ORIGINAL ARTICLE

Effect of high-intensity training on bone health and body composition in lung transplant recipients: A secondary analysis of a randomized controlled trial

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Abstract

Background: Loss of bone mineral and skeletal muscle mass is common after lung transplantation (LTx), and physical activity (PA) may prevent further deterioration. We aimed to assess the effects of 20-week high-intensity training (HIT) on body composition, bone health, and PA in LTx recipients, 6–60 months after surgery.

Methods: In a randomized controlled trial, 51 LTx recipients underwent Dual-energy X-ray absorptiometry (DXA), and PA level and sedentary time were objectively recorded by accelerometers for seven consecutive days. Of these, 39 participants completed the study, including 19 participants in the HIT group and 20 participants in the standard care group.

Results: Following the intervention, ANCOVA models revealed a nonsignificant between-group difference for change in lean body mass (LBM) and bone mineral density (BMD) of the lumbar spine of 0.4% (95% CI = −3.2, 1.5) ($p = .464$) and 1.0% (95% CI=−1.3, 3.4) ($p = .373$), respectively. Trabecular bone score (TBS) of the lumbar spine (L1-L4), however, increased by 2.2 ± 5.0% in the exercise group and decreased by −1.6 ± 5.9% in the control group, giving a between-group difference of 3.8% (95% CI=0.1, 7.5) ($p = .043$). There were no between-group differences in PA or sedentary time.

Conclusion: High-intensity training after LTx improved TBS significantly, but not PA, LBM or BMD.

KEYWORDS
clinical trials, dual-energy X-ray absorptiometry, exercise training, osteoporosis, sarcopenia

1 | INTRODUCTION

Lung transplantation (LTx) is a life-saving treatment for patients with terminal lung disease. Although LTx prolongs survival and improves quality of life in appropriately selected patients, it is also associated with morbidities that may complicate long-term outcomes, among them osteoporosis and sarcopenia.[1,2]

A high prevalence of osteoporosis has been reported following solid organ transplantation, and LTx recipients seem to be the most susceptible.[3,4] Studies have shown a bone mineral density (BMD)

reduction of 12–15% within the first 2 months after LTx.[5,6] The loss of BMD is a well-known consequence of immunosuppressive therapy with glucocorticoids and calcineurin inhibitors, which are prescribed to all transplant recipients to prevent organ rejection.[3,7] Glucocorticoids also induce muscle loss,[8] leading to sarcopenia. Low muscle mass has been suggested to occur in 33% of LTx recipients 2 years after surgery.[9] These negative effects may be counteracted with increased levels of physical activity (PA). Unfortunately, physical activity levels have been reported to be low in this patient population.[10]

To date, two randomized controlled trials have investigated the effect of exercise training on BMD after LTx, and demonstrated muscular strength training to effectively reverse the loss of bone mineral in the lumbar vertebrae, when this region was targeted specifically.[5,6] Whether or not exercise training leads to recovery of muscle mass in this population is, however, unclear. Despite an increase in muscle strength after LTx, no change in fat-free mass was observed after 12 weeks of home-based exercise training.[11]

Previous studies and current rehabilitation recommendations after LTx involve primarily exercise training at moderate intensity. However, studies in other disease populations have shown high-intensity training to be superior to moderate-intensity training in improving physical fitness-related outcomes such as muscle strength. Given the reported prevalence of osteoporosis and sarcopenia, and the low levels of physical activity among LTx recipients, we evaluated the effect of high-intensity endurance and strength training (HIT) on body composition, bone health, and PA after LTx. We hypothesized that HIT would improve body composition, bone health, and PA as compared with standard care.

2 | MATERIALS AND METHODS

2.1 | Study design

This national, single-blind, single-center study was part of a larger randomized controlled trial, the High Intensity training after Lung Transplant study (HILT), investigating the effects of HIT six to 60 months after LTx. The study was conducted at Oslo University Hospital, Norway, between September 2017 and January 2019. Eligible participants were ≥18 years of age with a stable medical condition in the opinion of the enrolling investigator. Exclusion criteria included inability to complete a symptom-limited maximal cardiopulmonary exercise test (CPET) on a treadmill, or participation in another ongoing study.

After baseline testing, the participants were randomized to either 20 weeks of HIT or standard care, in a 1:1 allocation ratio and put into sealed opaque envelopes generated by an external statistician. Block randomization of four to six participants was performed without any stratification.

All participants provided written informed consent prior to enrollment, and the study was performed in accordance with the Helsinki Declaration, approved by the Regional Committee for Medical and Health Research Ethics (REK South-East, no. 2017/399), and registered in ClinicalTrials.gov (NCT03155074).

2.2 | Outcomes

Effects on peak oxygen uptake and muscle strength have been reported previously.[12] Pre-specified secondary outcomes are reported here, including change in body composition (lean and fat body mass), BMD, lumbar spine trabecular bone score (TBS), and objective measures of physical activity (counts per minute, steps per day, sedentary time). All outcomes were evaluated at pre-randomization, and primarily repeated ≤7 days after the final intervention session or after 20 weeks ± 7 days for the control group.

2.3 | Dual-energy X-ray absorptiometry

Body composition and BMD were determined with *Dual*-energy *X-ray* absorptiometry (DXA). A narrow fan beam (GE Healthcare Lunar Prodigy) densitometer was used and all the scans were reanalyzed in the same Lunar software version enCORE 14.10 from GE Healthcare, according to a standard protocol. No hardware changes were made during the study period. Daily calibration was performed, and potential drift in densitometer values was monitored by quality assurance checks twice a week with an aluminum spine phantom block mounted to an acrylic block.[13] According to the device producer, the short- and long-term coefficients of variation were 0.8% and 1.4%, respectively. An ISCD (The International Society for Clinical Densitometry) Certified Clinical Densitometrist performed all the analyses (KG).

LBM and FBM (g and %) were measured from total body composition and sub-regions of interest (ROI's) for arms, legs, and trunk were analyzed. In addition, visceral- (VAT) and subcutaneous adipose tissue (SAT) were analyzed (g) in the android and gynoid ROI.[14]

The following BMD variables were evaluated: Anterior-posterior lumbar spine L1-L4 (LS), dual total hip (TH), ultra-distal (UD) and distal 33% radius (forearm) and whole body (WB), where BMD (g/cm²) and *Z*-score for these regions are reported. *Z*-scores were estimated by comparison to the Lunar reference database incorporated in the software, suitable for clinical use in the Norwegian population.[15] The Lunar reference includes BMD data from healthy subjects from the general American population.[16]

TBS was extracted from DXA L1-L4 images by using TBS iNsight software (version 2.1.2.0; Medimaps Group, Geneva, Switzerland).[17] Higher TBS indicate stronger microarchitecture less prone to fractures.[18] TBS >1.31 was defined as normal, 1.23–1.31 as partially degraded microstructure, and >1.23 as degraded microstructure.[19] TBS results from patients with BMI>37 kg/m² were excluded.[20]

2.4 | Measurement of physical activity

As previously described,[21] physical activity was measured by waist-borne accelerometers (ActiGraph GT1 M, LLC) for seven consecutive days during waking hours. The accelerometers were initialized and downloaded using ActiLife software (ActiGraph GT1 M, LLC). The participants were instructed to wear the accelerometer to their right hip and were asked to perform their daily activities as usual. The assessment started directly after baseline testing and was repeated after follow-up.[21] Wear days were deemed valid if the accelerometer was worn for at least 480 min/day and a minimum of two valid days.

All accelerometers extracted data from the vertical axis in 10 seconds epochs and were reanalyzed in order to produce PA and sedentary time variables using KineSoft (version 3.3.20). The following variables were evaluated: days and hours per day of wear time, mean counts per minute, mean steps per day, sedentary time, and time spend in moderate and vigorous intensity PA. Sedentary time was defined as <100 counts per minute and moderate-to-vigorous PA as ≥2020 counts per minute.[22] Adherence to PA recommendations was defined as accumulating a daily average of moderate-to-vigorous PA of >21.4 min/d accrued in bouts lasting ≥10 minutes, in accordance with World Health Organization's (WHO) recommendations.[23]

2.5 | Training intervention

The participants randomized to HIT were asked to follow an exercise program consisting of both endurance and muscular strength training three times a week for 20 weeks. The sessions were performed at fitness centers near the participant's home. Each session was estimated to take 60 min and was supervised one-on-one by certified personal trainers and physical therapists. The endurance training consisted of uphill interval walking on a treadmill with an intensity of 85–95% of the participant's peak heart rate measured during a previously described cardiopulmonary exercise test (CPET).[12] The endurance training was followed by muscular strength training and included three sets of 6–12 repetition maximum (RM) by leg press, arm press, back extension, and seated row using stationary machines. The training program was individually tailored, the training intensity and weight load were adjusted according to the participant's level of fitness and improvements during the intervention, and dose modification was permitted.

2.6 | Standard care

Participants randomized to standard care were asked to follow the institution's general recommendations for maintaining physical fitness.[24]

2.7 | Statistics

Data are reported as mean ± standard deviation (SD) unless otherwise stated. Changes in outcome measures were expressed as both absolute and percentage differences. Group comparisons were based on analysis of covariance (ANCOVA) with baseline scores entered as covariates. For BMD, the use of bisphosphonates (yes/no) was also entered as a covariate. However, bisphosphonate use did not change the results and the model is not shown. All analyses were conducted under the intention-to-treat principle, and missing values were not imputed. Per-protocol analysis was also performed, where participants were included if the attendance was ≥70% of the planned 60 sessions. Pearson's correlation coefficients were used to assess associations between PA and LBM, BMD, and TBS. Comparison of participants meeting and not meeting the WHO recommendation for PA was performed by independent samples t-tests. A p-value <.05 was considered statistically significant. All analyses were performed using SPSS version 26.0 (IBM Statistics).

3 | RESULTS

Of the 54 LTx recipients who qualified and consented to take part in the HILT study, 51 participants underwent DXA scan and 50 participants had successful physical activity recordings at baseline evaluation. Figure 1 shows the participant flow through the study. The 51 participants with baseline DXA scan are included in this study and baseline characteristics are presented in Table 1. There were no baseline differences between the groups (p >.05).

Seven (14%) participants had BMI ≥30 kg/m^2. Baseline DXA-scan revealed a FBM of 40 ± 2% for women and 35 ± 8% for men. Accordingly, 43 participants (84%) were classified as obese, having a FBM ≥30% for women or ≥25% for men.

PA level and sedentary time at baseline have previously been reported.[21] In total seven of 50 (14%) participants met WHO's recommendations for daily PA.[21] FBM was 30 ± 8% among those who met the recommendations and 39 ± 8% for those who did not, giving at between-group difference of 8% (95% CI=1, 15, p = .020). There was no difference in LBM (p = .470), TBS (p = .154) or BMD (p = .890). In addition, FBM % was moderately correlated with PA (counts per minute) (r = −.429, p = .002). No correlations were found between counts per minute and LBM (r = 0.137, p = .352), BMD (r = 0.006, p = .966), or TBS (r = 0.221, p = .131) of the lumbar spine (L1-L4) measured at baseline.

3.1 | Effects of HIT

Thirteen (72%) of the participants with pre- and post-DXA scan adhered to the exercise training by completing >70% of the prescribed sessions. No serious adverse events were observed during testing or during training.
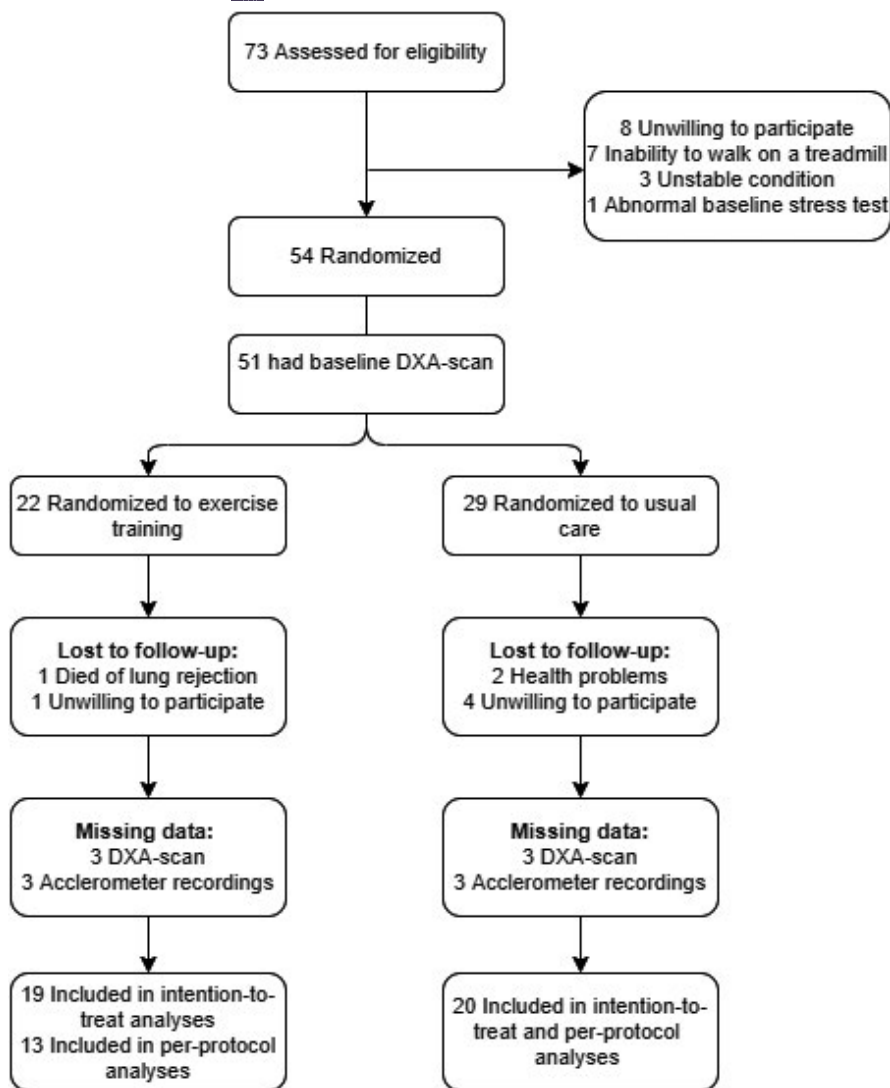
3.1.1 | Total body composition

The effects of HIT on body composition are presented in Table 2 and Figure 2. Thirteen participants in the HIT group (72%) and 13 participants in the control group (68%) increased their LBM during the intervention, while five participants in the HIT group (23%) and six participants in the control group (21%) experienced a decrease in LBM. For percentage change in SAT, there was a significant between-group difference of −13% (95% CI = −26, −1) ($p = .04$) (Figure 2) in favor of HIT.

3.2 | Bone mineral density and trabecular bone score

Fourteen participants in the HIT group (78%) and 15 participants in the control group (79%) increased their total BMD during the intervention, while four participants in each group had a lower total BMD at follow-up. Table 3 and Figure 2 show the intervention effects on BMD and TBS. TBS of the lumbar spine (L1-L4) increased by 2.2 ± 5.0% in the exercise group and decreased by −1.6 ± 5.9% in the control group, giving a significant between-group difference of 3.8% (95% CI = 0.1, 7.5) ($p = .043$) (Figure 2). The results for per-protocol analyses revealed similar results.

3.3 | Physical activity level

Changes in PA, sedentary time, and time spent in moderate-to-vigorous physical activity are presented in Table 4. Percentage change in steps per day was 10 ± 39% and 14 ± 29% ($p = .596$) for the HIT and control group, respectively. Counts per minute increased by 7 ± 35% in the HIT group and by 6 ± 32% ($p = .713$) in the control group. There was no significant between-group difference. Ten participants in each group (56% in the HIT group and 59% in the control group) increased their daily counts per minute during the intervention.

TABLE 1 Baseline characteristics of the study participants

	All n = 51	HIT group n = 22	Control group n = 29	p-value
Female, no. of patients, %	26 (51)	13 (59)	13 (45)	.323
Age, years	51.3 ± 13.0	51.6 ± 12.3	51.1 ± 13.7	.897
Time since LTx, months	29.3 ± 16.1	32.5 ± 16.2	26.7 ± 15.9	.192
Weight, kg	77.0 ± 14.9	74.4 ± 17.0	79.1 ± 13.1	.286
Height, cm	170.9 ± 9.0	170.1 ± 9.5	171.5 ± 8.8	.595
Body Mass Index, kg/m^2	26.3 ± 4.1	25.6 ± 4.6	26.8 ± 3.7	.291
Oxygen uptake and pulmonary function				
Peak oxygen uptake, mL·kg^{-1}·min^{-1}	22.0 ± 7.0	22.0 ± 7.3	22.1 ± 7.0	.864
Peak oxygen uptake, % of predicted	63 ± 16	64 ± 18	63 ± 15	.886
FEV_1, L	2.5 ± 0.8	2.5 ± 0.7	2.7 ± 0.8	.549
FEV_1, % of predicted	81 ± 26	81 ± 27	81 ± 25	.959
DL_{CO}, mmol/(min·kPa)	6.3 ± 1.5	6.1 ± 1.5	6.5 ± 1.5	.400
DL_{CO}, % predicted	76 ± 18	75 ± 19	77 ± 17	.690
Medication				
Alendronate no. of patients, %	14 (27)	5 (23)	9 (31)	.515
Tacrolimus/Cyclosporine no.	19/32	7/15	12/17	
Diagnosis prior to LTx, no. of patients (%)				
COPD	21 (41)	9 (41)	12 (41)	.974
Interstitial lung disease	15 (29)	8 (36)	7 (24)	.361
Pulmonary hypertension	6 (12)	1 (5)	5 (17)	.281
Lymphangioleiomyomatosis	2 (4)	1 (5)	1 (3)	.848
Cystic fibrosis	2 (4)	2 (9)	0 (0)	.101
Other (ARDS, GvHD, systemic sclerosis)	5 (10)	1 (5)	4 (14)	.281
Self-reported socioeconomic factors no. of patients (%)				
Married	20 (39)	9 (41)	11 (38)	.971
Higher education	17 (33)	7 (32)	10 (34)	.722
Employed	20 (39)	6 (27)	14 (48)	.108
Bone mineral density measured by DXA				
Lumbar spine (L1-L4), g/cm^2	1.073 ± 0.187	1.054 ± 0.143	1.087 ± 0.216	.541
Total hip, g/cm^2	0.850 ± 0.129	0.832 ± 0.130	0.864 ± 0.140	.390
Ultra-distal radius, g/cm^2	0.453 ± 0.119	0.415 ± 0.108	0.482 ± 0.120	.050
33% radius, g/cm^2	0.888 ± 0145	0.875 ± 0.150	0.898 ± 0.145	.593
Total body, g/cm^2	1.077 ± 0.119	1.056 ± 0.117	1.093 ± 0.139	.319
Normal, no. of patients (%)*	9 (18)	3 (14)	6 (21)	.513
Osteopenia, no. of patients (%)*	22 (43)	8 (36)	14 (48)	.403
Osteoporosis, no. of patients (%)*	20 (39)	11 (50)	9 (64)	.099
Trabecular bone extracted from lumbar spine DXA				
Trabecular bone score	1.223 ± 0.141	1.225 ± 0.110	1.221 ± 0.165	.996
Normal, no. of patients (%)**	12 (22)	4 (18)	8 (27)	.434
Partially degraded, no. of patients (%)**	12 (22)	8 (36)	4 (14)	.062
Degraded, no. of patients (%)**	27 (50)	10 (45)	17 (57)	.362

Abbreviations: ARDS, acute respiratory distress syndrome; BMD, bone mineral density; BMI, body mass index; COPD, chronic obstructive lung disease; DL_{CO}, diffusion capacity in the lungs for carbon monoxide, DXA, *Dual*-energy *X-ray* absorptiometry; FEV_1, forced expiratory volume in one second; GvHD, graft vs host disease; LTx, lung transplantation; TBS, trabecular bone score.

*T-score in any BMD variable ≤-2.5 was defined as osteoporosis, ≤-1>−2.5 as osteopenia and >−1 as normal.; **TBS >1.31 was defined as normal, 1.23-1.31 as partially degraded microstructure and >1.23 as degraded microstructure.

TABLE 2 Effects of high-intensity training on body composition measured by DXA-scan

	Pre Mass		Post absolute change			
	HIT group (n = 18)	Control group (n = 19)	HIT group (n = 18)	Control group (n = 19)	Between-group difference (95% CI)*	*p*-value*
Total body lean mass, kg	44.99 ± 6.63	46.93 ± 8.70	0.20 ± 1.98	0.63 ± 1.14	-0.40 (−1.49, 0.68)	0.456
Legs lean mass, kg	1.49 ± 2.61	1.56 ± 2.99	0.06 ± 1.09	0.02 ± 0.71	-0.02 (−0.63, 0.59)	0.941
Arms lean mass, kg	4.63 ± 1.30	5.35 ± 1.68	0.06 ± 0.52	-0.07 ± 0.48	0.12 (−0.23, 0.46)	0.504
Trunk lean mass, kg	22.25 ± 3.13	23.12 ± 4.31	-0.26 ± 1.17	-0.60 ± 0.92	0.41 (−0.39, 0.94)	0.411
Total body fat mas, kg	27.62 ± 7.92	28.50 ± 11.60	-0.13 ± 1.85	0.30 ± 1.71	-0.47 (−1.66, 0.73)	0.435
Gynoid fat mass, kg	4.30 ± 1.13	4.58 ± 1.95	-0.05 ± 0.30	0.04 ± 0.32	-0.12 (−0.3, 0.09)	0.282
Android fat mass, kg	2.46 ± 1.15	2.61 ± 1.46	-0.03 ± 0.31	0.04 ± 0.23	-0.09 (−0.26, 0.86)	0.317
Subcutaneous adipose tissue, kg	1.70 ± 0.66	1.67 ± 1.06	-0.04 ± 0.19	0.07 ± 0.19	-0.10 (−0.23, 0.03)	0.120
Visceral adipose tissue, kg	1.09 ± 0.94	1.26 ± 0.96	-0.01 ± 0.03	-0.05 ± 0.02	0.02 (−0.13, 0.17)	0.799

Abbreviations: DXA, Dual-energy X-ray absorptiometry; HIT, high-intensity training.

*ANCOVA analyses, adjusted for pre-intervention score.

4 | DISCUSSION

After 20 weeks of HIT, a significant treatment effect on trabecular bone score and subcutaneous adipose tissue was observed. In contrast, lean body mass, fat body mass, bone mineral density, and physical activity level did not differ significantly from standard care.

TBS has been suggested to be a more sensitive marker of bone health than BMD in patients treated with glucocorticoids, and provides additional information regarding bone quality beyond BMD.[25] Our findings support this, as we found a favorable and significant effect of HIT on the lumbar spine microstructure indicated by an increase in TBS, while BMD only revealed minor and nonsignificant changes. We hypothesize that the specific muscular strength training initiated on the lower back (leg press, back extensions) contributed to this positive effect, in addition to a high ground reaction force generated by brisk uphill walking. This would be in keeping with previous studies demonstrating that brisk walking at intensity >75% of maximal oxygen uptake can prevent bone loss.[26] To our knowledge, the effect of exercise training on TBS has not been investigated in LTx recipients. However, one study investigating the effect of a 20-week power/plyometric training protocol among elderly women found similar significant changes in lumbar spine TBS and tibia trabecular thickness, while cortical bone remains unchanged.[27]

Despite the significant effects on TBS of the lumbar spine, HIT did not improve BMD compared to standard care. It has previously been shown that 6 months of isolated strength training on the lumbar spine may reverse vertebral osteoporosis in LTx recipients.[28] However, nonsignificant, positive trends toward higher BMD scores in the exercise group were observed in this study. This may indicate that a longer intervention period is required for significant changes in BMD. As the typical bone remodeling cycle lasts three to eight months, it has been proposed that an intervention must last a minimum of 6–9 months to detect skeletal changes.[26] It must also be

emphasized that the implemented exercise training program (brisk uphill walking and muscular strength at 6-12 repetition maximum) did not include high-impact jumping/plyometric exercises or isolated strength exercises targeted on specific bone structures. Such exercise training may be more effective in improving BMD in a given area.[26,28] Taken together with poor bone health in this population prior to LTx,[4] our findings suggest a multifactorial approach to optimizing bone health following LTx. Such an approach should include proactive evaluation of bone active drugs, the use of low glucocorticoid dosing protocols, and encouragement of exercise training with a focus on the axial strain.

Regarding body composition, total LBM and lean mass for legs and arms separately remained unchanged after HIT. This was somewhat surprising, as we have previously reported significant improvements in muscle strength, measured by one-repetition-maximum in leg and arm press following the intervention.[12] Our findings, however, are consistent with the findings reported in a study of 12 LTx recipients, which demonstrated an increase in quadriceps twitch tension, but no change in fat-free mass after three months of home-based cycle ergometer training.[11] Improvement in muscle strength has therefore been suggested to be caused by neuromuscular adaptation, rather than muscle hypertrophy.[11] The HIT group decreased SAT by 6% during the intervention, while the control group increased SAT by 8%. This significant finding may highlight the positive trends observed in body composition after the intervention, also in other compartments.

We have previously reported PA level in this LTx population,[21] and the majority (86%) were classified as inactive. The HIT intervention did not increase PA or reduce sedentary time significantly compared to standard care. Given the positive effects PA may have on body composition and bone health, we explored the association between PA and LBM, FBM, BMD, and TBS. FBM % was moderately associated with PA and those who met WHO recommendations (n = 7)

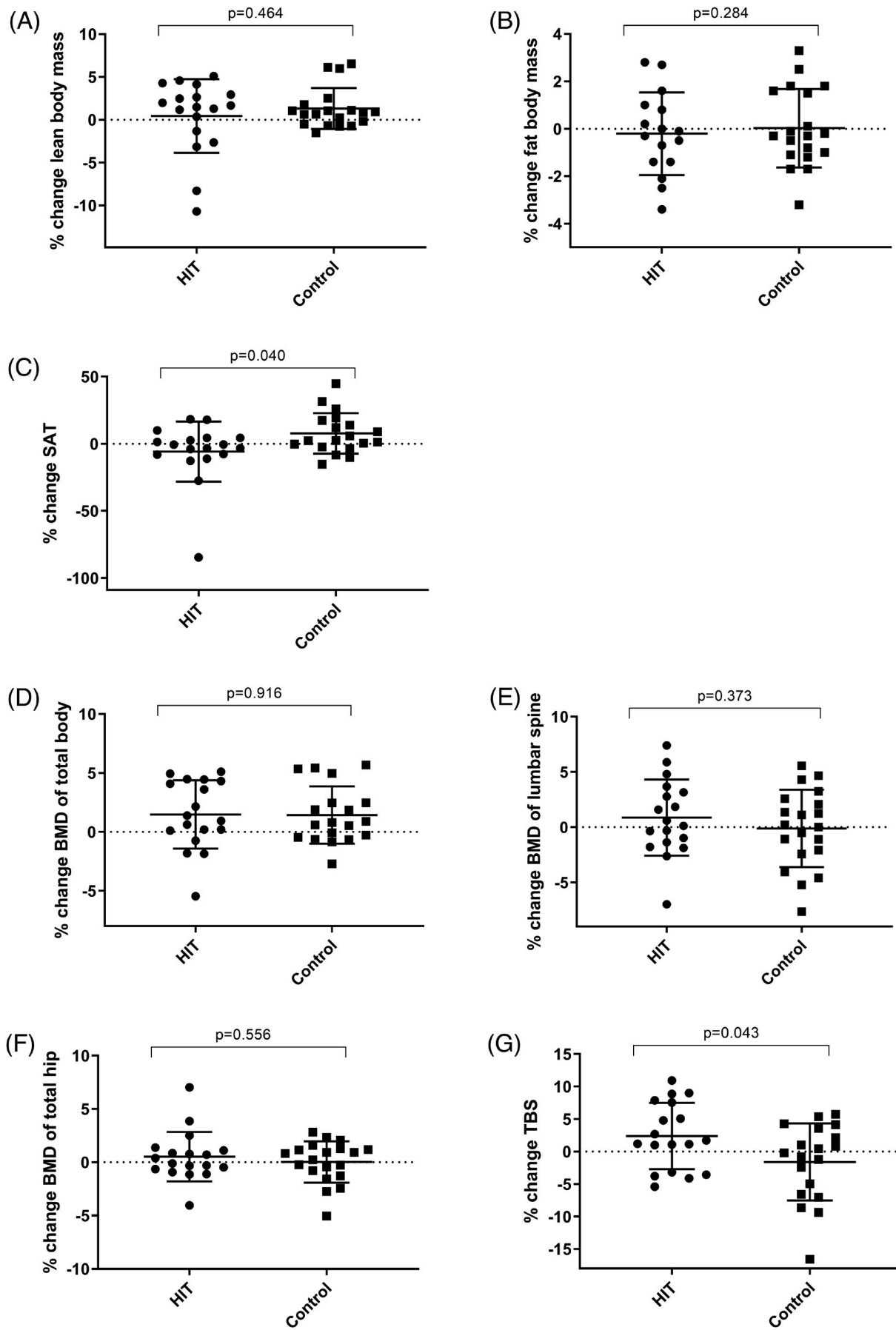**FIGURE 2**   Percentage change in (A) lean body mass, (B) fat body mass, (C) subcutaneous adipose tissue (SAT), (D) bone mineral density (BMD) of total body, (E) BMD of lumbar spine (L1-L4), (F) BMD of total hip, and (G) lumbar spine trabecular bone score (TBS) after 20 weeks of high-intensity training (HIT) and controls

TABLE 3 Effects of high-intensity training on lumbar spine trabecular bone score and bone mineral density measured by DXA

	Pre Z-score		Post Absolute change in Z-score			
	HIT group (n = 18)	Control group (n = 19)	HIT group (n = 18)	Control group (n = 19)	Between-group difference (95% CI)*	p-value*
TBS lumbar spine (L1-L4)	-1.03 ± 1.18	-1.02 ± 0.95	0.27 ± 0.58	-0.12 ± 0.64	0.42 (0.03, 0.82)	.038
BMD lumbar spine (L1-L4)	-0.90 ± 1.23	-0.77 ± 1.56	0.02 ± 0.27	-0.07 ± 0.29	0.09 (−0.10, 0.28)	.337
BMD total hip	-0.99 ± 0.82	-0.91 ± 0.63	0.03 ± 0.15	0.02 ± 0.12	0.02 (−0.08, 0.10)	.733
BMD ultra-distal radius	-1.13 ± 1.82	-0.20 ± 1.81	-0.28 ± 0.51	-0.38 ± 0.91	-0.09 (−0.54, 0.36)	.681
BMD 33% radius	-0.26 ± 1.13	-0.19 ± 0.99	-0.02 ± 0.32	-0.20 ± 0.30	0.18 (−0.03, 0.39)	.098
BMD total body	-0.21 ± 0.80	-0.14 ± 0.81	0.20 ± 0.31	0.16 ± 0.26	0.04 (−0.26, 0.23)	.696

Abbreviations: BMD, bone mineral density; CI, confidence interval; HIT, high-intensity training; TBS, trabecular bone score.

*ANCOVA analyses, adjusted for pre-intervention score.

TABLE 4 Effects of high-intensity training on physical activity measured by accelerometers

	Pre		Post Absolute change			
	HIT group (n = 18)	Control group (n = 17)	HIT group (n = 18)	Control group (n = 17)	Between-group difference (95% CI)*	p-value*
Steps per day	5261 ± 2909	5398 ± 3606	-94 ± 2458	747 ± 1629	-961 (−2376, 453)	0.176
Counts per min	251 ± 136	270 ± 158	-12 ± 115	4 ± 115	-34 (−103, 35)	0.317
MVPA, min/day (% of total wear time)	31 ± 24 (4%)	33 ± 30 (4%)	-2 ± 20 (0%)	4 ± 20 (0%)	-8 (−21, 6)	0.260
ST, min/day (% of total wear time)	591 ± 63 (78%)	547 ± 71 (76%)	-13 ± 71 (−1%)	19 ± 66 (−1%)	-14 (−57, 29)	0.501

Abbreviations: HIT, high-intensity training; MVPA, moderate to vigorous physical activity; ST, sedentary time.

*ANCOVA analyses, adjusted for pre-intervention score.

had 8% lower FBM compared to those who did not (n = 41) at baseline testing. No differences were detected for the other variables.

The randomized controlled trial on which this analysis was based is the first study to utilize high-intensity training after LTx. Methodological strengths of this study include the randomized design, the objective and quantitative measurement of PA, and the use of the gold standard measurement, DXA, to assess both body composition and BMD. A limitation to this study was the suboptimal adherence to the training regime.[12] Five participants in the HIT group completed <70% of the prescribed sessions. However, excluding those participants from the analysis did not change the results significantly. Another limitation is the number of participants who missed the follow-up (n = 8), as they may not be missing at random. Furthermore, the parent study was powered for (VO$_{2peak}$)[12] and not for secondary outcomes, as reported here. The sample size may therefore have been too small to detect significant differences in body composition and BMD (type II error). Testing for several outcomes also amplifies the probability of a false-positive finding (type I error). It must therefore be taken into consideration that the observed difference in TBS might be due to chance only.

In conclusion, 20 weeks of HIT improved some, but not all, measures of bone health and body composition in LTx recipients. While trabecular bone score increased and subcutaneous adipose tissue decreased, there were no improvements in lean body mass, fat body mass, bone mineral density, or physical activity level. Our findings provide important initial insights regarding the potential impact of HIT on LTx recipients' bone health and body composition. However, further studies are warranted to determine which exercise training modality (endurance and/or muscular strength) is most effective with respect to these outcomes.

CONFLICT OF INTEREST
None.

AUTHOR CONTRIBUTIONS

DATA AVAILABILITY STATEMENT

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