Relation between duration and intensity of first exercise and "warm up" in ischaemic heart disease

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Objective—To determine the importance of the duration and intensity of "warm up" exercise for reducing ischaemia during second exercise in patients with exertional angina.
Design—Randomised crossover comparison of three warm up exercise protocols.
Patients—18 subjects with stable ischaemic heart disease and > 0.1 mV ST segment depression on treadmill exercise testing.
Interventions—The warm up protocols were 20 minutes of slow exercise at 2.7 km/h, symptom limited graded exercise for a mean of 7.4 (range 5.0 to 10.5) minutes, and three minutes of symptom limited fast exercise of similar maximum intensity.
Main outcome measures—ST segment depression during graded treadmill exercise undertaken 10 minutes after each warm up protocol or no warm up exercise.
Results—Compared with exercise with no warm up, the duration of graded exercise after earlier slow warm up increased by 4.9% (95% confidence interval (CI), −3.3% to 13.7%), after graded warm up by 10.3% (95% CI, 5.6% to 15.2%), and after fast warm up by 16% (95% CI, 6.2% to 26.7%). ST segment depression at equivalent submaximal exercise decreased after slow warm up by 27% (95% CI, 5% to 44%), after graded warm up by 31% (95% CI, 17% to 44%), and after fast warm up by 47% (95% CI, 27% to 61%). Compared with slow warm up exercise, the more intense graded and fast warm up protocols significantly increased the duration of second exercise ($p = 0.0072$) and reduced both peak ST depression ($p = 0.0026$) and the rate of increase of ST depression ($p = 0.0069$).
Conclusions—In patients with exertional angina the size of the warm up response is related to the maximum intensity rather than the duration of first exercise.
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Keywords: exercise; angina; warm up; preconditioning

Several studies have objectively measured reduction in exertional angina and ST depression after earlier warm up exercise in patients with ischaemic heart disease.[1–3] It has been suggested that this "warm up" response could be a form of ischaemic preconditioning which is cardioprotective.[4,5] Alternatively warm up may be the result of progressive recruitment of coronary collateral vessels which increase perfusion to the ischaemic territory on second exercise.[6,7]

Standard guidelines for exercise training in patients with ischaemic heart disease recommend that maximum exercise intensity is kept below the level needed to induce myocardial ischaemia as determined by exercise testing.[8,9] However, in previous studies which describe reduced ischaemia on second exercise, the warm up exercise was at least to onset of angina, and ST segment depression was present on the ECG.[1–3,10] It is uncertain whether lower intensity exercise insufficient to induce angina or ST segment depression will induce a warm up response. The aim of this study is to assess the importance of the intensity and duration of warm up exercise for reducing myocardial ischaemia during later exercise in patients with ischaemic heart disease.

Methods

STUDY POPULATION

We studied 18 subjects with chronic stable angina and > 0.1 mV ST segment depression during treadmill exercise testing. All subjects had a history of myocardial infarction or > 70% diameter stenosis on coronary angiography. Exclusion criteria were acute myocardial infarction or unstable angina during the preceding three months, known aortic stenosis (gradient > 20 mm Hg), left main stem coronary disease (diameter stenosis > 50%), cardiomyopathy, severe hypertension (blood pressure > 180/120 at rest), congestive heart failure, mitral valve prolapse, diabetes mellitus, or resting ST segment changes on the ECG. Mean age was 66 (range 51 to 74) years. Fifteen subjects were male and three female, seven had a history of myocardial infarction, and one was a current smoker.

The study was approved by the institutional ethics committee and all participants gave written informed consent.

EXERCISE PROTOCOL

Each participant underwent a practice exercise test to determine the time of onset of angina, ST segment depression, and peak exercise time. A modification of the standard Bruce protocol was used in which speed and gradient increased in equal increments every minute. At 3, 6, 9, and 12 minutes, work performed was equivalent to the standard Bruce protocol. On different days and in random order each participant then undertook one of three warm up exercise tests, slow, graded, or fast, as described below, or no warm up exercise. After 10 minutes of rest a second exercise test was performed using the modified Bruce protocol

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Table 1 Comparison of warm up exercise tests: exercise intensity, heart rate, rate–pressure product, and ST depression at peak exercise

		Characteristics of warm up exercise			*p Values*		
	Rest	*Slow warm up*	*Graded warm up*	*Fast warm up*	*Slow v rest*	*Graded + fast v slow*	*Fast v graded*
Exercise duration (min)	–	20 (20 to 20)	7.4 (5.0 to 10.5)	3 (3 to 3)	–	–	–
Treadmill speed (km/h)	–	2.7 (2.7 to 2.7)	5.2 (4.4 to 6.7)	5.0 (2.7 to 6.7)	–	–	–
Treadmill gradient (%)	–	0 (0 to 0)	13.7 (12.5 to 16.0)	13.6 (10.0 to 16.0)	–	–	–
Heart rate (beats/min)	72 (57 to 100)	87.3 (73 to 112)	124 (96 to 144)	134 (105 to 169)	< 0.00001	< 0.00001	0.0001
Rate–pressure product (beats/min × mm Hg × 10^{-3})	9.96 (7.42 to 13.00)	13.2 (9.64 to 18.8)	21.5 (16.8 to 28.8)	23.3 (17.1 to 31.4)	< 0.00001	< 0.00001	0.0035
ST depression at peak (mV)	0.036 (0.02 to 0.06)	0.035 (0.01 to 0.06)	0.13 (0.09 to 0.20)	0.13 (0.08 to 0.25)	0.71	< 0.00001	0.41

Values are geometric mean (range).

described above. Heart rate, blood pressure, and ST segment changes on this second exercise test were measured to assess the effects of each warm up protocol.

The slow warm up protocol was designed to avoid symptoms or ECG evidence of ischaemia. Exercise was for 20 minutes at 2.7 km/h with no gradient. In the graded warm up protocol the modified Bruce exercise test described above was performed with exercise continued to the stage on the practice test when the subject would normally stop or when ST segment depression was > 2.0mV. The duration of the fast warm up protocol was three minutes. Treadmill gradient and speed were increased rapidly to the final three levels of exercise on the practice test.

Exercise tests were performed at the same time of day at least three hours after a light meal. Antianginal treatment was withheld for 48 hours and subjects were rested for one hour before beginning exercise. A 12 lead ECG was recorded every 30 seconds during and at peak exercise. The level of ST segment depression in lead V5 was monitored continuously using a video monitor, and heart rate was measured automatically from the ECG. Blood pressure was measured every minute during exercise using a mercury sphygmomanometer.

ANALYSIS OF THE ECG

ST segment depression was measured 0.06 seconds after the J point by an ECG computer with signal averaging capacity (Cardiovit AT 60; Schiller AG, Baar, Switzerland). ECGs were reviewed to ensure the level of ST segment depression measured by the ECG computer was not influenced by a wandering baseline, development of bundle branch block, or an ectopic beat. The level of ST segment depression for all 12 leads at 30 second intervals during exercise was entered onto a computer spreadsheet blind to warm up protocol. For missing values the average of the measurement made 30 seconds before and after was used. The rate at which ST depression increased with time (measured in mV/10 min) was calculated for each lead using linear regression. To compare ST segment depression at equivalent submaximal exercise for each subject the longest submaximal time completed in all exercise tests was chosen. Comparisons were based on the lead with the greatest ST depression as measured by the statistic of interest (peak ST depression, submaximal ST depression, or rate of ST depression increase) in each exercise test. Although all subjects reached 0.1 mV ST depression during practice exercise, several did not reach this level of ST depression on graded exercise after earlier warm up exercise. For this reason time to 0.1 mV ST segment depression was not used as a study end point.

STATISTICS

Data were analysed using a logarithmic transformation which enabled the results to be evaluated as proportional changes. To be consistent with the multiplicative scale induced by the logarithmic transformation, tables 1 and 2 summarise the results using geometric rather than arithmetic means. Comparison between the warm up protocols was made using random effects regression with a separate analysis for each measurement compared.[11] The models account for the within subject correlation that occurs because each subject completed three warm up protocols. Random effects models were fitted using the lme function in the statistical package Splus, with unstructured covariance and restricted maximum likelihood

Table 2 Comparison of graded treadmill exercise following earlier warm up exercise on slow, graded, and fast protocols

		Exercise characteristics following warm up			*p Values*		
	No warm up	*Slow warm up*	*Graded warm up*	*Fast warm up*	*Slow v no warm up*	*Graded + fast v slow*	*Fast v graded*
Heart rate (beats/min)	124 (96 to 144)	126 (99 to 155)	130 (102 to 164)	133 (106 to 177)	0.33	0.37	0.30
Rate–pressure product (beats/min × mm Hg × 10^{-3})	21.5 (16.8 to 28.8)	21.9 (16.4 to 31.0)	24.0 (18.4 to 30.5)	24.1 (17.5 to 32.2)	0.45	0.000092	0.84
Exercise duration (min)	7.4 (5.0 to 10.5)	7.8 (6.0 to 10.0)	8.2 (6.0 to 10.5)	8.6 (6.5 to 11.0)	0.25	0.0072	0.15
ST depression at peak (mV)	0.126 (0.09 to 0.20)	0.135 (0.100 to 0.190)	0.107 (0.040 to 0.170)	0.096 (0.030 to 0.20)	0.21	0.0026	0.23
Increase in ST depression (mV/10 min)	0.208 (0.099 to 0.610)	0.188 (0.102 to 0.478)	0.151 (0.055 to 0.422)	0.119 (0.025 to 0.337)	0.24	0.0069	0.025
Submaximal ST depression (mV)	0.113 (0.06 to 0.19)	0.082 (0.020 to 0.150)	0.077 (0.040 to 0.130)	0.060 (0.020 to 0.150)	0.019	0.072	0.005

Values are geometric means (ranges).
Heart rate, rate–pressure product, and submaximal ST depression were measured at the equivalent submaximal stage of exercise.
p Values were computed using random effects regression and test the indicated differences between the characteristics of the graded exercise that followed the various warm up protocols.

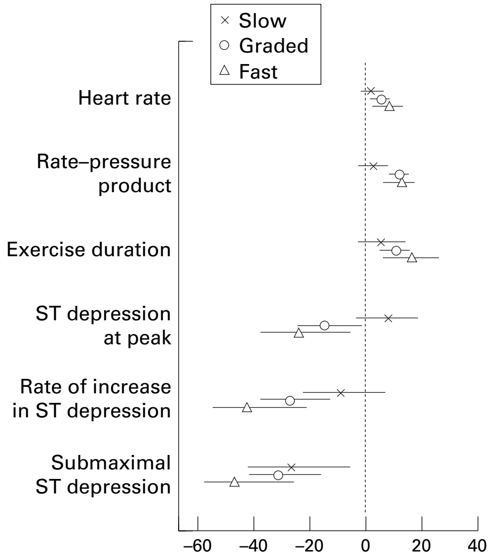

Figure 1 Mean percentage difference with 95% confidence intervals for graded exercise after slow, graded, and fast warm up protocols compared with graded exercise with no preceding warm up exercise.

estimation. Probability (p) values are from the Wald statistic in these models.

Results

The warm up exercise protocols are compared in table 1. At the end of slow warm up exercise, heart rate and rate–pressure product were increased compared with rest, but there was no increase in ST segment depression. The graded exercise protocol was of longer duration than the fast protocol, but maximum work load was similar. Maximum heart rate and rate–pressure product were greater for the fast than the graded protocol but there was no significant difference in ST segment depression at peak exercise.

Heart rate, rate–pressure product, exercise time, and measures of ST segment depression on graded treadmill exercise undertaken 10 minutes after no warm up exercise and each of the three warm up protocols are given in table 2. The warm up response is measured by the change from the equivalent measurement on the same graded exercise protocol without preceding warm up exercise (fig 1). The magnitude of this difference increased from slow to graded and fast warm up exercise protocols, respectively: exercise time increased by 4%, 10%, and 16%; the rate at which ST segment depression developed during exercise decreased by 9%, 27%, and 43%; and ST depression decreased at both peak exercise (+7%, −15%, −24%) and at the equivalent submaximal level of exercise (−27%, −31%, −47%) (fig 1).

Compared with the slow warm up protocol, second exercise after the more intense graded and fast warm up protocols was longer, the rate at which ST depression increased during exercise was less, and the amount of ST segment depression at peak exercise was reduced (table 2). When compared with the graded protocol, the fast warm up protocol produced a greater reduction in ST depression at equivalent submaximal exercise and a lower rate of increase of ST segment depression on second exercise (table 2). Improvement in ST segment depression on exercise after the graded and fast warm up protocols occurred despite a higher heart rate and rate–pressure product at an equivalent submaximal stage of exercise.

The role of ischaemia on first exercise for inducing the warm up response on second exercise was assessed in an exploratory analysis. Reduction in ST depression after the slow warm up protocol, which had the same duration and intensity for all subjects, was compared between subjects. Because ST segment depression during slow warm up was minimal, ST depression on graded exercise which could be measured more reliably was used to estimate the likelihood of ischaemia during slow warm up exercise. After slow warm up exercise compared with no warm up, reduction in ST segment depression at an equivalent stage of exercise was greater for subjects who on graded exercise had more ST segment depression ($p = 0.0060$), a greater rate of increase in ST depression ($p = 0.00018$), and a shorter exercise time ($p = 0.0078$) (fig 2).

Discussion

It is known that warm up exercise sufficient to induce angina and ST segment depression can reduce myocardial ischaemia on subsequent exercise,[1–3 10] but the intensity and duration of exercise required for this adaptive response has been uncertain. Previous studies which have examined the warm up effect have not directly compared different exercise protocols. In the current study a short, fast warm up exercise

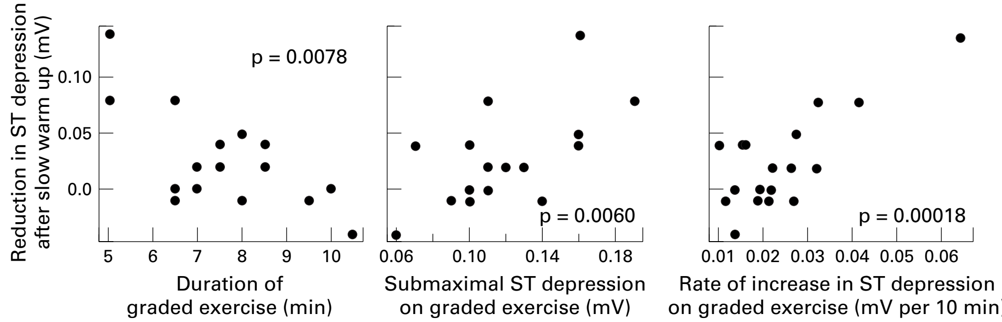

Figure 2 Relation between ST segment depression on graded exercise with no warm up and the magnitude of warm up induced by the slow exercise protocol. Warm up is measured as the reduction in ST depression at an equivalent submaximal stage of exercise; p values test if the slope of the regression line through the points on the plot is significantly different from zero.

protocol which induced the greatest increase in heart rate and rate–pressure product resulted in the greatest reduction in ST segment depression during subsequent exercise undertaken after 10 minutes of rest. In the graded warm up exercise protocol, exercise intensity was increased more gradually to the same workload but peak heart rate and rate–pressure product were lower and the reduction in ST depression on second exercise was slightly less. Twenty minutes of low intensity exercise which did not induce ST segment depression had the smallest influence on ischaemia on second exercise. These observations suggest the warm up effect depends on the maximum intensity of first exercise rather than its duration.

POSSIBLE MECHANISMS OF WARM UP

The mechanisms for warm up have not been clearly defined. Reduction in ST segment depression on second exercise occurred despite an increase in heart rate and rate–pressure product, indicating equivalent or greater cardiac work and weighing against peripheral vasodilatation as the explanation for warm up. The slow preliminary exercise protocol did not induce ST segment depression but did induce a small warm up response. It is possible this was because of ischaemia below the threshold for ST segment depression on the surface ECG. A role for ischaemia is supported by an exploratory analysis in which reduction in ST depression on second exercise after the slow warm up protocol was greater for individuals who developed ST depression more rapidly during graded exercise. The findings of the current study are consistent with either ischaemic preconditioning[4 5] or an increase in myocardial perfusion owing to collateral recruitment[6 7] as the mechanism for warm up.

IMPLICATIONS FOR EXERCISE TRAINING

In general population studies, reduction in cardiovascular risk increases with the duration and intensity of regular exercise performed.[8 12 13] Meta-analyses of randomised clinical trials indicate overall benefits of regular exercise in patients with stable coronary artery disease participating in rehabilitation programmes.[14 15] Angiographic studies suggest that regular and more vigorous physical activity is most effective for reducing disease progression.[16 17] The benefits of regular exercise occur despite a small risk of vigorous exertion triggering myocardial infarction[18 19] or sudden death.[20]

To reduce the risks of exercise for persons with inducible myocardial ischaemia, guidelines recommend 10 minutes of stretching and light callisthenics to increase heart rate gradually and prevent musculoskeletal injury.[8 9] Guidelines also suggest that myocardial ischaemia should be avoided during exercise, either by ensuring heart rate does not increase by more than 20 beats/min, or using treadmill testing to choose a maximum exercise heart rate at least 10 beats/min below the ischaemic threshold. The results of the current study suggest that a short period of more vigorous exercise sufficient to induce myocardial ischaemia is most effective for reducing myocardial ischaemia on subsequent exercise. Possible hazards of this approach are uncertain but may be less if more intense exercise is of short duration and followed by rest or low level activity to allow recovery of ischaemia and time for the adaptive changes to occur. In persons without ischaemic heart disease the benefits of exercise training can be achieved as well with multiple short bouts of exercise as with a longer duration of lower intensity exercise.[21 22] The appropriate rest period following first or warm up exercise has also not been systematically assessed. In studies of warm up, rest periods of more than four minutes have been evaluated,[10] but patients with symptomatic angina who describe warm up following initial exercise may stop for a shorter time before resuming exercise without angina.

CONCLUSIONS

In patients with exertional angina warm up exercise can allow exertion to the same or higher level with less ischaemia. In this study the size of this adaptive response was related to the maximum intensity rather than to the duration of first exercise, and the presence of myocardial ischaemia. Further study is needed to assess the safety and benefits of short periods of more vigorous exercise in patients with inducible myocardial ischaemia.

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