)	1.1	3.03	0.99 (0.98 – 0.99)	1.51	4.16
Back endurance measured via load cell (sec)	0.97 (0.95 – 0.99)	5.95	16.49	0.98 (0.96 – 0.99)	13.32	36.76
Endurance time of Ito test (sec)	0.99 (0.98 – 0.99)	10.21	28.17	0.98 (0.97 – 0.99)	13.05	36.01
Endurance time of TLS test (sec)	0.95 (0.89 – 0.97)	12.76	35.05	0.98 (0.95 – 0.99)	14.18	39.13

ICC: Intraclass Correlation Coefficient; 95% CI: 95% Confidence interval.
Note. Values are shown in mean ± standard deviation.