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Original Article

Physical Testing in Cancer Patients: Practical Testing in a Clinical Setting

Kanserli Hastalarda Fiziksel Testleme: Klinik Ortamda Pratik Testleme

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ABSTRACT

Objective: Muscle strength assessment in cancer rehabilitation is normally performed using the one repetition maximum (1RM) strength test for several muscle groups. 1RM testing is not easy in a clinical setting; and therefore, in this study, we aimed to determine the test-retest reliability and the relation to 1RM muscle strength of functional movement tests in a group of diverse cancer patients, curatively treated with chemotherapy.

Material and Methods: The study sample included 26 participants, of whom 13 were post-chemotherapy patients and 13 were healthy controls (mean±SD); age 45.9±13.6 years; weight 80.2±12.7 kg; BMI 26.4±3.77; leg press 1RM strength value/kg 2.06±0.70. The following tests were performed-the vertical jump test, stair-climb test, 5-times chair-rise test, 30-seconds chair rise, push-up test, and hand grip strength test and the results were correlated with the leg press 1RM strength values. The tests were performed twice with a minimum gap of seven days in between.

Results: The control group showed significantly better results in the 1RM strength tests and most other tests than the post-chemotherapy group. The vertical jump test results showed the best correlation with leg press strength, and the push-up test variable showed the best correlation with upper extremity 1RM strength.

Conclusion: The vertical jump and push-up tests are the most valid in the clinical setting. These tests assist exercise physicians in determining muscle strength at various stages of the cancer process and rehabilitation, which help specify training goals individually for each patient.

Keywords: Oncology, physical screening, strength

ÖZ

Amaç: Kanser rehabilitasyonunda kas gücü değerlendirmesi, normalde birkaç kas grubu için bir tekrarlı maksimum (1RM) kuvvet testi kullanılarak yapılır. Klinik ortamda 1RM testi kolay bir uygulama değildir. Bu nedenle, bu çalışmada kemoterapi ile küratif tedavi gören farklı kanser hastalarından oluşan bir grupta fonksiyonel hareket testlerinin test-tekrar test güvenilirliğini ve 1RM kas gücü ile ilişkisini belirlemeyi amaçladık.

Gereç ve Yöntemler: Çalışma örneklemi 13'ü kemoterapi hastası ve 13'ü sağlıklı kontrol olan 26 katılımcıdan oluşmaktaydı. Yaş ortalaması ve standart sapması 45,9±13,6 yıl; ağırlık 80,2±12,7 kg; BMI 26,4±3,77; bacak presi 1RM değeri/kg 2,06±0,70 idi. Dikey sıçrama testi, merdiven tırmanma testi, 5 kez sandalyeden kalkma testi, 30 saniyelik sandalyeden kalkma testi, itme testi ve el kavrama gücü testi yapıldı. Sonuçlar bacak presi 1RM ile ilişkilendirildi. Testler minimum yedi gün arayla iki kez yapıldı.

Bulgular: Kontrol grubu 1RM güç testlerinde ve diğer testlerin çoğunda kemoterapi sonrası gruba göre önemli derecede daha iyi sonuçlar gösterdi. Dikey sıçrama testi sonuçları bacak pres kuvveti ile en iyi korelasyonu gösterdi ve itme testi değişkeni üst ekstremite 1RM gücü ile en iyi korelasyonu gösterdi.

Sonuç: Dikey sıçrama ve itme testleri klinik ortamda en geçerli olanlardır. Bu testler, egzersiz uzmanlarına kanser sürecinin çeşitli aşamalarında ve rehabilitasyonda kas gücünü belirlemede ve her hasta için ayrı ayrı eğitim hedeflerinin belirlemesine yardımcı olur.

Anahtar Kelimeler: Onkoloji, fiziksel tarama, güç

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Introduction

Recent studies show that 80% of women with breast cancer, the most common type of cancer overall, are expected to survive for 10 or more years.[1] Because of the vast increase in breast cancer survivors and in the survival time, long-lasting side effects are also increasing. Fatigue, cardiovascular complications, body composition changes, such as sarcopenic obesity, osteoporosis, lymphedema, etc., often linger for years and greatly affect the quality of life (QoL) of breast cancer survivors.[2] Research from our group has shown that QoL in breast cancer patients improves after high-intensity strength training.[3,4] As side effects vary from person to person, the need for personalized side effect (lifestyle) treatment in cancer is warranted to positively affect patient's survival, health outcomes, and quality of life (QoL). However, for personalized interventions to be effective, a more profound understanding of patho-physiological pathways that cause these side effects in cancer is needed.

It is well known that cancer patients benefit from physical rehabilitation programs.[5] However, physical training of cancer patients is complex owing to the diversity of treatments within the different stages of the disease, their associated adverse effects, and a diversity of morbidities. For instance, physical exercise has been shown to counteract side effects of breast cancer treatment and to improve health status and QoL.[6] Several intervention studies have shown positive effects of supervised physical activity after cancer treatment on both the physical as well as psychosocial competence of patients. These effects comprise, besides an increase in cardiopulmonary function, muscle strength, and bone mineral density, an improvement of the QoL and a reduction in the level of fatigue.[2,6-8]

Physical activity has proven to reverse several side effects by changing the body composition, reduce feelings of fatigue, increase muscle strength, aerobic capacity, and QoL post cancer treatment.[9-11] Most interventional studies, which analyzed the effect of physical activity during cancer treatment or rehabilitation in the last decade, focused on aerobic exercises rather than strength exercises. Only a few studies have specifically focused on strength training for cancer survivors, and these have also proven to increase muscle strength, QoL, and decrease fatigue.[12,13]

The importance of high-intensity strength training in patients treated with chemotherapy is the relation between strength values and health-related QoL (HRQOL).[12] The one repetition maximum (1RM) values of several strength exercises showed moderate to high correlation to the physical functioning scale in the HRQOL questionnaire before and after treatment. One study showed that cancer rehabilitation with high-intensity resistance training is also effective in long term (over a period of one year), indicating that high-intensity strength training is important in cancer rehabilitation programs.[14]

The determination of muscle strength in the cancer rehabilitation programs is mainly determined by a 1RM test[15] or an indirect 1RM test.[7, 8, 16, 17] The 1RM test determines the maximum amount of weight that can be lifted over a full range of motion once during any strength exercise.[18] The relation of muscle strength to HRQOL in cancer survivors makes the specific 1RM data valuable for clinicians because they can closely follow progress and specify training schedules on an individual basis. Unfortunately, the 1RM test is time consuming to conduct in a clinical setting.[18] In addition, 1RM testing is equipment specific, which makes it difficult to compare data obtained from multiple training centers. Exercise physicians would benefit from a clinical applicable test that shows a good association with 1RM values as it would allow them to compare strength values in relation to HRQOL.

To date, no standard test is available for assessment of muscle strength in the (post) cancer population in a clinical setting. Physicians prefer a simple test that can easily be performed within minutes. Such an alternative test for 1RM testing will have to demonstrate a high correlation with 1RM data.

Therefore, in this study, our aim was to determine the test-retest reliability and the association with 1RM muscle strength of lower and upper extremities functional movement test in a group of former cancer patients, curatively treated with chemotherapy.

Material and Methods

Participants

Thirteen female patients who were treated curatively with chemotherapy and 13 individuals without a history of cancer, were assigned to an 18-week high-intensity strength training program (HITS) and control program (CONT), respectively.

The post-chemotherapy patients were recruited from the Maxima Medical Centre, Veldhoven, who volunteered to participate in the high-intensity resistance training program. Only patients who finished their initial chemotherapy treatment at least six weeks ago and not longer than 18 months ago were included. The subjects of the control group were individuals who performed regular physical training at the test center and were recruited by personal invitation. All the participants agreed voluntarily to participate. The project was approved by the ethical review committee of the Antwerp University (number B300201837317 03-09-2018), and informed consent was obtained from all the patients.

The participants had to meet the following criteria:

Inclusion criteria:

- Age between 18–70 years.
- Diagnosed free of cancer for at least six weeks.
- Cancer treatment included chemotherapy.

Exclusion criteria:

- Current chemotherapy treatment or in last six weeks before start of measurement
- Patients with lymphedema.
- Lacking the ability to perform basic motor skills like sitting down, standing up, jumping, or lying down.
- Severe emotional instability, cognitive disorders, or pain complaints.
- Other serious diseases which may affect their physical performance capacity (like cardiac disease or rheumatoid arthritis).

As all the patients of chemotherapy were participants of the training program; they were, prior to the program, screened by a sports physician to assess whether they were capable of joining the training program. The inclusion and exclusion criteria were part of the primary screening process. The control population was screened by a physiotherapist and had to match the same criteria as the chemotherapy population, except for the cancer treatment criterion.

A flowchart (Figure 1) with subject/patient flow is shown below.

Testing methods

For the upper extremity, two tests were analyzed-the hand grip strength test and the push-up test. For the lower extremity, four tests were analyzed-the 5-times chair-rise test, 30-second chair-rise test, stair-climb test, and the vertical jump test. In addition, indirect 1RM measurements for bench press, vertical row, and leg press were tested to determine the relation to muscle strength for each test. After the first test, all the participants completed the EORTC-QoL questionnaire (Table 1)

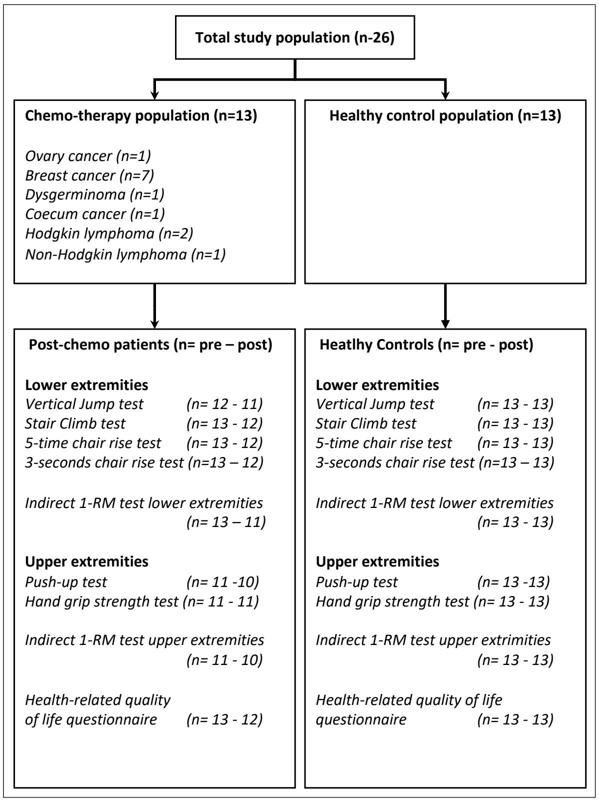

Figure 1. Flowcharts with the Number of Participants Pre- and Post-Testing

All tests were performed at baseline (T=0) and approximately one week after baseline (T=1). At each test moment, all tests were performed twice with two minutes of rest in between. The order of testing was similar for all participants. All the tests were continuously monitored by the same observer to prevent the test from inter-observer variability. The attempt with the highest primary variable value was used for further analysis. The participants were asked not to perform any kind of physically heavy-weight performance exercises 24 hours prior to testing.

Warming up

All the participants performed the same warming-up protocol before starting with the tests. The warming up consisted of 5-minute ergometer cycling at 80 W (1 W/kg). Next, all participants performed three test jumps and three test push-ups for familiarization purposes.

Vertical jump

The vertical jump test was performed as a countermovement jump. The participant had to stand still on the platform before starting. After countdown the participant had to make a countermovement by slightly bending the knees and then quickly jump as high as possible with his chest and head (Figure 2). It was important to jump as high as possible, not just lifting up the feet to lengthen flight time. The participant was free to move his arms during the test. The participant was verbally encouraged before the jump.

The jump data were measured using a force platform (Performance tester by Galileo2000, 100 Hz sample rate) connected to a personal computer to determine body weight (during stand still), ground reaction force, flight time, and power in the acceleration phase of the jump. The software that corresponds with the platform (Logger Pro 3.5.0, Vernier Software, Texas, USA) was used to perform the calculations.

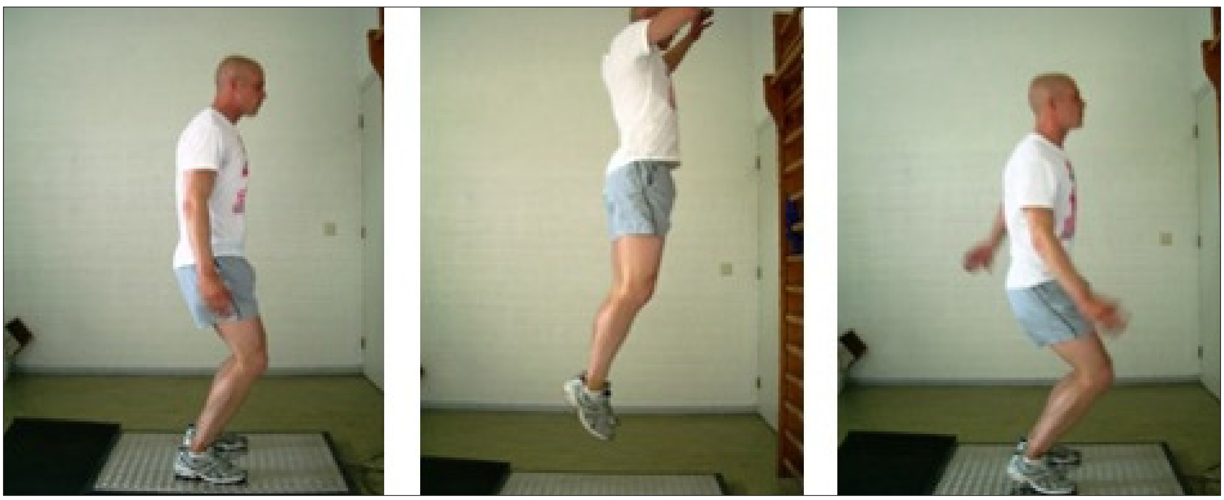

Figure 2. Execution of the Vertical Jump Test

Table 1. Tests, Execution, Materials and Primary Output Parameters (EORTC-QLQ C30 = Health-related Quality of Life scale for patients with cancer)

Name test	Execution of the test	Materials used	Primary output parameters
Vertical jump test	The participant had to stand still on the platform before starting. After countdown, the participant had to make a countermovement by slightly bending the knees and then quickly jump as high as possible with his chest and head.	Force platform (Performance tester by Galileo2000, 100 Hz sample rate) (Software: Logger Pro 3.5.0, Vernier Software, Texas USA)	Maximum power per kg body weight
Stair-climb test	The participant had to walk up the stairs as fast as possible without skipping steps. In case of falling, the side bars could be grabbed, but the measurement was terminated and was restarted after a 5-minute break.	Facility available stairs (2,94 meters vertical displacement) – 20 cm per step	- time
5-time chair-rise test	Participants had to stand up and sit down 5 times completely and as fast as possible. It was important that the participant fully extended his hips and knees and touched the back rest of the chair during sit down. The arms of the participant remained crossed during the entire test. The chair was placed against a wall to prevent it from slipping backward.	A chair with a solid back rest but without arm rests and minimal upholster was used for this test. The seat height of this chair was 45 cm	- time for 5 complete rises and sit downs
3-seconds chair-rise test	Participants had to perform as many correct chair rises as possible in 30 seconds. The rest of the testing protocol was identical to the one of the 5-time chair-rise test.	The same chair that as used for the 5-time chair-rise test, was used for this test	Number of repetitions in 30 seconds
Push-up test	The participant had to perform one push-up with both hands on the force platform. Behind the platform was a mat to make the testing position more comfortable. The participant had to support his body weight on the feet, knees and hands. The hands were shoulder-width apart, while the elbows were extended. At the start of the test, the participant flexed the elbows and lowered the body to just above the platform, without resting the participant then quickly extended the elbows again, creating an explosive push-up movement. During this push-up the hands were allowed to leave the platform. Through this movement, the participant had to try to push himself off as quick and hard as possible.	Force platform (Performance tester by Galileo2000, 100 Hz sample rate) (Software: Logger Pro 3.5.0, Vernier Software, Texas USA)	impulse per kg body weight
Hand grip strength test	This test was performed according to the protocol of the American Society of Hand Therapists.[19]	Jamar, Chicago, USA	highest amount hand grip force per kg body weight
Indirect 1RM tests	The bench press was performed lying down on a flat bench with the elbows flexed to 90° and extend to nearly straight. The vertical row was performed on a vertical row machine. The chest had to touch the chest support all the time and the participant remained with his head in the same position during the entire test. The leg press test was performed on a horizontal leg press machine. The participant was lying in supine position, with the knees at an angle of approximately 70° at the start and the participant had to extend his legs to nearly straight, and flex the knees until 90° again for each leg press movement. Before starting each test 10 repetitions of the movement with a very low weight were allowed. The test was performed with an estimated 10-RM weight. The number of correctly performed movements were recorded.	All equipment Technogym, Italy	The Brzycki's equation was used to calculate the 1-RM value from the number of repetitions and test weight. The primary variables were the 1-RM bench-press value per kg body weight (BP 1RM/kg), 1-RM vertical-row value per kg body weight (VR 1-RM/kg) and the 1-RM leg press value per kg body weight (LP 1RM/kg).
Health-related quality of life questionnaire	The test divides quality of life in six functional scales (physical, role, cognitive, emotional, social functioning and global functioning of life). The main interest of the questionnaire in this research was the relation of physical functioning with the quality of life. The test was completed once, at the end of the first day of testing.	(EORTC-QLQ C30)	

The dependent variable was the developed maximum power per kg body weight (maxP/kg). Other variables that were used as secondary parameters for the vertical jump test were jump height (JH, calculated from flight time), jump height per kg body weight (JH/kg), maximum force per kg body weight (maxF/kg), and impulse per kg bodyweight (Imp/kg). The attempt with the highest maxP/kg was used for further analysis.

Stairs climb test

The available stairs at the training facility was used. This stair contained 15 steps and a vertical displacement of 2.94 m. Side bars were present on both sides of the stairs. The participant had to walk up the stairs as fast as possible without skipping steps. If there was a risk of falling, the side bars could be grabbed; but the measurement was terminated and was restarted after a 5-minute break.

In brief, the participant had to stand 20 cm away from the first step with both feet next to each other at the bottom of the stairs. At a signal of the observer, the participant began climbing the stairs as quick as possible. During the test, the participant was verbally encouraged. When the participant touched the final step with the last foot lifted, time was stopped. Timing was noted using a stopwatch. Time was the primary variable in this test. The other variable was power per kg body weight (P/kg). The power generated during the test was calculated by the formula: power = (body weight × 9.81) × (2.94/stair-climb time). The body weight was measured on the force platform during the vertical jump test. The fastest time was used for further analysis.

5-time chair-rise test

A chair with a solid backrest but without armrests and minimal upholster was used for this test. The seat height of this chair was 45 cm. Participants had to stand up and sit down 5 times completely and as fast as possible. It was important that the participants fully extended their hips and knees and touched the backrest of the chair during sit down. The arms of the participant remained crossed during the entire test. The chair was placed against a wall to prevent it from tipping over backward. The primary variable in this test was the time needed to perform five complete rises and sit down again. Participants performed two attempts with at least two minutes of rest in between, and the fastest time was used for further analysis. Timing was noted using a stopwatch, and the observer verbally encouraged the participant.

30-second chair-rise test

The same chair that as used for the 5-time chair-rise test, was used for this test. Participants had to perform as many correct chair rises as possible in 30 seconds. The rest of the testing protocol was identical to the one of the 5-time chair-rise test. The primary variable in this test was the number of repetitions. Only fully completed repetitions count. Participants had to perform two attempts with at least two minutes of rest in between, the best attempt was used for further analysis.

The push-up test

The participant had to perform one push-up with both hands on the force platform. Behind the platform was a mat to make the testing position more comfortable. The participant had to support his/her body weight on the feet, knees, and hands (Figure 3). The hands were shoulder-width apart, whereas the elbows were extended. At the start of the test, the participants flexed their elbows and lowered the body to just above the platform; and then without resting, the participant quickly extended the elbows again, creating an explosive push-up movement. During this push-up, the hands were allowed to leave the platform. Through this movement, the participant had to try to push himself off as quick and as hard as possible. It was important that the participant kept the knees, hips, and shoulders in a straight line during the entire test, and the observer monitored this. He also verbally encouraged the participant.

The primary variable was the impulse per kg body weight (Imp/kg). The secondary variables were maximum power per kg body weight (maxP/kg), maximum force per kg body weight (maxF/kg), and mean force per kg body weight (meanF/kg). The data used in this test were collected during the acceleration phase of the push-up. The attempt with the highest Imp/kg will be taken into further analysis.

Hand grip strength test

The participants had to perform hand grip strength tests with both hands twice. For this test, a Jamar handheld dynamome-

Figure 3. Execution of the Push-Up Test

ter (Jamar, Chicago, USA) was used to determine the peak grip force in kg pressure. This test was performed according to the protocol of the American Society of Hand Therapists.[19] The participant sat on a chair with his arm adducted to the side and elbow flexed at 90˚. The dynamometer handle was set at position 2. The participants were asked to squeeze the handle for 3–5 seconds as hard as possible. Both hands were tested, and data were written down as dominant and non-dominant hand. At least, two minutes of rest was taken between the first and second attempts. During the test, the participant was verbally encouraged.

The primary variable in this test was the highest amount of hand grip force per kg body weight (hgf/kg). The secondary variable was the hand grip force (hgf). The highest value of the primary variable was used for further analysis.

Indirect 1RM tests

The participant had to perform three indirect 1RM tests: 1) bench press, 2) vertical row, and 3) leg press. The estimated number of repetitions before the participant could perform no more correct movements was approximately 10.

The bench press was performed lying down on a flat bench. During the execution, the elbows had to be flexed to 90° and extended to nearly straight. The vertical row was performed on a vertical row machine (Technogym, Italy). To perform the movement correctly, the horizontal hand grip was used, and the arms had to be fully extended at the start. The handles were pulled back until the imaginary line between the hand grip bars would have made contact with the upper body. The important fact was that the chest had to touch the chest support all the time, and the participants remained with their heads in the same position during the entire test. The leg press test was performed on a horizontal leg press machine (Technogym, Italy). To execute the movement correctly, the participants laid down in a supine position, with the knees at an angle of approximately 70° at the start. The participants then extended their legs to nearly straight and flexed the knees to 90° again for each leg press movement.

Before starting each test, the participants performed approximately 10 repetitions of the movement with a very low weight to get accustomed to the test. The actual test was performed with an estimated 10RM weight. During the test, the number of correctly performed movements was recorded. During the test, the participants were continuously verbally encouraged. If the participants were able to do more than 13 repetitions, the test was terminated; and after two minutes of rest, the weight was increased and the test repeated. The Brzycki's equation was used to calculate the 1RM value from the number of repetitions and test weight. Because of the high intensity of the indirect 1RM tests, these tests were performed just once per testing moment to prevent unwanted exhaustion. The primary variables for these tests were the 1RM bench-press value per kg body weight (BP 1RM/kg), 1-RM vertical-row value per kg body weight (VR 1-RM/kg), and the 1-RM leg press value per kg body weight (LP 1RM/kg).

Health-related quality of life questionnaire

All the participants completed the European Organization for Research and Treatment of Cancer Core QoL Questionnaire C30 (EORTC-QLQ C30) to determine their QoL. The test divides QoL into six functional scales (physical, role, cognitive, emotional, social functioning, and global functioning of life). The main point of the questionnaire in this study was the correlation between physical functioning and QoLq. The test was completed once at the end of the first day of testing.

Statistical analysis

For each of the primary and secondary variables, the mean and standard deviations (SD) were calculated for both test populations as well as the total test population. The difference between the groups was analyzed using the independent t-test. The lowest level of significance was set at $P < .05$. All the 0.05 significance levels are marked by*, and all 0.01 significance levels are marked by **. A correlation analysis was performed for the overall test population and both test groups separately to compare them. Pearson r correlation coefficient (r) was calculated to determine the test-retest reliability of each test variable. The 95% confidence intervals (CI) were calculated using Fisher's z transformation.[20] The Pearson correlation coefficient (plus CI) was also calculated to determine the relation of the test variables to muscle strength (as determined by the indirect 1RM tests).

In addition, the correlation and CI of the indirect 1RM data and the physical functioning score as determined by the EORTC-QLQ C30 questionnaire was determined. The correlation data was categorized as 0.26–0.49 as low correlation, 0.50–0.69 as moderate correlation, 0.70–0.89 as high correlation, and 0.90–1.00 as very high correlation.

All statistical analyses were performed with Statistical Package for Social Sciences version 24 (IBM SPSS Corp., Armonk, NY, USA).

Results

Test population

Two groups of 13 people participated in this study, including one group of curatively treated chemotherapy patients and one group of controls. The characteristics of both groups are shown in Table 1. Table 2 shows the baseline values of both groups for all the test variables.

One post-chemotherapy participant was not able to perform the lower extremity tests at the retest moment owing to a bruised hip after a car accident. Three post-chemotherapy participants were unable to perform the push-up test and bench-press 1RM tests because of either longstanding shoulder injuries (n=1) or decreased shoulder mobility after breast cancer treatment (n=2). One post-chemotherapy participant developed a minor shoulder injury during the push-up test, which prevented her from performing the retest of the push-up test.

Test-Retest Reliability Lower Extremity Tests

The test-retest correlation values for all of the lower extremity test variables are stated in Table 3. All the variables measured in the vertical jump test showed highly significant test-retest correlation. The primary variable maximal power/kg was a little more accurate in the control group ($r = 0.987$, $P < .001$) than in the post-chemotherapy group ($r = 0.917$, $P < .001$); but the reliability over the total test population was also very high ($r = 0.963$, $P < .001$). The secondary variables jump height and jump height/kg also had very high test-retest correlations in all of the test populations.

The stair-climb test was highly significant in all variables. The secondary test variable power/kg showed reliable outcomes as well, which were slightly better than the primary variable, time, in the total population and the post-chemotherapy group.

The 5-time chair-rise time was highly significant in the control group and showed a very high correlation value ($r = 0.906$, $P < .001$). The post-chemotherapy group also had a significant correlation but this was moderate ($r = 0.673$, $P = .017$). In the total test population, the reliability correlation value was close to the control group value ($r = 0.885$, $P < .001$).

The 30-second chair-rise test was highly significant in both separate populations, but the best score was in the total test population ($r = 0.882$, $P = .000$).

Test-Retest Reliability Upper Extremity Tests

The test-retest correlation values for all of the upper extremity test variables are stated in Table 4. The reliability score of the push-up test values were generally less than those of the hand grip strength test. The primary variable impulse/kg of the push-up test showed a moderate but significant correlation in the overall test population ($r = 0.667$, $P = .002$). The control group value was significant as well ($r = 0.708$, $P = .007$), but not in the post-chemotherapy group ($r = 0.829$, $P = .083$), although this correlation value was considered high. The secondary variables max force/kg and mean force/kg were significant and showed high correlation in all test populations, especially in the post-chemotherapy group.

In the hand grip strength test, the correlation values were all highly significant. The test-retest correlation values were in general higher in the total test population and post-chemotherapy group than in the control group, but they were all still high. The total test population showed the best reliability with hand grip strength in the primary variable dominant hand/kg ($r = 0.952$; $P < .001$).The same variable also had a good test-retest correlation values in the control group; however, the post-chemotherapy group showed slightly better scores with the secondary variables.

Relation of lower extremity tests to leg strength

The correlation values of the lower extremity test variables with leg press 1RM strength are shown in Table 5. The vertical jump test secondary variables jump height/kg showed the best correlation values to the leg press 1RM value in the total test population ($r = 0.895$, $P = .000$). The primary value maximum power/kg was also highly related but not as much as the jump height/kg. The post-chemotherapy group did show better correlation values

Table 2. Subject Characteristics

	Total group	Post-chemotherapy group	Control group	
	Value	Value	Value	*P*
Age (years), mean±SD	45.9±13.6	46.0±13.7	45.9±14.2	.978
Age (years), range	18–66	24–66	18–63	
Sex (n), Male	13	4	9	
Sex (n), Female	13	9	4	
Weight (kg), mean±SD	80.2±12.7	80.9±11	79.4±14.7	.775
Weight (kg), range	58.6 – 110.9	65.6 – 100.5	58.6 – 110.9	
Height (m), mean±SD	1.74±0.086	1.72±0.094	1.75±0.078	.374
BMI ($kg*m^2$)±SD	26.4±3.77	27.3±3.51	25.7±3.79	.283

Abbreviations: n is the number of subjects tested; $kg*m^2$ = body weight divided by height to the power 2; *P*: statistical value for significance.

Table 3. Primary Test Values and Characteristics and Differences between the Two Study Populations

	Total group			Post-chemotherapy group			Control group			
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	*P*
VJ P/kg	37.72	12.74	26.35–59.9	32.89	9.07	26.35–56.97	42.17	10.37	29.75 – 59.9	.026*
PU Imp/kg	2.09	0.73	0.65–3.27	1.88	0.88	0.65 – 3.27	2.24	0.59	1.19 – 3.15	.262
SCT time	4.46	0.62	3.34–5.68	4.84	0.56	3.99 – 5.68	4.12	0.47	3.34 – 4.80	.002*
HGF dom/kg	0.55	0.15	0.30–0.91	0.46	0.08	0.30 – 0.58	0.64	0.15	0.48 – 0.91	.001**
HGF non-dom/kg	0.50	0.12	0.28–0.82	0.44	0.08	0.28 – 0.56	0.56	0.12	0.41 – 0.82	.004*
CRT5 time	7.00	1.00	4.97–9.12	7.65	0.56	6.87 – 9.12	6.39	0.94	4.97 – 8.10	.001**
CRT30 rep	20.86	3.36	15 – 28	19.08	2.02	15 – 21	22.50	3.56	18 – 28	.008*
BP1RM/kg	0.59	0.30	0.19 – 1.25	0.47	0.29	0.19 – 1.25	0.69	0.28	0.35 – 1.24	.087
VR1RM/kg	0.70	0.21	0.33 – 1.08	0.59	0.19	0.33 – 1.08	0.81	0.17	0.49 – 1.08	.007*
LP1RM/kg	2.06	0.70	1.06 – 3.61	1.63	0.37	1.06 – 2.19	2.45	0.71	1.39 – 3.61	.002*

Abbreviations: VJ, vertical jump; PU, push-ups; SCT, stair-climb test; HGF, hand grip force; CRT5, -time chair-rise test; 30-seconds chair-rise test; BP1RM, bench press 1-repetition maximum; VR1RM, vertical-row 1-repetition maximum; LP1RM, leg press 1-repetition maximum. Statistical significance is set at $P < .05$. * denotes statistical significance

Table 4. Test-Retest Reliability Correlation Values of the Lower Extremity Functional Tests

	Total group		Post-chemotherapy group		Control group	
	r	95% CI	*r*	95% CI	*r*	95% CI
Vertical jump test						
Max Power/kg (W/kg)	0.963**	0.90–0.98	0.917**	0.71–0.97	0.987**	0.97– 0.99
Max Force/kg (F/kg)	0.814**	0.60–0.91	0.683*	0.38–0.94	0.796**	0.44–0.93
Jump height (cm)	0.955**	0.90–0.98	0.933**	0.74–0.98	0981**	0.93–1.00
Jump height/kg (cm/kg)	0.957**	0.90–0.98	0.883**	0.59–0.96	0.993**	0.97– 0.99
Impulse/kg (N*s/kg)	0.934**	0.84–0.97	0.855**	0.53–0.96	0.967**	0.90–1.00
Stair-climb test						
Time (s)	0.872**	0.72–0.94	0.719**	0.24–0.91	0.961**	0.86–0.98
Power/kg (W/kg)	0.911**	0.80–0.96	0.755**	0.33–0.92	0.955**	0.86–0.98
5-Time chair-rise test						
Time (s)	0.885**	0.76–0.95	0.673*	0.15–0.89	0.906**	0.72–0.97
30-second chair-rise test						
Number of repetitions (N)	0.882**	0.76–0.95	0.800**	0.42–0.94	0.873**	0.61–0.96

Table 5. Test-Retest Reliability Correlation Score of the Upper Extremity Functional Tests

	Total group		Post-chemotherapy group		Control group	
	r	95% CI	*r*	95% CI	*r*	95% CI
Push-up test						
Impulse/kg (N*s/kg)	0.667**	0.29–0.86	0.829	0.30–0.96	0.708**	0.28–0.90
Max Power/kg (W/kg)	0.105	0–0.55	0.432	0–0.87	0.243	0.00–0.69
Max Force/kg (F/kg)	0.881**	0.70–0.95	0.954*	0.74–1	0.866**	0.61–0.96
Mean Force/kg (F/kg)	0.886**	0.72–0.95	0.930*	0.65–0.98	0.913**	0.72–0.97
Hand grip test						
HGF dom hand/kg	0.952**	0.89–0.97	0.940**	0.80–0.98	0.923**	0.74–0.97
HGF dom hand	0.948**	0.89–0.97	0.971**	0.90–1.00	0.883**	0.67–0.96
HGF non-dom hand/kg	0.917**	0.82–0.96	0.915**	0.74–0.97	0.882**	0.64–0.96
HGF non-dom hand	0.929**	0.84–0.96	0.964**	0.86–0.98	0.880**	0.64–0.96

Abbreviations: HGF, hand grip force; dom, dominant. **significantly different.

Table 6. Pearson Correlation Score of Lower Extremity Test Variables with Leg Press 1RM Strength

	Total group		Post-chemotherapy group		Control group	
	r	95% CI	*r*	95% CI	*r*	95% CI
Vertical jump test						
Max Power/kg (W/kg)	0.791**	0.57–0.90	0.778**	0.37–0.93	0.741**	0.32–0.91
Max Force/kg (N/kg)	0.757**	0.52–0.88	0.662*	0.13–0.89	0.655*	0.17–0.88
Jump height (cm)	0.811**	0.61–0.91	0.775**	0.37–0.93	0.800**	0.44–0.93
Jump height/kg (cm/kg)	0.895**	0.78–0.95	0.892**	0.64–0.96	0.856**	0.58–0.95
Impulse/kg (N*s/kg)	0.864**	0.70–0.93	0.806**	0.44–0.94	0.816**	0.49–0.94
Stair-climb test						
Time (s)	−0.789**	0.57–0.90	–0.697*	0.21–0.90	−0.750**	0.34–0.92
Power/kg (W/kg)	0.822**	0.62–0.91	0.700*	0.21–0.90	0.764**	0.35–0.92
5-Time chair-rise test						
Time (s)	−0.563**	0.21–0.78	–0.557	0–0.85	−0.218	0–0.68
30-Sec chair-rise test						
Number of repetitions (N)	0.546**	0.12–0.74	0.729**	0.27–0.91	0.242	0–0.69

**significantly different.

than the control group. The total test population exceeded the scores of both test populations separately for all variables.

The stair-climb test primary variable time showed a high correlation with the leg press 1RM values in all populations. However, the total test population had the best results with the secondary variable power/kg ($r = 0.822$, $P < .001$).

The correlation values of the 5-time chair-rise test with the leg press 1RM values were moderate but significant in the total test population ($r = -0.563$, $P = .003$). The two separate populations score significantly less in this test and reveal a weak relation to leg press strength.

The relation of the 30-second chair-rise test to leg press strength ($r = 0.546$, $P = .005$) is rather similar to the 5-time chair-rise test. The total test population reveals a moderate significant relation, but both test groups showed a large difference in relation again.

Relation of upper extremity tests to upper extremity strength
The correlation values of the upper extremity test variables to bench-press 1RM strength are shown in Table 6, and the values with the vertical-row 1RM strength are shown in Table 3. The push-up test showed a high significant correlation to the bench-press 1RM and the vertical-row 1RM value with the variables maximum and mean force/kg in all test populations. In the total test population impulse/kg, maximum and mean force/kg showed a significant correlation to chest press and vertical row strength. For each population and 1RM strength test, the variable maximum force/kg showed the best relation.

Health-related quality of life
None of the 1RM tests show any significant correlation with the physical functioning scale as determined by the EORTC-QLQ C30 questionnaire, for all the populations.

Discussion

To the best of our knowledge, this is the first study to demonstrate the test-retest reliability of multiple functional and clinical applicable tests and their association with muscle strength in a group of patients with cancer. We found that the functional vertical jump test and the explosive push-up test were both applicable in a clinical setting in a population of patients with cancer and healthy volunteers and provided an immediate and practical tool for healthcare workers in the clinical setting.

The vertical jump test
The vertical jump test showed the best correlation with the 1RM of all the lower extremity tests, especially with variables maximum power/kg, jump height, and jump height/kg. Maximum power/kg and jump height have been considered very reliable in several studies not only with younger adults[21, 22] but also in an older population.[23] This study found a higher reliability than the tests with young adults; however, the testing methods vary considerably, making comparisons difficult. The variable jump height/kg has not been mentioned in literature, making comparison impossible.

The association between the vertical jump test and leg strength as measured by leg press is very strong, especially jump height/kg, impulse/kg, and maximum power/kg showed a strong correlation. Our results are similar to previously reported findings that showed a relationship of several variables to leg strength,[24] but jump height/kg surpasses the previous reported levels in literature in terms of reliability and validity compared with leg strength. Similar to other variables, jump height normalized to body weight shows a better relationship with relative leg strength than regular jump height. As this is a clinically easy-to-measure parameter, it is noteworthy that this variable has not been described yet.

In fact, the presence of an association between the vertical jump performance and leg press strength is not surprising because in this closed kinetic chain, the concentric part of the exercise is similar to the propulsive part in the vertical jump performance.

Push-up test
The push-up test proved to be highly reliable for the secondary variables (maxP/kg; maxF/kg and meanF/kg), but less so for the primary variable (Imp/kg). Although the primary variable was significantly higher, it was not as high as reported by Hrysomallis et al.[25] An explanation for these lower values is not easy to provide, but the difference of the test population and the execution of the test itself are most likely. For instance, Hrysomallis et al. tested the push-up on a group of young adult men (mean age 23 years) with several years of strength training experience.[25] The test was executed in a regular push-up starting position, whereas in our set-up the participants started supporting their body weight on hand and knees. The latter is more applicable in a clinical setting with patients.

The association of the push-up test with upper extremity muscle strength, as measured by a 1RM in vertical row and bench press was the highest for the maximum force/kg. The mean force/kg and impulse/kg showed a significant association as well but was less prominent. Although the bench press is expected, because of its near identical kinematic pattern as the push-up, to have a higher association with to the 1RM bench press, we surprisingly found a smaller though better association with the 1RM vertical row. Currently, we have no explanation for this finding, but can conclude that the push-up test is a reliable and valid clinical applicable test when peak force is used a major outcome parameter.

The lower extremity test
The test-retest reliability of all the lower extremity strength tests is high in the overall test population, but not in the post-chemotherapy group. In our study, the test-retest reliability scores were consistently lower than in the control group, including the 1RM leg press/kg value. A possible explanation for these findings is the fact that the post-chemotherapy group had just started the high-intensity strength training program; and thus, strength adaptation was still in the lower part of the adaptation curve.

The stair-climb test
The stair-climb test proved to be a reliable test for the total test population. The observed difference between the two test populations is caused by the fact that many of the participants in the control group were used to specific stair climbing. Being used to a certain stairs can make a person feel more confident in climbing it. This was noticeable in the control group. In this group, generally much more risk was taken in the stair-climb performance than the other test group. This resulted in more re-runs when a test performance was incorrect owing to skipping stairs or tripping because of the high speed. In contrast, post chemotherapy, the patients were not completely used to the stairs in the beginning.

However, the general learning effect of this test was low at just 2.0% (2.4% in the control group and 1.5% in the post-chemotherapy group). This means that the learning effect owing to getting used to the stairs was not noticed in this study. Therefore, confidence in performance and balance might be more important in explaining the difference between the groups than the learning effect in a week. Here, a combination of uncertainty about the stairs and possibly also confidence in climbing this at a high speed can explain the difference between the reliability results between the groups, something that possibly could have been avoided by allowing the participants to use the handrail solely for balance in case they were not confident enough during the stair climb.[27]

The variable power/kg in the stair-climb test shows really good relation to leg strength in the overall test group. Previous literature basically only related stair-climb performance to leg power rather than leg strength.[27, 28] The stair-climb power showed a correlation varying from $r = 0.47$ to $r = 0.88$ in different test populations. The stair-climb time had a correlation of $r = 0.81$ with leg extensor power.[28] The results of this study showed that the stair-climb power/kg test had a high relation to leg strength in the total test population.

The chair-rise tests

The lower reliability results of the 5-time chair-rise test and 30-second chair-rise test, which can still be considered high, can most likely be explained by the fact that the chair-rise test shows a significant learning error in the article of Rittweger et al.[23] Over 76% of all the data that are used in current reliability analysis of both chair-rise tests shows an increased retest value over the test value. The general learning error in this study was 10.2% for 5-time chair-rise test and 9.0% for the 30-second chair-rise test. This is even higher than calculated by Rittweger et al.[23] The learning effect of the other lower extremity tests, calculated by the primary variables, was not as high as both chair-rise tests (vertical jump 2.6% and stair-climb test 2.0%).

Although the general correlation value for reliability of both chair-rise tests is high, it is slightly less than found in literature by other authors. The difference in reliability between the two test groups cannot be explained by the learning error as this is similar for both populations.

The 5-time chair-rise test is significantly related to leg strength in the total test population; however, in both groups separately, the relation is much lower (especially the control group) and not significant. The relation of the chair-rise test to leg strength was found to be moderate by Taaffe et al. and high in the study of Kalapotharakos et al.[29, 30] These differences are most likely related to the different interpretations of leg strength in these studies, which also differs a lot from the one currently used. The relation of leg press strength and 5-time chair-rise test in this study is significant, but much lower than the other lower extremity functional tests.

The 30-second chair-rise test shows a high relation in leg strength in the post-chemotherapy group, but a very low relation in the control group. This leads to a significant and moderate relation of the 30-second chair-rise test and leg press strength in the overall test population ($r = 0.546$). The current results are actually less than the ones found by Jones et al.[30], who tested the 30-second chair-rise test in a group of healthy people over 60. The large difference found between the two separate test populations was caused by the larger scattering of the test results in the control group. The results in this group range from 18 to 29 chair rises, whereas the post-chemotherapy group had a range of 15–21. The reason why the range is higher in the control group is most likely owing to a methodological error. During the test, participants have to extend the hips and knee and bring the upper body above the feet. Some test participants who scored very high test scores performed the chair-rise test with knee and hip extension but did not bring their upper bodies properly above the feet (they were still hanging to the back). This shortened chair-rise time and made increased test performance possible. A more or less similar explanation exists for the large difference between the two test populations in the relation of leg strength and the 5-time chair-rise test performance. This could have been prevented by a more decisive observer, which would have led to a more expected relation of the 30-second chair-rise test and leg strength.

The hand grip strength test

The hand grip strength test shows high reliability scores for each variable. The primary variable dominant hand grip force/kg is the value that shows the highest correlation value for each test population. These data are similar to the data found in previous literature; however, these tests were not allometrically scaled by body weight.[32]

The hand grip strength test is significantly related to the bench-press strength in the total test group. The variables hand grip strength/kg for dominant and non-dominant hand were both moderately related. In addition, the relation to the vertical row strength is significant, but only slightly less than the relation to the bench-press strength. This shows that there is a decent relation to hand grip strength and upper extremity 1RM strength, something which has not been analyzed in previous literature thus far. However, the push-up test with the maximum force/kg variable showed a better relation to upper extremity strength and is therefore preferable for use in further research.

Health-related quality of life

Although QoL is an important clinical outcome for healthcare workers, no significant correlation could be found between the 1RM test values and HRQOL. This is in contrast with the previous work from our research group.[8] The most obvious explanation for this result is the small number of participants. Including HRQOL in future research is essential to further understand the value of different muscle strength tests in relation to QoL.

Limitations

One of the limitations of this study was the fact that we included different types of cancer in the patient group. This could have affected the outcome parameters although we were not able to find previous publications on the effect of different cancer types on outcomes. No previous studies have been published concerning clinical tests on strength parameters, which makes comparison at least difficult. This could be considered another limitation of our study. Finally, the sample size was not optimal, and future studies should confirm the relevant findings of this study, especially the QoL scores.

Conclusion

The functional vertical jump test and the explosive push-up test, both have shown to be excellent tests for use in a clinical setting in a population with a wide range of strength capacities and partly recent patients with cancer. The variable jump height/kg body weight of the vertical jump test is the best usable variable for lower extremity strength testing in this population. The variable maximum force/kg body weight of the push-up test is the best usable variable for upper extremity strength testing in this population.

Future research should be aimed at determining the clinical feasibility of the use of these functional tests from diagnosis onwards; however, for now we advise the use of the vertical jump test as the largest part of muscle mass is used for this test.

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