Altered left ventricular geometry and torsional mechanics in high altitude-induced pulmonary hypertension: a 3-D echocardiographic study

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Conflict of interests

Toshiba Switzerland kindly provided the Artida ultrasound system and working station for the duration and sole purpose of the study.

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Background
Torsion and LV Function

Fiber cross-interactions

Matrix deformation

Amplification

FS 15-20%

double helix - torsion

deformable myofiber sheets

+ 

EF 60%

LV twist and torsion

Subepicardium: left hand helix (R₂)
Subendocardium: right hand helix, (R₁)

Torque Arm
R₂ > R₁

LV Twist (°) = apical rotation - basal rotation
base-apex distance

LV Torsion (°/cm) = apical rotation - basal rotation
base-apex distance

Basal level: clockwise rotation (-)
Apical level: counterclockwise rotation (+)

figure source: P. Sengupta et al. JACC Img. 2008
Determinants of twist and torsion

**Imaging-related variability**

- variable LV length:
  - inter-subject variability
  - torsion?

- variable scan planes:
  - rotation = level dependent
  - true apical?

**(patho-)physiologic factors**

- General myofibre mechanics:
  - Preload (↑) & Afterload (↓)
  - Contractility (↑)

- Epi- vs Endo torque ratio:
  - conc. remodeling = $R_2 >> R_1$
  - specific endo- or epi- disease

**LV geometry, RV pressure?**

- eccentricity (D-shaping) \(^1\)
- pulmonary pressure \(^1\)
- sfericity \(^2\)

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\(^1\) S. Puwanant,...JD Thomas et al. Circulation 2010
\(^2\) B. van Dalen et al. J Appl Physiol 2010

B. van Dalen et al. JASE 2008
"irreversible" increase in pulmonary artery pressure (PAP) is associated with geometrical changes and reduced LV Torsion at unchanged LVEF compared to control group.¹

...many baseline differences...
...chronic = multiple potential mechanisms...

"acute and reversible" increase in PAP within same individual

...paired comparison...
...acute = no structural remodelling yet...

AIM: to study the relation PAP-geometry-LV torsion

¹ S. Puwanant,...JD Thomas et al. Circulation 2010
Methods
Study design: low and high altitude

Monte Rosa: altitude (n=22)
D0 → 3600m D1 → 4559m
Altitude Echo at D3 and D4

Basel: Echo core-lab

Basel: Echo core-lab

Zürich: baseline (n=26)

Margherita

Basel

Zürich 450m

Margherita 4459m
### general study parameters

**O₂ - Circulation**

- Arterial Oxygen $\leftarrow$ pulse oxymetre Saturation ($\text{SatO}_2$)
- Circulation $\leftarrow$ Heart rate / Cardiac Index (CI) from 3-D stroke volume

### RV function / loading

- **RV volumes** $\leftarrow$ 2-D areas in AP4Ch (RV EDA / RV ESA)
- **RV function** $\leftarrow$ 2-D fractional area change (RV FAC)
- **RV preload** $\leftarrow$ VCI size+variation & RV EDA
- **RV afterload** $\leftarrow$ s/d PAP by TV/PV regurgitation gradient (TR- / PR-PG)

### LV function / loading

- **LV volumes** $\leftarrow$ 3-D volumes (LV ESV / LV EDV)
- **LV function** $\leftarrow$ 3-D ejection fraction (LV-EF)
- **LV strains** $\leftarrow$ 3-D speckle tracking derived strains and torsion
- **LV preload** $\leftarrow$ transmitral E / mean annular TDI Ea (E/Ea) & LV-EDV
- **LV afterload** $\leftarrow$ invasive blood pressure (sys / dias BP)

Toshiba Artida ultrasound system and working station kindly provided by Toshiba Switzerland
3-D deformation

Alignment of axes (as in CMR)
- “true 2-Ch” (0° to IVS)
- “mod. 4-Ch” (90° to 2-Ch)
- 3 SAX (evenly distributed, 90° to long axis)

→ long axis

Automated 3-D speckle tracking
- Strains (circum., long., radial)
- rotation, twist, torsion
- LV EF and LV volumes
3-D geometry

Alignment of axes (as in CMR)
- “true 2-Ch” (0° to IVS)
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Automated 3-D speckle tracking
- Strains (circum., long., radial)
- Rotation, twist, torsion
- LV EF and LV volumes

Definition of LV geometry, both diastolic / systolic

LV eccentricity
Areas: 2Ch / 4Ch

LV sphericity
Volume / length (ml/cm)

SAX apex
C3
mod. 4-Ch

Area
38 cm²

Length
8.7 cm

C5
true 2-Ch

Area
42 cm²

D sept-lat
D ant-inf

SAX mid
SAX base
Haemodynamics & Loading

**O₂ - Circulation**

- **SatO₂ (%)**
  - 450m: 90%
  - 4559m D3: 85%
  - 4559m D4: 80%
  - p<0.01

- **CI (l/min/m²)**
  - 450m: 2.2 l/min/m²
  - 4559m D3: 2.6 l/min/m²
  - 4559m D4: 3 l/min/m²
  - p<0.01
Haemodynamics & Loading

**O₂ - Circulation**
- Heart rate (bpm):
  - p<0.01
- Cl (l/min/m²):
  - p<0.01

**Afterload**
- PAP (mmHg):
  - p<0.01
- E/Ea Ratio:
  - p=NS

**LV Preload**
- Systemic BP (mmHg):
  - p=NS
- ED Volume (ml):
  - p=NS
<table>
<thead>
<tr>
<th></th>
<th>450m</th>
<th>4559m D3</th>
<th>4559m D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV EDA (cm²)</td>
<td>20 ± 4.6</td>
<td>22 ± 4.3</td>
<td>22 ± 4.6</td>
</tr>
<tr>
<td>RV ESA (cm²)</td>
<td>11 ± 3.0</td>
<td>13 ± 3.0</td>
<td>12 ± 2.9</td>
</tr>
<tr>
<td>RV FAC (%)</td>
<td>46 ± 9.9</td>
<td>42 ± 8.3</td>
<td>45 ± 9.0</td>
</tr>
<tr>
<td>LV EDV (ml)</td>
<td>117 ± 22</td>
<td>114 ± 27</td>
<td>118 ± 22</td>
</tr>
<tr>
<td>LV ESV (ml)</td>
<td>50 ± 11</td>
<td>50 ± 15</td>
<td>49 ± 12</td>
</tr>
<tr>
<td>LV SV (ml)</td>
<td>67 ± 13</td>
<td>64 ± 13</td>
<td>69 ± 13*</td>
</tr>
<tr>
<td>LV EF (%)</td>
<td>57 ± 4.6</td>
<td>57 ± 4.3</td>
<td>59 ± 5.2</td>
</tr>
<tr>
<td>Strain Circum. (%)</td>
<td>-28.3 ± 4.0</td>
<td>-27.6 ± 3.1</td>
<td>-29.2 ± 4.6</td>
</tr>
<tr>
<td>Strain Longit. (%)</td>
<td>-16.0 ± 2.8</td>
<td>-16.4 ± 1.8</td>
<td>-17.3 ± 2.1</td>
</tr>
<tr>
<td>Strain Radial (%)</td>
<td>34.8 ± 7.1</td>
<td>32.5 ± 7.5</td>
<td>35.6 ± 6.7</td>
</tr>
</tbody>
</table>

# p<0.01 vs low altitude, ‡ p<0.05 vs low altitude, * p<0.05 high altitude D3 vs D4.

All p-values corrected for multiple repeated measurements.
LV Geometry & Torsion

LV Sphericity (ml/cm)

- 450m
- 4559m D3
- 4559m D4

p=NS

LV Eccentricity

p<0.05

LV Twist (°)

- 450m
- 4559m D3
- 4559m D4

p=0.09

LV torsion (°/cm)

p<0.01

p<0.05
Geometry vs Torsion

Diastolic Eccentricity

\[ R = -0.33 \quad p < 0.01 \]

Systolic Eccentricity

\[ R = -0.38 \quad p < 0.01 \]
Conclusions
Conclusions

High altitude exposure is associated with pulmonary hypertension, mild D-shaping of the ventricle and reduced ventricular torsion... without changes in global left ventricular function and preload. (changes in ) torsion only correlated with (changes in) ventricular eccentricity...

**Taken together, these data suggests a direct relation between LV geometry and torsional mechanics.**
3-D speckle tracking

3D instead of 2D speckle tracking
- geometry assumption free (LV mass / volume)
- through plane tracking
- distance apex-base standardized twist \(\rightarrow\) torsion
- standardized alignment / planes

Disadvantages
- image quality
- frame rate (19 Hz)
\(\rightarrow\) global strains / torsion
\(\rightarrow\) limited to ejection / peak

Toshiba Artida 3-D Acquisition + 3-D tracking software
Thank You for Your Attention