Original Article
CLINICAL TRIALS: BEHAVIOR, PHARMACOTHERAPY, DEVICES, SURGERY

Obesity

Effects of Obesity on Functional Capacity

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Objective: To assess the relationships between BMI and walking speed, balance control, sit-to-stand performance (a measure of mass specific lower limb power), and endurance.

Design and Methods: Thirty-six women with a BMI $\geq$ 30 kg/m^2 and 10 women with normal body weight (BMI between 18 kg/m^2 and 25 kg/m^2) were enrolled in this observational study. The obese group comprised 12 persons with a BMI $\geq$ 30 and $<$35 (obese), 14 subjects with a BMI $\geq$ 35 and $<$40 (severe obesity) and 10 people with a BMI $\geq$ 40 kg/m^2 (morbid obesity). All subjects underwent a clinical examination, a gait test, an endurance test (6 minutes walking test), a mass specific lower limb power test (five times sit-to-stand) and a balance test.

Results: Obese women exhibited slower fast gait speeds ($P < 0.05$) with correspondingly shorter stride lengths, poorer sit-to-stand performance ($P < 0.05$), and endurance ($P < 0.05$). However, once the state of severe obesity was reached, additional weight gain (morbid obesity) does not seem to decrease these functional capacities any further.

Conclusion: This study underlines the importance of assessing obese patients' related physical problems in an early stage of obesity in order to focus exercise regimens and promote appropriate health behaviors.

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Introduction

Obesity is a medical condition in which excess body fat has adverse health effects. The severity of obesity can be classified in three groups, according to the World Health Organization's classification based on subjects' Body Mass Index (BMI) (1): BMI $\geq$ 30 and $<$ 35 kg/m^2 (obese), BMI $\geq$ 35 and $<$ 40 kg/m^2 (severe obesity), and BMI $\geq$ 40 kg/m^2 (morbid obesity).

To control weight and maintain general good health, attention should not only be paid to the food and drink consumed but also to the amount of energy metabolized by physical activity. The World Health Organization recommends a minimum of 150 minutes of moderate-intensity aerobic exercise per week. Most of the currently promoted exercise regimens feature walking. Furthermore, the ability to walk safely is an important component of participating actively in social life and in maintaining a good quality of life.

However, recent studies have identified various negative consequences of obesity such as gait alterations (2-4), posture deficits (5,6) and greater risk of falling (7). Obesity is associated with functional decline (8), altered spatiotemporal gait parameters (e.g. lower gait speed, shorter strides, and increased step width) (4,9-11), and a significantly higher metabolic cost of walking compared to people with normal body weight (12,13). Obesity also negatively affects balance control (6,14). Greve et al. (6), for example, showed that increased body weight produces antero-posterior instability in both sexes, and medio-lateral destabilization in males. Along with these functional deficits, and when submitted to daily postural stress and perturbations, obese people seems to be at higher risk of falling than normal body weight individuals(7).

Despite significant advances in the understanding of the nature of obesity and its consequences on gait and posture, many questions regarding obese people's functional capacities and daily physical functions remain unanswered (15). To date, most studies have considered the relationship between obesity and a single, specific, functional capacity (such as gait, endurance, or balance). However, the associations between obesity and functional capacities are multifaceted and complex. In order to develop effective and subject-centered prevention and treatment strategies, a more systematic and more comprehensive approach, which could provide an overview of obese patients' functional deficits and functional decline in daily life activities, is needed

Thus, in order to deepen our understanding of how increased body weight affects functional capacities, this study investigated the

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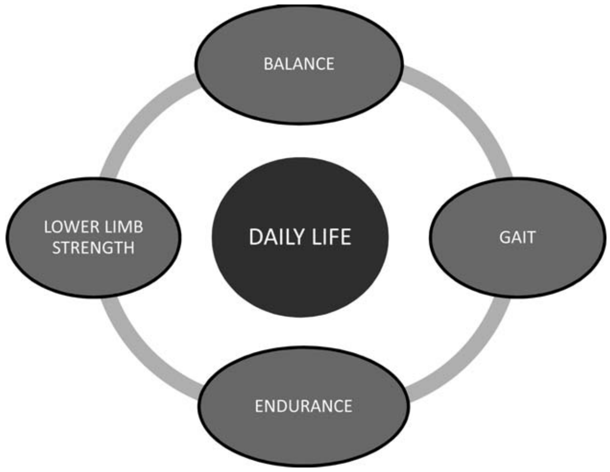

FIGURE 1 Six-minutes walking distance and chair rise performance per subject group. Legend: The graphs represent the mean and SD

relationships between BMI and four different functions and activities currently required during routine daily life (Figure 1: (1) comfortable and fast walking speed, (2) balance control on an unstable surface, (3) mass specific lower limb power (evaluated by the time needed to stand up and sit down five times from a chair), and (4) endurance evaluated with the individual's 6-minute walking distance.

Methods

Ethics

The study protocol was approved by the local ethics committee and all participants signed the informed consent form.

Subjects

Thirty-six women with a BMI $\geq$ 30 kg/m^2 and 10 women with normal body weight (BMI between 18 and 25 kg/m^2) were enrolled in this study. For the obese group we recruited 12 persons with a BMI $\geq$ 30 and $<$ 35 (obese), 14 subjects with a BMI $\geq$ 35 and $<$ 40 (severe obesity), and 10 people with a BMI $\geq$ 40 kg/m^2 (morbid obesity) according to the World Health Organization's classification (1).

All subjects were recruited at the service of Therapeutic Education for Chronic Diseases, at the Department of Community Medicine at the University Hospitals of Geneva in Switzerland.

Subjects had to fulfill the following inclusion criteria:

- Being able to walk 10 m without a walking aid
- No foot ulcer at the moment of data acquisition
- No orthopedic, surgical, or neurological (other than diabetic peripheral polyneuropathy) problems affecting the gait
- Absence of nondiabetic neuropathy (e.g. because of chronic alcohol consumption, thyroid dysfunction)

As many people with obesity also suffer from type 2 diabetes, we did not exclude diabetic subjects. We checked if subjects suffered from peripheral neuropathy and kept track of it. Peripheral neuropathy was defined by the absence of both patellar and ankle reflexes and evaluated by the vibration perception threshold using a 128-Hz Rydel-Seiffer® tuning fork at the hallux and internal malleolus of both feet. The patient was asked to respond if he/she could no longer feel the vibration, and the vibration was determined on the 9-point grading scale (0/8-8/8) of the tuning fork. The patient was considered to have neuropathy if the vibration perception threshold was $<$ 4 (16).

The medical history of each participant accounted for the presence, or absence of depression.

Clinical examination

All subjects underwent a careful clinical examination by a physician in order to check the in- and exclusion criteria.

Functional capacity tests. After the clinical examination, subjects underwent different functional capacity tests: a walking test at a comfortable, then at a fast gait speed on a 10-m level surface (m/s) (17), a test of postural control on a stable and unstable surface (18), a five times sit-to-stand test reflecting lower body function (19-21) and a 6-minute walking test reflecting aerobic endurance (22).

Material, test procedure, and data processing

Gait. Subjects walked twice along the 10-m level walkway at a comfortable speed and twice at a fast speed (17). Gait was recorded at 100 Hz using a 12 camera (MX 3+ model) motion capture system (Vicon; Oxford Metrics, Oxford, UK). Reflective spherical markers were placed at the heel, and the second metatarsal joint. Foot contact and foot-off events were recorded at 1000 Hz with synchronized footswitches (AURION, Zerowire, IT), placed at the heel and at the head of the first metatarsal head. Spatiotemporal gait parameters (speed, cadence, stride length) were extracted with a custom program in Matlab R2008b (The MathWorks, Natick, USA.)

Balance control. Balance control was evaluated with two AMTI platforms (AccuGait, AMTI, Watertown, MA). Every subject was tested in four test conditions, namely on a stable surface with eyes open, on a stable surface with eyes closed, on an unstable surface (Airex Balance Pad Elite mat of 6 cm) with eyes open, and on an unstable surface (Airex Balance Pad Elite mat of 6 cm) with eyes closed. Foot position and rest time of 15 s between trials were imposed. For every test condition three recordings of 30 s at 1000 Hz were used and the best performance of the three trials was used for statistical analysis. During the data processing, the first two, and the last 2 s were deleted in order to make sure that the recording started from the time point when participants were stable, and stopped before they had begun focusing on the end of the task. Additionally, a low-pass 4th order Butterworth filter with a cutoff frequency of 10Hz was applied. The order of the test conditions was randomized. The location of the centre of pressure (COP) on each plate (right COP and left COP), and with the two plates taken as a single one (COPnet) were computed. The total speed of the COP (Net COP speed) as well as the COP speed in the anterior–posterior

(COP AP-Speed) and medio-lateral (COP ML-Speed) direction were then retained for statistical analysis (18).

Sit-to-stand test which reflects a mass specific lower limb power. Subjects were requested to perform five sit-to-stand repetitions as rapidly as possible (21). For this test, subjects had to sit in an armless stool without any backrest. The height was adjusted so that when sitting subjects had a 90° flexion at their hip and knee. We then instructed the participant to cross her arms over her chest. On the instruction "GO" the subject stood up and sat down again five times, and the time it took to complete five repetitions was recorded (19,21).

Endurance evaluated with the 6-minute walking test. The 6-minute walking test is a commonly used, objective measure of functional exercise capacity in individuals with moderately severe impairments (22). Subjects were requested to walk the maximum possible distance back and forth along a flat 20-m walkway over a time of 6 min (22).

Statistics

Statistics were performed with SPSS version 18 for Windows. Descriptive statistics were used to provide an overview of the demographic data and of the functional capacity tests. All data were then checked for normal distribution using the Shapiro-Wilk test. The functional parameters of the four groups were then compared using an ANOVA and a Bonferrroni post hoc analysis.

Results

The demographic data and relevant clinical information of the normal weight subjects (n = 10) the obese subjects (n = 10), the subjects with severe obesity (n = 14), and the morbidly obese group (n = 10) are presented in Tables 1 and 2.

Spatiotemporal gait parameters (speed, cadence, and stride length)

People in the normal weight group had a mean, self selected gait speed of 1.53 ± 0.22 ms^{-1}. As body weight increased, people decreased their gait speed. People with a BMI between 30 and 35 kg/m^2 walked at a self selected speed that was similar to the speed of the normal body weight group (1.34 ± 0.20 ms^{-1}; $P \geq 0.05$). However, people with a BMI between 35 and 40 kg/m^2 walked significantly slower (1.15 ± 0.15 ms^{-1}; $P < 0.001$) than normal weight subjects. The fast walking speed was already significantly different between normal weight subjects and people with a BMI between 30 and 35 kg/m^2 (2.11 ± 0.20 ms^{-1} vs 1.82 ± 0.15 ms^{-1}; $P = 0.001$). The normal and fast gait speed continued to decrease as BMI increased until the category "severely obese". No difference could be identified between the severely obese group and morbidly obese group for the self selected and fast speed (Tables 1 and 2).

In the obese group and the severely obese group, cadence continued to decrease (120.04 ± 11.47 vs 109.49 ±7.31; $P = 0.032$) at self selected speed, but stride length remained similar ($P > 0.05$). At fast walking speed, there was no further change, and again no change occurred between the severely obese group and morbidly obese group, whether for the self selected speed condition, or for the fast speed condition.

Balance control test on a stable surface and unstable surface

No difference was detected for COP-speed between the normal body weight group and the different groups of obese subjects in any of the four conditions (eyes open and eyes closed on a stable and unstable surface) (Table 3).

Sit-to-stand test

Obese people needed more time to complete five sit-to-stand repetitions. The main difference could be observed between people with a normal BMI (8.28 ± 1.42 s) and the obesity category (11.29 ± 3.14 s) ($P = 0.026$). However, even if the time needed to perform these five chair rises continued to increase with the obesity level until the category "severely obese", no difference could be observed between obese people and people with a severe or morbid obesity ($P \geq 0.05$) (Figure 2a).

Six-minutes walking test

Endurance was progressively less in the groups with greater obesity. People with a BMI of less than 25 kg/m^2 walked 613.4 ± 45.9 m in 6 min. People in the obese category walked 532.3 ± 62.7 m, people in the severely obese category walked 487.3 ± 61.2 m, and people in the morbidly obesity category only walked 462.8 ± 68.2 m. Post hoc analysis revealed a significant difference between the individuals with a normal BMI and all the other three BMI categories ($P < 0.05$). However, the differences between obese, severely obese, and morbidly obese groups were not significant (Figure 2b).

Discussion

This study investigated the influence of BMI on four physical functions necessary in routine daily life. The main results of this study show that obese women have slower gait speeds and accompanying shorter stride lengths, relatively less powerful lower limbs (respectively, they need more time to realize five sit-to-stand movements) and a poorer endurance than in normal weighted people.

TABLE 1 Description of spatiotemporal gait parameters per subject group

	Normal walking			Fast walking		
BMI	Speed (m/s)	Cadence (Steps/min)	Stride length (m)	Speed (m/s)	Cadence (Steps/min)	Stride length (m)
< 25	1.53 (0.22)	122 (11.51)	1.50 (0.10)	2.11 (0.20)	147 (12.71)	1.73 (0.10)
≥ 30 < 35	1.34 (0.20)	120 (11.47)	1.34 (0.13)	1.82 (0.25)	144 (14.29)	1.52 (0.17)
≥ 35 < 40	1.15 (0.15)	109 (7.31)	1.26 (0.12)	1.73 (0.21)	136 (6.70)	1.53 (0.14)
≥ 40	1.18 (0.15)	109 (4.39)	1.29 (0.17)	1.63 (0.19)	130 (7.37)	1.51 (0.19)

TABLE 2 Multiple comparison of gait parameters between different obesity groups

			Normal walking	Fast walking
			Mean Diff (SD)	Mean Diff (SD)
Gait speed	BMI < 25	BMI ≥ 30 < 35	0.191 (0.078)	0.291 (0.092)[a]
	BMI < 25	BMI ≥ 35 < 40	0.384 (0.075)[c]	0.374 (0.089)[c]
	BMI < 25	BMI ≥ 40	0.347 (0.081)[c]	0.476 (0.096)[c]
Cadence	BMI < 25	BMI ≥ 30 < 35	1.745 (3.913)	2.768 (4.564)
	BMI < 25	BMI ≥ 35 < 40	12.321 (3.784)[b]	10.59 (4.413)
	BMI < 25	BMI ≥ 40	12.421 (4.087)[a]	16.886 (4.767)[b]
Stride Length	BMI < 25	BMI ≥ 30 < 35	0.159 (0.055)[a]	0.214 (0.065)[a]
	BMI < 25	BMI ≥ 35 < 40	0.237 (0.053)[c]	0.203 (0.063)[a]
	BMI < 25	BMI ≥ 40	0.213 (0.057)[b]	0.222 (0.068)[a]

Mean+SD:
[a]$P < 0.05$;
[b]$P < 0.01$;
[c]$P < 0.001$

Nevertheless, beyond a state of severe obesity, additional weight gain (morbid obesity) does not seem to influence these functional capacities any more. As regards to balance, there were no differences between normal-body weight women and obese women.

Most other studies concerning obese people investigated the influence of weight loss programs and/or physical activity programs on individuals' body composition, physical performance, and cardiovascular risk factors. For example, the study of Maffiuletti et al. reported a clinical success (higher percent of fat-free mass, muscle strength, HDL-cholesterol, increased self-reported physical activity level, and lower total cholesterol and glucose levels) after a hospital-based, body weight reduction program lasting 3 weeks for severely obese individuals, in particular females (23).

Few studies (13,24-26) evaluated the effect of weight loss programs on functional capacities and movement characteristics, and few demonstrated that weight loss increased gait speed, stride length, swing time, hip range of motion, maximal knee flexion, ankle plantar flexion, 1-leg limb stance time, and self-reported physical function, whilst also reducing frailty.

One study, by Hergenroeder et al. (26) recently evaluated the influence of BMI on functional capacities. The authors assessed self-

TABLE 3 Description of COP-range and COP-speed during a balance task on a stable and unstable surface

	Stable surface EO			Stable surface EC		
	COP-speed (mm/s)	COP-speed-ML (mm/s)	COP-speed-AP (mm/s)	COP-speed (mm/s)	COP-speed-ML (mm/s)	COP-speed-AP (mm/s)
BMI < 25	9.96 (1.41)	6.29 (1.31)	6.235 (0.67)	11.31 (1.64)	6.504 (1.25)	7.65 (1.58)
BMI ≥ 30 < 35	9.40 (2.12)	4.63 (0.99)	7.082 (1.97)	11.92 (2.79)	5.079 (1.17)	9.53 (2.54)
BMI ≥ 35 < 40	8.15 (1.63)	4.17 (1.01)	5.978 (1.41)	10.06 (1.27)	4.42 (0.77)	8.02 (1.37)
BMI ≥ 40	9.03 (4.15)	5.00 (3.01)	6.029 (2.16)	9.58 (3.57)	4.485 (2.22)	7.39 (2.65)
	Unstable surface EO			Unstable surface EC		
	COP-speed (mm/s)	COP-speed-ML (mm/s)	COP-speed-AP (mm/s)	COP-speed (mm/s)	COP-speed-ML (mm/s)	COP-speed-AP (mm/s)
BMI < 25	16.82 (3.72)	7.66 (1.47)	13.08 (3.52)	27.88 (6.93)	9.84 (1.92)	24.12 (6.71)
BMI ≥ 30 < 35	18.64 (4.22)	7.72 (2.17)	15.32 (3.68)	38.67 (15.99)	13.47 (6.03)	33.44 (13.64)
BMI ≥ 35 < 40	15.18 (3.24)	7.09 (1.36)	11.58 (1.89)	31.18 (6.27)	11.63 (2.38)	26.39 (5.48)
BMI ≥ 40	15.39 (4.24)	7.53 (2.04)	11.66 (3.55)	30.96 (11.08)	13.43 (5.99)	25.01 (8.10)

*The balance data normal weight group were calculated with $N = 9$ instead of $N = 10$ and the severe obese group with $N = 8$ instead of $N = 10$ because of a technical problem during data acquisition.
AP, antero-posterior; ML, medio-lateral; COP, center of pressure; EO, eyes open; EC, eyes closed.

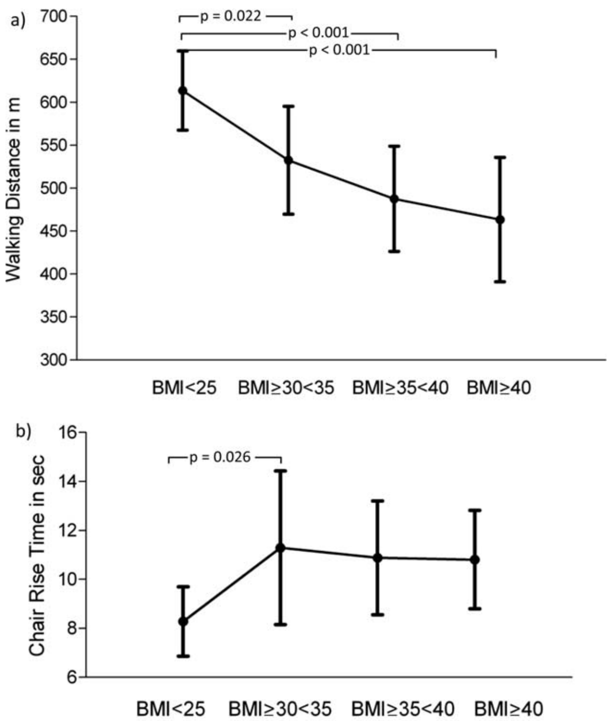

FIGURE 2 Six-minutes walking distance and chair rise performance per subject group. Legend: The graphs represent the mean and SD

reported, and performance-based physical function in obese adult women and stated that those with severe obesity were most impaired but that adult women with less severe obesity also demonstrated significant deteriorations in physical function. In comparison to this study, our test protocol also included balance measures and spatio-temporal gait parameters.

The present systematic, multifaceted, and highly standardized test protocol, including quantitative, reliable, and valid measurement systems, enabled us to provide a comprehensive overview of obese patients' functional deficits and their decline in daily life activities. Overall, the results demonstrate the detrimental influence of obesity on functional capacities and obesity's negative impact on daily life activities such as gait and the sit-to-stand movement.

In our study, gait speed was found to be decreased, which goes along with the findings of other studies (27,28). The study of Dufek et al. (27) was conducted on adolescents and identified significant differences in gait velocity between obese people and lean people. These authors found differences in walking speed between severe and morbid obesity groups (1.18 ms^{-1}) that were similar to ours. They stated that models to predict BMI percentiles from kinematic walking parameters were generally stronger for females than males, which might be an issue. Hergenroeder et al. (28) evaluated the gait speed of sedentary adult women with a stop watch. The walking speeds they recorded in the different obesity groups were somewhat lower than in our study, but again, these authors found a significant difference between normal body weight people and obese subjects. Only one study (29), which did not reveal a gait speed difference between different obesity categories, could be identified. Their control group presented rather low gait speed (1.08 ms^{-1}) compared to what is normally known in the literature, which might explain their nonsignificant result.

Walking involves repeated loss and recovery of balance. Perhaps a low gait speed helps obese people to keep their dynamic balance through a more controlled gait pattern. Another explanation for the decreased gait speed could be shorter stride length or lower cadence. The present results show that obese people tend to adjust stride length rather than cadence, which is a novel finding and has not yet been noted elsewhere. Maybe the fat mass over the abdomen and in the hip region limits the degree of potential hip flexion, which, consecutively, might lead to decreased gait speed. However, it is also possible that obese people choose a more secure gait and shorten their stride length as a consequence of decreased walking speed. Indeed, Browning et al. (30), have shown that there is no independent obesity effect on stride length. Further studies are needed to answer this question. In any case it has to be mentioned that the stride length "differences" stated do not themselves imply any mobility limitation.

The decrease of aerobic endurance has already been shown by other authors such as Hergenroeder et al. (28), who also stated that individuals with obesity had a poorer performance compared to those with normal weight during a 6-minutes walking test. An explanation for that might be the previously demonstrated higher energy expenditure during walking and altered mechanical efficiency (12,31,32) in obese people compared to a lean population. Perhaps obesity increases the cost of supporting body weight because of less mass specific lower limb power (33). The combination of supporting more weight on the legs and swinging a heavier leg probably causes greater metabolic expenditure in obese people during walking, and hence decreased aerobic endurance. The slower walking speed may also simply be a strategy to reduce ground reaction forces and net muscle moments or torque (30).

According to the present results, the fact that obese people have been shown to have a greater risk of falling (34) seems to be more related to dynamic, rather than static components. In contrast to Greve et al. (6) obese people did not present any balance deficits in the current study. This could be explained by the fact that there is no real reason that obese people should encounter a balance disadvantage, as long as the center of gravity remains within the base of support, which is the case in a static situation. However, once the center of gravity of obese individuals falls outside of the base of support, recovering balance may become more difficult than for normal weighted people, because of the greater body weight to be moved, and obese individuals' relatively inferior mass specific lower limb power. Further studies investigating the limits of stability of obese people or gait variability indexes might help to elucidate the greater fall risk in this population. Within this context, although conducted in elderly, one should further consider the review of Piirtola et al. (35). They showed that a relatively good balance performance during quiet standing does not guarantee a secure gait as only five of nine prospective studies demonstrated a relationship between standing COP motion and falls.

The greater sit-to-stand time, which reflects lower body function in obese people, showed similar results to previous studies conducted on obese subjects (28). Even if it has been shown that obese individuals are at least as strong as nonobese individuals (36), and that obese people use different strategies to stand up after being seated, the increase in rising time in obese people in our study reflects poor lower body functional capacity, relatively to body weight. One of our previous studies, which evaluated the sit-to-stand movement from a more biomechanical point of view, revealed that BMI was the only predictor for individuals' rising velocity. BMI further explained 36.6% of maximal force and 52.7% of rate of force development. As the sit-to-stand movement not only reflects lower body functions but is also an important daily life activity, which is executed around 60 times per day by functionally independent adults (37), it deserves particular focus in exercise regimens.

This study clearly indicates the negative impact of obesity on functional capacities. Health professionals who are working with obese people need to be able to assess obese patients' related physical problems in order to fine tune exercise regimens and to promote appropriate health behaviors. They should be aware that a combination of weight loss programs and exercise regimens can help to achieve better functional capacities, which might reduce other health hazards.

An issue that might have influenced the results is the fact that patients were recruited when they came to the Service of Therapeutic Education for Chronic Diseases to enroll in a therapeutic education program for weight loss, which means that all the patients included presented at least minimal autonomy in daily life activities. Additionally, we only included females in our study, and therefore males could show different results. The relatively small sample size within the different obesity categories could also be criticized.

At this stage, functional capacities were evaluated in a standardized laboratory setting. In order to have an entirely comprehensive view, future research investigating the influence of BMI on functional capacities should further identify differences in subjects' real life settings, such as in daily life activities or in their quality of life. It might be that an increase in BMI beyond a certain obesity category may further decrease individuals' daily life activity level and their quality of life even if their functional capacities remain similar.

In conclusion, this study showed that compared to normal weight subjects, obese people exhibit lower gait speeds with correspondingly shorter stride lengths, poorer sit-to-stand performance, and endurance. Beyond a certain degree of obesity, additional weight gain (morbid obesity) does not seem to decrease these functional capacities any more. However, the limits stated should caution readers to not draw conclusions too easily or to misinterpret the results. Although mobility stops decreasing after a BMI of 35, our results should not encourage people to dismiss further weight gain as being inconsequential. Rather, our study underlines the importance of assessing obese patients' related physical problems at an early stage of obesity in order to focus exercise regimens and promote appropriate health behaviors. O

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