RIB STRESS FRACTURES IN ELITE ROWERS

Anders Vinther, Research Physiotherapist, ph.d.
Herlev Hospital, Copenhagen, Denmark & Lund University, Sweden

World Rowing Coaches Conference, Copenhagen 2010
RIB STRESS FRACTURES IN ELITE ROWERS

Danish National Rowing Team
Physiotherapist 1999 – 2001

Rib stress fracture research since 2000
Ph.d. January 2009
RIB STRESS FRACTURES IN ELITE ROWERS

1. Stress fractures in general
   - Definition
   - Pathogenesis

2. Rib stress fractures in elite rowers
   - Epidemiology
   - Suggested risk factors and injury mechanisms

3. Investigations of:
   - Bone Mineral Density (BMD)
   - Muscular co-contraction
   - Muscle strength
   - Rowing technique
   - Testosterone and BMD in male lightweight rowers
   - Biomechanics of slide-based ergometer rowing
Stress fracture:

Definition:

“A stress fracture can be defined as a partial or complete bone fracture that results from repeated application of stress lower than the stress required in order to fracture the bone in a single loading.”

Bone stress is the load or force applied per unit area and results in bone deformation known as bone strain.

Brukner P, Bennell KL, Matheson G
Stress fracture:

Stress fractures are developed over time when the natural remodeling of bone cannot compensate for (repair) the accumulating microdamage caused by a combination of the repetitiveness of the bone strain, the strain rate, the strain magnitude and the limited periods of recovery allowed between exposure to the bone strain.


Figure from: Brukner P, Bennell KL, Matheson G. *Stress fractures*. Australia: Blackwell Science; 1999.
RIB STRESS FRACTURES IN ELITE ROWERS

Continuum of clinical responses to bone loading:

- Normal remodeling
- Accelerated remodeling
- Stress reaction
- Stress injury
- Stress fracture
- Complete fracture

Brukner, Bennell and Matheson. Stress fractures, 1999
RIB STRESS FRACTURES IN ELITE ROWERS

RIB STRESS FRACTURES IN ELITE ROWERS

Mechanical loading

Intrinsic factors (skeletal, muscle, joint, and biomechanical factors)

Bone strain

Strain magnitude and rate, and number of loading cycles

Bone damage

No damage

Damage-related remodeling

Strain-related modeling and/or remodeling

Extrinsic (training) and intrinsic (gender) factors

Damage repair

Imbalance between damage and remodeling

Accumulation of damage

Stress reaction

Pathology continuum

Altered skeletal properties (bone geometry and/or material properties)

Asymptomatic

Stress fracture

Complete bone fracture

Feedback to positively influence skeletal factors
Fig. 3. Relationship between the bone strain continuum and diagnostic findings on bone scan, MRI or CT.
RIB STRESS FRACTURES IN ELITE ROWERS

Anders Vinther, RPT, Ph.D, Herlev Hospital and Lund University
”The Pathology and prevention of rib stress fractures will be one of the most useful areas of research in rowing injuries.”


Model for sport injury prevention

1. Establishing the extent of the injury problem:
   - Incidence
   - Severity

2. Establishing the aetiology and mechanisms of sports injuries

3. Introducing a preventive measure

4. Assessing its effectiveness by repeating step 1

van Mechelen et al. 1992
RIB STRESS FRACTURES IN ELITE ROWERS
- Introduction:

Incidence: 6.1 – 12 % (Warden et al. 2002)
  Danish national rowing team incidence 2002: 16.7%

Severity: Average time from diagnosis to resumed training: 3-8 weeks
  2 Danish rowers missed the 2002 World Championships due to rib stress fractures

Location: Anywhere in the ribs 2 to 10 - 93 % in the ribs 4 to 8 (Warden et al. 2002)

Diagnosis: History, clinical examination and 99m Technetium MDP bone scan
RIB STRESS FRACTURES IN ELITE ROWERS
- Suggested mechanisms of injury and risk factors:

Stress forces induced to the ribs by muscular contractions

Rib cage compression

Rowing technique

Changed training routines

Bone mineral density

Bone geometry

Bone remodeling
RIB STRESS FRACTURES IN ELITE ROWERS
- Suggested mechanisms of injury and risk factors:

Stress forces induced to the ribs by muscular contractions
Rib cage compression
Rowing technique
Changed training routines
Bone mineral density
Bone geometry
Bone remodeling
RIB STRESS FRACTURES IN ELITE ROWERS
- Suggested mechanisms of injury and risk factors:

Stress forces induced to the ribs by muscular contractions
Rib cage compression
Rowing technique
Changed training routines
Bone mineral density
Bone geometry
Bone remodeling
RIB STRESS FRACTURES IN ELITE ROWERS
- Suggested mechanisms of injury and risk factors:

Stress forces induced to the ribs by muscular contractions

Rib cage compression

Rowing technique

Changed training routines

Bone mineral density

Bone geometry

Bone remodeling

<table>
<thead>
<tr>
<th></th>
<th>2.77</th>
<th>2.77</th>
<th>2.84</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (cm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moment of inertia (cm⁴)</td>
<td>.61</td>
<td>1.06</td>
<td>1.54</td>
</tr>
<tr>
<td>Bending strength (%)</td>
<td>100%</td>
<td>149%</td>
<td>193%</td>
</tr>
</tbody>
</table>
RIB STRESS FRACTURES IN ELITE ROWERS
- Suggested mechanisms of injury and risk factors:

Stress forces induced to the ribs by muscular contractions
Rib cage compression
Rowing technique
Changed training routines
Bone mineral density
Bone geometry
Bone remodeling

RIB STRESS FRACTURES IN ELITE ROWERS
- Study design:

Material:

7 Danish national team rowers with previous rib stress fractures and 7 controls matched for gender, age, height, weight and training experience.

Aim:

To investigate if the rowers with previous rib stress fractures are different from their matched controls with respect to the following parameters.
RIB STRESS FRACTURES IN ELITE ROWERS
-Measurements and methods: DEXA scans:

Study 1
RIB STRESS FRACTURES IN ELITE ROWERS

- Results: L2 - L4 BMD

% of normal young adult reference population:

Controls: 115.3 (108 - 127)
RSF: 99.1 (85 - 111)

(p = 0.028)

g·cm⁻²:

Controls: 1.40 (1.27 - 1.57)
RSF: 1.22 (1.02 - 1.37)

(p = 0.028)

RIB STRESS FRACTURES IN ELITE ROWERS
- Measurements and methods:

Neuromuscular activity and magnitude of co-activation of serratus anterior, obliquus externus abdominis and trapezius middle and lower fibers during the rowing stroke.

Method:
EMG-analysis during high intensity ergometer rowing.
RIB STRESS FRACTURES IN ELITE ROWERS

-Results: EMG

CoActiv 1 - serratus vs. obliquus

% EMG signal overlap / EMGmax

Serratus anterior and Trapezius lower fibers

RSF

Control

% EMG signal overlap

RIB STRESS FRACTURES IN ELITE ROWERS
- Measurements and methods:

Velocity of the seat and the handle during the rowing stroke.
Shoulder flexion angle during the rowing stroke.

Method:
2-D video analysis.
RIB STRESS FRACTURES IN ELITE ROWERS
- Results: 2-D video analysis

Study 2

Velocity of the seat (blue) and handle (red)

Average seat velocity first 0-0.6 sec: RSF: 0.25 ms\(^{-1}\) Controls: 0.15 ms\(^{-1}\) (p<0.05)
Seat-handle-difference first 0-0.6 sec: RSF: 0.18 ms\(^{-1}\) Controls: -0.01 ms\(^{-1}\) (p<0.075)

RIB STRESS FRACTURES IN ELITE ROWERS
- Measurements and methods:

Elbow flexion strength relative to knee extension strength.

Method:
Biodex - isokinetic muscle strength - angle velocity: 30°/sec
RIB STRESS FRACTURES IN ELITE ROWERS
- Results: BIODEX

-Force presented as Nm and ratio calculated as knee-ext./elbow-flex.: 

- Controls (n=7):
  - Elbow-flexion: 57.87 Nm
  - Knee-extension: 268.19 Nm
  - RATIO: 4.8 (3.5-5.1)

- RSF (n=7):
  - Elbow-flexion: 60.66 Nm
  - Knee-extension: 253.49 Nm
  - RATIO: 4.2 (4.2-5.3)

- Ratio difference: (p = 0.043)

RIB STRESS FRACTURES IN ELITE ROWERS
-Hormonal factors and BMD:

Material:
13 male lightweight Danish national team rowers.

Aim:
To investigate possible associations between testosterone levels and BMD in elite lightweight male rowers.

Endurance trained male athletes display testosterone levels reduced to 60-85% of untrained controls. (Hackney 2001, review)
Testosterone and BMD in male lightweight rowers
- Correlations:

Total Testosterone and L2-L4 BMD

$r_s: 0.63 \ p=0.021$
Testosterone and BMD in male lightweight rowers

- Correlations:

L2-L4 BMD and Training Years:

\[ r_s: 0.73 \quad p=0.005 \]
Testosterone and BMD in male lightweight rowers

- Main result:

A significant correlation between L2-L4 BMD and Testosterone remained after controlling for Training Years by calculation of partial correlation: $r_s: 0.61 \ p<0.05$


Study 3
Placing the rowing ergometer in slides: Implications for injury risk
SLIDES?

Picture from: www.concept2.com
Background:

A prospective investigation of injury incidence found that time spent on ergometer training was related to risk of injury (Wilson F. et al. 2008)
Aim:

To investigate force production during ergometer rowing with and without slides.

To evaluate if placement of the ergometer in slides may reduce the risk of musculo-skeletal overuse injury.
Hypothesis:

Rowing in slides may change the biomechanics of the rowing stroke:

1. Increase stroke rate
2. Reduce Peak Force of each rowing stroke
Background:

Rib loading is related to handle force. 
*(Warden et al. 2003, Abstract)*

Force production at the handle is related to the overall loading of the rower.

Compressive force up to 4.6 times body weight in female rowers - calculated from handle force. 

LBP is the most frequent injury and rib stress fracture is the injury causing the most time lost from training and competition. 
*(Rumball et al. 2005 Sports Med)*
Material:

22 National Team Rowers:
8 women (5 lightweight and 3 open class)
14 men (9 lightweight and 5 open class)

Picture from: World Championships 2006

Picture from: World Championships 2007, Simon Lorenz
Methods:

Handle force was measured with a strain-gauge.

Handle excursion was measured with a potentiometer attached to the fly-wheel axis.

Sampling frequency: 1000 Hz.

Picture from: www.concept2.com
Test procedure:

- Self paced warm-up.
- 2 x 3.5 minutes of ergometer rowing at 75-80 % of maximal power output - with and without slides in a randomized order.
- 1 trial of similar duration in stationary ergometer with stroke rate identical to slide trial. (Study 4)
Results:

Equal external power output and exercise intensity:

Men and Women (N=22):

Power:

Slides: 281.9 Watt (76.8 % max)
Stationary: 280.1 Watt (76.3 % max)

Heart Rate:

Slides: 158.4 bpm (86.1 % max)
Stationary: 156.6 bpm (85.1 % max)
Results:

Stroke Rate:

**Men (N=14):**
- Slides: 28.7
- Stationary: 25.9
- Difference: 2.8 (95% CI: 2.0-3.6)

**Women (N=8):**
- Slides: 25.7
- Stationary: 25.0
- Difference: 0.7 (95% CI: 0.08-1.6)
Results:

Peak Force **Men (N=14):**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationary</td>
<td>887 N</td>
<td></td>
</tr>
<tr>
<td>Slides</td>
<td>811 N</td>
<td></td>
</tr>
</tbody>
</table>

**Difference:** 76 N (95% CI: 57-95 N)
Results:

Peak Force **Women (N=8):**

- **Slides:** 612 N
- **Stationary:** 622 N

**Difference:** 20 N (95% CI: 8-31 N)
Conclusion:

Placement of the rowing ergometer in slides decreased the Peak Force production in each rowing stroke.

The external power output was maintained.

Picture from: World Championships 2007, Simon Lorenz
Perspectives:

Rowing in slides may reduce the risk of overuse injury without compromising the training efficiency and rowing performance of the rowers.

Prospective controlled studies are required to test this hypothesis.
Aim:

To investigate neuromuscular activity of muscles suggested to be involved in the development of rib stress fractures during ergometer rowing with and without slides.

To relate neuromuscular activity to force production during ergometer rowing.
Methods:
Study 4 + EMG signals from the following muscles:

- Trapezius Middle and lower fibers
- Deltoideus posterior fibers
- Latissimus Dorsi
- Serratus Anterior
- Obliquus Externus Abdominis
- Vastus lateralis
- Tibialis Anterior

Picture from: www.concept2.com
Handle Force:

MALE ROWERS

Drive: 1 2 3 4 5 6 7 8
Recovery: 1 2 3 4 5 6 7 8

Force N

- - Stationary
Slides

800
700
600
500
400
300
200
100
0
EMG:

2A - MALE ROWERS

Trapezius Middle Fibers n=12
- - - Stationary
- - - Slides

% EMGmax

Force N

DRIVE RECOVERY
Average normalized EMG from thoracic muscles during the rowing stroke divided into 8 phases:
Average normalized EMG from thoracic muscles during the rowing stroke divided into 8 phases:

**2C - FEMALE ROWERS**

- Latissimus Dorsi n=8
  - Stationary
  - Slides

**2C - MALE ROWERS**

- Latissimus Dorsi n=13
  - Stationary
  - Slides

**2D - FEMALE ROWERS**

- Deltoidus Posterior Fibers n=7
  - Stationary
  - Slides

**2D - MALE ROWERS**

- Deltoidus Posterior Fibers n=13
  - Stationary
  - Slides (P=0.007)
Average normalized EMG from thoracic muscles during the rowing stroke divided into 8 phases:

2E - FEMALE ROWERS
% EMGmax

2E - MALE ROWERS
% EMGmax

2F - FEMALE ROWERS
% EMGmax

2F - MALE ROWERS
% EMGmax

Obliquus Externus Abdominis
n=8

Serratus Anterior
n=6

Obliquus Externus Abdominis
n=11

Serratus Anterior
n=11

Force N

Force N

P=0.021
Average normalized EMG from leg muscles during the rowing stroke divided into 8 phases:
Timing of Peak EMG of thoracic muscles and Peak Force:

Peak EMG Trapezius: 106-185 ms

Peak EMG Latissimus Dorsi: 57-129 ms

Warden et al. 2002
Conclusions:

Placement of the rowing ergometer on slides affected the neuromuscular activity of the leg muscles more than the thoracic muscles.

Regardless of ergometer condition the timing of Peak neuromuscular activity of the scapular retractors coincided with the timing of Peak Force at the handle.

A gender difference in neuromuscular activity of m. serratus anterior was observed.
Thank you!
Supervisors:
Charlotte Ekdahl
Inge-Lis Kanstrup
Per Aagaard

Co-Authors:
Tine Alkjær
Erik Christiansen
Peter Magnusson
Benny Larsson

- Rowing ergometer and slides provided by Reiner Modest, Modest Sport
- Measuring equipment provided by Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark
- Laboratory facilities provided by Department of Neuroscience and Pharmacology, The Panum Institute, The Sports Medicine Research Unit, Bispebjerg Hospital and Department of Clinical Physiology, Herlev Hospital