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Review

Balance Control in Obese Subjects during Quiet Stance: A State-of-the Art

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Abstract: Obese individuals are characterized by a reduced balance which has a significant effect on a variety of daily and occupational tasks. The presence of excessive adipose tissue and weight gain could increase the risk of falls; for this reason, obese individuals are at greater risk of falls than normal weight subjects in the presence of postural stress and disturbances. The quality of balance control could be measured with different methods and generally in clinics its integrity is generally assessed using platform stabilometry. The aim of this narrative review is to present an overview on the state of art on balance control in obese individuals during quiet stance. A summary of knowledge about static postural control in obese individuals and its limitations is important clinically, as it could give indications and suggestions to improve and personalize the development of specific clinical programs.

Keywords: posture; stability; force platform; stabilometry; posturography; obesity

1. Introduction

Postural stability can be explained as the ability of one's motor control to maintain the standing posture, even during external perturbations. It is often described as static (quiet standing) or dynamic (maintaining a stable position while undertake a prescribed movement) [1].

Postural stability is achieved when a subject can regain equilibrium after being disturbed. Postural control requires the integration of inputs from various sensory systems, which are: (a) the proprioceptive system (receptors in joints, muscles, tendons, skin) [2], (b) the visual system [3] and (c) the vestibular system (semicircular canals and macular otoliths) [4]. Sensorimotor integration and balance regulation rely on the cerebellum; most of the evidence of the function of the cerebellum in humans comes from patients with cerebellar damage who display balance abnormalities and gait ataxia [5].

This multimodal (integrating visual, vestibular, and proprioceptive inputs) and redundant control causes chaotic center of mass (CoM) oscillations known as postural sway [6–8]. In clinics the quality and integrity of balance control is generally assessed using various measures of postural sway [6].

Instrumental evaluation with platform stabilometry or static posturography is a technique where CoM fluctuations are represented by the center of foot pressure (CoP) displacements [9] and it consists in the measurement of forces exerted against a force platform during quiet stance. This method is widely used in clinical settings to evaluate the integrity of the postural control system and to obtain functional markers on fine competencies and their development in different testing conditions (i.e., eyes open vs. eyes closed, feet position, and presence of external stimuli) [10]. Commonly, the study of properties of the CoP trajectory in clinics is performed using traditional time series, in particular analyzing length, displacement excursion, velocity and frequency analysis. The main advantages of these analysis techniques are the simplicity of the experimental set-ups and the safety for the subjects evaluated, a particularly important consideration in pathological conditions [11]. However, some limitations are present: (a) the lack of a normal pattern due to intra- and inter-individuals variability; (b) the difficulties inherent to standardizing the measurement experimental set-up (reproducibility of the experimental protocol, environmental conditions, random errors, signal processing); and (c) the presence of highly coupled parameters measured by means of the force platform [12,13]. Due to the presence of these limitations, it is necessary to have reliable methods available to extract physiologically significant information from the platform data [11,14]. Alongside the study of properties of the CoP trajectory using traditional time series, some advanced mathematical methods have been developed applying a dynamic approach, such as entropy and fractal dimension (FD) analysis [11,15,16]. Even if previous studies [14,17,18] suggested that these methods could represent reliable techniques complementary to the analysis in time and frequency domain in order to evaluate postural control, their use in clinical setting is not yet widespread.

Balance is a fundamental element in carrying out daily life activities. Aging and various pathologies increase the postural instability which can lead to falls [19]. In particular, some anthropometric measurements (height and weight) are demonstrated to significantly influence both postural sway and postural stability [12,20,21]. The excessive presence of fat adds mass to different regions and modifies the body geometry [22]: in this way the altered CoM position leads to balance impairments [23].

It is estimated that in 2016, more than 1.9 billion adults aged 18 years and older were overweight; of these over 650 million were obese [24]. A recent paper suggests that by 2030 nearly one in two adults in the United States will be obese and nearly one in four adults will have severe obesity [25]. Patients with obesity have intrinsically reduced postural stability and balance as compared with their normal-weight counterparts. This reduced stability increases linearly with body mass index (BMI). They are at increased risk of falling at any age [26]. Although many studies investigated the risk of falling in obese individuals, balance exercises in these individuals are often not implemented in the rehabilitation program. After implementing a rehabilitation program with specific balance exercises, patients with obese have shown to improve their balance control. Maffiuletti et al. [19] showed that just 4-min of specific balance training incorporated into the physical exercise routine improved postural stability in patients with severe obesity. The recommended exercise program for patient with obesity is a multicomponent 90-min exercise program that includes 15-min balance training, 15-min flexibility, 30-min aerobic exercise and 30-min high-intensity resistance training [27]. Different aspects of balance control can be addressed:

1. Treatment of biomechanical constraints (weakness, reduced range of motion, reduced flexibility, and improper postural alignment).
2. Weight shifting exercise to treat reduced limits of stability.
3. Sensory retraining of balance control.
4. Training of anticipatory postural adjustments focused on improving postural preparation for transition from one position to another (sit-to-stand single-leg-stance, step initiation, and compensatory forward stepping).
5. Training postural responses to perturbations.
6. Dynamic stability during gait (i.e., walking in different directions and environments).

The consensus is that obese individuals exhibit poor postural stability [28,29]; the aim of this review will be to present an overview on the state of art on balance control in obese individuals during quiet stance. A summary of our current knowledge about static postural control in obese individuals is important from a clinical perspective, as it could allow for the development of clinical programs that are more oriented towards the needs of this population, even avoiding the risk of comorbidity due to falls.

2. Methods

We conducted an extensive search of the relevant literature, with a focus on studies/articles published in the last 15 years (2004–2019). The literature search was performed in November 2019 on the following electronic databases: Web of Science, PubMed MEDLINE, Scopus, and Mendeley. Customized queries including keywords and Boolean logic with AND/OR operators were entered in this form: "(balance OR posture OR stability) AND (posturography) AND (obesity)", with document type set to "Article". The search was limited to full original articles written in English. Bibliographies of identified papers were hand searched for supplemental relevant items.

All included studies had to meet the following criteria: overweight and obese adults (18–75 years; with body mass index (BMI) ≥ 25 Kg/m^2); studies assessing obese patients with genetic obesity; evaluations performed with force platform. We excluded studies that were not primarily focused on the evaluation of quiet standing evaluation (dynamic balance) in obese subjects, or non-adult participants and elderly subjects.

3. Results

A total of 27 records were retrieved from the electronic databases. Eight items were added by visual inspection of reference lists and review articles. After removing seven duplicates, titles and abstracts screening led to exclude four papers. Out of the remaining 24 articles, 12 failed to meet inclusion criteria. The main reasons for exclusion were as follows: studies assessing elderly or non-adult patients; patients with neuropathy; the presence of other pathologies (multiple sclerosis). The selection process is summarised in Figure 1.

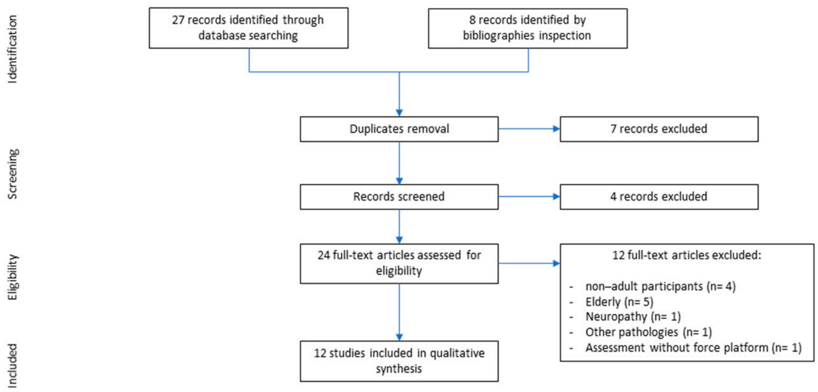

Figure 1. Diagram of study selection.

Table 1 presents a summary of the papers on postural ability in obese individuals with the demographic characteristics of the evaluated individuals and some details of the experimental set-up (trial duration, conditions, feet position, analyzed parameters).

Table 1. Summary of the main details of the reviewed studies.

Source	Year	Country	# Participants and Gender (# M/F)	Age (Yrs.)	BMI (Kg/m^2) (the Weight (kg) Is Reported When BMI Is Not Present)	Parameters	Trial Duration	Conditions	Foot Position
Hue et al. [30]	2007	Canada	Total: 59 (M)	40.5 ± 9.5	35.2 ± 11.7	CoP RMS (AP and ML) CoP Range (AP and ML) Sway area Mean CoP velocity (AP and ML) RMS of CoP velocity	35 s (last 30 s used for the analysis)	Eyes open/eyes closed	Feet 10 cm apart
Teasdale et al. [31]	2007	Canada	Total: 44 (M) Divided into Control group: 16 Obese group: 14 Morbid group: 14	Control group: 38.6 ± 9.4 Obese group: 37.9 ± 7.7 Morbid group: 44.4 ± 8.9	Control group: 22.7 ± 2.2 Obese group: 33 ± 3 Morbid group: 50.5 ± 6.8	CoP RMS (AP and ML) CoP Range (AP and ML) Mean CoP velocity (AP and ML)RMS of CoP velocity	35 s (last 30 s used for the analysis)	Eyes open/Eyes closed	Feet together
Menegoni et al. [32]	2009	Italy	Total: 44 M: 22/F: 22	19–58	M:41.1 ± 4.1 F:40.2 ± 5	CoP RMS (AP and ML) CoP Range (AP and ML) Mean CoP velocity (AP and ML)	60 s	Eyes open	Standardised (distance between heels approx. 8 cm and angle between feet of 30°)
Blaszczyk et al. [33]	2009	Poland	Total. 100 (F)	18–53	37.2 ± 5.2	CoP range (AP and ML) CoP length	30 s	Eyes open/eyes closed	Feet apart and slightly turned out
Cimolin et al. [17]	2011	Italy	Total: 11 (PWS) M: 5/F: 6	34.4 ± 3.7	41.4 ± 8.1	CoP Range (AP and ML) CoP length peak of the spectrum (AP and ML) FD	30 s	Eyes open	Feet at a 30° angle
Cruz-Gomez et al. [34]	2011	Mexico	Total: 180 M: 90/F: 90 Divided into Lean (%): M: 41; F: 37 Overweight (%): M: 48; F: 33 Obese (%): M: 11; F: 30	12–67 (M:34.9 ± 12.27; F:36.76 ± 12.02)	M:25.97 ± 3.73 F:26.83 ± 4.77	CoP length CoP area CoP velocity	25.6 s	1. Hard surface and eyes open. 2. Hard surface and eyes closed. 3. Soft surface and eyes open. 4. Soft surface and eyes closed	According to the manufacturer reference
Rigoldi et al. [35]	2011	Italy	Total: 45 (DS) (gender not detailed)	22–46	57.9 + 10.8 Kg	CoP Range (AP and ML) CoP length peak of the spectrum (AP and ML)	30 s	Eyes open/eyes closed	Feet at a 30° angle

Table 1. *Cont.*

Source	Year	Country	# Participants and Gender (# M/F)	Age (Yrs.)	BMI (Kg/m^2) (the Weight (kg) Is Reported When BMI Is Not Present)	Parameters	Trial Duration	Conditions	Foot Position
Hita-Contreras et al. [36]	2013	Spain	Total: 100 (F)	57.51 ± 3.99	27.10 ± 4.71	CoP RMS (AP and ML) Sway area Mean CoP velocity (AP and ML)	30 s	1. Eyes open 2. Eyes closed 3. Foam surface and eyes open 4. Foam surface and eyes closed	Feet at a 30° angle
Cimolin et al. [37]	2014	Italy	Total 59 M: 15; F: 11 M: 6; F: 7 (PWS) M: 11; F: 9 (DS)	34.2 ± 10.7 32.4 ± 4.2 (PWS) 29.1 ± 8.1 (DS)	40.6 ± 4.6 40.3 ± 6.6 (PWS) 35.8 ± 6.2 (DS)	CoP Range (AP and ML) CoP length peak of the spectrum (AP and ML) FD	30 s	Eyes open	Feet at a 30° angle
Cieslinska-Swider et al. [38]	2017	Poland	Total: 80 (F) Divided into Group A: 40 with android type of obesity Group G: 40 with gynoid type of obesity	Group A: 38 ± 12 Group G: 36 ± 11	Group A: 37.6 ± 5.5 Group G: 36.9 ± 5.1	CoP range (AP and ML) CoP mean velocity CoP peak velocity	30 s	Eyes open/eyes closed	Feet apart and slightly turned out
Hirjakova et al. [39]	2018	Slovakia	Total: 22 M: 13/F: 9	32.5 ± 1.3	32.0 ± 0.9	CoP Range (AP and ML) Mean CoP velocity (AP and ML)	50 s	Eyes open	Self-selected stance width
Cieslinska-Swider et al. [8]	2019	Poland	Total: 32 (F)	35.9 ± 9.8	36.4 ± 5.2	CoP range (AP and ML) CoP mean velocity CoP peak velocity	30 s	Eyes open/eyes closed	Feet apart and slightly turned out

Abbreviations: M: male; F: female; PWS: Prader–Willi syndrome; DS: Down syndrome; BMI: body mass index; ROM: range Of motion; AP: antero-posterior; ML: medio-lateral; FD: fractal dimension.

3.1. Study Population

The sample size of participants ranged from n = 11 to n = 180 (mean age range: 19 years to 60 years). A total of 860 subjects were involved (approximately 60% females and 40% males), but we could not exclude subjects overlapping in studies conducted by the same research group.

Experimental Set-up and Parameters

In terms of the experimental set-up, the common postural techniques are used in terms of trial duration (30 s or 60 s) and conditions (eyes open and eyes closed). On the contrary, some differences were found as for the feet position; this could represent a bias as it is demonstrated that anthropometric measurements (e.g., maximum foot width), and the foot position could influence balance [12]. Almost all the studies have been conducted using parameters obtained by time-domain analysis of the CoP trajectory (length, displacement excursion, velocity).

To the best of our knowledge, most studies in obese individuals have adopted the traditional time-domain approach. However, a growing number of studies have been designed to explore other approaches for the analysis of the CoP trajectories during quiet standing and to characterize the preferential involvement of specific neuronal loops in postural regulation (frequency), its irregularity and complexity (entropy), its chaotic pattern (fractal dimension method), etc. [40].

Nevertheless, these alternative methodologies have not been used in obese patients. To our knowledge, only few researches [17,37] quantified posture using the FD approaches in addition to the time and frequency domain in genetic obese patients (Prader-Willi syndrome and Down syndrome). The results showed that patients presented higher CoP fluctuations in both AP and ML directions with longer CoP trajectory than the control group [35,41–43] and similar values as for the frequency analysis. Furthermore, the pathological individuals presented larger excursions of CoP with the same velocity of oscillation if compared to normal weight individuals. In addition, patients with genetic obesity exhibited higher FD values, which were higher in patients with Down syndrome. According to these results, the time domain parameters do not seem to clearly highlight early anomalies in postural maintenance: the traditional method does not investigate the chaotic fluctuations of CoP trajectories. Frequency analysis and dynamical system theory could identify early changes and may match time frequency analysis to assess balance. However, the clinical interpretation of the results is not completely clear and requires further in-depth investigation.

3.2. Gender Effects

Gender differences (considering in particular gynoid and android shape) are observed in terms of body mass distribution, even if android fat distribution is also found in females, especially in postmenopausal women: nevertheless, the research for possible gender-specific differences in balance has reported contradictory findings. Some studies were conducted just on a specific gender (males or females).

3.2.1. Males

Hue et al. [30] observed that obese men presented higher instability, in both the antero-posterior (AP) and medio-lateral (ML) CoP excursions, than normal weight individuals; an improvement was found in severely obese men after weight loss [31] and specific balance training [19]. This result supports the suggestion that body weight is an important predictor of postural stability [30].

3.2.2. Females

Blaszczyk et al. [33] observed a significant postural instability in all obese patients; CoP fluctuations were higher in patients with the highest body mass index (>40 kg/m^2). In another study, Cienliska-Swider et al. [38] quantified CoP characteristics in a group of obese women with android type of obesity as compared with a group of obese women with gynoid type of obesity, standing with eyes open and closed. They found that women with abdominal obesity showed a larger sway range in the AP direction under both conditions and a greater maximal CoP velocity than subjects with gynoidal obese type under the eyes closed condition. Women with abdominal obesity seem to exhibit greater postural instability in comparison with women with gynoid fat distribution. In another study conducted by the same authors [8] on young obese women, they found that participants exhibited sagittal plane postural instability only with their eyes closed. After body weight reduction, ML static stability decreased, directly connected to a change in the base of support. Recently, Hita-Contreras [36] analyzed the relationship between body weight/body fat distribution and postural balance and their correlation with falls in postmenopausal women, which are characterized by weight gain and increased central adiposity. In the obese group, higher excursions were found in the antero-posterior direction under both eyes-open and eyes-closed conditions, as well as for the CoP velocity. In particular, in overweight and obese individuals with an android body fat distribution a good correlation with the risk of falling was found. Similar results were found in obese older women, suggesting that obesity has a negative impact on the capacity of older woman to adequately use proprioceptive information for posture control [44].

3.2.3. Males vs. Females

If instability was generally observed both in obese males and female, it is not clear whether gender could influence balance. Cruz-Gomez et al. [34] assessed the influence of BMI group (lean/overweight/obese) and gender on the postural sway of adolescents and adults during quiet upright stance in four conditions (eyes open/closed on hard/soft surface). The postural stability of obese subjects decreases with eyes closed, if compared to normal weight individuals, with no influence of the gender. Thus, they found no interactions between the BMI group and the gender, independently of the age of the subjects. On the contrary, in another study, Menegoni et al. [32] identified a gender-specific effect in obese individuals: both genders displayed instability in AP direction, while only males presented ML destabilization. The difference in male and female body tissue distribution could potentially offer two related explanations to these outcomes. While males typically store more fatty tissue around their abdomen, (android shape), females usually carry fat around the hips and the upper portion of their legs (gynoid shape) [45]. AP instability is exacerbated in both populations by greater overall mass which leads to higher ankle torque. The male distribution of mass, however, results in increased loading of the pelvic girdle which, in turn may contribute to greater ML CoP excursion. Similar, yet alternatively, the anatomically lower position of fat storage associated with the female gynoid shape has a consequently lower CoM than the male android shape.

3.3. General Considerations

In general, body weight is considered a predictor of postural instability [30], from adolescence onwards [26]. In obese individuals there is significantly greater forward CoP displacement during dynamic standing balance activities [46]. Excessive body weight affects posture linearly with the increase of BMI ($0.39 < \text{rho} < 0.60$, $p < 0.05$) [47,48], similarly to the later stages of pregnancy [31], the center of gravity shifts forward, lumbar lordosis increases together with the pelvic forward tilt, dorsal kyphosis and secondary cervical lordosis become more pronounced [49]. Otherwise, increased CoP parameter values and therefore increased postural instability during quiet stance has been reported in both morbidly and slightly obese subjects [39]. Two hypotheses have been proposed to explain the presence of higher oscillations in obese individuals in comparison with normal weight subjects: a) the reduction of plantar sensitivity due to the hyper activation of the plantar mechanoreceptors for the continuous pressure of supporting the large mass; b) the presence of high mechanical request in obese subjects due to a whole body center of mass further away from the axis of rotation causing a greater gravitational torque [30].

4. Conclusions

According to this narrative review, the research investigating the effect of adiposity on postural balance is limited and, to date, has primarily focused on parameters related to time-domain approach during bipedal stance.

Because of the elevated mass to height ratio of excessively muscular people, BMI becomes a relatively ineffective method for differentiating between highly overweight subjects and bulky, yet fit, muscular subjects. This could be a potential explanation for the discrepancies found in studies using BMI as their sole classification metric. The relationship between excessive adiposity and balance may be better explained using different measures of fat percentage. Rather, by including the ratio of circumference between waist and hip, researchers could add a quantitative parameter (in addition to the traditional BMI) which characterizes the shape of a subject and subsequently ensure better homogeneity amongst groups.

Considering that the prevalence of obesity is increasing at a rapid rate all over the world, health systems will have to face the growing problems directly related to obesity. It is now known that an increase in BMI is associated with an increase in functional limitation, decreased stability and an increased risk of falls. Complications associated with falls are often more difficult to treat in obese individuals in comparison with normal-weight subjects. Targeted physical activity and rehabilitation would seem to lead to improvements in terms of balance in obese people; it is still unclear whether a regular exercise program and weight loss could be the first steps in countering the reduced balance related to obesity. Balance exercises are often neglected in rehabilitation programs; evidence exists that majority of patients with obesity complain of dizziness, but they seem to underestimate the risk of fall; considering the increased risk of fall, balance exercises for the patient with obesity should be implemented even in the absence of specific balance disorders.

The main limitation of this review is mainly related to the age of the evaluated patients. A more extensive review could be conducted evaluating also the effects of age (elderly) and non-adult participant's (children and adolescents). In addition, it could be interesting to consider dynamic balance training in these patients, which has been proven improving balance performance and decreases falls in these subjects.

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