Mechanisms of Injury and Countermeasures for EVA Associated Upper Extremity Medical Issues: Extended Vent Tube Study

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Issue

- During NBL training sessions a large amount of moisture accumulates in the glove due to the design because the liquid ventilation cooling garments do not extend completely into the hands and ventilation/cooling of the hand glove section is limited.
- Many astronauts develop subungual redness and fingernail pain following their NBL training sessions with subsequent onycholysis occurring over subsequent weeks (see example below):

![Image of fingernails with onycholysis](image)

- Various attempts have been made to reduce or avoid this problem, including trimming fingernails, taping the fingertips, or adding Dermabond medical grade superglue to the fingertip. An additional study using the product Hard as Nails found some positive effects as a countermeasure However, in general this remains a problem.
Issue (Concluded)

• Generally, six weeks is needed to recover tissue tensile strength, and an average of six months is needed for the injured nail to fully regrow.
• The EMU NBL schedule continues regular training sessions for the astronauts right up to the launch date of their assigned shuttle mission, thus resulting in a persistence of these injuries into the space flight and EVAs.
• Secondary infections following the development of oncholysis can also be seen.
• This problem of oncholysis is related to the Phase 6 gloves and did not occur with the use of the previous Series 4000 gloves. Recent evaluation appears to suggest that the thimble-like, semi-rigid “finger caps” of the restrainer component of the series 4000 gloves may have transmitted loads more uniformly throughout the fingertip, compared to the Phase 6 gloves which may concentrate the load at the fingernail and nail matrix.
Study Goal

• To determine the role that moisture plays in the injury to the fingers and fingernails during EVA training operations in the Neutral Buoyancy Laboratory

• Current Extravehicular Mobility Unit (EMU, with a PLSS) as configured in the NBL was used for all testing and a vent tube was extended down a single arm of the crewmember during the test; vent tube was moved between left and right arm to serve as experimental condition being investigated and the other arm served as control condition
Extended Vent Tube Configuration
Glove Design
Delfin Moisture Measuring Meters

- **Moisture Meter (SC)** – hydration of skin surface via capacitance (proportional to water content)
  - 1 min contact
  - Feedback signal enables constant probe pressure
- **PikoMeter** - similar to SC but no pressure control
  - Quick response signal for reading
- **VapoMeter** – measures water loss from different surfaces (transepidermal water loss; TEWL)
  - Closed cylindrical chamber with sensors for relative humidity (RH%) and temperature
  - Signal for contact time
  - 16 to 20 seconds for calculation of TEWL from increase in RH%
Moisture Measure Points
Study Procedures

Pre and Post EVA Sim:

- Questionnaire
- Moisture Measures
- Photos
Moisture Data Summary: S2 & S3 Runs

![Graph showing moisture data summary for S2 & S3 runs.](image)
Moisture Data Summary:
S4 & S5 Runs

![Graph showing Relative Hydration Ratio (RHR) for different instruments and locations.

Legend:
- S4-1 (E)
- S4-1 (C)
- S4-2 (C)
- S4-2 (E)
- S5-1 (E)
- S5-1 (C)
- S5-2 (C)
- S5-2 (E)

Instrument and Location:
- SC: Dorsum Palmar Long Finger
- Piko: Dorsum Palmar Long Finger
- Vapo: Long Nail

Moisture Data Summary: S4 & S5 Runs
Moisture Data Summary: S6 & S7 Runs
Moisture Data Summary:
Avg by Vent Tube Location

E = Vent Tube at Nondominant Hand

E = Vent Tube at Dominant Hand

Instrument and Location

Relative Hydration Ratio (RHR)
Moisture Data Summary: Avg of All Runs

![Graph showing relative hydration ratio (RHR) for different instruments and locations.](image-url)
Moisture Data Statistics

• Mann-Whitney U (Independently ordered samples; Vent tube hand vs. Control hand)
• For all runs
  – Dorsum, \( p = .061, N=11 \)
  – Ring Finger, \( p = .278, N=11 \)
• For Nondominant Hand (Vent tube on that hand)
  – Dorsum, \( p = .251, N=5 \)
  – Ring Finger, \( p = .094, N=5 \)
• For Dominant Hand (Vent tube on that hand)
  – Dorsum, \( p = .200, N=6 \)
  – Ring Finger, \( p = .754, N=5 \)
Moisture Differences, Hand Sizes, and Vent Tube Use

Dorsum RHR Difference vs. Nondominant Hand Size

\[ y = -3.8179x + 34.417 \]
\[ R^2 = 0.9461 \]

Dorsum RHR Difference vs. Dominant Hand Size

\[ y = 1.2605x - 10.019 \]
\[ R^2 = 0.0889 \]

Ring Finger RHR Difference vs. Nondominant Hand Size

\[ y = -1.7705x + 16.394 \]
\[ R^2 = 0.9183 \]

Ring Finger RHR Difference vs. Dominant Hand Size

\[ y = 0.7523x - 6.6696 \]
\[ R^2 = 0.1722 \]
Dorsum RHRs, Hand Size, and Vent Tube Use

VT Dorsum RHR vs. Nondominant Hand Size

\[ y = 2.1601x - 16.73 \]
\[ R^2 = 0.7241 \]

Control Dorsum RHR vs. Dominant Hand Size

\[ y = -2.2398x + 23.2 \]
\[ R^2 = 0.746 \]

Control Dorsum RHR vs. Nondominant Hand Size

\[ y = -0.5947x + 8.3449 \]
\[ R^2 = 0.0789 \]

VT Dorsum RHR vs Dominant Hand Size

\[ y = -2.21x + 21.615 \]
\[ R^2 = 0.5558 \]
Ring Finger RHRs, Hand Size, and Vent Tube Use

**VT Ring Finger RHR vs. Nondominant Hand Size**

\[ y = 0.3127x - 1.0656 \]

\[ R^2 = 0.3149 \]

**Control Ring Finger RHR vs. Dominant Hand Size**

\[ y = -1.6518x + 17.33 \]

\[ R^2 = 0.7421 \]

**Control Ring Finger RHR vs. Nondominant Hand Size**

\[ y = 0.0907x + 1.5556 \]

\[ R^2 = 0.0263 \]

**VT Ring Finger RHR vs. Dominant Hand Size**

\[ y = 0.7181x - 3.9849 \]

\[ R^2 = 0.2061 \]
Questionnaire Data Summary:

Level of Thermal Discomfort
Questionnaire Data Summary: Level of Skin Moisture

![Bar Chart]

- Profusely more
- Substantially more
- Moderately more
- Slightly more
- Normal

Legend:
- Left Hand
- Right Hand
- Vent Tube

Note: The chart details are not legible due to the image quality.
Questionnaire Data Summary: Level of Hand Discomfort

![Bar Chart]

- Extremely High
- High
- Moderate
- Low
- None

Legend:
- Left Hand
- Right Hand
- Vent Tube
Questionnaire Data Summary: Level of Nail Discomfort
Comfort Gloves in Use at NBL

<table>
<thead>
<tr>
<th>Comfort Gloves</th>
<th>Subject</th>
<th>Estimated Relative Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon Tricot (coated with silver biocide)</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Thin Spectra - Large</td>
<td>2, 3</td>
<td>2</td>
</tr>
<tr>
<td>Thin Spectra - Large Mod</td>
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<td>2.5</td>
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<td>PL-2 form Manzella</td>
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<td>3</td>
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<tr>
<td>Thick Spectra</td>
<td>4, 7</td>
<td>4</td>
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<tr>
<td>Mod Spectra w/Back Hand Pads (MAX-10)</td>
<td>5</td>
<td>5</td>
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</table>

- Piko Dorsum RHR is correlated with comfort glove thickness for the nondominant hand in the control condition: Spearman $R = -0.865, p = 0.058$
- Piko Dorsum RHR is highly correlated with comfort glove thickness for the nondominant hand in the vent tube condition: Spearman $R = -1, p = 0.000$
- Moisture Meter Dorsum RHR is correlated with comfort glove thickness for the dominant hand in the vent condition: Spearman $R = +0.883, p = 0.020$
Summary

• 2 of 6 participants had symptoms alleviated on hand with vent tube (trend: p=.121)
• Moisture measures are more controlled and consistent with moisture meter as opposed to piko meter
• RHR at Dorsum and first Ring Finger joint tend to support hypothesis that extended vent tube improves moisture removal
• Extended vent tube tends to be more effective on non-dominant hand and the smaller hand
• Study Limitations
  – Glove fit interaction
  – Anthropometry interaction
  – Task interaction
• Vent Duct diffuser redesign could improve air flow distribution to hand and fingers
• Reducing hand/finger moisture via ventilation can reduce EVA training-associated symptoms in some crewmembers
Backup Charts
Moisture Data Summary:

<table>
<thead>
<tr>
<th>Vent Tube</th>
<th>SC:</th>
<th>Dorsum</th>
<th>Palmar</th>
<th>Lng Finger</th>
<th>Rng Finger</th>
<th>Piko:</th>
<th>Dorsum</th>
<th>Palmar</th>
<th>Long Finger</th>
<th>Rng Finger</th>
<th>Vapo:</th>
<th>Lng Nail</th>
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<td>0.68</td>
<td>1.20</td>
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Pre-Run Moisture Measures (First Run)
Average Moisture Data with Standard Error of the Mean

![Average Moisture Data with Standard Error of the Mean](image_url)
Hand Discomfort Ratings vs. Dorsum RHR

For the Control Hand:

\[ y = 0.3609x \]
\[ R^2 = 0.1713 \]

For the Vent Tube Hand:

\[ y = 0.2832x \]
\[ R^2 = 0.5936 \]
Hand Discomfort Ratings vs. Ring Finger RHR

**Control Hand**

- Equation: $y = 0.3609x$
- $R^2 = 0.1713$

**Vent Tube Hand**

- Equation: $y = 0.2832x$
- $R^2 = -0.5936$
Nail Discomfort Ratings vs. Dorsum RHR

**Graph 1:**
- **Equation:** $y = 0.2589x$
- **$R^2$:** 0.0231

**Graph 2:**
- **Equation:** $y = 0.1755x$
- **$R^2$:** 0.8589
Nail Discomfort Ratings vs. Ring Finger RHR

Ringer Finger RHR - Control Hand

y = 0.2589x
R² = -0.0231

Ring Finger RHR - Vent Tube Hand

y = 0.2826x
R² = -0.0949
Subject Hand Anthropomorphic Data

|   | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | L10 | L11 | L12 | L13 | L14 | L15 | L16 | L17 | L18 | L19 | L20 | L21 | L22 |
|---|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|    |
| S4| 2.598 | 3.228 | 2.047 | 0.669 | 4.331 | 2.008 | 2.441 | 2.913 | 3.228 | 1.969 | 2.402 | 3.11 | 2.953 | 1.89 | 2.402 | 3.189 | 2.441 | 1.732 | 2.087 | 3.236 | 7.558 | 7.248 |
| S5| 2.835 | 2.953 | 2.685 | 0.984 | 4.374 | 2.244 | 2.795 | 3 | 3.248 | 2.283 | 2.756 | 3.248 | 2.811 | 2.165 | 2.677 | 3.311 | 2.311 | 2.283 | 2.37 | 7.85 | 9.529 | 7.689 |

Hand Circumference