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Feasibility and Reliability of Functional Muscle Tests in Lung Transplant Recipients

Thomas Kienbacher, MD, Grace Achim-Gunacker, MD, Melanie Pachner, MD, Katharina Kerschan-Schindl, MD, Patrik Gunacker, PhD, Richard Habenicht, BSc, Walter Klepetko, MD, Peter Jaksch, MD, Stephan Doblhammer, MD, and Gerold Ebenbichler, MD

Objective: This study investigates the feasibility, reliability, and correlations of recommended functional tests in lung transplant recipients shortly after surgery.

Design: This is an observational study.

Methods: Fifty patients (28 females) performed well-standardized maximum isometric back extension in a sitting position, handgrip strength, and Biering-Sørensen endurance tests shortly before discharge from the acute hospital, shortly thereafter, and 2 mos later after subacute rehabilitation.

Results: Back extension testing was well feasible, but only two thirds of the patients could perform the Biering-Sørensen test at baseline and they experienced a greater number of minor but no major adverse events. Absolute reliability measures and the intraclass correlation coefficients were excellent for the strength (0.97–0.98 [0.95–0.99]) and good for the endurance tests (0.69 [0.26–0.87]). Handgrip revealed high correlation with back strength (≥0.75) but not with Biering-Sørensen scores.

Conclusions: Well-controlled maximum back strength testing is feasible and reliable, and the scores are highly correlated with grip strength in lung transplant recipients shortly before hospital discharge. The Biering-Sørensen test should be limited to patients without dominant weakness and/or fear. Future research should investigate whether grip instead of back extension strength can safely be used for proper exercise prescription.

Key Words: Rehabilitation, Hand Strength, Muscle Strength, Physical Endurance, Correlation Study, Lung Transplantation

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Severe chronic lung diseases that ultimately lead to transplantation of the organ are frequently accompanied by long-term immobilization associated with degradation of skeletal muscles.[1,2] Immune suppressive medication, such as calcineurine inhibitors and steroids, and their adverse effects, such as diabetes mellitus and neuropathy, are all known to promote loss of muscle mass and impairment of the muscle fiber composition; these are in turn accompanied by decreased muscle strength and resistance to fatigue.[3,4] Such deficits in lumbar extensor muscles correlate with a loss of balance, postural alignment and control, and osteoporosis.[5–7] Thus, functional assessment to monitor strength and endurance scores is key for the prescription of appropriate load, resistance, and progression of exercise interventions for re-establishment of the overall health status in the early rehabilitation phase of lung transplant recipients (LuTxR).[8]

Back extension dynamometry has been shown to be safe and reliable in osteoporotic women when assessed in a prone position using specific strain gauge installations that were individually designed by the authors performing research.[9–11] Currently, there is no tradition of assessing back extension strength in clinical practice, but a recent comprehensive review recommended that achievement of proper form and alignment and the careful progression of intensity while loading an osteoporotic spine should be emphasized.[8,12] Commercially available devices certified for back strength testing and training of patients in clinical environments typically demand a sitting test position. They could potentially adversely challenge LuTxR

shortly after surgery or cause the biomechanical competence of an osteoporotic spine to be compromised, resulting in vertebral fractures or other major adverse events. Moreover, isometric strength of back extensors is not a good indicator of specific endurance, and thus, only the evaluation of both provides comprehensive information.[13] The Biering-Sørensen test[14] is probably the most used back extension endurance test in a clinical environment, and it enjoys the most support without the need of special equipment. However, patients with severe muscular impairment could be too weak to properly perform it.[15] Based on a comprehensive literature review, no study seems to exist that has examined the feasibility, the adverse events, and the reliability of these functional back muscle tests in LuTxR shortly after surgery.

Previous authors found that handgrip strength is a reliable tool, and it provides an estimate of back extension strength in healthy women and in older female patients with low back pain.[16,17] In addition, it has been recommended to diagnose sarcopenia[18] and to classify quality of life in postmenopausal osteoporosis as well as the risk of functional deficits in various medical conditions.[19] Dynamometry is easily available, quickly done, and almost free from risk of adverse events. Thus, specific testing could possibly help reduce the number of maximum back strength and/or endurance performances necessary in early rehabilitation of LuTxR. Nevertheless, these methods must be tested to prove adequate reliability and sensitivity to change before clinical use with patients, and measurements must be properly correlated with those of back strength and/or endurance.

This study for the first time sought to investigate (1) the feasibility (emphasizing adverse events), (2) the within-day and the between-day reliability, and (3) the test-specific sensitivity to change of the handgrip, the maximum isometric back extension strength, and the Biering-Sørensen endurance test at the completion of a subacute rehabilitation program shortly after lung transplantation. Furthermore, the study sought to demonstrate (4) the correlations between these maximum performance tests.

METHODS

Patients

Between November 2011 and May 2014, a total of 50 (28 females) LuTxR who had undergone lung transplantation at the Department of Thoracic Surgery at the University Hospital of Vienna and had agreed to participate in this observational study were enrolled. Of these, a total of 30 patients originated from foreign countries and were consecutively recruited. The remaining 20 patients were Austrian citizens who had been matched according to age and sex. All LuTxR underwent daily postsurgical acute rehabilitation as a criterion standard from transplantation to discharge from hospital. Immediately thereafter, Austrian citizens received mandatory 4 to 6 wks of inpatient rehabilitation (only inpatient rehabilitation is reimbursed by social security), whereas for economic reasons, the foreigners participated in an outpatient rehabilitation program, which had similar content but less supervision at the outpatient Department of Physical Medicine and Rehabilitation of the same hospital.

The number of included patients was chosen in accordance with previously published recommendations.[20] Patients of both sexes were included if they had undergone transplantation of one or two lungs, if they could stand without support for a minimum of 5 mins, and walk with or without an assisting device for a minimum of 50 m. Exclusion criteria were the following: not fulfilling the inclusion criteria, psychiatric disorders, peripheral neurologic deficits in the lower limbs (except peroneal compression neuropathy), and severe neurologic diseases. Eligible patients were examined by physical medicine and rehabilitation specialists and performed a 6-min-walk test. If patients were unable to understand the German or English language, a translator was made available.

The data collection was performed in accordance with the directives given in the Declaration of Helsinki. The study protocol was approved by the ethics committee of the Medical University of Vienna (Number EK 999/2011). Before inclusion, all patients received oral and written information about the study and signed a consent form. This study conforms to all Strengthening the Reporting of Observational Studies in Epidemiology guidelines and reports the required information accordingly (see Checklist, Supplemental Digital Content, http://links.lww.com/PHM/A515).

Assessment

Isometric trunk extension muscle measurements were collected using specially designed measuring and training units that test trunk extension strength (F110 extension; David Health Solutions Ltd, Helsinki, Finland). The dynamometer is described elsewhere in detail.[21] It consists of a "hip fixation mechanism" that is composed of the following five components: footplates adjustable to lower leg length, knee pads adjustable to thigh length, a pelvic belt, a seat adjustable for height, and a dorsal back pad. Participants were seated on the isometric machines in accordance with the manufacturer's recommendations, that is, with the longitudinal axis of their knees parallel to the seat, their trunk flexed forward at 30 degrees, and their arms hanging relaxed to each side. A monitor provided real-time display of the torques produced to the patients.

Handgrip strength was obtained from a handheld dynamometer (Jamar; Lafayette Instrument Company, Lafayette, IN).

Back muscle endurance was measured according to the method described by Biering-Sørensen[14] using a commercially available bench with straps for fixation of patients' lower limbs and a stopwatch to monitor the time elapsed.

The first assessment was performed shortly before or immediately after hospital discharge. A repetition of all tests was conducted 1 to 2 days later. All patients were retested a third time after completion of a subacute rehabilitation involving a muscle training program, approximately 2 to 3 mos later. On each test day, the patients were asked to perform a total of the following three tests: (1) the maximum isometric back extension, (2) the maximum handgrip strength, and (3) the Biering-Sørensen endurance. The sequence of strength tests was varied, whereas the Biering-Sørensen test was always performed last. All tests were conducted by two physical medicine and rehabilitation specialists (GE, KK-S) who have long-standing experience conducting these tests in LuTxR. All protocols were performed in a standardized way, and the

verbal instructions for the maximum strength tests given to the patients were provided in accordance with the manufacturers' recommendations. In addition, a staff pool comprising four master thesis students was available for assisting the physiatrists.

Isometric Back Extension Strength Testing

After secure positioning, the patients performed a few warm-ups at very low loads manually applied by the testers. This was done so that the LuTxR could familiarize themselves with the equipment and test procedure.[11,21] Thereafter, they performed three consecutive supervised maximum isometric contractions. If the best two tests varied by more than 10% or if the peak moment was achieved later than 3 secs after the onset of the contraction, further trials were permitted until a consistent maximum was achieved. Resting intervals between two repetitions were a minimum of 20 secs, whereas patients were encouraged to fully extend their back without load. All values obtained were monitored and recorded.

Handgrip Strength Testing

Patients were tested according to the American Society of Hand Therapists' recommendations.[22] They were seated in an upright position without support for the back, both feet on the floor and with both elbows 90 degrees flexed and the wrists in neutral position. After familiarization with the procedure, they performed a series of three maximum grip strength tests, alternating between the right and left hand (each test was followed by rest interval of 20 secs). If the best two tests varied by more than 10%, a further test was conducted to achieve a consistent maximum. All values were monitored and recorded.

Biering-Sørensen Endurance Testing

Patients were positioned with the help of the physician in the prone position on an examination bed with the patient's iliac crests matching the edge of the bed. Before the test started, the trunk was placed in a horizontal position and the load of the patient's trunk was fully supported by the physician who held the patient's shoulders and chest. The patients' arms were crossed in front of their chest. During the positioning, special attention was paid to the surgical wound to avoid any pain or discomfort. The patients' legs were fixed with straps to the surface of the bench. From this position, the patients were then asked to gradually and actively take over the load of their trunk and to maintain the position for as long as possible. The test was stopped if the patients were unable to hold the horizontal trunk position correctly or if 300 secs had been elapsed. The time spent in the trunk unsupported position was monitored using a stop watch operated by an assistant. This test was performed only once per test day without repetition to avoid any overexertion of the patients.

Main Outcomes

Scores were produced for the maximum isometric back extension moments (newton meters [Nm]), the maximum grip strength from right and left hands (kilogram), and the back extension endurance time (second).

Statistical Analysis

All statistical analyses were performed using R (Core Team[23]) environment for statistical computing. Within-day reliability of the handgrip and back extension strength scores was calculated from all values recorded, whereas for between-day reliability or the longitudinal changes between baseline, day 2, and the end of rehabilitation, the mean of the best two values was analyzed. Between-day reliability of the Biering-Sørensen endurance test was calculated accordingly from the single score per test day. Procedures that tested the reliability of the measurements followed previously published recommendations.[20,24] Distribution of data was visually investigated with histograms and box plots and verified by Shapiro-Wilk test and Quantile-Quantile diagrams. Heteroscedastic data were logarithmized.

Recommendations for calculating reliability indices as recently suggested by Almosnino et al.[25] were followed. These included the following statistical procedures for the test variables obtained from one test day or between two test days: (1) the systematic bias was calculated by the changes in the means and accompanying 95% confidence intervals (95% CIs) between day 1 and day 2 (between-days); (2) the between-days precision of measurements was determined by calculating the standard error of measurement (SEM $= SD\sqrt{(1.00 - r)}$ where "SD" is the standard deviation and "r" is the test-retest intraclass correlation coefficient [ICC]) or relative to its mean in % (SEM%), the smallest detectable difference (SDD $= 1.96 \times \sqrt{2} \times$ SEM) derived from the first and the second test day and its respective SDD in absolute values or relative to its mean in % (SDD%),[26] Bland-Altman plots; and (3) relative reproducibility using the ICC2,1, which was chosen for generalization purposes and revealed similar results when our sample was compared with an ICC model (ICC3,1).[27] The coefficient of variation was calculated to assess within-day reliability of strength measures.

Coefficients of correlation between different muscle function tests were calculated with Spearman ρ and Pearson correlation tests with the data pooled from the third assessment. Additional averages from the scores of both hands were calculated for the correlations. Data were logarithmized. In the case of high correlations, regression of logarithmized data was intended to allow transformation of maximum handgrip strength to maximum back extension strength scores.

RESULTS

Of the 50 LuTxR enrolled into the study, 22 had a body mass index of less than 18.5 kg/m^2 at baseline, 12 had diabetes, and 33 were diagnosed with osteoporosis or osteopenia (Table 1). Six patients refused the second testing. Two of them withdrew their consent because of deteriorated health unrelated to the testing, two took this decision for personal reasons, and the other two were not available because they had already been transferred to rehabilitation. At the end of rehabilitation, nine patients did not participate in the third assessment. Of these, four foreign patients could not reach the clinic because they had already returned home and another five patients refused testing for nonmedical reasons.

The mean handgrip strength increased from 16 to 23.5 kg from the first to the third evaluation (+44%), back extension

TABLE 1. Demographics and time intervals

	n	Mean (SD)	Median (1 Qu., 3 Qu.)[a]
Age, yr	50	43.50 (12.80)	40.00 (29.00–50.75)
BMI (1st assessment), kg/m^2	50	19.57 (3.95)	—
BMI (3rd assessment), kg/m^2	41	21.52 (4.15)	—
BMI difference 3rd to 1st assessment, kg/m^2	41	1.68 (1.88)	1.91 (0.57–2.25)
BMI (BMI < 18.5) at baseline, kg/m^2	22	15.73 (1.52)	—
Duration of intensive care, day	45	16.09 (30.17)	8.00 (6.00–16.00)
Time from transplantation to 1st assessment, day	49	31.37 (33.09)	21.00 (16.00–33.00)[b]
Duration between 1st and 2nd assessment, day	44	1.52 (1.44)	1.00 (1.00–1.00)
Duration between 1st and 3rd assessment, day	41	79.95 (35.85)	68.00 (56.00–89.00)
6-min walking test, at baseline, m	50	372.12 (105.18)	—
5-repetition sit-to-stand chair rising test, at baseline, sec	35 (15[c])	13.39 (5.40)	12.50 (11.55–15.50)
Glucocorticoid (prednisolone), mg	49	36.22 (48.08)	25.00 (25.00–35.00)
Tacrolimus, mg	48	11.56 (5.92)	11.00 (8.00–15.00)
Cyclosporine, mg	1	400.00 (—, —)	—
Mycophenolate mofetil, mg	24	697 (1122)	—
Mycophenolic acid, mg	2	1260 (255)	—
Diabetic	12	—	—
Osteoporosis/osteopenia	33	—	—
Bilateral lung transplantation	1	—	—
Cystic fibrosis	16 (11[d]/5[e])	—	—
Lung fibrosis	13 (10[d]/5[e])	—	—
Idiopathic	9 (8[d]/1[e])	—	
Secondary	4 (2[d]/2[e])	—	
Idiopathic pulmonary hypertension	7 (5[d]/2[e])	—	—
Chronic obstructive pulmonary disease IV	8 (0[d]/8[e])	—	—
Alpha 1 antitrypsin deficiency (emphysema)	2 (1[d]/1[e])	—	—
Alveolar microlithiasis	1 (1[d]/0[e])	—	—
Bronchiectasies	3 (2[d]/1[e])	—	—

[a]Median, first, and third quartile in case of nonnormal distribution.

[b]Significant difference ($P \leq 0.05$) between foreign and homeland LuTxR.

[c]Unable to perform the test.

[d]Foreign LuTxR ($n = 30$).

[e]Homeland LuTxR ($n = 20$).

BMI, body mass index.

strength increased from 69 to 133 Nm (+93%), and back endurance increased from 14 to 49 secs (+350%) (Table 2).

All the LuTxR successfully performed the back extension and the handgrip strength tests at all times. Seven patients (14%) were unable to perform the first Biering-Sørensen endurance test although their grip and back extension strength were similar to that of other patients on all assessment days. Another 10 (20%) of the LuTxR who were significantly and persistently weaker in back and grip strength until postrehabilitation compared with the remaining patients were unable to perform the Biering-Sørensen test on both the first and second assessment. Patients complained of significant back muscle pain three times of the 540 back strength tests (0.56%) and seven times during the 161 endurance tests (4.35%). No major adverse effects such as vertebral fractures or other injuries were observed during or after any of the tests.

For strength tests, the within-assessment coefficients of variation were found to be approximately 10% with larger values for the handgrip than for the back extension strength tests (Table 3). Repeating the strength and endurance tests for the second assessment, approximately 2 days later, revealed no significant changes in the mean of any of the test results (Table 2). The between-assessment precision of maximum strength performance measurements revealed values for the SEM (SEM in percent [SEM%]) of less than 10%. Moreover, the SEM% values observed for the back extension strength indicated that this test is more precise than measuring maximum handgrip strength. The Biering-Sørensen endurance test was found to be less precise than the strength tests with a SEM% value of 18.7%. Likewise, the respective SDDs (SDD%) were found to be smallest for the back extension, followed by the handgrip strength and the Biering-Sørensen test (Table 3). If the SDD% values were compared with the longitudinal changes at the end of rehabilitation, all the handgrip, the back extension strength, and the endurance outcomes improved to a clearly greater extent than was required by the threshold values indicative for monitoring a true change. According to a widely used classification,[27] the ICC values revealed excellent relative reliability for any of the strength tests investigated. Relative reliability of the back muscle endurance test was found to be

TABLE 2. Absolute values and differences

	1st Assessment (*n* = 50)	2nd Assessment (*n* = 44)	Difference 2nd to 1st Assessment	3rd Assessment (*n* = 41)	Difference 3rd to 1st Assessment
	Mean (SD)	Mean (SD)	Mean (95% CI)	Mean (SD)	Mean (95% CI)
Handgrip[a] (left), kg	14.95 (12.90)	14.86 (12.11)	0.05 (−1.17 to 1.27)	22.33 (17.06)	7.09 (3.91 to 10.26)
Handgrip[a] (right), kg	17.14 (12.51)	17.78 (12.46)	0.76 (−0.31 to 1.82)	24.25 (13.32)	6.78 (4.43 to 9.92)
Handgrip[a] (mean left/right), kg	16.18 (12.52)	16.48 (12.15)	0.41 (−0.61 to 1.42)	23.52 (14.71)	6.98 (4.46 to 9.51)
Back extension strength,[a] Nm	68.67 (48.95)[b]	71.95 (47.25)[b]	2.47 (−2.49 to 7.44)	133.43 (74.33)[b]	63.21 (49.75 to 76.67)
Biering-Sørensen, sec[c]	14.04 (9.44)	17.57 (13.79)	3.62 (−0.70 to 7.94)	48.76 (28.85)	40.61 (29.40 to 51.82)

[a]Two best out of three.

[b]Significant difference (*P* ≤ 0.05) between foreign and homeland LuTxR.

[c]Invalid attempts excluded.

good if data from those patients who were able to perform the first and second assessment were considered (Table 3).

Handgrip strength tests (right, left, and scores from both hands pooled) were significantly correlated with isometric back extension strength and exceeded mean correlation values of 0.74 (Table 4). There were, however, no such correlations between the back endurance and either the hand or back extension strength tests.

DISCUSSION

Assessment of back muscle function early after surgery is highly important for the proper exercise prescription to re-establish the overall health status of LuTxR. This study for the first time investigated the feasibility, adverse effects, reliability, and correlations of specific test results employed in routine patient care. Findings revealed the following: (1) maximum back extension and handgrip strength tests were feasible and without major adverse events; (2) all the reliability parameters were excellent and demonstrated a true change caused by an exercise intervention; (3) whereas before rehabilitation, one third of the LuTxR were unable to perform the Biering-Sørensen endurance test, for those patients who successfully performed the test, there were more minor but no major adverse events, the relative test reliability was good, and the changes at the end of rehabilitation well exceeded the SDD; and (4) handgrip was highly correlated with the back strength but not the endurance test.

All patients could perform maximum back and grip strength testing from the very first assessment. We observed only three minor events (muscular pain in the lower back region) of 540 tests (0.56%) according to the Consolidated Standards of Reporting Trials extension for reporting harms.[28] Notably, based on the diagnosis and medical treatment established by the Department of Thoracic Surgery performing the transplantation (Table 1), two thirds of the LuTxR (33/50) experienced osteoporosis or osteopenia that preferably affects the vertebral bodies. Thus, the patients with test associated complaints had immediate radiographic evaluation and consultation through emergency surgery. According to these consultations, they were all able to proceed with the study and rehabilitation without any restrictions or specific treatment.

These results are well in line with a previous study by our group, in which only 1 (0.53%) of 210 patients with chronic low back pain refused reassessment because of test-related symptom aggravation.[29] These patients had only moderate pain levels without dominant weakness, but our observation was confirmed by other authors because they found excellent patient compliance and no fractures with application of high-intensity loads in severely affected women with very low bone mass.[30] Notably, in the current study, special emphasis was put on proper positioning of the patients, control of the performance technique to avoid jerky excursions that can provoke peak compressive loads and shear, and low-load familiarization exercise at the beginning before increasing to the maximum

TABLE 3. Within- and between-day reliability

	Within-Assessment Reliability	Between-Assessment Reliability[a]		
	Coefficient of Variation, Mean (SD), 1st/2nd/3rd Assessment	ICC[b] (95% CI)	SEM% (SEM[c])[d]	SDD% (SDD[c])[d]
Handgrip (left)	15.10 (12.84)/15.37 (12.18)/12.67 (9.05)	0.98 (0.96–0.99)	6.13 (1.45)	16.97 (4.03)
Handgrip (right)	10.22 (9.38)/12.54 (9.49)/10.60 (9.32)	0.97 (0.95–0.99)	5.30 (1.78)	14.68 (4.95)
Handgrip mean (left/right)	13.69 (24.48)/12.00 (7.57)/10.08 (7.52)	0.98 (0.96–0.99)	4.84 (1.41)	13.42 (3.92)
Back extension strength	9.00 (9.00)/8.30 (6.02)/6.58 (4.98)	0.98 (0.97–0.99)	2.55 (5.49)	7.06 (15.21)
Biering-Sørensen[e]	—/—/—	0.69 (0.26–0.87)	18.69 (5.43)	51.81 (15.05)

[a]From log-transformed data.

[b]Between assessment 1 and 2.

[c]From linear approximation of logarithmic data.

[d]Assessment 1 and 2 pulled.

[e]Only 1 measurement per assessment.

TABLE 4. Correlations (Spearman ρ)

	Handgrip (Left/Right)	Back Extension	Biering-Sørensen
	1st/2nd/3rd Assessment Correlation Coefficient (95% CI)	1st/2nd/3rd Assessment Correlation Coefficient (95% CI)	1st/2nd/3rd Assessment Correlation Coefficient (95% CI)
Handgrip (left)	0.98 (0.97 to 0.99)[a]/0.99 (0.98 to 1.00)[a]/0.99 (0.98 to 1.00)[a]	0.85 (0.75 to 0.92)[a]/0.83 (0.69 to 0.91)[a]/0.76 (0.59 to 0.87)[a]	0.27 (−0.12 to 0.59)/0.18 (−0.21 to 0.52)/0.22 (−0.09 to 0.49)
Handgrip (right)	0.98 (0.97 to 0.99)[a]/0.99 (0.97 to 0.99)[a]/0.98 (0.96 to 0.99)[a]	0.86 (0.76 to 0.92)[a]/0.79 (0.63 to 0.89)[a]/0.70 (0.46 to 0.83)[a]	0.33 (−0.06 to 0.63)/0.20 (−0.18 to 0.54)/0.14 (−0.18 to 0.43)
Handgrip (left/right)	—	0.87 (0.77 to 0.93)[a]/0.82 (0.68 to 0.90)[a]/0.75 (0.57 to 0.87)[a]	0.28 (−0.12 to 0.59)/0.15 (−0.23 to 0.50)/0.19 (−0.12 to 0.47)
Back extension		—	0.40 (0.00 to 0.69)[a]/0.16 (−0.25 to 0.52)/0.22 (−0.11 to 0.51)
Biering-Sørensen			—

[a]$P < 0.05$.

weight. Thus, the exact standardization of test protocols, guidance of the patients by experienced examiners, and consideration of manufacturers' instructions seem key for the avoidance of serious harm to these patients.

The strength tests were guided by two different examiners, but all the within- and between-day reliability including the precision of measurements was excellent. This procedure likely reflects the every-day clinical practice, where experienced hospital staff change according to their individual times on duty. The results of the LuTxR who reached only about a third of the usual back extension strength scores were similar to our previous experience with chronic low back pain patients older than 60 yrs, which revealed no relevant changes of the mean scores if retested 1 to 2 days later.[29] Thus, back extension and grip strength measurements can be recommended for LuTxR with severe functional muscle impairment. Notably, there was no correlation between the length of intensive care or time between transplantation and the first assessment and the absolute back strength, grip strength, or the Biering-Sørensen endurance scores. Moreover, inclusion of homeland and foreign LuTxR allowed us to cover the whole spectrum of diagnoses leading to lung transplantation and thus likely strengthened the generalizability of our results. In addition, the longitudinal changes of the variables of interest were similar between these two patient groups.

Seven patients could perform the Biering-Sørensen test at the second but not at the first assessment 2 days ago. Such unfeasibility was clearly triggered by fear because, in absolute numbers, these patients' back extension strength was greater than that of other patients who were performing well. Ten other patients with a significant deficit in lumbar extensor strength were unable to pursue both the first and the second endurance tests before rehabilitation started. In 4.35% of the tests (with a 1.1 times higher rate in LuTxR with osteoporosis/osteopenia), significant back pain was reported without any further adverse events indicating an eight-fold higher risk compared with the back strength measurements. Thus, Biering-Sørensen testing should be limited to patients without distinct back muscle weakness and fear.

One could expect that the Biering-Sørensen test, which demands a very strenuous, completely horizontal trunk position, would lead to worse reliability measures as compared with the isometric back muscle test, which involves a gradual muscle exertion limited by individual capability. Notably, the endurance test has proven sufficiently sensitive to change that it can be recommended for clinical use in patients who have 10-fold lower back muscle endurance before rehabilitation starts compared with other less disabled patients.

The correlation between handgrip and isometric back strength but not the Biering-Sørensen test was significant in this study. These findings suggest that isometric maximum back extension tests could be replaced by handgrip strength testing. After such, a procedure could help clinicians who hesitate to perform maximum back extension strength measurements in the early phase after transplantation because it has less potential for discomfort and requires less effort from the patients to overcome fear. In addition, it could help save financial resources because the equipment is inexpensive and the test requires less time.

Based on the logarithmized results of our regression analyses, maximum handgrip strength of 15 kg would translate to 62-Nm back extension strength. Considering the lower limit of the 95% CI for safety purposes (48.2 Nm), proper loading of the LuTxRs' back muscles with 40% of the maximum at the beginning of a training intervention would correlate with 19 Nm on a David back extension device. These data may be consistent with those from healthy women and older female patients with low back pain[16,17] but the onset and slope of the regression that served as the basis of the strength translation may change with the patients' individual training state and type of physical activity. Thus, it is important to note that our findings apply exclusively to LuTxR in the subacute phase of rehabilitation. Overall, one-to-one adjustment of the back muscle training resistance and progression through handgrip strength could result in potential pain exacerbation could induce pronounced weakness through overuse and could cause danger of injury. Further research is needed to demonstrate the feasibility, safety, and efficacy of this procedure.

Limitations

One may argue that the study results could have been biased by LuTxR not adhering to study protocols by not giving their best performance during back strength and endurance

testing. However, the patients with the worst scores were also unable to stand up without support in the five-repetition sit-to-stand chair rise test (35 of 50 LuTxR were able) (Table 1) and to pursue the first and second Biering-Sørensen test. Notably, we did not evaluate fear avoidance behavior, which likely affected their ability to perform this endurance test. Moreover, high correlation between back extension and grip strength reflects a true or close to true maximum. Mannion et al.[31] found that motivation, psychological disturbances, and negative thoughts have a high impact on the results of the Biering-Sørensen test. These parameters were not investigated in our study, but we believe that our patient group was rather homogenous, and we hope that any error made is not relevant. Optimum timing would require all tests to be conducted at the same time of the day to account for diurnal changes of performance and equal periods between tests. Both could not consistently be maintained in all cases because of organizational limitations. This specially affected the third test, which was held 2 mos after the first. It is further unknown how the postrehabilitation relates to the preoperative scores or controls because we are unable to provide these data.

CONCLUSIONS

Back extension strength measurements are feasible, reliable, and sensitive to clinical change in LuTxR shortly after transplantation. Tests can be recommended for clinical use before the start of subacute rehabilitation if they are carefully standardized and controlled. When patients are not overly weak or dominated by fear, they are able to conduct the Biering-Sørensen test with good sensitivity to change. Correlations suggest that back extension strength is likely impaired if patients demonstrate reduced grip strength. Further research is needed to identify subgroups of patients in which handgrip strength can safely be used for proper back muscle exercise prescription.

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