Pituitary (2019) 22:497–506
https://doi.org/10.1007/s11102-019-00979-3

Static and dynamic balances of patients with acromegaly and impact of exercise on balance

Ozlem Haliloglu[1] · Nuri Topsakal[2] · Filiz Camliguney[2] · Ozge Polat Korkmaz[1] · Serdar Sahin[1] · Birol Cotuk[2] · Pinar Kadioglu[1] · Oya Erkut[2]

Published online: 1 August 2019

Abstract

Purpose Patients with acromegaly may have balance abnormalities due to changes in body composition. We aim to compare static and dynamic balances in patients with acromegaly and healthy volunteers, and to evaluate the effects of exercise on balance in patients with acromegaly.

Methods This prospective study included 25 patients with acromegaly followed at endocrinology clinic of Cerrahpasa Medical Faculty and 13 healthy volunteers. The acromegalic patients were divided into 2 groups. Group A ($n=11$) attended an exercise program 3 days/week for 3 months, whereas group B ($n=14$) and healthy volunteers (Group C) were exercise-free. Bipedal and unipedal stance static and dynamic balance tests were performed using a Prokin 252N device.

Results The ages, demographic characteristics, and body compositions were similar. In acromegalic patients, the static balance parameters of displacement of center-of-pressure in anterior–posterior direction (C.o.P.Y) while eyes open ($p=0.002$) and on left leg ($p=0.001$), in left–right direction (C.o.P.X) on right leg ($p=0.03$), eyes-closed average medio-lateral velocity (AMLV) ($p=0.001$) and the dynamic parameter of forward/backward front/right standard deviation (FBFRSD) ($p=0.02$) were significantly different from healthy controls. When the exercise effect on balance was evaluated between group A and B, there were significant improvements in most parameters of dynamic balance measurements of both forward–backward and medial–lateral sway (FBFRSD, FBDME, and RLBLSD) ($p=0.02$, $p=0.02$, and $p=0.004$, respectively) after exercise in group A.

Conclusions Patients with acromegaly had impairments at various static and dynamic balance parameters, especially in posterior direction. After a 3-month exercise program, the dynamic balance profoundly improved, but static balance was relatively preserved in patients with acromegaly.

Keywords Acromegaly · Dynamic balance · Exercise · Static balance

Introduction

Acromegaly is a chronic debilitating disease resulting from growth hormone (GH) hypersecretion, usually from a pituitary adenoma. Besides the mechanical effects of the pituitary tumor as headache and visual disturbances, patients with acromegaly have to face many other comorbidities resulting from the effects of excessive insulin like growth factor-1 (IGF-1) secretion such as glucose intolerance, hypertension, uncontrolled diabetes mellitus, musculoskeletal problems and physical changes such as enlarged extremities and facial deformities [1, 2]. The slow and insidious progression of disease leads to these signs becoming more evident [3].

One of the main causes of disability in patients with acromegaly is the change of body composition. Growth hormone hypersecretion leads to an increase in body water and lean body mass and reduction of fat tissue [4]. Acromegalic arthropathy is also an important cause of morbidity. It is usually manifested as a degenerative disease and affects both axial and peripheral joints, whereas it has been documented that joint space widening caused by periarticular soft tissue

✉ Pinar Kadioglu
kadioglup@yahoo.com

[1] Division of Endocrinology-Metabolism and Diabetes, Department of Internal Medicine, Cerrahpasa Medical Faculty, Istanbul University-Cerrahpasa, Istanbul, Turkey

[2] Department of Sport Health and Science, School of Physical Education and Sports, Marmara University, Istanbul, Turkey

hypertrophy may preserve as an early stage of arthropathy [5–7].

Balance is the capacity of the nervous system to detect instability and to generate appropriate responses that bring the center of mass back to the support base [8]. Balance is maintained by the contribution of the visual, somatosensory, and vestibular systems, and may be adversely affected by musculoskeletal disorders, diseases or aging [9]. Balance is classified as static balance and dynamic balance. Static balance is defined as maintaining steadiness on a fixed, firm, unmoving base of support and dynamic balance is the ability to transfer the vertical projection of the center of gravity around the supporting base [10, 11]. Both static and dynamic balance are crucial to maintaining postural stability. It has been shown that exercise improves balance control in different age groups and disease states [12–14].

Patients with acromegaly may have changes in balance due to musculoskeletal abnormalities, changes in body composition, and visual disturbances. Although there are scant data about static and dynamic balance in acromegaly, to our knowledge, the effect of exercise on balance has not been evaluated before in patients with acromegaly. In this study, we aimed to compare static and dynamic balance in patients with acromegaly and healthy controls, and to evaluate the effect of exercise on both static and dynamic balance in patients with acromegaly.

Materials and methods

Subjects and study design

Twenty-five patients with acromegaly followed at the Endocrinology and Metabolism Department of Istanbul University-Cerrahpasa, Cerrahpasa Medical Faculty, who accepted to participate and 13 healthy volunteers who had a sedentary lifestyle were included in the study. Participants who had vestibular or neurologic diseases, visual field defects and refractory errors or physical disabilities were not enrolled in the study. All the patients and healthy controls were right-handed. The patients with acromegaly were divided into two groups as patients who attended to an exercise program that included a 75-minute exercise session 3 days per week for 3 months (group A), and patients who did not attend an exercise program (group B). The exercise program consisted of warming, cardio, balance, strength and stretching (20 min-walking, 5 min-stretching, 20 min-walking, 20 min-balance and strength exercises, 10 min-stretching). Group B and healthy volunteers (group C) did not take any exercise.

The demographic characteristics and disease states of patients with acromegaly were recorded from the medical files. The pre and post exercise body mass indices (BMI) were also recorded.

The disease remission status of patients was assessed according to the Endocrine Society guidelines [15]. Other pituitary hormonal status was also evaluated and those with deficiencies were under replacement therapy (patients with TSH deficiency took levothyroxine and patients with FSH-LH deficiency took estrogen replacement therapies). All deficient hormones were in normal limits.

Balance measurements

Both the static and dynamic balance measurements were made using a Prokin 252N (Pk-Manop-05-en-01 Bergomo, Italy) (Fig. 1). This device has a screen monitor and a tilting board where the patients stood on. The patients saw the galleries on the screen monitor. The tilting board has four decelerator pistons that could modify the active resistance of the board needed in dynamic balance measurements. The system evaluates the visual (by the galleries on screen monitors), auditory (by the responses to the trainer's verbal instructions) and also proprioceptive feedbacks (by adjusting the pressure to the tilting board according to the visual input coming from the screen) of the patients.

Adopted from software Prokin 5.0 Operator's Manual.

Fig. 1 The Prokin 252N device Adopted from software Prokin 5.0 operator's manual

After explaining the procedure to the participants, heights, weights, and ages were entered into the computer and the instrument was calibrated. At the end of each test, the subject was requested to rest for 2–4 min while the instrument was being calibrated again. No verbal feedback was given to the participants during the measurements except the necessary cases. The tests were applied only once in order to prevent bias of learning due to repetition.

(a) Static balance tests (30 s)

The bare feet of the subjects were placed on the balance platform. The distance between the feet was 10 cm and the projection of the maximum point of the medial arcs was placed on the X-axis. The participants were asked to hold themselves fixed in (0) point by looking at the screen in front of them, their hands were placed on their waist (Fig. 2a).

(a1) *Bipedal stance* was performed as either eyes open (EO) or eyes closed (EC). The obtained data were assessed in terms of center of pressure in the medial–lateral direction on X-axis projection (C.o.P.X), Center of Pressure in the anterior–posterior direction on Y-axis projection (C.o.P.Y), forward–backward standard deviation (FBSD), medium-lateral standard deviation (MLSD), average forward–backward velocity (AFBV; mm/s), average medio-lateral velocity (AMLV; mm/s), perimeter (P; mm), and ellipse area (E; mm^2).

(a2) *Unipedal stance* was measured on the right and left leg, respectively, while the eyes were open, and the same parameters performed in the bipedal stance were evaluated.

(b) Dynamic balance test (equilibrium/disequilibrium test; 60 s)

At the beginning of this test, the adjustment of the stability of the tilting board was done and the pistons of the axis on which the measurements will be done were relaxed whereas the pistons of the other axis were hardened. The patients stood on the swinging tilting board. In the test, the participants were shown some galleries which were depicted on screen monitor. The aim was to enter the galleries and to maintain the tilting board as firmly as possible. In this test, medio-lateral (right-left: RL) and antero-posterior (forward–backward: FB) directions were used (Fig. 2b). Front/

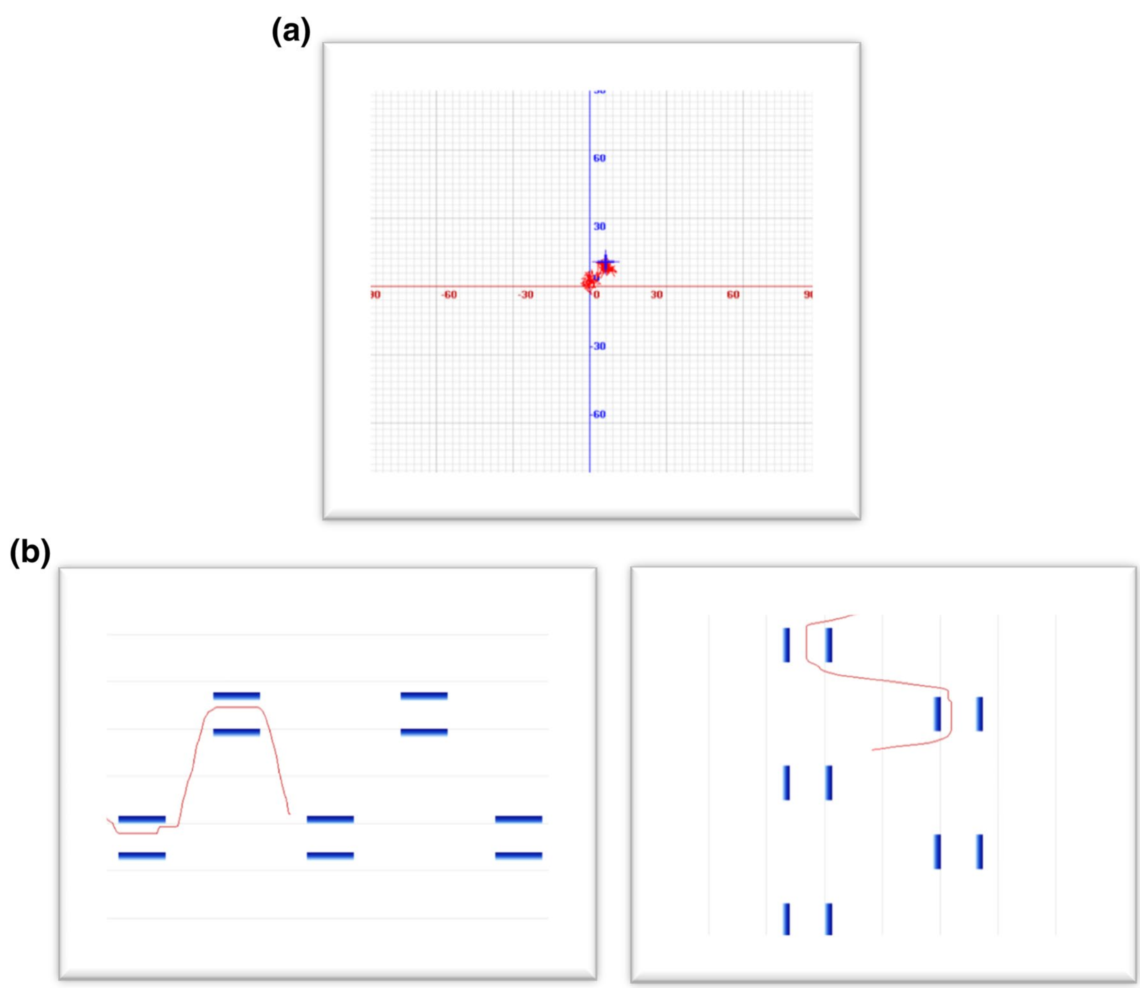

Fig. 2 The galleries that participants saw at the time of static (**a**) and dynamic (**b**) balance measurements

right standard deviation (FRSD), backward/left standard deviation (BLSD), and distance medium error (DME) parameters were assessed.

The study was approved by the local ethics committee of Istanbul University Cerrahpasa Medical Faculty and all procedures performed in studies involving human participants were in conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Statistical analyses

The data were statistically analyzed using the Statistical Package for the Social Sciences for Windows version 24.0 (SPSS, Chicago, IL) program. The results are expressed as means and standard deviations. The normality of distribution was assessed using the Shapiro–Wilk test. The categorical variables were assessed using Pearson's Chi square test or Fisher's exact test. The independent samples *t* test was used to compare the ages, weights, heights, and BMIs, and the Mann–Whitney *U* test was used to compare the balance parameters of the patients with acromegaly and the healthy volunteers. Wilcoxon signed-rank test was used for the comparison of pre and post-exercise values. $p < 0.05$ was considered as statistically significant.

Results

A total of 25 patients with acromegaly (11 patients in group A and 14 patients in group B) and 13 healthy volunteers (group C) were evaluated in the study.

The ages, sex, educational status, and physical characteristics of the entire study group were similar between patients with acromegaly and healthy controls (Table 1). In patients with acromegaly, the pre-exercise BMI values of group A were slightly higher than in group B (33.9 ± 4.7 vs. 30.0 ± 4.1 kg/m^2; p = 0.03), but ages (44.7 ± 8.5 years vs. 45.8 ± 5.7 years; p = 0.69) and post-exercise BMIs (33.1 ± 4.5 vs. 29.7 ± 3.91 kg/m^2; p = 0.05) were similar. The BMI values of group A were significantly decreased after 3 months of exercise (33.9 ± 4.7 vs. 33.1 ± 4.5 kg/m^2; p = 0.04), whereas it did not change in group B (30.0 ± 4.1 vs. 29.7 ± 3.9 kg/m^2; p = 0.30).

When the balance parameters of all patients with acromegaly were compared with the healthy controls, the pre-exercise static and dynamic balance values of the acromegaly group were used because the healthy controls did not take any exercise program. In bipedal static balance measurements, there was a difference of EO C.o.P.Y (p = 0.002) and EC AMLV (p = 0.001) values between the groups. In unipedal stance analysis, displacement of C.o.P.Y on the left leg (p = 0.001) and C.o.P.X on the right leg (p = 0.03) was seen in patients with acromegaly when compared with the healthy controls. Other bilateral and unilateral static balance values were similar between the groups. In the dynamic balance tests, only FBFRSD (p = 0.02) values were different between the groups.

Table 1 Ages and physical characteristics of all study group

	Patients with acromegaly[a] (n = 25)	Healthy controls (n = 13)	p
Age (years)	45.3 ± 6.9	44.8 ± 6.4	0.62
Sex (F/M)	20/5	8/5	0.26
Height (cm)	164.1 ± 8.7	168.0 ± 10.6	0.21
Weight (kg)	85.8 ± 15.1	84.0 ± 10.2	0.77
BMI (kg/m^2)	31.7 ± 4.7	30.0 ± 4.1	0.32

Data are expressed as mean ± standard deviation

BMI: Body mass index

[a]The weight and BMI results of acromegaly group shown in the table are the pre-exercise values

The disease characteristics of the acromegaly intervention group (group A) and the acromegaly control group (group B) were similar (Table 2). The mean levothyroxine doses that patients with thyroid-stimulating hormone (TSH) deficiency took were similar between the groups (122.8 ± 3.75 mg vs. 121.8 ± 10.2 mg; p = 0.88).

Static and dynamic balance measurements before and after exercise in patients with acromegaly are presented in Table 3.

The pre and post exercise bipedal stance values of patients with eyes open were similar, whereas the post-exercise values of C.o.P.Y with eyes closed were found to be better than pre-exercise values in both group A (p = 0.01) and group B (p = 0.02). In dynamic balance measurements, the FBFRSD, FBDME, and RLBLSD values were found to be better after exercise (p = 0.02, p = 0.02, and p = 0.004, respectively) in group A, but did not change in group B.

Discussion

In our study, we found that patients with acromegaly had impairments in some static and dynamic balance parameters, especially in the posterior direction when compared with healthy volunteers. In addition, when the effect of exercise on balance was assessed in patients with acromegaly, we determined that static balance was relatively preserved but dynamic balance profoundly improved after a 3-month exercise program. To our knowledge, this is the first study to assess the effect of exercise on balance in patients with

Table 2 Disease characteristics of patients with acromegaly

	Acromegalic intervention group (Group A) n = 11	Acromegalic control group (Group B) n = 14	p
Remission status, n(%)			1.0
Remission (+)	7(63.6%)	9 (64.2%)	
Remission (−)	4 (36.4%)	5 (35.8%)	
Patients underwent surgery	10	10	1.0
Medical treatment use	9	9	1.0
Radiotherapy need	2	4	0.66
Hypopituitarism	4	6	1.0
ACTH deficiency	0	0	
TSH deficiency	3	4	
FSH/LH deficiency	1	2	
Co-morbidities			1.0
Diabetes mellitus	2	3	
Hypertension	3	3	
Diabetes mellitus + Hypertension	2	3	
Dyslipidemia	3	3	

acromegaly with a device that evaluates visual, auditory, and proprioceptive feedback.

Balance represents a complex interplay between the sensory and motor systems. It depends on the feedback of sensory information from visual, vestibular, and somatosensory sources. The central nervous system processes information by comparing one's previous experience and body posture with reflex motor activity [16]. Abnormalities affecting this sensori-motor complex such as musculoskeletal disorders, diseases, or aging may affect balance [9].

It is well-known that body composition changes in acromegaly. Body water and lean body mass increase, whereas body fat decreases in patients with acromegaly [4]. Moreover, long-term GH and IGF-1 hypersecretion may lead to acromegalic arthropathy, which is characterized by cartilage hypertrophy in the early stages and classic degenerative joint disease in the later stages of the disease [4, 6]. These musculoskeletal and body compositional changes, together with possible visual abnormalities caused by surgery, may lead patients to face changes in balance.

It was shown in previous studies that the hypertrophied muscle mass of patients with acromegaly, contrary to expectations, was associated with weakness and that there was no functional benefit of this muscle mass. [17, 18]. Nagulesparen et al. found that there was hypertrophy in type 1 fibers, but atrophy was seen in type 2 fibers [19]. Guedes da Silva et al. showed that patients with acromegaly had less peripheral muscle strength and greater fatigability than healthy controls [20]. These large but weaker muscles might not have the expected positive effect on balance.

In literature, there are scant data about balance in patients with acromegaly. Lopes et al. studied posture and static balance in 28 patients with acromegaly and showed that patients with acromegaly had impairments of static balance in both anteroposterior and mediolateral directions [8]. Homem et al. evaluated balance in 17 older patients with acromegaly and found balance problems in the medial–lateral direction in patients with acromegaly compared with healthy controls. They extrapolated that the medial–lateral instability seen in their study group might be related with the deterioration in age-related somatosensory inputs [21]. Atmaca et al. evaluated balance and fear of falling in 48 patients with acromegaly and found impaired dynamic but preserved static balance in acromegalic subjects [22]. In our study, we found that the dynamic balance of patients with acromegaly was similar to healthy volunteers, but there was a displacement of center of mass posteriorly in patients with acromegaly when compared with healthy volunteers. Considering that the BMIs were similar between the groups, we thought that the patients with acromegaly might have adjusted their weight centers further backwards to maintain balance given that they had more lean body mass and muscle mass compared with healthy individuals. Consistent with our study, it was shown in the literature that patients with obesity had static balance impairments but they adapted their gait pattern and had similar dynamic gait stabilities compared with healthy non-obese controls [23–25]. Additionally, it is known that enthesopathy, which is a frequent sign of acromegaly, may cause impairments in proprioceptive responses [1, 8, 26]. In previous studies, it was suggested that impaired balance seen in patients with acromegaly might be related to disturbances in proprioception, but to date, no studies have evaluated proprioception. It is noteworthy that the device

Table 3 Eyes open and eyes closed bipedal stance static (a), unipedal stance static (b) and dynamic (c) balance measurements before and after exercise in patients with acromegaly **(A)**

Bılateral stance	Eyes open			Eyes closed		
	Group A[a] (n = 11)	Group B[b] (n = 14)	p[c]	Group A[a] (n = 11)	Group B[b] (n = 14)	p[c]
(A)						
C.o.P.X						
Pre-exercise	− 1.7 ± 8.9	0.07 ± 6.6	0.64	− 4.2 ± 10.2	1.3 ± 12.2	0.13
Post-exercise	− 3.9 ± 16.0	1.43 ± 7.8	0.44	− 6.5 ± 17.9	0.29 ± 12.0	0.27
p[d]	0.68	0.37		0.45	0.55	
C.o.P.Y						
Pre-exercise	− 13.7 ± 8.9	− 6.14 ± 9.0	0.05	− 21.0 ± 7.5	− 13.7 ± 9.1	0.05
Post-exercise	− 5.8 ± 16.9	− 9.25 ± 11.7	0.32	− 2.0 ± 21.1	− 6.2 ± 11.4	0.66
p	0.21	0.50		**0.01**	**0.02**	
FBSD						
Pre-exercise	6.8 ± 1.7	7.7 ± 4.8	0.82	8.2 ± 1.1	7.2 ± 1.7	0.05
Post-exercise	5.6 ± 1.3	6.0 ± 1.3	0.30	7.7 ± 1.4	6.5 ± 1.3	**0.04**
p	0.08	0.25		0.32	0.17	
MLSD						
Pre-exercise	4.0 ± 2.2	4.4 ± 2.4	0.63	3.7 ± 1.1	3.0 ± 1.5	0.14
Post-exercise	3.6 ± 2.1	3.8 ± 2.6	0.80	3.0 ± 1.2	2.7 ± 0.9	0.88
p	0.85	0.24		0.10	0.75	
AFBV (mm/sec)						
Pre-exercise	14.7 ± 3.0	15.7 ± 4.6	0.70	20.0 ± 4.8	19.2 ± 4.9	0.65
Post-exercise	13.9 ± 3.7	15.4 ± 4.0	0.16	19.0 ± 5.1	17.9 ± 3.6	0.60
p	0.53	0.75		0.32	0.32	
AMLV (mm/sec)						
Pre-exercise	7.0 ± 2.9	9.5 ± 4.1	0.05	7.6 ± 2.7	6.3 ± 1.9	0.26
Post-exercise	8.1 ± 3.9	9.0 ± 5.7	0.74	7.3 ± 3.4	5.7 ± 1.4	0.26
p	0.91	0.64		0.72	0.42	
P (mm)						
Pre-exercise	476.3 ± 101.5	551.9 ± 167.2	0.11	592.2 ± 141.2	558.0 ± 126.4	0.54
Post-exercise	478.0 ± 139.7	533.2 ± 170.9	0.26	566.8 ± 137.1	523.8 ± 95.3	0.52
p	0.72	0.92		0.64	0.43	
E (mm^2)						
Pre-exercise	465.5 ± 277.3	609.3 ± 470.1	0.72	544.6 ± 218.0	395.2 ± 258.9	**0.04**
Post-exercise	386.9 ± 282.9	497.4 ± 570.4	0.52	427.9 ± 171.7	320.2 ± 136.9	0.12
p	0.32	0.39		0.09	0.43	
Unılateral stance	Rıght leg		p[c]	Left leg		p
	Group A[a] (n = 11)	Group B[b] (n = 14)		Group A (n = 11)	Group B (n = 14)	
(B)						
C.o.P.X						
Pre-exercise	12.9 ± 5.6	9.1 ± 5.1	0.16	− 14.0 ± 11.5	− 12.1 ± 12.3	0.70
Post-exercise	6.1 ± 7.2	8.1 ± 8.9	0.58	− 14.1 ± 12.6	− 13.7 ± 8.1	0.60
p[d]	**0.04**	0.61		0.96	0.75	
C.o.P.Y						
Pre-exercise	− 0.2 ± 20.0	9.2 ± 13.2	0.23	9.9 ± 14.0	8.2 ± 9.4	0.95
Post-exercise	3.3 ± 14.7	3.9 ± 14.2	0.70	4.2 ± 8.3	4.7 ± 10.1	0.58
p	0.47	0.30		0.15	0.20	
FBSD						

Table 3 (continued)

Unılateral stance	Rıght leg		p^c	Left leg		p
	Group A[a] (n = 11)	Group B[b] (n = 14)		Group A (n = 11)	Group B (n = 14)	
Pre-exercise	9.5 ± 3.9	8.3 ± 1.4	0.91	8.2 ± 2.1	9.3 ± 2.8	0.40
Post-exercise	7.3 ± 1.4	7.6 ± 1.0	0.75	7.0 ± 1.9	7.9 ± 0.9	0.13
p	0.06	0.13		0.11	**0.04**	
MLSD						
Pre-exercise	7.7 ± 2.4	7.0 ± 2.0	0.41	7.0 ± 0.7	7.5 ± 1.5	0.42
Post-exercise	6.5 ± 1.4	6.1 ± 1.4	0.43	6.6 ± 1.3	6.8 ± 1.5	0.82
p	0.05	**0.01**		0.21	**0.03**	
AFBV (mm/sec)						
Pre-exercise	29.7 ± 7.9	36.1 ± 10.0	0.11	29.9 ± 5.9	36.2 ± 10.9	0.13
Post-exercise	27.4 ± 6.9	28.8 ± 4.7	0.22	26.0 ± 6.0	33.1 ± 8.2	**0.03**
p	0.06	**0.01**		**0.04**	0.13	
AMLV (mm/sec)						
Pre-exercise	33.3 ± 8.1	36.2 ± 11.0	0.38	32.8 ± 7.3	37.3 ± 8.0	0.16
Post-exercise	28.7 ± 6.6	31.2 ± 7.9	0.38	29.0 ± 7.6	34.8 ± 7.6	0.06
p	0.05	**0.03**		0.08	0.18	
P (mm)						
Pre-exercise	1271.0 ± 296.0	1452.5 ± 470.6	0.10	1252.1 ± 221.3	1477.6 ± 322.9	0.07
Post-exercise	1049.9 ± 414.9	1210.5 ± 233.7	0.20	1061.2 ± 326.0	1365.7 ± 292.5	**0.02**
p	**0.02**	**0.02**		0.11	0.13	
E (mm^2)						
Pre-exercise	1423.2 ± 1091.9	1131.9 ± 584.9	0.93	1076.0 ± 352.1	1326.6 ± 625.7	0.58
Post-exercise	890.8 ± 311.3	868.0 ± 236.5	0.62	886.0 ± 340.3	1019.7 ± 320.4	0.35
p	**0.04**	**0.04**		0.18	**0.04**	

Dynamıc balance	Group A[a] (n = 11)	Group B[b] (n = 14)	p^c
(C)			
FBFRSD			
Pre-exercise	1.71 ± 0.94	1.60 ± 0.93	0.78
Post-exercise	1.02 ± 0.39	1.74 ± 1.48	0.29
p^d	**0.02**	0.87	
FBBLSD			
Pre-exercise	2.03 ± 1.03	2.05 ± 0.88	0.70
Post-exercise	1.39 ± 0.73	2.41 ± 1.77	0.09
p	0.08	0.77	
FBDME			
Pre-exercise	1.60 ± 1.50	2.13 ± 3.00	0.87
Post-exercise	0.39 ± 0.60	1.78 ± 1.90	**0.01**
p	**0.02**	0.55	
RLFRSD			
Pre-exercise	1.31 ± 0.81	1.89 ± 1.15	0.17
Post-exercise	1.22 ± 0.59	2.07 ± 1.36	0.15
p	0.96	0.73	
RLBLSD			
Pre-exercise	2.07 ± 1.10	2.02 ± 1.14	0.97
Post-exercise	1.17 ± 0.50	1.89 ± 1.47	0.26
p	**0.004**	0.33	
RLDME			

Table 3 (continued)

Dynamıc balance	Group A[a] (n = 11)	Group B[b] (n = 14)	p[c]
Pre-exercise	0.93 ± 0.85	1.97 ± 2.63	0.60
Post-exercise	0.60 ± 0.68	1.60 ± 2.53	0.32
p	0.18	0.80	

Statistically significant p values are highlighted in bold

C.o.P.X X axis projection, *C.o.P.Y* Y axis projection, *FBSD* forward–backward standard deviation, *MLSD* medium-lateral standard deviation, *AFBV* average forward–backward velocity, *AMLV* average medium-lateral velocity, *P* perimeter, *E* ellipse area, *FBFRSD* forward–backward front/right standard deviation; *FBBLSD* forward–backward backward/left standard deviation; *FBDME* forward–backward distance medium error; *RLFRSD* right-left front/right standard deviation; *RLBLSD* right-left backward/left standard deviation

[a]Group A: acromegalic patients who took exercise

[b]Group B: acromegalic control group

[c]The p value expresses the difference of the parameters between Group A and B; Mann–Whitney *U* test was used for the analyses

[d]The p value expresses the difference of pre- and post-exercise parameters in the same Group; Wilcoxon signed rank test was used for the analyses

we used in our study evaluated all visual, auditory, and proprioceptive feedbacks and was therefore highly sensitive.

The positive effects of exercise on balance have been shown in many studies with athletes and in various disease states and different age groups related to balance impairments [27–32]. There are studies showing that exercise improves quality of life and body composition and increases muscle strength in patients with acromegaly [33, 34]. However, the effect of exercise on balance in acromegaly was evaluated for the first time in this study, and we showed that the most impressive changes were seen in the dynamic balance parameters. Although the FBFRSD, FBDME, and RLBLSD values were significantly improved, all the dynamic parameters became better with exercise but some did not reach statistical significance.

By contrast, there was no marked difference in bipedal static measurements and various improvements in some but not all unilateral static balance parameters. The reason for this discrepancy might be that the exercise program was a group-based program instead of personal training. Muscle groups that each individual uses in daily life vary according to the occupation and lifestyle of the person. If a personal training program was applied instead of a group-based program, the individual muscle groups that needed to be strengthened would be specifically worked and the impact of the exercise on balance could be shown more clearly.

The strength of this study is that it is the first study to evaluate the visual, auditory, and proprioceptive responses in balance measurements with an objective and highly sensitive method in patients with acromegaly. Additionally, the impact of exercise on balance in patients with acromegaly was evaluated for the first time. However, the study had some limitations. First, the study population was small. Moreover, the duration of the exercise program was short. It is probable that we could more clearly determine the positive effects of exercise on balance if the duration of exercise was longer. One other limitation was the difference in some of the static balance parameters seen in the patients with acromegaly who did not take any exercise. Although the BMI values of the patients in this group did not change in the 3-month period, their daily activities might be increased and this may have caused the change. Despite these limitations, this study may induce larger-scale studies that may enlighten cause-and-effect relationships of balance in patients with acromegaly. Since balance impairments are significant comorbidities that affect the quality of life of patients with acromegaly, exercise programs may become an adjunctive method in the management of the disease.

In conclusion, we determined various impairments in static and dynamic balance parameters of patients with acromegaly when compared with healthy controls, and the imbalances of both static, but particularly dynamic measurements, were improved by a short-term exercise program. Exercise programs may be recommended to patients with acromegaly as an adjunctive therapy in order to prevent probable balance and gait problems related to the comorbidities of acromegaly.

Acknowledgements We thank Mr. David F. Chapman for his help regarding English language editing.

Funding The study was supported by the Research Fund of Istanbul University, Istanbul, Turkey (Project No: 22561).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights The study was approved by the local ethics committee of Istanbul University Cerrahpasa Medical Faculty and all procedures performed in studies involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Colao A, Ferone D, Marzullo P, Lombardi G (2004) Systemic complications of acromegaly: epidemiology, pathogenesis, and management. Endocr Rev 25(1):102–152
2. Woodhouse LJ, Mukherjee A, Shalet SM, Ezzat S (2006) The influence of growth hormone status on physical impairments, functional limitations, and health-related quality of life in adults. Endocr Rev 27(3):287–317
3. Ben-Shlomo A, Sheppard MC, Stephens JM, Pulgar S, Melmed S (2011) Clinical, quality of life, and economic value of acromegaly disease control. Pituitary 14(3):284–294
4. Katznelson L (2009) Alterations in body composition in acromegaly. Pituitary 12(2):136–142
5. Johanson NA, Vigorita VJ, Goldman AB, Salvati EA (1983) Acromegalic arthropathy of the hip. Clin Orthop Relat Res 173:130–139
6. Claessen KM, Mazziotti G, Biermasz NR, Giustina A (2016) Bone and joint disorders in acromegaly. Neuroendocrinology 103(1):86–95
7. Wassenaar MJ, Biermasz NR, Bijsterbosch J, Pereira AM, Meulenbelt I, Smit JW, Roelfsema F, Kroon HM, Romijn JA, Kloppenburg M (2011) Arthropathy in long-term cured acromegaly is characterised by osteophytes without joint space narrowing: a comparison with generalised osteoarthritis. Ann Rheum Dis 70(2):320–325
8. Lopes AJ, da Silva DP, Kasuki L, Gadelha MR, Camilo GB, Guimaraes FS (2014) Posture and balance control in patients with acromegaly: results of a cross-sectional study. Gait Posture 40(1):154–159
9. Kinzey SJ, Armstrong CW (1998) The reliability of the star-excursion test in assessing dynamic balance. J Orthop Sports Phys Ther 27(5):356–360
10. Goldie PA, Bach TM, Evans OM (1989) Force platform measures for evaluating postural control: reliability and validity. Arch Phys Med Rehabil 70(7):510–517
11. Sell TC (2012) An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. Phys Ther Sport 13(2):80–86
12. do Carmo CM, Almeida da Rocha B, Tanaka C (2017) Effects of individual and group exercise programs on pain, balance, mobility and perceived benefits in rheumatoid arthritis with pain and foot deformities. J Phys Ther Sci 29(11):1893–1898
13. Duregon F, Vendramin B, Bullo V, Gobbo S, Lucia C, Di Blasio A, Neunhaeuserer D, Zaccaria M, Bergamin M, Ermolao A (2017) Effects of exercise on cancer patients suffering chemotherapy-induced peripheral neuropathy undergoing treatment: a systematic review. Crit Rev Oncol Hematol 121:90–100
14. Hamed A, Bohm S, Mersmann F, Arampatzis A (2017) Exercise dynamic stability under unstable conditions increases muscle strength and balance ability in the elderly. Scand J Med Sci Sports 28(3):961–971
15. Katznelson L, Laws ER Jr, Melmed S, Molitch ME, Murad MH, Utz A, Wass JA, Endocrine S (2014) Acromegaly: an endocrine society clinical practice guideline. J Clin Endocrinol Metab 99(11):3933–3951
16. Hugel F, Cadopi M, Kohler F, Perrin P (1999) Postural control of ballet dancers: a specific use of visual input for artistic purposes. Int J Sports Med 20(2):86–92
17. Freda PU, Shen W, Reyes-Vidal CM, Geer EB, Arias-Mendoza F, Gallagher D, Heymsfield SB (2009) Skeletal muscle mass in acromegaly assessed by magnetic resonance imaging and dual-photon x-ray absorptiometry. J Clin Endocrinol Metab 94(8):2880–2886
18. Khaleeli AA, Levy RD, Edwards RH, McPhail G, Mills KR, Round JM, Betteridge DJ (1984) The neuromuscular features of acromegaly: a clinical and pathological study. J Neurol Neurosurg Psychiatr 47(9):1009–1015
19. Nagulesparen M, Trickey R, Davies MJ, Jenkins JS (1976) Muscle changes in acromegaly. Br Med J 2(6041):914–915
20. Guedes da Silva DP, Guimaraes FS, Dias CM, Guimaraes Sde A, Kasuki L, Gadelha MR, Camilo GB, Lopes AJ (2013) On the functional capacity and quality of life of patients with acromegaly: are they candidates for rehabilitation programs? J Phys Ther Sci 25(11):1497–1501
21. Homem TS, Guimaraes FS, Soares MS, Kasuki L, Gadelha MR, Lopes AJ (2017) Balance control and peripheral muscle function in aging: a comparison between individuals with acromegaly and healthy subjects. J Aging Phys Act 25(2):218–227
22. Atmaca A, Tander B, Kan EK, Ulus Y, Ecemis GC, Akyol Y, Tomak L (2013) Assessment of balance performance and fear of falling in acromegalic patients: a comparative study. J Endocrinol Invest 36(9):759–763
23. Liu ZQ, Yang F (2017) Obesity may not induce dynamic stability disadvantage during overground walking among young adults. PLoS ONE 12(1):e0169766
24. Bučková K, Lobotková J, Hirjaková Z, Bzdúšková D, Hlavačka F (2014) Postural control assessed by limit of stability in obese adults. Act Nerv Super Rediviva 56(3–4):87–90
25. Hue O, Simoneau M, Marcotte J, Berrigan F, Doré J, Marceau P, Marceau S, Tremblay A, Teasdale N (2007) Body weight is a strong predictor of postural stability. Gait Posture 26(1):32–38
26. Pompeu JE, Romano RS, Pompeu SM, Lima SM (2012) Static and dynamic balance in subjects with ankylosing spondylitis: literature review. Rev Bras Reumatol 52(3):409–416
27. Lam FM, Huang MZ, Liao LR, Chung RC, Kwok TC, Pang MY (2018) Physical exercise improves strength, balance, mobility, and endurance in people with cognitive impairment and dementia: a systematic review. J Physiother 64(1):4–15
28. Lee JH, Howell DR, Meehan WP 3rd, Iverson GL, Gardner AJ (2017) Effects of exercise on sport concussion assessment tool-third edition performance in professional athletes. Orthop J Sports Med 5(9):2325967117727261
29. Kargarfard M, Shariat A, Ingle L, Cleland JA, Kargarfard M (2017) Randomized controlled trial to examine the impact of aquatic exercise training on functional capacity, balance, and perceptions of fatigue in female patients with multiple sclerosis. Arch Phys Med Rehabil 99(2):234–241
30. Lacroix A, Hortobagyi T, Beurskens R, Granacher U (2017) Effects of supervised vs. unsupervised training programs on balance and muscle strength in older adults: A systematic review and meta-analysis. Sports Med 47(11):2341–2361
31. Demontis A, Trainito S, Del Felice A, Masiero S (2016) Favorable effect of rehabilitation on balance in ankylosing spondylitis: a quasi-randomized controlled clinical trial. Rheumatol Int 36(3):333–339
32. Atilgan OE (2013) Effects of trampoline training on jump, leg strength, static and dynamic balance of boys. Sci Gymnast J 5(2):15–25

33. Hatipoglu E, Topsakal N, Atilgan OE, Alcalar N, Camliguney AF, Niyazoglu M, Cotuk HB, Kadioglu P (2014) Impact of exercise on quality of life and body-self perception of patients with acromegaly. Pituitary 17(1):38–43
34. Hatipoglu E, Topsakal N, Erkut Atilgan O, Camliguney AF, Ikitimur B, Ugurlu S, Niyazoglu M, Cotuk HB, Kadioglu P (2015) Physical and cardiovascular performance in cases with acromegaly after regular short-term exercise. Clin Endocrinol (Oxf) 83(1):91–97