Determinants of Overweight and Obesity in Lung Transplant Recipients

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Key Words

Activities of daily living · Resting energy expenditure · Overweight · Lung transplantation

Abstract

Background: Obesity-related diseases have been shown to affect post-lung transplantation survival. An estimated 30% of lung transplant recipients develop overweight. **Objective:** The aim of this study was to examine the possible determinants of large increases in weight after lung transplantation. The contribution of physical activity, food intake, and resting energy expenditure was examined in lung transplant recipients. **Methods:** In this cross-sectional study 21 overweight lung transplant recipients (11 men, mean age 57 ± 7 years; BMI 30 ± 3) and 21 normal-weight lung transplant recipients (11 men, mean age 56 ± 5 years; BMI 22 ± 3) were matched for disease, gender, age, prescribed medication, and time since lung transplantation. Physical activity was measured by a pedometer and a questionnaire; resting energy expenditure was measured by the ventilated-hood technique, and daily food intake by a dietician. Additionally, fat-free mass, lower-body strength, and fatigue were measured. **Results:**

The overweight lung transplant recipients had a significantly lower number of steps per day ($4,686 \pm 3,266$ vs. $7,524 \pm 3,448$ steps/day, $p = 0.01$) and a lower fat-free mass (64 ± 9 vs. $75 \pm 6\%$, $p < 0.05$) compared to normal-weight recipients. Obese subjects had a lower percentage of predicted resting energy expenditure level compared to normal-weight recipients (90 ± 14 vs. $100 \pm 14\%$ predicted, $p = 0.04$). **Conclusion:** Our data suggest that overweight in lung transplant recipients is associated with a lower fat-free mass and lower levels of physical activity and resting energy expenditure compared to normal-weight recipients.

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Introduction

Lung transplantation is one of the treatment options in patients with end-stage lung disease [1–3]. Thirty percent of the living lung transplant recipients of the University Medical Center Groningen are overweight [body mass index (BMI) >25]. In line, Culver et al. [4] showed that a similar percentage (33%) of their lung transplant recipients were overweight or obese. Obesity-related dis-

Table 1. Characteristics of the normal-weight and overweight/obese lung transplant recipients

	Normal-weight lung transplant recipients (n = 21)	Overweight/obese lung transplant recipients (n = 21)
Gender (M/F)	11/10	11/10
Age, years	56 ± 5	57 ± 7
Underlying disease (COPD/lung fibrosis)	17/4	17/4
Lung transplantation (unilateral/bilateral)	5/16	5/16
Time since lung transplantation, months	85 ± 49	73 ± 48
BMI before lung transplantation	21 ± 3	24 ± 3
Actual BMI	22 ± 3	30 ± 3*
Actual weight, kg	66 ± 13	88 ± 11*
Fat-free mass, %	75 ± 6	64 ± 9*
Fat-free mass index	17 ± 3	19 ± 2*
FEV ₁ , l	3.1 ± 0.6	3.1 ± 0.5
FEV ₁ , % predicted	87 ± 32	82 ± 24
FEV ₁ , % of baseline	84 ± 14	83 ± 14
Prednisolone, mg/kg	5 ± 3	5 ± 3

Results are presented as means ± standard deviations. * $p < 0.05$.

eases such as type II diabetes, hypertension, and cardiovascular disorders affect post-lung transplantation survival [5–9]. Five years after lung transplantation almost 17% of deaths are accounted for by malignancies and cardiovascular causes [10]. The 90-day mortality after lung transplantation increases five-fold when the BMI before lung transplantation exceeds 27 [2, 6, 9, 11]. In the healthy male population weight gain is associated with a reduction in pulmonary function [12].

The principal factors for developing overweight and obesity in the general population are limited physical activity, excessive food intake, and low resting energy expenditure [13–16]. Up to now, there has only been scarce information about the factors contributing to the development of overweight in lung transplant recipients. Ongoing administration of immunosuppressive therapy is associated with steroid myopathy and reduced skeletal muscle function in lung transplant recipients, which can cause limited exercise capacity [1, 17–21] and consequently, in the long term, reduced daily physical activity. Indeed, in the first year after lung transplantation a 40% lower number of steps compared to healthy controls was observed [22]. However, after 2 years the number of steps per day was found to be comparable to that of healthy persons [21]. The ongoing corticosteroid intake may also stimulate appetite and lead to an increased BMI, as demonstrated in kidney and heart transplant recipients [23, 24]. A decreased resting energy expenditure may theoretically also contribute to an increased BMI, as was

shown in liver transplant recipients [25]. This contrasts with findings in healthy obese women that showed that obesity was linked to high values of resting energy expenditure and the fact that resting energy expenditure increased with higher BMI [26]. Obviously, we can only speculate about the specific underlying factors of overweight in lung transplant recipients. To prevent or to treat the development of overweight in a causal way, we believe it is very important to understand the underlying factors and their relationship.

The aim of this cross-sectional study was to examine the possible determinants of large increases in weight after lung transplantation. In this study the role of daily physical activity, resting energy expenditure, and daily food intake was examined in lung transplant recipients with the most prevalent underlying lung conditions, i.e. chronic obstructive pulmonary disease (COPD) and lung fibrosis.

Patients and Methods

Patients

In this study 42 lung transplant recipients of the University Medical Center Groningen were included (table 1). The inclusion criteria for all participants were: age >18 years, lung transplantation more than 1 year ago, COPD or lung fibrosis as the underlying disease state, and having signed a written informed consent form.

In the overweight/obese group only recipients with a weight gain of more than 10% since lung transplantation and an actual

BMI over 25 in the last 6 months were selected. The normal-weight lung transplant recipients were actively matched and had a BMI lower than 25 and a maximal weight gain of 2 kg in the last 6 months. The 2 groups were matched on the basis of the following criteria: disease (COPD or lung fibrosis), gender, age, prescribed immunosuppressive medication including cyclosporine versus tacrolimus, and time since lung transplantation. Exclusion criteria for both groups were: inability to walk independently, being a lung transplant recipient who had just started a diet or changed their eating habits, and symptoms of chronic rejection of the lung (based on the severity of bronchiolitis obliterans syndrome graded by the recommendations of the International Society for Heart and Lung Transplantation) [27]. The study protocol was approved by the local ethics committee of the hospital and all patients signed an informed consent form. According to the χ^2 power analysis of Portney and Watkins [28] a sample size of 42 recipients was needed (d.f. = 3, α = <0.05, w = 0.50).

All lung transplant recipients received postoperative immunosuppression induction consisting of rabbit anti-thymocyte globulins (Thymoglobulin) or anti-CD25 monoclonal antibodies (Simulect), and maintenance triple immunosuppression with cyclosporine (Neoral) (transplantation era 1990–2000) or tacrolimus (Prograf) (transplantation era 2001–2009) plus azathioprine (Imuran) or mycophenolate mofetil (Cellcept) plus prednisolone (postoperative dose 0.2 mg/kg, tapering to 0.1 mg/kg during the first postoperative year, and further tapering in the long term).

Methods

Body Composition: BMI and Fat-Free Mass

Body weight was measured with a reliable scale (in kilograms) with which the BMI was calculated (weight in kilograms divided by height in meters squared). The fat-free mass was measured by bioelectrical impedance analysis (Bodystat 1500) and is expressed as a percentage of the total body weight and as a fat-free mass index [29].

Daily Physical Activity

Performance-based daily physical activity was measured using a Digiwalker SW-200 (Yamax, Tokyo, Japan). This pedometer has been proven to accurately detect steps taken as an indication of the volume of daily physical activity [30]. It has been proven to have high convergent (r = 0.80) and discriminative validities (r = 0.80–0.90) [31, 32]. In this study patients were instructed to wear the pedometer for 10 days (from waking up until going to bed) and to record the number of steps per day in a diary. The number of minutes spent swimming, doing fitness exercises, or cycling were also reported in the diary and were converted into steps. Conversion was based on the metabolic equivalent of task (MET) per minute of these physical activities [33]. For example, 1 min of swimming is about 150 steps, and 1 min of fitness or cycling is about 100 steps. Steps per day including the converted steps were expressed as step equivalents. To exclude a novelty effect, the last 7 out of 10 daily records were used for further processing.

Questionnaire-based daily physical activity was assessed with the Short Questionnaire to Assess Health-Enhancing Physical Activity (SQUASH) [34]. This questionnaire is designed to give an indication of the habitual activity level and has been shown to be reliable and valid (r = 0.36–0.74) [34]. Physical activity was expressed as total minutes per week and as MET per minute.

Resting Energy Expenditure

Resting energy expenditure was measured using the ventilated-hood technique [35]. Criteria for a valid resting energy expenditure were: a minimum of 15 min of steady state and no food intake for at least 4 h before the measurement. Testing was performed in the morning and the standard estimated error had to be smaller than 5% [35]. Resting energy expenditure was measured for 15–20 min [35].

Food Intake

Food intake was estimated by a trained dietician using an extensive food anamnesis to determine the daily amount of food intake, proteins, carbohydrates, and fat.

Lower-Body Strength

Lower-body strength was assessed using the sit-to-stand test. This test involves counting the number of times, within 30 s, that the patient can come to a full stand from a seated position without using his or her arms [36]. The 30-second sit-to-stand test has been shown to be reliable (test-retest correlation r = 0.80) and has been validated against the gold standard measure for lower-body strength: the leg press test [36]. According to Jones et al. [36] (1999), intraclass reliability is r = 0.89 (test-retest) and the criterion validity related to the leg press is r = 0.77 (test-retest).

Fatigue

Fatigue based on daily activities in the household, body care, and social activities was measured with the Dutch Exertion Fatigue Scale (DEFS) [37]. The DEFS contains 9 questions which can be answered on a 5-point scale ranging from 0 (no) to 4 (yes) [37]. A low score on the DEFS represents a low score of fatigue in daily activities (Cronbach's α = 0.91 and ρ = 0.91) [37].

Statistical Analysis

The statistical program SPSS (version 16.0) was used to analyze the data. Results are presented as means $\pm$ standard deviation. Post hoc we decided to split the overweight/obese lung transplant recipients into an overweight group and an obese group for further analysis. Mann-Whitney U tests were used to compare normal-weight and overweight/obese lung transplant recipients and to compare male and female lung transplant recipients. Multiple regression analysis (forward method) was performed to determine the variables contributing to overweight and obesity in lung fibrosis and COPD lung transplant recipients. BMI was the dependent variable. Independent variables were: percentage of fat-free mass, number of steps per day, resting energy expenditure, food calorie intake per day, lower-body strength, and fatigue. Significance levels were set at α = 0.05.

Results

Daily Physical Activity

Performance-based daily physical activity (number of steps per day and step equivalents) was significantly higher in normal-weight lung transplant recipients as compared to overweight/obese lung transplant recipients

Table 2. Outcome measures of normal-weight and overweight/obese lung transplant recipients

Outcome measures	Normal-weight group (n = 21)	Overweight/obese group		
		total (n = 21)	overweight (n = 12)	obese (n = 9)
Daily physical activity				
Steps/day, n	7,524 ± 3,448	4,686 ± 3,266*	5,919 ± 3,826	3,146 ± 1,481 ⁺
Step equivalents, n	9,759 ± 3,960	6,028 ± 3,728*	7,348 ± 3,797	4,378 ± 3,102 ⁺
SQUASH, min	1,587 ± 952	1,506 ± 959	1,525 ± 1,013	1,481 ± 949
SQUASH, MET/min	5,397 ± 4,422	5,046 ± 2,996	5,049 ± 2,629	5,042 ± 3,562
Food intake				
Total intake, calories/day	2,532 ± 845	2,116 ± 388	2,000 ± 386	2,259 ± 360
Proteins, %	16 ± 3	16 ± 3	16 ± 3	16 ± 3
Carbohydrates, %	41 ± 9	41 ± 7	41 ± 6	43 ± 8
Fat, %	40 ± 8	42 ± 6	41 ± 6	41 ± 7
Saturated fat, %	14 ± 4	16 ± 3	16 ± 3	15 ± 2
Resting metabolic rate				
Ventilated hood, kcal/day	1,506 ± 279	1,594 ± 205	1,603 ± 177	1,580 ± 259
Ventilated hood, % predicted	100 ± 14	93 ± 10**	94 ± 8	90 ± 14 ⁺⁺
Lower-body strength				
Sit-to-stand repetitions, n	11 ± 2	10 ± 4	11 ± 3	9 ± 6
Fatigue				
DEFS	7 ± 7	11 ± 10	7 ± 7	16 ± 11 ⁺⁺

Results are presented as means ± standard deviations. * p = 0.01; ** p = 0.05, differences between the normal-weight group and overweight/obese group; ⁺ p < 0.01; ⁺⁺ p < 0.05, differences between the normal-weight group and the obese group.

(table 2). When looking at the overweight (BMI > 25) and obese (BMI > 30) lung transplant recipients separately, the normal-weight lung transplant recipients had a higher number of steps per day and step equivalents compared to overweight lung transplant recipients, though this difference was not significant. The normal-weight lung transplant recipients had a higher number of steps per day (fig. 1) and a higher number of step equivalents compared to obese lung transplant recipients. There was also a significant difference in daily physical activity between overweight and obese lung transplant recipients. Questionnaire-based physical activity was not significantly different between normal-weight and overweight/obese lung transplant recipients. In normal-weight lung transplant recipients men had a lower number of steps per day compared to women, though this difference was not significant (6,692 ± 2,050 vs. 8,667 ± 4,689 steps/day). In overweight/obese lung transplant recipients men had a significantly higher number of steps per day compared to women (6,510 ± 3,241 vs. 2,408 ± 2,233 steps/day, p = 0.006).

Fig. 1. Normal-weight lung transplant recipients had a higher number of steps per day compared to overweight lung transplant recipients, though this difference was not significant. The normal-weight lung transplant recipients had a significantly higher number of steps per day compared to obese lung transplant recipients (p < 0.01). There was also a significant difference in the number of steps per day between overweight and obese lung transplant recipients (p < 0.01).

Table 3. Multiple regression analysis for the determinants of BMI in lung transplant recipients

Determinants	B	Standard error	Beta	T value	p value
Constant	39.901	5.468		7.297	<0.001
Fat-free mass (% predicted)	-0.359	0.076	-0.597	-4.697	<0.001
Ventilated hood (kcal/day)	0.009	0.003	0.362	3.091	0.004
Physical activity (steps/day)	0.000	0.000	-0.251	-2.061	0.046

$R^2 = 0.547$.

Resting Energy Expenditure

There was a significant difference in resting energy expenditure expressed as a percentage of the predicted resting energy expenditure between normal-weight and overweight/obese lung transplant recipients (table 2). When looking at the overweight and obese lung transplant recipients separately, the predicted resting energy expenditure was significantly higher in the normal-weight lung transplant recipients compared to the obese lung transplant recipients. The resting energy expenditure in normal-weight men was significantly higher compared to women ($1,671 \pm 211$ vs. $1,299 \pm 210$ kcal/day, $p = 0.003$).

Food Intake

There was no significant difference in food intake between normal-weight and overweight/obese lung transplant recipients (table 2). There was also no significant difference when the overweight/obese group was divided into 2 groups. The normal-weight male lung transplant recipients had a higher total food intake compared to women ($3,067 \pm 764$ vs. $1,944 \pm 451$ kcal/day, $p = 0.002$).

Lower-Body Strength

Two overweight lung transplant recipients were not able to perform the sit-to-stand test. There was no significant difference in lower-body strength between normal-weight and overweight/obese lung transplant recipients (table 2). There was also no significant difference when the overweight/obese group was divided into 2 groups.

Fatigue

There was no significant difference in fatigue between normal-weight and overweight/obese lung transplant recipients. The overweight lung transplant recipients had a lower score of fatigue compared to the obese lung transplant recipients, though this difference was not significant. Fatigue was significantly lower in normal-weight

Fig. 2. BMI before lung transplantation and the change in BMI after transplantation. BMI are expressed as means and 95% confidence intervals. Overweight lung transplant patients continue to increase their BMI after lung transplantation, while normal-weight patients tend to keep their BMI stable after lung transplantation. Up to 48 months, all patients are included in this figure. There is no difference in the number of patients per group over time in this figure.

lung transplant recipients compared to obese lung transplant recipients.

BMI and Determinants for BMI

The BMI was calculated every 3 months in all lung transplant patients. The mean BMI of overweight lung transplant recipients continuously increased after transplantation, while the BMI of the normal-weight group remained relatively stable (fig. 2).

In order to find the determinants of BMI, the following variables were included in the multiple regression analysis: percentage of fat-free mass, number of steps per day, resting energy expenditure, food calorie intake per day, lower-body strength, and fatigue. BMI was the dependent variable. Determinants for a higher BMI were a lower mean number of steps per day, a lower percentage

of fat-free mass, and a lower resting energy expenditure (table 3). Together these variables explained 55% of the variance in BMI.

Discussion

This is the first study to systematically investigate the underlying factors of overweight in lung transplant recipients by comparing overweight/obese lung transplant recipients with matched normal-weight recipients. Explaining variables for overweight and obesity in lung transplant recipients with lung fibrosis and COPD in this study were a lower percentage of fat-free mass, a lower mean number of steps per day, and a lower resting energy expenditure. In contrast, food intake, body strength, and fatigue did not contribute to the variance in BMI.

The number of steps per day of lung transplant recipients shown in this study is in line with previous research [21]. Importantly, the number of steps per day was significantly lower in overweight/obese lung transplant recipients as compared to normal-weight lung transplant recipients. According to Tudor-Locke and Bassett [38] activity scores can be labeled as 'sedentary' for the obese lung transplant recipients, as 'low' for the overweight group, and as 'somewhat active' for the normal-weight group. Whether a lower number of steps per day in overweight/obese patients is a cause or consequence of a high BMI is difficult to determine in this cross-sectional study. Obviously, a longitudinal study design is needed to prove this. If overweight/obese lung transplant recipients would increase their number of steps per day to the level of normal-weight lung transplant recipients and stick to their eating habits, it is estimated that the BMI would be similar between the 2 groups after 87 months. Interestingly, the time since lung transplantation is also around this number of months. We suspect that when lung transplant patients increase their number of steps per day after transplantation to about 7,500 steps/day, the large increase in BMI after lung transplantation can slowly be reduced. It is intriguing that being overweight/obese was associated with self-reported fatigue, which is in line with findings in healthy (non-lung transplant recipients) individuals [39]. In our study, fatigue was not associated with daily physical activity (data not shown). Apparently fatigue is not the driving force behind decreased daily physical activity and a higher BMI.

The questionnaire-based daily physical activity was higher, though not significantly, in the normal-weight lung transplant recipients compared to the overweight

and obese lung transplant recipients. Because the SQUASH also assesses household work, this could explain in part why the performance-based method demonstrated a significant difference and the questionnaire-based method did not.

Strikingly, the food intake (kilocalories/day) of the overweight and obese lung transplant recipients is lower, though not significantly, compared to normal-weight lung transplant recipients. This difference might be explained by an underreported energy intake. For example, 1 study in healthy individuals demonstrated that both men (31–36%) and women (27–32%) underreported their energy intake based on a food frequency questionnaire [40]. Importantly, the percentage of underreported energy intakes in this study increased with a higher BMI [40]. Whether underreported energy intakes really matter in our study is questionable as we did not use a self-administrated food questionnaire; instead, a trained and dedicated dietician took the food anamnesis. Furthermore, it is conceivable that lung transplant recipients are more eager to care for their weight and eating habits because they are frequently seen and alerted by their pulmonary physicians.

One of the explaining variables for overweight and obesity in the present study was a lower resting energy expenditure. Looking at table 2 it can be acknowledged that subjects with overweight/obesity burn more calories per day (due to more body weight), yet they burn less calories per day if expressed as the percentage predicted. Apparently, overweight/obese subjects are relatively less metabolically active at rest. Indeed the latter fits with the finding of a lower fat-free mass. Confirming these findings, other studies have shown that about 81% of the variability in resting energy expenditure can be explained by fat-free mass, fat mass, age, and gender [41, 42]. Another explanation for the lower resting energy expenditure found in our overweight/obese patients may be their lower physical activity level as the literature suggests that lower physical activity associates with a lower resting energy expenditure [43].

A number of methodological characteristics of this study are relevant for a correct interpretation. In the overweight group there were some patients with a BMI above 25 (range 19.4–27.3) before lung transplantation. For this study we selected the overweight recipients on the basis of a weight gain of more than 10% since lung transplantation and an actual BMI of over 25 during at least the last 6 months. In both the overweight group and the normal-weight group the distribution of BMI was normal.

The internal validity of this study is limited due to the observational nature of the study and its small sample size. Nevertheless, this is one of the scarce studies that systematically examined the underlying factors of overweight and obesity in a well-characterized group of lung transplant recipients. Moreover, we have put much effort into adequately matching normal and overweight/obese subjects.

In conclusion, our data suggest that overweight/obese lung transplant recipients are less physically active and have a lower resting metabolism. We believe that the lower percentage of fat-free mass is in line with these 2 findings. Importantly, a higher food intake did not significantly contribute to a higher BMI. The clinical relevance of this data is that lung transplant recipients should be encouraged to participate in exercise programs after lung

transplantation and should aim for a rather high daily physical activity level in order to prevent the development of overweight or obesity.

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References

- Ambrosino N, Bruschi C, Callegari G, et al: Time course of exercise capacity, skeletal and respiratory muscle performance after heart-lung transplantation. *Eur Respir J* 1996;9: 1508–1514.
- Orens JB, Becker FS, Lynch JP III, Christensen PJ, Deeb GM, Martinez FJ: Cardiopulmonary exercise testing following allogeneic lung transplantation for different underlying disease states. *Chest* 1995;107: 144–149.
- Stiebelhner L, Quittan M, End A, et al: Aerobic endurance training program improves exercise performance in lung transplant recipients. *Chest* 1998;113:906–912.
- Culver DA, Mazzone PJ, Khandwala F, Blazey HC, Decamp MM, Chapman JT: Discrepant utility of ideal body weight and body mass index as predictors of mortality in lung transplant recipients. *J Heart Lung Transplant* 2005;24:137–144.
- Adeseun GA, Rivera ME, Thota S, Joffe M, Rosas SE: Metabolic syndrome and coronary artery calcification in renal transplant recipients. *Transplantation* 2008;86:728–732.
- Gonzalez-Castro A, Llorca J, Suberviola B, Diaz-Reganon G, Ordóñez J, Minambres E: Influence of nutritional status in lung transplant recipients. *Transplant Proc* 2006;38: 2539–2540.
- Isomaa B, Almgren P, Tuomi T, et al: Cardiovascular morbidity and mortality associated with the metabolic syndrome. *Diabetes Care* 2001;24:683–689.
- James PT, Leach R, Kalamara E, Shayeghi M: The worldwide obesity epidemic. *Obes Res* 2001;9(suppl 4):228S–233S.
- Kanasky WF Jr, Anton SD, Rodrigue JR, Perri MG, Szwed T, Baz MA: Impact of body weight on long-term survival after lung transplantation. *Chest* 2002;121:401–406.
- Christie JD, Edwards LB, Aurora P, et al: Registry of the International Society for Heart and Lung Transplantation: twenty-fifth official adult lung and heart/lung transplantation report – 2008. *J Heart Lung Transplant* 2008;27:957–969.
- Madill J, Gutierrez C, Grossman J, et al: Nutritional assessment of the lung transplant patient: body mass index as a predictor of 90-day mortality following transplantation. *J Heart Lung Transplant* 2001;20:288–296.
- McKay RT, Levin LS, Lockey JE, et al: Weight change and lung function: implications for workplace surveillance studies. *J Occup Environ Med* 1999;41:596–604.
- Brown A, Siahpash M: Risk factors for overweight and obesity: results from the 2001 National Health Survey. *Public Health* 2007; 121:603–613.
- Lahti-Koski M, Pietinen P, Heliovaara M, Vartiainen E: Associations of body mass index and obesity with physical activity, food choices, alcohol intake, and smoking in the 1982–1997 FINRISK Studies. *Am J Clin Nutr* 2002;75:809–817.
- Blair SN, Brodney S: Effects of physical inactivity and obesity on morbidity and mortality: current evidence and research issues. *Med Sci Sports Exerc* 1999;31:S646–S662.
- Ravussin E, Bogardus C: A brief overview of human energy metabolism and its relationship to essential obesity. *Am J Clin Nutr* 1992;55:242S–245S.
- Lands LC, Smountas AA, Mesiano G, et al: Maximal exercise capacity and peripheral skeletal muscle function following lung transplantation. *J Heart Lung Transplant* 1999;18:113–120.
- Reinsma GD, ten Hacken NH, Grevink RG, van der BW, Koeter GH, van WE: Limiting factors of exercise performance 1 year after lung transplantation. *J Heart Lung Transplant* 2006;25:1310–1316.
- Levy RD, Ernst P, Levine SM, et al: Exercise performance after lung transplantation. *J Heart Lung Transplant* 1993;12:27–33.
- McKenna MJ, Fraser SF, Li JL, et al: Impaired muscle Ca^{2+} and K^{+} regulation contribute to poor exercise performance post-lung transplantation. *J Appl Physiol* 2003;95:1606–1616.
- Bossenbroek L, ten Hacken NH, van der Bij W, Verschuuren EA, Koeter GH, de Greef MH: Cross-sectional assessment of daily physical activity in chronic obstructive pulmonary disease lung transplant patients. *J Heart Lung Transplant* 2009;28:149–155.
- Langer D, Gosselink R, Pitta F, et al: Physical activity in daily life 1 year after lung transplantation. *J Heart Lung Transplant* 2009;28: 572–578.
- Jeziro D, Krajewska M, Madziarska K, et al: Posttransplant overweight and obesity: myth or reality? *Transplant Proc* 2007;39: 2772–2775.
- Grady KL, Costanzo-Nordin MR, Herold LS, Srinivasan S, Pifarre R: Obesity and hyperlipidemia after heart transplantation. *J Heart Lung Transplant* 1991;10:449–454.
- Richardson RA, Garden OJ, Davidson HI: Reduction in energy expenditure after liver transplantation. *Nutrition* 2001;17:585–589.

- 26 Das SK, Saltzman E, McCrory MA, et al: Energy expenditure is very high in extremely obese women. *J Nutr* 2004;134:1412–1416.
- 27 Estenne M, Maurer JR, Boehler A, et al: Bronchiolitis obliterans syndrome 2001: an update of the diagnostic criteria. *J Heart Lung Transplant* 2002;21:297–310.
- 28 Portney LG, Watkins M: *Foundations of Clinical Research: Applications to Practice*. Upper Saddle River, Pearson Education, 2008.
- 29 Kyle UG, Genton L, Mentha G, Nicod L, Slosman DO, Pichard C: Reliable bioelectrical impedance analysis estimate of fat-free mass in liver, lung, and heart transplant patients. *JPEN J Parenter Enteral Nutr* 2001;25:45–51.
- 30 Schneider PL, Crouter SE, Lukajic O, Bassett DR Jr: Accuracy and reliability of 10 pedometers for measuring steps over a 400-m walk. *Med Sci Sports Exerc* 2003;35:1779–1784.
- 31 Tudor-Locke C, Williams JE, Reis JP, Pluto D: Utility of pedometers for assessing physical activity: convergent validity. *Sports Med* 2002;32:795–808.
- 32 Tudor-Locke C, Williams JE, Reis JP, Pluto D: Utility of pedometers for assessing physical activity: construct validity. *Sports Med* 2004;34:281–291.
- 33 Ainsworth BE, Haskell WL, Whitt MC, et al: Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;32:S498–S504.
- 34 Wendel-Vos GC, Schuit AJ, Saris WH, Kromhout D: Reproducibility and relative validity of the short questionnaire to assess health-enhancing physical activity. *J Clin Epidemiol* 2003;56:1163–1169.
- 35 Haugen HA, Melanson EL, Tran ZV, Kearney JT, Hill JO: Variability of measured resting metabolic rate. *Am J Clin Nutr* 2003;78:1141–1145.
- 36 Jones CJ, Rikli RE, Beam WC: A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res Q Exerc Sport* 1999;70:113–119.
- 37 Tiesinga LJ, Dassen TW, Halfens RJ: DUFs and DEFS: development, reliability and validity of the Dutch Fatigue Scale and the Dutch Exertion Fatigue Scale. *Int J Nurs Stud* 1998;35:115–123.
- 38 Tudor-Locke C, Bassett DR Jr: How many steps/day are enough? Preliminary pedometer indices for public health. *Sports Med* 2004;34:1–8.
- 39 Resnick HE, Carter EA, Aloia M, Phillips B: Cross-sectional relationship of reported fatigue to obesity, diet, and physical activity: results from the Third National Health and Nutrition Examination Survey. *J Clin Sleep Med* 2006;2:163–169.
- 40 Subar AF, Kipnis V, Troiano RP, et al: Using intake biomarkers to evaluate the extent of dietary misreporting in a large sample of adults: the OPEN study. *Am J Epidemiol* 2003;158:1–13.
- 41 Ravussin E, Lillioja S, Anderson TE, Christin L, Bogardus C: Determinants of 24-hour energy expenditure in man: methods and results using a respiratory chamber. *J Clin Invest* 1986;78:1568–1578.
- 42 Bader N, Bösny-Westphal A, Dilba B, Müller MJ: Intra- and interindividual variability of resting energy expenditure in healthy male subjects – biological and methodological variability of resting energy expenditure. *Br J Nutr* 2005;94:843–849.
- 43 Stiegler P, Cunliffe A: The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports Med* 2006;36:239–262.