Exercise-induced improvements in liver fat and endothelial function are not sustained 12 months following cessation of exercise supervision in nonalcoholic fatty liver disease

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Supervised exercise reduces liver fat and improves endothelial function, a surrogate of cardiovascular disease (CVD) risk, in nonalcoholic fatty liver disease (NAFLD). We hypothesised that after a 16-week supervised exercise program, patients would maintain longer-term improvements in cardiorespiratory fitness, liver fat and endothelial function. Ten NAFLD patients (5/5 males/females, age 51 ± 13 years, body mass index 31 ± 3 kg m− 2 (mean ± s.d.)) underwent a 16-week supervised moderate-intensity exercise intervention. Biochemical markers, cardiorespiratory fitness (VO2peak), subcutaneous, visceral and liver fat (measured by magnetic resonance imaging and spectroscopy respectively) and brachial artery flow-mediated dilation (FMD) were assessed at baseline, after 16 weeks of supervised training and 12 months after ending supervision. Despite no significant change in body weight, there were significant improvements in VO2peak (6.5 ml kg − 1 min − 1 (95% confidence interval 2.8, 10.1); P = 0.003), FMD (2.9% (1.5, 4.2); P = 0.001), liver transaminases (Po0.05) and liver fat (−10.1% (−20.6, 0.5); P = 0.048) immediately after the 16-week supervised training. Nevertheless, 12 months after ending supervision, VO2peak (0.9 ml kg − 1 min − 1 (−3.3, 5.1); P = 0.65), FMD (−0.07% (−2.3, 2.2); P = 0.95), liver transaminases (P40.05) and liver fat (1.4% (−13.0, 15.9); P = 0.83) were not significantly different from baseline. At 12 months following cessation of supervision, exercise-mediated improvements in liver fat and other cardiometabolic variables had reversed with cardiorespiratory fitness at baseline levels. Maintenance of high cardiorespiratory fitness and stability of body weight are critical public health considerations for the treatment of NAFLD (Clinicaltrials.gov identifier: NCT01834300).

INTRODUCTION

Nonalcoholic fatty liver disease (NAFLD) increases liver-related morbidity and mortality,[1] yet cardiovascular disease (CVD) is the leading cause of its mortality.[2] We need effective sustainable interventions to reverse NAFLD and reduce cardiovascular risk. In the absence of approved pharmacological treatment, structured exercise and/or dietary modification are recommended as first-line treatment in NAFLD.[3] The cardiometabolic benefits of supervised exercise, which include reduced liver fat, enhanced peripheral insulin sensitivity and microvascular and conduit artery endothe-lial function,[4,5] do not require weight loss. Parallel improvements in liver fat and cardiac structure and function6 emphasise the role of exercise as an intervention to reduce both hepatic and CVD risk.

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We hypothesised that after a 16-week supervised exercise program, patients would maintain the longer-term improvements in cardiorespiratory fitness, liver fat and endothelial function. To test, this we re-examined a subset of previously reported patients [4,5] 12 months after ending exercise supervision.

MATERIALS AND METHODS

At baseline, NAFLD was diagnosed by a hepatologist based on raised transaminases (after exclusion of secondary causes) with confirmation of elevated liver fat (⩾5.5%) by proton magnetic resonance spectroscopy. All participants were physically inactive (<2 h per week of low-intensity physical activity), normotensive, normoglycaemic, non-smoking Caucasians, with no history of excessive alcohol intake (males <21 and females <14 units per week) or any contraindications to exercise; females were post-menopausal.

Patients who completed a 16-week structured and supervised exercise intervention were offered the opportunity to repeat assessments 12 months later. From the original study cohort, 10 patients who completed the exercise intervention[4,5] (5 males and 5 females; 51 ± 13 years; body mass index 31 ± 3 kg m− 2) under-went repeat assessments 12 months later. All participants remained with similar alcohol intake and as normotensive, normoglycaemic, nonsmokers. Liverpool Central Research Ethics Committee approved the study, and all participants gave written informed consent.

Measurements were performed fasted at baseline, after 16 weeks of supervised exercise training and 12 months after its end.[5] Anthropo-metric measurements were taken and blood samples collected for plasma glucose, lipid profiles and liver enzymes.

Magnetic resonance scanning at 1.5T was performed as previously described.[5] Abdominal visceral (VAT) and subcutaneous adipose tissue (SAT) were calculated from whole-body axial T1-weighted fast spin echo scans. Total abdominal adipose tissue (AT) = VAT+SAT. Liver fat was measured using proton magnetic resonance spectroscopy and expressed as % CH2 lipid amplitude relative to water signal.

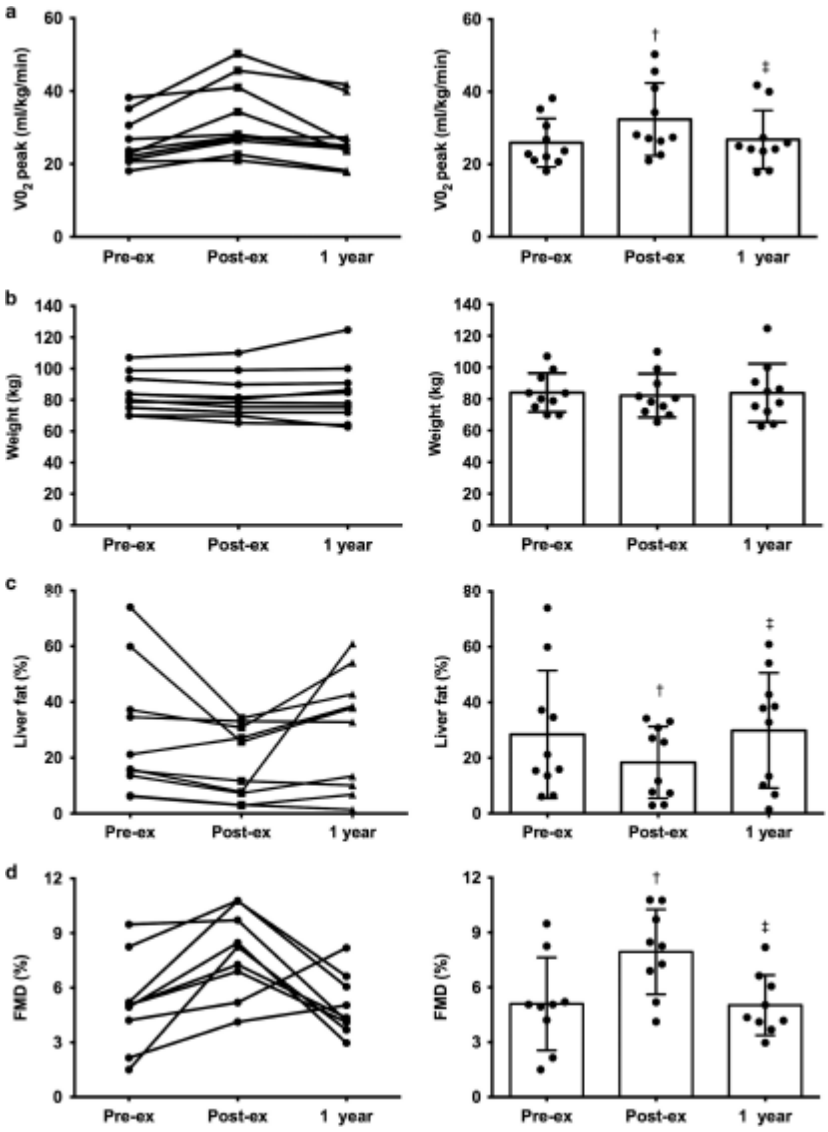

Figure 1. Changes in (a) cardiorespiratory fitness (VO2peak), (b) body weight (c) liver fat (%), and (d) flow-mediated dilation FMD (%) at baseline ('Pre-ex'), following 16 weeks of supervised exercise training ('Post-ex') and 12 months following cessation of exercise supervision ('1 year'). Data are presented as mean (95% CI) and as individual patient values. †Significantly different from baseline (P<0.05). ‡Significantly different from immediately following 16 weeks of supervised exercise training (P<0.05).

High-resolution ultrasound (Terason, t3000, Aloka, Burlington, MA, USA) was used to image the brachial artery after 30 min of supine rest. Endothelial-dependent function was assessed as flow-mediated dilation (FMD): brachial artery diameter, flow and shear stress were measured before and after 5 min of forearm cuff inflation, and FMD was calculated as peak artery diameter following hyperaemia, expressed as % increase using an allometric model. Endothelium-independent function was assessed by imaging 1 min before and 10 min after sublingual (400 µg) glyceryl trinitrate.[7]

Cardiorespiratory fitness [(5)] was assessed on a treadmill erg-ometer, initially 2.7 km h − 1 at 5° gradient, with step-wise increments every 1 min. VO2peak was calculated from expired gas (Oxycon Pro, Jaegar, Hoechberg, Germany) as the highest consecutive 15 s period of oxygen uptake in the last

min before exhaustion. No self-reported or objective assessment of physical activity and/or exercise was made following the cessation the 16-week structured exercise intervention.

For the exercise training intervention, an exercise physiologist provided supervision and guidance. Based upon individual basal fitness, participants underwent 30 min of moderate-intensity aerobic exercise 3 times/week at 30% heart rate reserve (HRR), progressing weekly based on HR responses in the initial 4 weeks. Intensity increased to 45% HRR for the following 4 weeks, until week 8, where HRR remained at 45% but each session increased to 45 min. From week 12, participants were exercising 5 times/week for 45 min at 60% HRR. Upon completion of the supervised exercise, patients had no contact from the research team for 12 months.

A general linear model with repeated measures was employed to evaluate differences between baseline, immediate and 12-month post-training data. Analyses were performed using SPSS 21.0 (SPSS, Chicago, IL, USA). All data in the text, figure and table, including changes, are presented as mean (95% confidence intervals), except age and body mass index (presented as mean and s.d.). Intraobserver coefficients of variation for measurements of liver fat and FMD were 6.0(ref. 8) and 6.7%,9 respectively.

RESULTS

Body weight did not change significantly from baseline over the training period (change = − 1.9 kg (−1.5, 5.2); P = 0.29), or 12 months following its completion (−0.2 kg, (−3.6, 3.1); P = 0.90; Figure 1).

VO2peak increased (6.5 ml kg − 1 min − 1 (2.8, 10.1); P = 0.003) and waist circumference decreased (−6 cm (−9, −); P = 0.004) following training, but had returned to baseline 12 months later (0.9 ml kg − 1 min − 1 (−3.3, 5.1); P =0.67 (Figure 1) and − 1 cm (−7, 5); P =0.60 (Table 1), respectively).

Liver fat (−10.1% (−20.6, 0.5); P = 0.048), alanine aminotransferase (−20 U l − 1 (−41, 1); P = 0.05) and aspartate aminotransferase (−11 U l − 1 (−21, − 1); P = 0.04) decreased following training but had returned to baseline 12 months later (1.4% (−13.0, 15.9); P =0.83); Figure 1; 10 U l− 1 (−21, 41); P = 0.48 & 2 U l − 1 (−11, 16); P = 0.70; Table 1 respectively). There were no significant changes in VAT, SAT or total AT (P40.20; Table 1).

FMD improved (2.9% (1.5, 4.2); P = 0.001) following training, but had returned to baseline 12 months later (−0.07% (−2.3, 2.2); P =0.95; Figure 1). There were no significant differences in endothelium-independent (glyceryl trinitrate mediated) dilation (P = 0.74; Table 1).

Table 1. Characteristics of NAFLD patients at baseline ('Pre-Ex'), immediately following 16 weeks of supervised exercise training ('Post-Ex') and 12 months following ('1 year') the cessation of supervised exercise

	Pre-Ex	*Post-Ex*	*1 Year*	P-*value*
Anthropometrics				
Weight (kg)	84.4 (75.6, 93.1)	82.1 (72.7, 91.5)	83.8 (70.6, 97.0)	0.40
BMI (kg m^{-2})	30 (28, 32)	29 (27, 31)	30 (27, 33)	0.37
Waist circumference (cm)	103 (97, 108)	97 (91, 104)[a]	101 (97, 108)[b]	0.03
Systolic BP (mm Hg)	128 (123, 134)	125 (120, 130)	129 (120, 136)	0.23
Diastolic BP (mm Hg)	79 (74, 85)	76 (74, 81)	78 (71, 85)	0.59
Fitness (l min^{-1})	2.23 (1.61, 2.85)	2.73 (1.9, 3.55)[a]	2.28 (1.63, 2.93)[b]	< 0.01
Liver enzymes				
ALT (U l^{-1})	57 (33, 81)	37 (25, 48)[a]	67 (40, 94)[b]	0.05
AST (U l^{-1})	39 (26, 51)	28 (24, 31)[a]	41 (31, 51)[b]	0.04
GGT (U l^{-1})	85 (18, 152)	60 (18, 103)	68 (38, 99)	0.26
Glucose and lipid profile				
Glucose (mmol l^{-1})	5.0 (4.6,5.4)	4.9 (4.5, 5.3)	5.2 (4.7, 5.6)	0.40
Cholesterol (mmol l^{-1})	5.4 (4.6, 6.1)	5.3 (4.6, 5.9)	5.7 (5.0, 6.5)	0.10
Triglyceride (mmol l^{-1})	2.0 (1.6,2.4)	1.9 (1.6,2.2)	1.9 (1.4, 2.4)	0.85
HDL (mmol l^{-1})	1.4 (1.2, 1.5)	1.4 (1.3, 1.5)	1.5 (1.3, 1.7)	0.16
LDL (mmol l^{-1})	3.1 (2.6, 3.6)	3.0 (2.4, 3.6)	3.3 (2.6, 4.0)	0.12
Chol/HDL ratio	3.8 (3.3, 4.4)	3.8 (3.1, 4.5)	3.9 (3.2, 4.6)	0.89
Adipose tissue deposition				
VAT (l)	5.5 (3.9, 7.1)	5.5 (4.1, 6.8)	5.0 (3.9, 6.0)	0.20
SAT (l)	8.2 (6.0, 10.3)	7.7 (5.6, 9.8)	7.9 (5.0, 10.8)	0.27
Total abdominal AT (l)	13.7 (11.3, 16.0)	13.1 (11.2, 15.1)	12.8 (9.1, 15.5)	0.23
Brachial artery function				
GTN-mediated dilation (%)	13.5 (9.1, 17.8)	14.6 (10.1, 19.0)	14.1 (10.5, 18.7)	0.74

Abbreviations: ALT, alanine aminotransferase; AST, aspartate aminotransferase; AT, adipose tissue; BMI, body mass index; BP, blood pressure; Chol, cholesterol; GGT, γ-glutamyltransferase; GTN, glyceryl trinitrate; HDL, high-density lipoprotein; LDL, low-density lipoprotein; NAFLD, nonalcoholic fatty liver disease; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue. Data are presented as mean (95% confidence interval (CI)). [a]Significantly different from baseline ($P < 0.05$). [b]Significantly different from immediately following 16 weeks of supervised exercise training ($P < 0.05$).

Patients who lost the most weight during the 16-week intervention period had the smallest gain in liver fat between weeks 16 and 68 (P = 0.03); 1 kg reduction in body weight at 16 weeks reduced the change in liver fat by ~ 4.5% in the following 52-week period.

CONCLUSION

Longitudinal data suggest that although vigorous physical activity can prevent liver fat accumulation, adherence to current national and international physical activity guidelines alone is not sufficient to prevent NAFLD.[10] A recent study demonstrated that 8-weeks of aerobic exercise can reduce liver fat, irrespective of exercise volume and intensity.[11] Following 16 weeks of supervised exercise training in the present cohort, liver fat significantly decreased and FMD increased by 2.9%, extrapolated from meta-analysis data to confer a CVD risk reduction of ~ 17%.[12] Nevertheless, this improvement had disappeared 12 months after cessation of exercise supervision.

To the authors' knowledge, no study to date has undertaken longer-term follow-up of the exercise-induced improvements in liver and vascular health following cessation of supervision. This study suggests that short-term exercise interventions have only short-term benefits.

In contrast, improvements in liver transaminases, liver fat and insulin resistance observed after a 6-month hypocaloric diet with dietary counselling were maintained for 17–36 months after ending counselling, despite modest weight regain;[13] however, this study did not examine the effects on CVD risk, the leading cause of mortality in NAFLD.[2,14] In our study, changes in liver fat and FMD were strongly associated with changes in cardiorespiratory fitness, suggesting that maintenance of exercise-induced improvements in cardiometabolic parameters depends upon sustained cardiorespiratory fitness. It therefore appears that exercise and hypocaloric diet interventions modulate liver fat content across different time courses and perhaps via distinct mechanisms.

Indeed, as little as 7 consecutive days of 60 min treadmill walking improves liver fat and increases insulin sensitivity in obese individuals with NAFLD.[15] These data suggest that an increase in levels of physical activity with exercise training dynamically modulates liver fat, and that to achieve prolonged cardiometabolic benefits, higher levels of fitness must be maintained. Although the patients were counselled on the benefits of exercise and encouraged to maintain their exercise training without further guidance, physical fitness returned to preintervention level, suggesting that long-term supervision or alternative strategies of exercise provision are required.

Limitations of this exploratory pilot study include a relatively small patient cohort, and a lack of intermediate post-intervention assessments and measures of insulin resistance. Follow-up assessments were based on patient choice and thus there is the possibility of cohort bias.

In summary, although 16 weeks of supervised exercise effectively improves liver fat and endothelial function in NAFLD, the cardiometabolic benefit of training is not sustained 12 months after ending supervision. To overcome the NAFLD epidemic we need an effective mechanism to promote long-term maintenance fitness.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We thank all patients for their participation in the study. This study was funded by the European Federation for the Study of Diabetes (EFSD).

AUTHOR CONTRIBUTIONS

GJK, PR, AMU, DJG, NTC, HJ and DJC: conception and design of research; CJAP, VSS, FS-M, HJ and DJC performed experiments; CJAP, VSS, GJK, FS-M, AMU, DJG, NTC, HJ and DJC analysed data; CJAP, VSS, GJK, PR, FS-M, AMU, DJG, NTC, HJ and DJC interpreted results of experiments; CJAP, VSS, PR, HJ and DJC prepared figures; CJAP, HJ and DJC drafted manuscript; CJAP, VS.S, GJK, PR, FS-M, AMU, DJG, NTC, HJ and DJC edited and revised manuscript; CJAP, VSS, GJK, PR, FS-M, AMU, DJG, NTC, HJ and DJC approved final version of the manuscript.

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