



A randomised study of home-based electrical stimulation of the legs and conventional bicycle exercise training for patients with chronic heart failure

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KEYWORDS

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Aims Recent guidelines recommend regular exercise in the management of patients with chronic heart failure (CHF). This study was designed to compare the safety and efficacy of conventional bicycle exercise and functional electrical stimulation (FES) of the legs as forms of home-based exercise training for patients with stable CHF.

Methods and results Forty-six patients (38 male) with stable NYHA Class II/III heart failure underwent a 6-week training programme using either a bicycle ergometer or electrical stimulation of the quadriceps and gastrocnemius muscles. In the bike group, significant increases were seen in 6-min walk (44.6 m, 95% confidence interval (CI) 29.3–60.9 m), treadmill exercise time (110 s, 95% CI 72.2–148.0 s), maximum leg strength (5.32 kg, 95% CI 3.18–7.45 kg), and quadriceps fatigue index (0.08, 95% CI 0.04–0.12) following training. In the stimulator group, similar significant increases were seen following training for 6-min walk (40.6 m, 95% CI 28.2–53.0 m), treadmill exercise time (67 s, 95% CI 11.8–121.8 s), maximum leg strength (5.35 kg, 95% CI 1.53–9.17 kg), and quadriceps fatigue index (0.10, 95% CI 0.04–0.17). Peak VO_2 did not change in either group following training, indicating a low-intensity regime. Quality of life scores improved following training when the bicycle and stimulator groups were considered together, but not when considered separately (–0.43, 95% CI –8.13 to –0.56).

Conclusions FES produces beneficial changes in muscle performance and exercise capacity in patients with CHF. Within this study, the benefits were similar to those observed following bicycle training. FES could be offered to patients with heart failure as an alternative to bicycle training as part of a home-based rehabilitation programme.

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Introduction

A number of recently published guidelines recommend a regular programme of exercise training for patients with chronic heart failure (CHF).^{1–4} The

majority of previous studies of exercise training in CHF have been hospital based,^{5–10} although there are now a number of studies confirming the effectiveness of home-based programmes.^{11–14} The ability to deliver such programmes within primary and secondary care is limited by available resources and safety concerns. In addition, co-morbidities that

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limit the ability to perform exercise are common in CHF patients, particularly the elderly,¹⁵ and some have such marked impairment of exercise capacity that they may be unable to undertake physical training.

Functional electrical stimulation (FES) is a method of exercising, which requires less baseline functional capacity to perform. It has been studied in other patients who cannot undertake conventional forms of exercise, e.g. patients with scoliosis,^{16,17} muscular dystrophy,¹⁸ and paraplegia.¹⁹ It is recognised to improve muscle fatigue resistance and muscle strength depending on the pattern and frequency of the electrical impulses used.²⁰ FES of the lower limb muscles is potentially attractive as a method of training in CHF as it is home-based, requires less motivation to use, and could be performed by patients unable to undertake conventional training owing to their symptoms of heart failure or other co-morbidities. Additionally, the devices are widely available and relatively inexpensive, typically costing around 160–250 Euros. However, FES has not been extensively investigated in patients with CHF. Two small trials found FES to produce improvements in muscle strength and metabolic measures of exercise capacity in highly selected patients around the time of cardiac transplantation.^{21,22} One further small uncontrolled trial in less symptomatic patients also demonstrated the safety of FES, and suggested improvements in quality of life and exercise capacity.²³ We have, therefore, compared the usefulness and tolerability of FES with conventional bicycle training for a group of stable CHF patients in a 6-week home-based randomised study.

Methods

Study population

Patients with stable heart failure and New York Heart Association class II–III symptoms were recruited from out-patient clinics. Stability was defined as no alterations in medical therapy within 1 month and no myocardial infarction within 3 months prior to inclusion. All subjects were limited in their ability to perform exercise by either breathlessness or fatigue as a consequence of heart failure, had documented left ventricular systolic impairment on echocardiography, and were on appropriate medical therapy including angiotensin converting enzyme inhibitors (ACEi), diuretic, digoxin, and beta-blockers (Table 1). None of the subjects was participating in an exercise programme prior to inclusion in the study. Patients

Table 1 Patient characteristics at baseline

	Bicycle group (n=24)	FES group (n=22)	p-Value
Age±SD, years	61.8±10.8	63.0±10.0	0.68
Sex, n (%)			
Male	21 (87.5)	17 (77.3)	0.30
Female	3 (12.5)	5 (22.7)	
CHF aetiology, n (%)			
IHD	16 (66.7)	13 (59.1)	0.60
DCM	8 (33.3)	9 (40.9)	
NYHA functional class, n (%)			
II	18 (75)	17 (77.3)	0.86
III	6 (25)	5 (22.7)	
Ejection fraction±SD, (%)	32.0±9.3	28.3±6.3	0.008
Medications, n (%)			
Diuretic	17 (71)	20 (91)	0.09
ACEi	22 (92)	22 (100)	0.27
Spirolactone	1 (4)	3 (14)	0.27
Digoxin	9 (38)	10 (45)	0.58
Beta-blocker	9 (38)	9 (41)	0.81

were excluded if they had co-existing respiratory, neurological, orthopaedic, or peripheral vascular disease that would prevent a bicycle exercise training programme.

Written informed consent was obtained from all the subjects and the protocol was approved by the local research ethics committee.

Patient assessment

At baseline, patients underwent 6-min walk test, cardiopulmonary treadmill exercise test, and quadriceps strength and fatigue testing on two separate occasions, at least 24 h apart, to familiarise themselves with assessments prior to randomisation. Results recorded at the second baseline visit were used as the pre-training values in the final analysis. Cardiopulmonary exercise data were collected during a symptom-limited modified Bruce treadmill exercise test and analysed using a zirconia fuel-cell oxygen analyser and infrared carbon dioxide analyser (Benchmark, Morgan, UK). The modified Bruce protocol consisted of a standard Bruce protocol with the additional two stages occurring before stage 1 of the standard Bruce test: stage 0 at 2.7 km/h, 0% slope and stage 1/2 at 2.7 km/h, 5% slope. Isometric quadriceps strength was measured by a piezoelectric strain gauge attached to an immobile quadriceps exercise bench and a computer. The visual trace produced was calibrated to provide a measurement of the equivalent weight lifted during isometric knee extension.

The quality of the visual trace indicated whether voluntary contractions reflected true maximal contractions. True maximal contractions demonstrated noise in the visual trace, whereas sub-maximal contractions produced smooth traces. Maximum strength was determined as the peak equivalent weight lifted from three maximal voluntary contractions of the quadriceps of the dominant leg and only contractions deemed to be maximal on the basis of the quality of the visual trace were accepted. Attempts were performed at least 1 min apart, and clear instructions were given to each subject prior to each test. A fatiguing protocol was then performed whereby patients applied a force to the isometric bench at 30% of the previously determined maximum every 2 s for 40 s of every minute over a 20-min period.²⁴ Maximum quadriceps strength was repeated at the end of the 20 min and fatigability index was expressed as the ratio between the first and second maximal measurements. Ejection fraction was measured on echocardiography by the Simpson biplane method at one of the baseline visits. The Minnesota 'living with heart failure' quality of life questionnaire was completed at the first baseline visit prior to the exercise performance tests. All assessments other than echocardiography were repeated on one occasion after the exercise training period.

Exercise training

Patients were randomised following baseline assessment to receive either a recumbent bicycle ergometer or a functional electrical muscle stimulator for home-use over a 6-week period. Those patients assigned to the bicycle group underwent a 1-h training session in the use of the bicycle and a chest-strap/wrist heart rate monitor (Polar). The bicycle was delivered to their home and they were instructed to use it daily for 30 min, for 5 days per week, aiming for 70% of the maximum heart rate determined from the previous treadmill exercise tests. Patients allocated to use stimulators (Boditek Ltd, UK) also underwent 1 h of instruction on how to use the device and how to adjust electrode position to achieve maximal muscle recruitment. Adhesive electrodes were positioned on the skin over the upper-lateral and lower-medial aspects of the quadriceps muscle of both legs and over the upper and lower portions of gastrocnemius muscles of both legs. The stimulator was configured to deliver a direct electrical current at 25 Hz for 5 s followed by 5 s of rest. The intensity of the stimulation was adjusted by the patient to achieve a visible muscle contraction that was not sufficiently strong to

cause discomfort or a significant movement at either the knee or the ankle joints. Patients used the stimulator at home for 30 min daily, 5 days per week for 6 weeks. There were no scheduled hospital visits during the training period. Subjects from both groups maintained a diary indicating the duration and intensity of exercise during each session over the training period. This diary was compared against subjects' verbal description of their experience with either the bike or muscle stimulator.

Statistical analysis

All data are expressed as mean \pm SEM unless otherwise stated. Normally distributed paired data were compared using a paired *t*-test and unpaired data with an unpaired *t*-test or a Pearson Chi-square test with Fisher's exact test where appropriate. A Mann-Whitney *U* test was used to compare unpaired data that were not normally distributed. One-way ANOVA was used to compare mean data at different time-points during the study. Analysis was performed using SPSS for Windows, version 11.0. A value of *p*<0.05 was considered statistically significant.

Results

Forty-nine patients were recruited and 46 completed the exercise training programme. Of the three who did not complete the study, one patient died following randomisation to the stimulator group due to increasingly severe heart failure, one patient assigned to the stimulator group dropped out of the study due to worsening symptoms of heart failure, and one patient assigned to the bicycle group dropped out of the study due to back discomfort. Baseline data for these patients were included in the final analysis with post-training data treated as missing data. Of the remaining 46 patients, no adverse effects were reported and their medical therapy remained unchanged for the duration of the study. Blood pressure and heart rate were recorded in five patients who underwent a 30-min period of electrical stimulation of the quadriceps and gastrocnemius muscles, and no acute changes were observed during stimulation (data not shown). Baseline characteristics for those patients who completed the exercise training programme are detailed in Table 1. Patients in the stimulator group had a lower ejection fraction at baseline, but otherwise there were no significant differences between the two groups for age, sex, heart failure aetiology, NYHA functional class, or heart failure drug treatments. Additionally, no significant

Table 2 Training-induced changes in exercise capacity and quality of life

	Whole group (n=46)	Bike training group (n=24)	FES group (n=22)
<i>Exercise time (s)</i>			
Pre-training	524±37	544±58	501±43
Post-training	614±40	654±58	568±53
p-Value	<0.001	<0.001	0.020
<i>Peak VO₂ (ml/kg/min)</i>			
Pre-training	18.8±0.84	19.0±1.14	18.6±1.27
Post-training	19.3±0.77	19.8±1.10	18.6±1.07
p-Value	0.380	0.276	0.932
<i>Quadriceps strength (kg)</i>			
Pre-training	45.7±2.0	48.8±3.0	42.3±2.6
Post-training	51.0±2.2	54.1±3.3	47.6±2.9
p-Value	<0.001	<0.001	0.009
<i>Quadriceps fatigue</i>			
Pre-training	0.77±0.03	0.76±0.03	0.77±0.03
Post-training	0.86±0.02	0.84±0.03	0.88±0.02
p-Value	<0.001	0.001	0.005
<i>Six-min walk distance (m)</i>			
Pre-training	493±18	495±24	491±26
Post-training	536±17	540±23	531±25
p-Value	<0.001	<0.001	<0.001
<i>Quality of life score</i>			
Pre-training	32.7±3.16	36.3±4.21	28.7±4.70
Post-training	28.4±2.91	31.0±3.66	25.5±4.61
p-Value	0.024	0.105	0.094

differences for markers of functional capacity or quality of life were observed at baseline between bicycle and stimulator groups (Table 2).

Baseline assessments were performed on two separate occasions. To identify any effect of repeated exercise testing on subjects' performance, these two baseline assessments were analysed in the context of the post-training results using a one-way ANOVA with post-hoc Bonferroni analysis. Small increases were observed for 6-min-walk distance and treadmill exercise time between the first and the second baseline measurements that did not reach statistical significance (Fig. 1). Peak VO₂ did not increase between the first and second baseline visits. The second baseline visit was used as the pre-training value for subsequent analyses.

Significant changes were observed following both forms of exercise training for markers of functional capacity (Table 2). Quality of life improved for the study group as a whole, as indicated by a lower score on the Minnesota questionnaire, but changes did not reach statistical significance when the training groups were examined independently. There was no significant change in peak VO₂ following the exercise programme in either training group.

The degree of change in indices of functional capacity observed following training, was compared between the two groups. Fig. 2 shows the mean absolute change in exercise capacity. Mean percentage increase in 6-min walk was 10.3% (95% CI 6.59–14.1) for the bike group and 9.52% (95% CI 5.92–13.1) for the stimulator group. Treadmill exercise time mean percentage increase was 33.0% (95% CI 10.8–55.3) for the bike group and 14.1% (95% CI 3.34–24.8) for the stimulator group. Mean percentage increase in maximum quadriceps strength was 11.9% (95% CI 6.67–17.0) for the bike group and 15.3% (95% CI 4.50–26.1) for the stimulator group. Mean percentage improvement in fatigue index was 12.2% (95% CI 4.48–19.9) for the bike group and 17.2% (95% CI 5.40–29.1) for the stimulator group. Mean percentage change in quality of life score was 2.47% (95% CI –28.8 to 33.8) for the bike group and –2.8% (95% CI –28.5 to 22.8) for the stimulator group. Mean percentage increase in peak VO₂ was 5.5% (95% CI –1.48 to 12.5) for the bike group and 2.97% (95% CI –4.32 to 10.2) for the stimulator group. No significant differences were seen between the bike and the stimulator groups in the degree of absolute or percentage change from baseline following training for any of the indices of exercise capacity or quality of life.

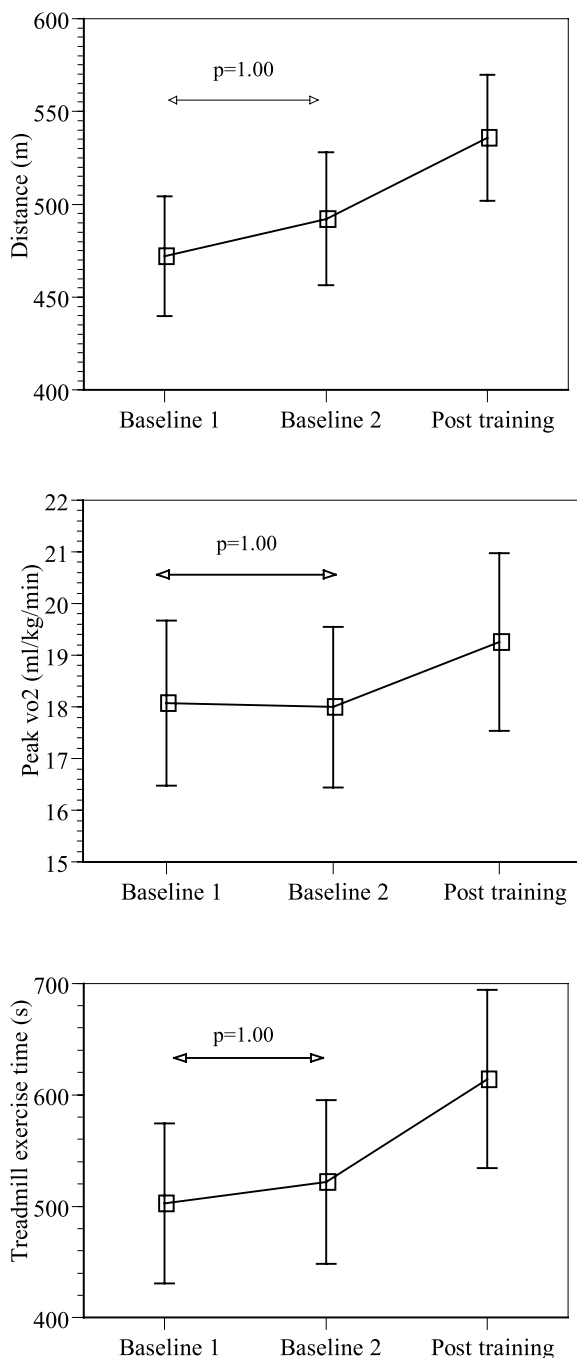


Fig. 1 Mean exercise performance for whole group at baseline and post-training ($n=46$).

Discussion

The safety of exercise training for stable CHF patients delivered in a supervised environment is now well established.^{5–10} There are also studies suggesting that it can be delivered at home safely and effectively.^{11–14} These studies have demonstrated significant benefits for a variety of outcome measures including exercise capacity and quality of

life and there is now preliminary evidence that prolonged training may have favourable effects on admission rates and mortality, although further controlled studies are required to confirm this fact.⁷ Recent guideline documents have, therefore, recommended an exercise training programme as a part of the comprehensive rehabilitation and management of patients with CHF,^{1–4} and there is a need to examine new ways to deliver exercise therapy to patients in the community without the need for intense supervision.

This is the first randomised trial comparing FES and conventional exercise training in a group of stable CHF patients. We have demonstrated that FES is well tolerated, safe, and results in significant improvement in markers of functional capacity. There was improvement in quality of life for both groups when examined together, and there was a trend towards improved quality of life when FES and bicycle groups were examined separately. FES appeared to produce similar improvements in exercise capacity as bicycle training for the patients participating in our study, and it is a potentially attractive form of therapy since it requires less motivation and can be performed whilst a subject is sedentary. As such, it may be suitable for those patients who are either unwilling or unable to perform more conventional forms of exercise. Conventional training and FES training are different, however. More muscle groups are utilised in conventional exercise regimes and there are significant changes in central haemodynamic variables during conventional exercise. Electrical muscle stimulation targets a smaller number of muscle groups, and we did not identify any significant change in haemodynamic variables during the periods of stimulation in five CHF patients. Although only a crude assessment of central response to local muscle stimulation, it is in keeping with other investigators who have identified no change in cardiac output²³ and only small changes in heart rate during periods of FES.²⁵ Whilst this supports the safety of this form of muscle training in CHF patients, further work to investigate both central and local haemodynamic effects of muscle stimulation in a heart failure population is required. Physical inactivity itself is a risk factor for cardiovascular disease, and the potential long-term benefits of training with electrical muscle stimulators may be offset by this risk if FES is the only form of training undertaken, although FES may be of benefit in combination with conventional exercise, or as a bridging therapy until a patient regains sufficient functional capacity to exercise conventionally. Formal tests of equivalence need to be

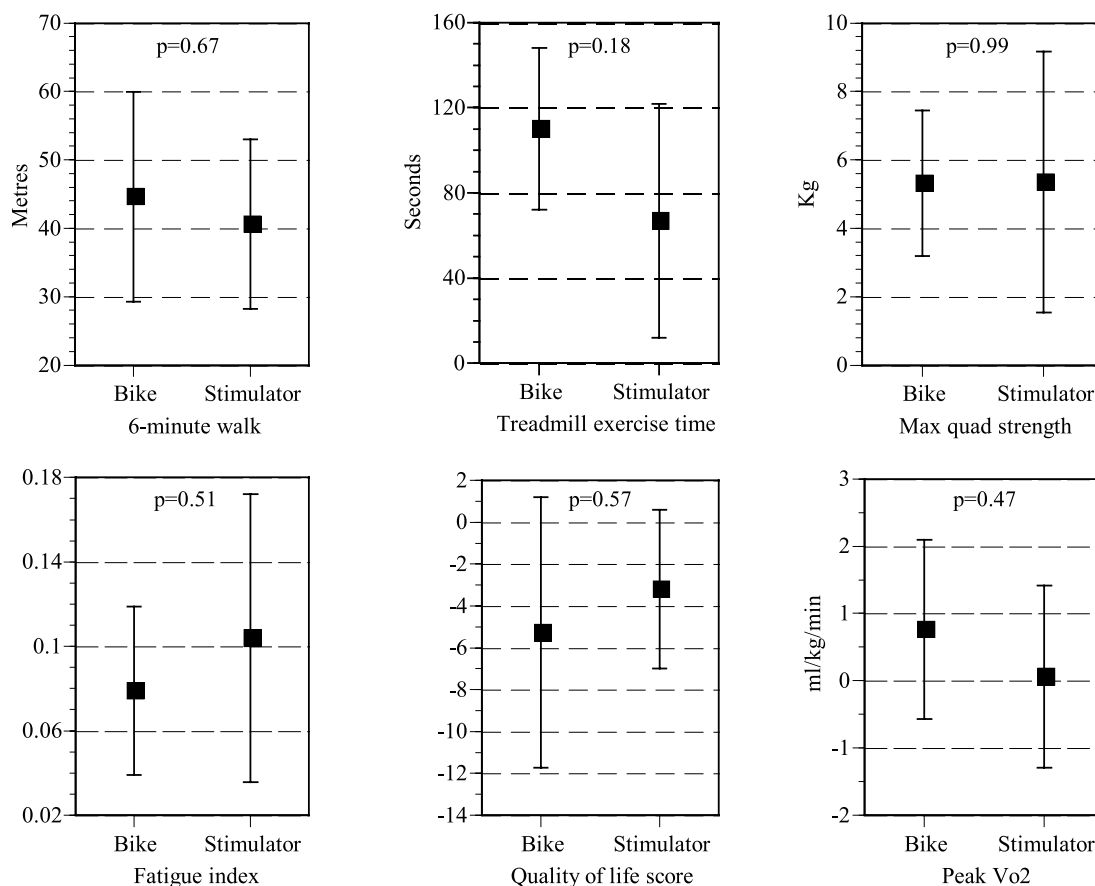


Fig. 2 Mean absolute improvements in exercise variables and quality of life following training. Error bars indicate 95% CI; *p*-values indicate differences in mean change between exercise groups.

performed in a larger trial to confirm that FES is as effective as conventional exercise.

Peripheral muscle is abnormal in heart failure patients, with atrophy of both type I and type II muscle fibres,²⁶ and an apparent switch in fibre-type proportion to the less fatigue resistant fast-twitch type IIB fibres.²⁷ The quantity of aerobic enzymes and the density of mitochondria are reduced, in consistent with a decreased capacity for aerobic metabolism.²⁸ As such, the peripheral muscle is weaker with a decreased mass, reduced aerobic capacity, and increased susceptibility to fatigue. Chronic low frequency FES, such as the one used in our study, has previously been shown to produce an increase in oxidative capacity with reduced fatigability, but little improvement in muscle strength.^{23,29} Higher frequency intermittent protocols are recognised to retain fatigue resistance by improving aerobic capacity while also improving muscle strength.^{21,30} The frequency and pulse duration of FES protocols may be important in determining the profile of changes obtained with training, and the use of a higher frequency protocol

preferentially targeting type II fibres might account for more marked improvements in the muscle strength compared to the improvements in fatigability. It is possible that in our study FES training-induced improvements due to a partial reversal of the unfavourable fibre-type distribution and increased aerobic capacity, but future studies with muscle biopsy before and after FES training are required to identify these changes.

Peak VO_2 did not improve following training in contrast to other studies.⁷⁻¹² The training period was short and of low intensity for both groups and this may account for the lack of change in peak VO_2 . Verbal reports from subjects were consistent with their training diaries, indicating compliance with the training programme. Unfortunately, with home-based programmes, it is difficult to be absolutely certain about patient compliance and it is possible that poor compliance could have been partly responsible for the lack of change in peak VO_2 . Compliance with a prescription for exercise is an important issue for both clinical trials and clinical practice, and exercise regimes that are poorly

tolerated during a trial are unlikely to be better tolerated in practice. Future studies focussing on compliance with home-based training regimes are required to investigate this area further. In the context of this trial, however, functional improvement as determined by 6-min walk, treadmill exercise time, and muscle strength and fatigability did occur, and this is important given that many patients with CHF will be unwilling or unable to undertake more intensive forms of training. In addition, we did observe an improvement in perceived quality of life, when the groups were considered together, and this is also an important consideration in patients with chronic symptoms and poor prognosis. Patients with the most severe symptoms may even be prepared to trade duration of life for quality,³¹ and whilst the effects of exercise training on prognosis remain to be fully established, improved quality of life remains a strong reason to recommend exercise therapy for selected patients. Peak VO_2 , however, is a marker of prognosis in heart failure,³² and whilst low-intensity training may improve other markers of functional capacity or quality of life, lack of improvement in peak VO_2 suggests that prognosis may remain poor for these patients.

Conclusions

Exercise therapy reverses some of the peripheral changes seen in CHF and improves muscle strength, exercise time, and perceived quality of life. FES of the lower limbs is effective at improving functional capacity and could be offered in the future as an alternative to conventional training as part of a community-based exercise training programme, depending upon the results of further studies.

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