High-Intensity Interval Training: Rehab Considerations for Health and Cardiovascular Risk

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Disclosures

No relevant financial relationships exist
Session Learning Objectives

After this session, attendees will be able to:

• Describe the difference between continuous moderate intensity training and high-intensity interval training.

• Explain the benefits of high-intensity interval training in both healthy individuals and in those with cardiac and metabolic disease.

• Compare prior knowledge and practice of exercise training with current literature.

• Explain safety concerns and current safety findings of high-intensity interval training research in healthy individuals and those with cardiac and metabolic disease.

• Apply the current concepts of high-intensity interval training in the clinical setting, with safety considerations for the discussed populations.
High Intensity Interval Training

- Abbreviated HIIT
- AKA sprint interval training (SIT), high intensity interval exercise (HIIE)
- Definition: Physical exercise that is characterized by brief intermittent bursts of vigorous activity, interspersed by periods of rest of low intensity exercise
Continuous Moderate Intensity Training

- Abbreviated CMIT
- AKA: Moderate continuous training (MCT), traditional endurance training, ET
- Continuous exercise
- Longer duration, no intervals
- Decreased intensity approx 65% VO$_{2\text{max}}$
- Increased volume compared to HIIT
Variables

- Intensity - % of VO$_{2\text{max}}$
- Duration of high intensity intervals
- Number of intervals performed
- Duration of rest
- Type of rest (active vs. passive)
<table>
<thead>
<tr>
<th>HIIT</th>
<th>Traditional Endurance Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity 80-170% $VO_{2\text{max}}$</td>
<td>Intensity 50-90% $VO_{2\text{max}}$</td>
</tr>
<tr>
<td>Interval duration 10 sec → 5 min, some protocols up to 15 min</td>
<td></td>
</tr>
<tr>
<td>Total duration 4-30 min</td>
<td>Total duration 30-120 min</td>
</tr>
<tr>
<td># of intervals 4-10</td>
<td>No intervals</td>
</tr>
<tr>
<td>Recovery 30 sec → 4 min, passive or active</td>
<td>No recovery</td>
</tr>
</tbody>
</table>
History of HIIT

- Woldemar Gerschler
- Per-Olaf Astrand
- Peter Coe
- Izumi Tabata
- Martin Gibala
Woldemar Gerschler – 1930’s

• German running coach who teamed up with cardiologist Dr. Herbert Reindel

• Together they applied Gerschler’s understanding of cardiovascular conditioning in search of a training method which would “maximize size, fitness and efficiency of the heart”

• Studied over 3000 athletes over a period of 21 days

• Training consisted of short distances 150-400 m at intensity to raise HR to 180 bpm, recovered to 120 bpm (must be within 90 sec) and then interval repeated

• As fitness improved, recovery time shortened
Per-Olaf Astrand – 1950’s

- Karolinska Institute, Stockholm
- One of the founding fathers of exercise physiology
- Studied physical working capacity of men and women and the physiological response to intermittent exercise
- Instrumental in getting the cycle ergometer to the US to be used in research and for training
Peter Coe – 1970’s

- Track and Field coach – training his son Sebastian Coe (Olympic gold medalist and former world record holder)
- Training philosophy based on Gerschler and Astrand
- Repeated 200 m run interspersed with 30 sec rest
Izumi Tabata – 1996
National Institute of Fitness and Sports, Tokyo

- Olympic speedskating
- 20 sec of intense exercise (170% VO$_{2\text{max}}$) followed by 10 sec rest x 4 min (8 cycles)
- 2 groups trained for 6 wks
- HIIT group: 4x/week intervals as above + 1 day traditional endurance training x 30 min
- ET group: 5x/week traditional endurance training x 60 min (70% VO$_{2\text{max}}$)
- ET ↑ VO$_{2\text{max}}$ 52 → 57 ml/kg/min
- HIIT lower end point but greatest change in VO$_{2\text{max}}$ 48 → 55 ml/kg/min
<table>
<thead>
<tr>
<th>2009 protocol</th>
<th>2011 protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>more intense</td>
<td>less intense for less trained athletes</td>
</tr>
<tr>
<td>3 min warm-up</td>
<td>3 min warm-up</td>
</tr>
<tr>
<td>60 sec intense exercise at 95% (\text{VO}_{2\text{max}}), 75 seconds rest</td>
<td>60 sec burst at 80-95% HRR, 60 sec rest</td>
</tr>
<tr>
<td>8-12 cycles</td>
<td>10 cycles</td>
</tr>
<tr>
<td>5 min cool down</td>
<td>5 min cool down</td>
</tr>
</tbody>
</table>
Benefits of HIIT
Healthy, Athletic Population

• ↑ VO$_{2\text{max}}$
• ↑ Muscle oxidative capacity
• ↑ Muscle buffering capacity
• ↑ Muscle glucose transport capacity
• ↑ GLUT4 protein content
• Improved endothelial function
• Improved athletic performance
• ↓ Time commitment
  • Most people fail to meet minimum physical activity guidelines citing “lack of time” as the major barrier to regular exercise participation
Muscle Oxidative Capacity

Derived from:
• Total # of mitochondria in a muscle
• Surface area of mitochondrial inner membranes or size
• Enzymatic activity of isolated mitochondria

Mitochondria = “powerhouse” of the cell
• Site of aerobic metabolism
• Traditional ET known to ↑ size and # of mitochondria in skeletal muscle
  • Mitochondrial biogenesis
• Must have sufficient training stimulus
• ET ↑ mitochondrial enzyme levels
• When energy needs ↑ in working muscle, # of mitochondria ↑ in order to keep up with demands
  • Activity- specific
Regulators of Mitochondrial Biogenesis

PGC-1α

• Transcriptional coactivator – AKA, a protein that increases gene expression by binding to an activator or transcription factor
  • Key regulator of energy metabolism, lactate metabolism, mitochondrial biogenesis and function, muscle fiber type determination
  • Prevents the accumulation of lactic acid therefore improving performance and delaying fatigue
  • ↓ expression of PGC-1α implicated in pathogenesis of type 2 DM (Handschin 2008)
• Also SIRT1 (activator of PGC-1α), Tfam (mitochondrial transcription factor A), NRF-1 (transcriptional activator: nuclear respiratory factor-1)
Mitochondrial Enzymes

Cytochrome c oxidase (COX II and COX IV)
Citrate Synthase (CS)

• Muscle oxidative capacity measured by ↑activity or protein content of mitochondrial enzymes

• Measured by muscle biopsy
Muscle Buffering Capacity

• The ability of muscles to neutralize the lactic acid that accumulates during high-intensity exercise, thus delaying the onset of fatigue.

• Muscle buffering capacity is improved by regular anaerobic training, but not by aerobic training

• Measured by muscle biopsy: amount of H⁺/g muscle
Resting Muscle Glycogen Content

- Storage of carbohydrate in skeletal muscle
- Major source of energy for active muscles
- Depleted with intense exercise
- Synthesized from glucose by glycogenesis
- Restored during rest

- Changes in carbohydrate metabolism normally associated with traditional ET
  - \( \uparrow \) Resting muscle glycogen content
  - \( \downarrow \) Rate of glycogen utilization
  - \( \uparrow \) Total muscle transporter protein (GLUT4)
GLUT4

- Insulin-regulated glucose transporter protein found in adipose tissue and striated muscle (skeletal and cardiac)

- Integral protein that triggers the action of insulin to increase glucose uptake and storage

- ↑ in muscle GLUT4 expression in trained individuals contributes to increase in the responsiveness of muscle glucose uptake to insulin. (Goodyear, 1998)
  - ↑ insulin sensitivity
Endothelial Function

- Endothelium: the monolayer of endothelial cells lining the lumen of the vascular beds
- Separates vascular wall from circulation and blood components
- Key regulator of vascular homeostasis

  - Growing body of evidence indicating endothelial dysfunction related to cardiovascular events

  - Regulates vascular tone, cellular adhesion, thromboresistance, smooth muscle cell proliferation, and vessel wall inflammation.

  - Alteration in endothelial function precedes the development of atherosclerotic changes and can also contribute to lesion development and later clinical complications

- Compared low volume SIT to traditional ET using 50Kj (approx 2 min) and 750Kj (approx 1 hour) cycling time trials
- Hypothesis:
  - SIT and ET will increase muscle oxidative capacity and 750Kj time trial performance due to major contribution from aerobic metabolism
  - SIT not ET will increase muscle buffering capacity and 50Kj time trial performance due to major contribution from non-oxidative metabolism

- 16 subjects, 8 healthy men to each group
- Baseline measurements: muscle biopsy and 50Kj and 750Kj cycling time trials
- Training: 14 days, 1-2 days recovery between sessions on MWF
  - SIT
    - 30 sec max cycling effort, 4 min recovery (Wingate)
    - 4 reps sessions 1 and 2, 5 reps sessions 3 and 4, 6 reps sessions 5 and 6
  - ET
    - 90-120 min cont cycling at 65% VO_{2peak}
    - 90 min sessions 1 and 2, 105 minutes sessions 3 and 4, 120 min sessions 5 and 6

<table>
<thead>
<tr>
<th></th>
<th>SIT</th>
<th>ET</th>
</tr>
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<tbody>
<tr>
<td><strong>50Kj</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>↓ 4.1%</td>
<td>↓ 3.5%</td>
</tr>
<tr>
<td>Power</td>
<td>↑ 435w → 453w</td>
<td>↑ 416w → 433w</td>
</tr>
<tr>
<td><strong>750Kj</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>↓ 10.1%</td>
<td>↓ 7.5%</td>
</tr>
<tr>
<td>Power</td>
<td>↑ 212w → 234w</td>
<td>↑ 199w → 212w</td>
</tr>
</tbody>
</table>
Results:

- **Muscle oxidative capacity**
  - Max activity of COX ↑ after training, no difference between groups
  - ↑ COX II and COX IV protein content, no difference between groups

- **Muscle buffering capacity**
  - ↑ 7.6% in SIT and 4.2% in ET, no difference between groups

- **Muscle glycogen content**
  - ↑ 28% in SIT and 17% in ET, no difference between groups

• 6 sessions of either low volume SIT or high volume ET induced similar improvements in muscle oxidative capacity, muscle buffering capacity and exercise performance

• 1st study to directly compare these 2 forms of training maintaining a different volume of exercise (approx 2.5 hrs vs. 10.5 hrs over 2 weeks)

- Considered a more practical model of HIIT but still time efficient when compared to Gibala, 2006
- Total duration low < 30 min/session
- ↓ intensity of intervals but ↑ duration
- ↓ recovery periods between intervals
- Approx 10-15 min of exercise in 20-30 min session

- Hypothesis: this training model will provide sufficient stimulus to improve muscle oxidative capacity and functional exercise performance similar to “all-out” Wingate based protocols

<table>
<thead>
<tr>
<th>Study Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 healthy subjects, 6 sessions over 2 weeks</td>
</tr>
<tr>
<td>Baseline measurements: muscle biopsy, 50Kj and 750Kj cycling time trials</td>
</tr>
<tr>
<td>Protocol:</td>
</tr>
<tr>
<td>• 3 min warm-up</td>
</tr>
<tr>
<td>• 60 sec at high intensity effort at VO$_{2peak}$</td>
</tr>
<tr>
<td>• 75 sec active rest (low intensity cycling at 30 W)</td>
</tr>
<tr>
<td>Sessions 1/2: 8 intervals</td>
</tr>
<tr>
<td>Sessions 3/4: 10 intervals</td>
</tr>
<tr>
<td>Sessions 5/6: 12 intervals</td>
</tr>
<tr>
<td>Total duration: 20-29 min</td>
</tr>
</tbody>
</table>
Results:

• ↓ Time:
  • 50Kj: 11% faster
  • 750Kj: 9% faster

• ↑ Power output:
  • 50Kj: 397w → 436w
  • 750Kj: 200w → 221w

• Mitochondrial enzymes:
  • ↑ max activity of COX 29%
  • ↑ protein content of COX II 35% and COX IV 38%

- “2 weeks of low volume constant load interval exercise is a practical strategy to induce mitochondrial biogenesis in skeletal muscle and increase functional exercise capacity”

- Induced similar changes to all-out Wingate-type training as well as larger volume traditional endurance training

- Metabolic and performance adaptations achieved with very low time commitment

- Study did not measure insulin sensitivity, but the increase in muscle glycogen and GLUT4 following training provides some evidence that insulin sensitivity may have been improved due to GLUT4 impact on glucose uptake and storage

**Study Design**

- Rats with MetS produced after artificial selection for low VO$_2$ > 15 generations
- Scored high on risk factors associated with MetS
- 24 rats in 3 groups: AIT (n=8), CME (n=8), or sedentary control (n=8)
- Baseline testing: VO$_{2\text{max}}$, BP, body weight, PGC-1$_\alpha$, endothelial function, blood glucose, cholesterol
- Training: 1 hour/day, 5 days/week until no change in VO$_{2\text{max}}$ for 3 consec weeks, 8 weeks total, uphill treadmill at 25 degree incline

<table>
<thead>
<tr>
<th>AIT</th>
<th>CME</th>
</tr>
</thead>
</table>
| 10 min warm up 50-60% VO$_{2\text{max}}$ | 10 min warm up 50-60% VO$_{2\text{max}}$
| 1 hour of intervals: 4 min at 85-90% VO$_{2\text{max}}$ interspersed with 3 min recovery 70% VO$_{2\text{max}}$ | Continuous running at 70% VO$_{2\text{max}}$ for remainder of session.
| | Duration eventually increased to 2 hr eventually to match training volume |

<table>
<thead>
<tr>
<th></th>
<th>AIT</th>
<th>CME</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{VO}_2\text{max} )</td>
<td>↑ 45%</td>
<td>↑ 10%</td>
</tr>
<tr>
<td>BW</td>
<td>↓ 5%</td>
<td>↓ 7%</td>
</tr>
<tr>
<td>Retroperitoneal fat weight</td>
<td>↓ 54%</td>
<td>↓ 55%</td>
</tr>
<tr>
<td>SBP</td>
<td>↓ 20 mmHg</td>
<td>↓ 6 mmHg</td>
</tr>
<tr>
<td>DBP</td>
<td>↓ 7-9 mmHg</td>
<td>↓ 7-9 mmHg</td>
</tr>
<tr>
<td>PGC-1( \alpha )</td>
<td>↑ 12-fold</td>
<td>↑ 6-fold</td>
</tr>
<tr>
<td>Endothelial function</td>
<td>↑ 2.7-fold</td>
<td>↑ 2-fold</td>
</tr>
<tr>
<td>Fasting BG</td>
<td>↓ 10-15%</td>
<td>↓ 10-15%</td>
</tr>
<tr>
<td>HDL</td>
<td>↑ 25%</td>
<td>no change</td>
</tr>
</tbody>
</table>

- Higher intensity exercise proved to be more effective than moderate intensity exercise at reducing risk factors for metabolic syndrome

- Matched volume of exercise indicates that the intensity of the training is what improved the cardiovascular risk factors
Cardiovascular Risk Factors

- More than one-third (34.9% or 78.6 million) of U.S. adults are obese
- 33% of American adults have HTN (78 million or 1 in 3)
  - Among hypertensive adults:
    - 82% are aware of their condition
    - 75% use anti-hypertensive meds
    - Only 53% have condition controlled to target levels
    - 1 in 5 US adults with HTN do not know they have it
    - 1 in 3 have pre-hypertension
Cardiovascular Risk Factors

• 2010: 19.7 million Americans with DM (8.3%)
• 8.2 million undiagnosed
• 38.2% pre-diabetes with abnormal fasting glucose
• 71 million American adults (33.5%) have high LDL, or “bad” cholesterol
• Only 1 out of every 3 adults with high LDL cholesterol has the condition under control
Safety Considerations

According to ACSM:

- Persons who have been living a sedentary lifestyle or periods of physical inactivity may be at a higher risk for coronary disease with high intensity exercise.
- Risk factors: Family hx, smoking, hypertension, diabetes (or pre-diabetes), hyperlipidemia, obesity.
- Medical clearance for anyone with these conditions.
- Important to establish a base fitness level before trying HIIT.
  - Consistent aerobic training 3-5x/week for 20-60 minutes per session.
HIIT in Cardiometabolic Disease

- Modes: uphill walking/running, cycle ergometer
- Intensities: based on baseline maximal/peak testing data (MHR, peak power, HRR/VO$_{2peak}$)
- Total duration per session: matched energy expenditure between HIIT and MCT (HIIT shorter)
- Interval durations varied
- All supervised
- Training periods 4-16 wks
- Either no adverse events or topic not addressed

## HIIT in Cardiometabolic Disease

<table>
<thead>
<tr>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑ VO2peak</td>
</tr>
<tr>
<td>↓ Blood pressure</td>
</tr>
<tr>
<td>↑ HDL</td>
</tr>
<tr>
<td>↓ Triglycerides</td>
</tr>
<tr>
<td>↓ Fasting glucose</td>
</tr>
<tr>
<td>↓ Oxidative stress and inflammation</td>
</tr>
<tr>
<td>↓ Fatty acid transport protein and FA synthase</td>
</tr>
<tr>
<td>↑ Adiponectin, insulin sensitivity, beta cell function</td>
</tr>
<tr>
<td>↑ PGC-1a</td>
</tr>
<tr>
<td>↑ Maximal rate of CA2+ uptake</td>
</tr>
<tr>
<td>↑ Availability of NO</td>
</tr>
<tr>
<td>↑ Cardiac function</td>
</tr>
<tr>
<td>↑ Enjoyment of exercise</td>
</tr>
<tr>
<td>↑ Quality of life</td>
</tr>
</tbody>
</table>

Aerobic Capacity in Cardiac Rehab

Peak VO$_2$ = strongest predictor of mortality

- Healthy men: 1 MET increase in peak VO$_2$ associated with 50% decrease in mortality rate over 8-year follow-up
- Men referred for ETT: 1 MET increase in VO$_{2peak}$ assoc with 12% improvement in survival
- Post-MI: Every 1 MET increase exercise capacity resulted in 8-14% reduction in all-cause death
- MI, CABG, IHD: most important single predictor of cardiac and all-cause death is VO$_{2peak}$
- HFrEF: 6% increase in VO$_{2peak}$ associated with 5% decrease in risk for all-cause mortality or hospitalization
- HF: VO$_{2peak}$ $\leq$ 14 ml/kg/min associated with high mortality
Moderate-Intensity Continuous Training in Cardiac Rehab

• Typically intensities 40-90% VO$_{2peak}$
  • Vigorous activity may increase risk of SCD and MI in certain patients

• 20% increase in VO$_{2peak}$

• Reduced morbidity and mortality in CHD

• Higher intensity training = reduced CV risk
  • Greater cardioprotective benefits: DBP, glucose control, VO$_2$
Moderate-Intensity Continuous Training in Cardiac Rehab

• May be sub-optimal for patients with higher fitness levels

• Possible threshold intensity over which exercise must be performed to have intrinsic benefits on the heart?

• HIIT allows patients to maintain higher intensities for longer periods than continuous
## HIIT in Cardiac Rehabilitation

### Study Design

- **N = 39 (23 males)**
- **Age: 18-75**
- **Symptom-limited CPX testing (ischemia excluded)**
- **Randomized to HIIT or MCT x 10 weeks**
- **Resistance training not permitted**

### Training Protocols

<table>
<thead>
<tr>
<th>HIIT</th>
<th>MCT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIIT</strong></td>
<td><strong>MCT</strong></td>
</tr>
<tr>
<td>Treadmill</td>
<td>Treadmill</td>
</tr>
<tr>
<td>5 min: warm-up</td>
<td>5 min: warm-up</td>
</tr>
<tr>
<td>3 min: 60-70% HRR</td>
<td>30 min: 60-80% HRR</td>
</tr>
<tr>
<td>4 min: 80-90% HRR</td>
<td>5 min: cool-down</td>
</tr>
<tr>
<td>3 min: 60-70% HRR</td>
<td></td>
</tr>
<tr>
<td>4 min: cool-down</td>
<td></td>
</tr>
</tbody>
</table>

Total: 40 min

HIIT in Cardiac Rehabilitation

Instructive Guide for Patients

<table>
<thead>
<tr>
<th></th>
<th>Moderate intensity</th>
<th>Higher intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed, mph</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Incline, %</td>
<td>0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Higher intensity HR
113-118 (bpm)

Moderate-intensity HR
98-105 bpm

Cumulative minutes

# HIIT in Cardiac Rehabilitation

## Results

<table>
<thead>
<tr>
<th>Patients completed</th>
<th>HIIT</th>
<th>MCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/21 (71%)</td>
<td>13/18 (72%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ex sessions (#)</th>
<th>HIIT</th>
<th>MCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean RPE</th>
<th>HIIT</th>
<th>MCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 (high)</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>12 (low)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Follow-Up</th>
<th>Baseline</th>
<th>Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise duration, min</td>
<td>13.3</td>
<td>15.1*</td>
<td>13.5</td>
<td>15.3*</td>
</tr>
<tr>
<td>Submax endurance (VO$_2$ at AT, ml/kg/min)</td>
<td>14.1</td>
<td>17.1*</td>
<td>14.2</td>
<td>14.9</td>
</tr>
<tr>
<td>Sub-max HR on CPX at end stage 2, bpm</td>
<td>98</td>
<td>90*</td>
<td>95</td>
<td>87*</td>
</tr>
<tr>
<td>VO$_2$peak, ml/kg/min</td>
<td>22.4</td>
<td>26*</td>
<td>21.8</td>
<td>23.5*</td>
</tr>
<tr>
<td>Peak O$_2$ pulse, ml/beat</td>
<td>14.2</td>
<td>15.8*</td>
<td>14.6</td>
<td>16.2*</td>
</tr>
</tbody>
</table>

* P < .05

HIIT in Cardiac Rehabilitation

Safety
• No events requiring hospitalization during or within 3 hrs post exercise
• No falls
• HIIT: 1 patient with knee pain, held training x 2 wks, returned at decr intensity
• MCT: 1 patient withdrew due to knee pain

Limitations
• No satisfaction instrument
  • Anecdotal reports favored HIIT, “less boring”
• Study not designed/ powered to assess safety or clinical events
• Small N
• Younger, mostly male patients w/ higher exercise capacities

HIIT in Cardiac Rehabilitation

Conclusions

• HIIT resulted in greater improvement than MCT in both peak exercise capacity and submaximal endurance
• In patients with stable CHD, HIIT could be integrated into a US-based CR model that used standard staff supervision and a visual instructive guide for patients.

# HIIT in Heart Failure

## Study Design

- **N** = 27 (20 males)
- Age: 50-80+
- EF < 40%, stable, optimal therapy, non-cachectic
- VO2peak testing
- Randomized to HIIT, MCT, or control x 12 weeks

## Training Protocols

<table>
<thead>
<tr>
<th></th>
<th>HIIT</th>
<th>MCT</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2x/wk supervised ex, 1x/wk independent</td>
<td>2x/wk supervised ex, 1x/wk independent</td>
<td>Every 3rd wk supervised ex</td>
</tr>
<tr>
<td>Treadmill</td>
<td>10 min: 50-60% VO2peak&lt;br&gt;4 min: 90-95% HRpeak&lt;br&gt;3 min: 50-70% HRpeak&lt;br&gt;3 min: cool-down</td>
<td>Treadmill 47 min: 70-75% HRpeak</td>
<td>Treadmill 47 min: 70% HRpeak&lt;br&gt;Follow family MD advice</td>
</tr>
<tr>
<td></td>
<td>Total: 38 min</td>
<td>Total: 47 min</td>
<td>Total: 47 min (q 3rd wk)</td>
</tr>
</tbody>
</table>

HIIT in Heart Failure

- Endothelial function
  - Brachial artery flow-mediated dilation (FMD)
- Echocardiography
- Muscle biopsy
  - PGC-1α (mitochondrial biogenesis)
- Sarcoplasmic reticulum Ca\(^{2+}\) ATPase-1 and -2 transport (skeletal muscle fatigue)

- Blood analyses
  - Glucose
  - Lipids (TC, HDL, LDL, Trig)
  - Hgb
  - hs-CRP
  - Creatinine

- Quality of life
  - MacNew Heart Disease Health-Related QOL

HIIT in Heart Failure

Significantly greater improvements in:
• Exercise Capacity
  • $\text{VO}_{2\text{peak}}$: HIIT 46% vs. MCT 14%
  • Work economy
    • 15% decr O2 cost
    • 8-bpm lower HR
    • 59% lower blood lactate at submax walking speed
• Borg RPE
  • HIIT 12 vs. MCT 17
• PGC-1$\alpha$: 47%
• SERCA: 60%

HIIT in Heart Failure

- LV Remodeling
  - LVDD (12%)
  - LVSD (15%)
  - LVEDV (18%)
  - LVESV (25%)
  - proBNP (40%)

- Systolic Function
  - LVEF 10% (35% relative increase)
  - SV 17%
  - Systolic mitral annulus excursion 30%
  - Peak systolic mitral annulus velocity 22%
  - Peak ejection velocity 19%

HIIT in Heart Failure

- Diastolic Function
  - LV relaxation 49%
  - LV filling pressure
    - HIIT 26%, MCT 15%
    - Isovolumic relaxation time 22%

- Endothelial Function
  - FMD significantly greater improvement in HIIT

- MacNew QOL
  - Significantly greater improvement in HIIT

HIIT in Heart Failure

Possible reasons for benefit?

• Lower baseline levels/higher exercise intensity than previous studies
• Improved mitochondrial function and calcium cycling in skeletal muscle with HIIT
• Endurance training well-established for improvement of endothelium-dependent vasodilation in CAD  
  • Possible increased bioavailability of NO in HIIT patients
• More intensive physical training = more rewarding, improved capacity for daily activities

HIIT in Heart Failure

Safety
• 1 patient from MCT died of cardiac causes unrelated to exercise training

Limitations
• Small sample, predominantly male
• Only post-infarct HF patients

HIIT in Heart Failure

Conclusions

• HIIT relative to individual’s max O2 uptake is feasible in elderly patients with chronic HF and severely impaired CV function

• Exercise intensity may be important factor for reversing LV remodeling, improving aerobic capacity, and improving QOL in patients with post-infarction HF

HIIT Protocol Optimization in CAD

HIIT Protocol Optimization in CAD

- Time to exhaustion with passive recovery phases significantly greater than with active recovery phases
- 18/19 patients rated Protocol A as preferred
- RPE lower during protocols with passive recovery
- Hypothesis:
  - Passive recovery $\rightarrow$ better muscle reoxygenation $\rightarrow$ restoration of phosphorylcreatine stores $\rightarrow$ reduced fatigue

HIIT Protocol Optimization in CAD

Safety

• No significant ventricular arrhythmias or abnormal BP responses
• 3 patients: ST segment depression ($\leq 2$ mm) and 2/10 angina, resolved during passive recovery

Limitations

• Small sample, predominantly male
• Cohort of CHD patients followed closely and exercise regularly
• Troponin levels not drawn to exclude myocardial injury

HIIT Protocol Optimization in CAD

Conclusions

• HIIT at 100% maximal aerobic power is feasible and appears safe in stable, fit, well-selected CAD patients

• Passive recovery leads to significantly longer total exercise duration

• 15/15 sec active/passive phases strikes balance between comfort/safety and maintaining near VO$_{2\text{max}}$
HIIT Protocol Optimization in HF

A

30/30 sec.

1,651 sec*
RPE 15

B

30/30 sec.

986 sec
RPE 18

C

90/90 sec.

1,574 sec*
RPE 16

D

90/90 sec.

961 sec
RPE 17

*M = P < .001, signif diff from B and D

HIIT Protocol Optimization in HF

- Time to exhaustion with passive recovery phases significantly greater than with active
- Time above $\%V_O^{2\text{peak}}$
  - $>90-100\%$: Protocol A < B, C, D ($p < .05$)
  - $>85\%$: no differences
- Oxygen pulse significantly higher in Protocol A
  - ? stimulus for LV contractility and/or muscle $O_2$ uptake
- Time spent at high $\%V_O^2$ in active vs. passive protocols differed depending on baseline $VO_2$

HIIT Protocol Optimization in HF

Safety
• “No safety issues”

Limitations
• Small sample, all male
• Relatively young with few comorbidities
• Only 4 protocols

Conclusions
• HIIT appears safe in men with mild to moderate HF
• Short intervals with passive recovery appears optimal

Ischemia with HIIT in CHD Patients


- No significant ventricular arrhythmias or abnormal BP responses
- 35% of subjects had exercise-induced ischemia during maximal ETT, but HIIT did not induce prolonged ischemia
- 3 HIIT subjects with ischemia during session: no more than 2 mm ST depression with normalization of this during passive recovery
- Baseline cTnT <0.04, no change at 20 min and 24 h after exercise
Ischemia with HIIT in CHD Patients


- 67 yo male with stable angina
- One 34-min HIIT session
- Ischemia x 20 min
- No significant arrhythmias or troponin-T elevation measured 24 h after session
- Warm-up angina phenomenon
HIIT Safety


### Study Design

- 4,846 cardiac rehab patients (70% male)
- Pre-rehab determination of VO\(_{2\text{peak}}\) and HR\(_{\text{peak}}\)
- Average 37 exercise sessions, each 1 hour

<table>
<thead>
<tr>
<th></th>
<th>HIIT</th>
<th>MCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex intensity</td>
<td>85-95% HR(_{\text{peak}})</td>
<td>60-70% HR(_{\text{peak}})</td>
</tr>
<tr>
<td>Total sessions</td>
<td>46,364</td>
<td>129,456</td>
</tr>
<tr>
<td>Adverse events</td>
<td>2 non-fatal cardiac arrests</td>
<td>1 fatal cardiac arrest</td>
</tr>
<tr>
<td>Adverse event rate</td>
<td>1/23,182 hours</td>
<td>1/129,456 hours</td>
</tr>
</tbody>
</table>

- Power = 23%
- Would require 21,000 patients for adequate power of 0.80 and \(P = .05\)
HIIT Safety in Cardiac Rehab

• Vigorous exercise transiently increases risk of AMI and SCD

• MI and SCD in supervised cardiac rehab programs: 1 in 50,000 to 100,000 patient-hours
  • 2 fatalities in 1.5 million patient-hours

• “Interval training” has been incorporated into cardiac rehab recommendations, but no specifics
HIIT Safety in Cardiac Rehab

AHA/AACVPR Scientific Statement

Core Components of Cardiac Rehabilitation/Secondary Prevention Programs: 2007 Update

A Scientific Statement From the American Heart Association Exercise, Cardiac Rehabilitation, and Prevention Committee, the Council on Clinical Cardiology; the Councils on Cardiovascular Nursing, Epidemiology and Prevention, and Nutrition, Physical Activity, and Metabolism; and the American Association of Cardiovascular and Pulmonary Rehabilitation

Gary J. Balady, MD, FAHA, Chair; Mark A. Williams, PhD, Co-Chair; Philip A. Ades, MD; Vera Bittner, MD, FAHA; Patricia Comoss, RN; JoAnne M. Foody, MD, FAHA; Barry Franklin, PhD, FAHA; Bonnie Sanderson, RN, PhD; Douglas Southard, PhD, MPH, PA-C

For aerobic exercise: F=3-5 days/wk; I=50-80% of exercise capacity; D=20-60 minutes; and M=walking, treadmill, cycling, rowing, stair climbing, arm/leg ergometry, and others using continuous or interval training as appropriate.
HIIT Summary

• Larger, multicenter trials needed
• Additional populations needed (e.g. women, AICD, HFpEF)
• Additional protocol options
• HIIT not appropriate for all cardiovascular patients
• Use of HIIT in cardiac rehab requires baseline ETT, as intensities must be relative to each individual
Cardiac Risk Associated with Vigorous Exercise

- Risk of sudden cardiac death during vigorous physical activity estimated at 1/year for every 15,000-18,000 previously asymptomatic individuals
- Sudden Cardiac Death (SCD):
  - 300,000-400,000 deaths annually in the US
  - Most common and often the first manifestation of coronary heart disease
  - Responsible for ≈50% of the mortality from CV disease in the US and other developed countries
- Commonly found among previously asymptomatic adults with SCD:
  - Acute coronary artery plaque disruption including plaque rupture or erosion
  - Acute thrombotic occlusion
Cardiac Risk Associated with Vigorous Exercise

Suggested triggering mechanisms of SCD during vigorous exercise:

- Increased wall stress from increases in heart rate and blood pressure
- Exercise-induced coronary artery spasm in diseased artery segments
- Increased flexing of atherosclerotic epicardial coronary arteries leading to plaque disruption and thrombotic occlusion

Rates of sudden cardiac death are disproportionately higher in the most sedentary individuals when they perform unaccustomed or infrequent exercise

**Importance of establishing base fitness before initiating vigorous exercise such as HIIT**
Vital Sign Assessment

- Purpose of CV risk factor assessment is to minimize the likelihood of an adverse event
  - Risk of death during exercise is low (6 in 100,000 in middle aged-men) BUT most of those deaths are attributed to undiagnosed CV disease
- AHA guidelines: HR and BP should be checked at every primary care visit
- ACSM recommendation: baseline HR and BP measurements before any activity
- Billek-Sawhney B, Sawhney R. Cardiovascular considerations in outpatient orthopedic physical therapy, 1998.
  - 68 people referred for outpatient PT
  - 62% had secondary CV disease
Vital Sign Assessment


- 59.5% strongly agree that HR/BP should be included in PT screening
- 38% *did not* measure HR in the week prior
- 43% *did not* measure BP in the week prior
- 6% *always* measured HR in the week prior
- 4.4% *always* measured BP in the week prior
- Reasons why not:
  - “Not important for my patient population”
  - “Nurses monitor VS”
  - “I measure VS when necessary”
Pop Culture

Google search:
• HIIT yields 2,225,000 results
• Tabata yields 2,550,000 results

• Pinterest: 100’s of detailed workouts under search headings HIT, Tabata, interval training, etc.
  • No specific formula
  • Common ratio of 2:1 work:recovery, but inconsistent
Pop Culture

- Men’s Fitness
- Sparkpeople
- NeilaRay.com
- Bodybuilding.com
- WebMD – detailed workout, some precautions
- Shape.com
- ACSM.org – good precautions
- Myfitstation.com
- Muscleandfitness.com
- Mindbodygreen.com
- Fitnessblender.com

- YouTube – 1000’s of videos with workout demo’s from Fitness Blender
- Workout videos with 500K up to 2 million views
  - No specific guidelines
  - Most with little to no precautions
References


References


References


