Spaceflight Decompression Sickness Contingency Plan

Joe Dervay, M.D.
Spaceflight Decompression
Sickness Contingency Plan

- Approach
- DCS Contingency Plan Overview
- Extravehicular Activity (EVA) Cuff Classifications
- On-orbit Treatment Philosophy
- Long Form Malfunction Procedure (MAL)
- Medical Checklist
- Flight Rules
- Crew Training
- Flight Surgeon / Biomedical Engineer (BME) Training
- DCS Emergency Landing Site
Medical Operations

Spaceflight Decompression

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Mission Support

On-orbit Flight Control Room (FCR) Staffing
• **Current ISS Prebreathe Protocols**
  - Four hour In-suit (Originally accepted by testing. Currently acceptable by analysis)
  - Campout (Accepted by analysis of related data/similarity to shuttle 10.2 psi staged protocol)
  - Exercise Prebreathe (Accepted by testing utilizing the criteria below)

• **Accept Criteria for ISS EVA Prebreathe Protocols***
  - One-year “DCS Risk Definition & Contingency Plan” effort designated accept criteria of research protocol
    - Decompression Sickness (DCS) < 15 % at 95% CL
    - Grade 4 Venous Gas Emboli (VGE) < 20 % at 95% CL
    - No Type II (serious) DCS

* This criteria was not applied to the shuttle protocols
• Operational Experience
  – To date, there have been 141 person-EVAs conducted with 10.2 psi Staged PB Protocol
    Final PB
    » 12-16 hr stay at 10.2 --- 20 75 min
    » 16-20 hr stay at 10.2 --- 4 60 min
    » 20-24 hr stay at 10.2 --- 12 50 min
    » 24 hr > stay at 10.2 ---- 105 40 min

  – In no case has there been any reported symptoms or signs of DCS
OBJECTIVE:

• Develop enhanced plan to diagnose, treat, and manage on-orbit DCS
  – Achieve new level of DCS awareness among flight controllers, astronauts, and the medical community

• Historically, few drivers to modify existing plan

• Significant upcoming increase in EVA activity to build and maintain ISS - “Wall of EVA’s”

• Important to involve International Partners with plan
APPROACH:

• Johnson Space Center multi-disciplinary team: Medical Operations, Astronaut Office, EVA Office, Mission Operations Directorate

• Consultation with military, civilian, and commercial experts

• Review of literature and databases

• Analysis of past Mission Control “Simulation” scenarios

• Overall plan reviewed by expert committee chaired by Dr. Lambertson (1998)
EVA “CUFF CLASSIFICATION” SYSTEM:

• Simple operational classification of DCS symptoms relevant to EVA crewmember

• Provides clear communication of symptoms and associated operational response.

• Defines actions required to place payload in safe configuration and repress affected crewmember

• Sensible system to encourage symptom reporting
### EVA CUFF CLASSIFICATIONS

<table>
<thead>
<tr>
<th>Cuff Class</th>
<th>Symptoms</th>
<th>Response</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Mild pain</strong>, at single or multiple sites and/or single extremity</td>
<td>Report in post EVA PMC. No future EVA impact.</td>
<td>1-8</td>
</tr>
<tr>
<td></td>
<td>paresthesia. Difficult to distinguish from suit pressure points.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Symptoms do not interfere with performance.</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><strong>Moderate cuff 1 symptoms that interfere with performance.</strong></td>
<td>Terminate EVA for both crew members, perform worksite clean-up only,</td>
<td>3,6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>minimize activity of affected crew member. Perform repress.</td>
<td>9-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Set up PMC post repress.</em></td>
<td></td>
</tr>
</tbody>
</table>
# EVA CUFF CLASSIFICATIONS (cont.)

<table>
<thead>
<tr>
<th>Cuff Class</th>
<th>Symptoms</th>
<th>Response</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td><strong>Severe cuff 1 symptoms</strong> or migratory, trunkal or multiple site paresthesia, unusual headache.</td>
<td>Terminate EVA. Assisted return of affected crew member to airlock, buddy perform worksite safing, then airlock repress. Set up PMC.</td>
<td>12,13</td>
</tr>
<tr>
<td>4</td>
<td><strong>Serious symptoms</strong> – Central neurological, cardiopulmonary.</td>
<td>Abort EVA. Crew assisted return to airlock. Repress affected crew member. Buddy perform worksite safing, then airlock depress, repress. Set up PMC.</td>
<td>14-19</td>
</tr>
</tbody>
</table>
## Medical Operations

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<table>
<thead>
<tr>
<th>Spaceflight Decompression Sickness Contingency Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RATIONALE:</strong></td>
</tr>
<tr>
<td>• Spacesuit itself creates pressure points, joint pains, and local paresthesias.</td>
</tr>
<tr>
<td>• Majority of pain symptoms (86%) in historic database improved or remained the same with time.</td>
</tr>
<tr>
<td>• Low risk of mild or moderate symptoms progressing to serious.</td>
</tr>
<tr>
<td>• Worksite safing important for potential Shuttle de-orbit as well as Station operations.</td>
</tr>
<tr>
<td>• May require 30-45 min. transit to airlock from worksite location.</td>
</tr>
<tr>
<td>• With serious symptoms, may need to depressurize affected crew member ASAP while solo crew member completes clean-up tasks.</td>
</tr>
</tbody>
</table>
TREATMENT PHILOSOPHY:

- Oxygen, pressure, and time are definitive measures
  - Fluids and medications are adjunctive

- Provide higher pressures and longer times than proven 2-hr. Ground Level Oxygen (GLO) – treat gas phase, not just symptoms

- Avoid breaking suit integrity for 20-30 min. for installation of Bends Treatment Apparatus (BTA) [increases suit pressure to 8 psi]

- Development of treatment flows, extensions

- Conversion into Malfunction (MAL) Procedures

- Enhanced Medical Checklist
  - Aftercare
  - Addresses late and recurrent “hit”
20.1 DCS TREATMENT

1. Determine Cuff Class

- Cuff Class 1
- Cuff Class 2 or 3 (Report to MCC)
- Cuff Class 4 (Report to MCC)

2. Continue EVA.
- If symptoms resolve upon REPRESS, go to Cuff Class 2.
- Report to Surgeon next PMC.

3. Terminate EVA (Cuff CL; 7)
- Unaffected crewmember slow safety tether, perform worksite cleanup and/or PLB safing.
- MCC for PLB config.
- Perform INGRESS (Cuff CL; 4).

If terminating for Cuff Class 3:
- PMC on AG 1
- COMM Mode – HL
- AUD CTR UHF AG 2 – T/R
- AG 1 – OFF

NOTE
DO NOT perform POST EMERGENCY REPRESS.

- Abort EVA (Cuff CL; 6) with ingress assist from unaffected crewmember.
- Unaffected crewmember perform PLB safing.

If single crewmember abort
- Outer hatch EVA LLV CLOCS (two) – remove.

- Unslow resuscitator from SOMS (MED CLO, CPR STATION, OXYGEN SUPPLEMENTAL).

4. Crewmember conscious?

- Yes
- No

5. Perform LICH REPLACEMENT (CREWMEMBER IN SUIT) EMU CONT PROCs, omitting steps 3, 17, 18.

6. Cap P < 10.2?

- Yes
- No

7. Perform 10.2 PSI MAINTENANCE (10.2 PSI CABIN).
- Leave O2 ACT – PRESS for 20 min.

8. DCS signs or symptoms resolved?

- Yes
- No

9. Leave O2 ACT – PRESS for addl 60 min.
- CMG report changes in DCS symptoms per DCS exam criteria to Surgeon as requested.

10. EVA terminated to prevent progression to Cuff Class 4. If Cuff 2, affected crewmember will assist other EV with mirror worksite cleanup, if possible, to expedite cleanup and then terminate EVA.

11. If estimated time reqd for DCS treatment exceeds LLOH consumables, a changeout should be performed.

12. For Cuff Class 3 only, affected crewmember waiting in A/L needs to be in contact with Surgeon via PMC.

13. For Cuff Class 4, symptoms may be secondary to Type 2 DCS, which may be a medical emergency.

14. Cuff Class 4 symptoms may be secondary to Type 2 DCS, which may be a medical emergency.

15. Unstow the resuscitator enables EV crew to be prepared to administer CPR, if reqd. Because it is critical to repress a Cuff Class 4 quickly, this may result in a one crewmember repress.

06/16/99
FS.20-7
EVA/101/BAS
DCS Neurological exam:

- Simple exam to assess symptoms, and follow over time (in-suit & out-of-suit)
- Can be performed by non-physician Crew Medical Officer (CMO)
- Challenge to perform exam with patient in the suit

<table>
<thead>
<tr>
<th>Facial Nerves</th>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>16 Facial Muscles</td>
<td>Crewmember raises eyebrows, squeezes eyes shut and puffs up cheeks without difficulty.</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
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<tr>
<td>Strength</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>17 Arm Bending Strength</td>
<td>Crewmember bends elbow, with palm towards face and holds for two seconds against examiner resistance. Repeat both sides.</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
</tr>
<tr>
<td>18 Leg Bending Strength</td>
<td>Crewmember bends knee and holds for two seconds against examiner resistance. Repeat both sides.</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
</tr>
<tr>
<td>Coordination Functions</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19 Finger-to-Finger</td>
<td>Starting with hands wide apart, Crewmember easily and accurately touches fingertips together with eyes closed.</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
</tr>
<tr>
<td>Sensory Function</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Gross Sensation</td>
<td>Examiner squeezes Crewmember’s forearms, feet and knees through suit. Crewmember should feel squeezing of the forearms, feet and legs.</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
</tr>
</tbody>
</table>

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MEDICAL KITS

• IV Fluids
  – Shuttle: 3.1 liters normal saline
  – ISS: 12.1 liters normal saline

• Medication
  – Compiled to cover broad range of potential conditions
    » Includes limited quantities of Dexamethasone and Lidocaine

• ISS Respirator – Autovent 2000 (Allied Health)

• ISS Defibrillator – PD 2000 (Zoll Medical)
FLIGHT RULES:

- Pre-established rules for Flight Control Team to respond in coordinated manner

- Avoid miscommunication across multiple disciplines

- Documents Cuff Classes, deorbit requirements to Primary Hyperbaric Care site (3 CONUS, Hickam, Guam), deorbit within 10 hrs. for unresolved Type II symptoms
## Spaceflight Decompression

### Sickness Contingency Plan

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### TRAINING:

- **Astronauts**
  - MAL checklists
  - New class on Medical Evaluation of DCS
    » Physiology, symptoms, treatment, neuro exam
    » Video of DCS Neurological exam

- **Flight Surgeon/Biomedical Engineer**
  - DCS syllabus, console requirements, CME courses

- **Mission Control Simulations**
DCS EMERGENCY LANDING SITES

• Primary Hyperbaric Care Landing Sites
  – Chamber capabilities, proximity to trauma center, points of contact being coordinated with DDMS medical personnel

• Russian Landing Site Capability and Response
  – Work in progress to further document plan
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PRP EXERCISE STRATEGIES

Upright dual arm and leg cycle exercise (ALE)

Semi-recumbent intermittent light exercise simulating astronaut tasks (ILE)
RESULTS: 2 HOUR PROTOCOLS

(not to scale)

Time (min) 0 100 110 150 170 180 210 215 250 280 520 525

Altitude

Phase I
Rest 10 min 9 DCS/47 trials = 19%

Phase II
Rest 75% VO₂ peak 40 min 0/45 = 0% EVA

Phase III
Rest Light Work 2/10 = 20% (1 cerebral DCS) Simulation

Phase IV
Rest 95 min Light Work 8/57 = 14%
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Mission Support

Extravehicular Activity (EVA) Monitoring
DCS Contingency Plan

- EVA Checklist Development
  - Shuttle / EMU
  - ISS / EMU
  - Russian / ORLAN

- Improved On-Orbit DCS Treatment
  - Insuit Treatment
  - BTA Mods
  - Hyperbaric Chamber Technology Dev.
  - Adjunctive Drug Therapy

- DCS Flight Rules Development
  - Mission Control DCS Simulation Program
  - Crew Flight Surgeon Training

- Ground Support Infrastructure
  - Primary Hyperbaric Landing Sites
  - Cooperative USAF/NASA Programs
  - Russian EMS Plan

- DCS Disposition Policy
EVA “CUFF CLASSIFICATION” SYSTEM:

- Simple operational classification of DCS symptoms relevant to EVA crewmember

- Provides clear communication of symptoms and associated operational response

- Defines actions required to place payload in safe configuration and repress affected crewmember

- Sensible system to encourage symptom reporting
FLIGHT RULES:

- Pre-established rules for Flight Control Team to respond in coordinated manner

- Avoid miscommunication across multiple disciplines

- Documents Cuff Classes, deorbit requirements to Primary Hyperbaric Care site (3 CONUS, Hickam, Guam), deorbit within 10 hrs. for unresolved Type II symptoms
RESULTS: 90 MIN PROTOCOLS
(not to scale)

Altitude (ft)

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>0</th>
<th>160</th>
<th>200</th>
<th>250</th>
<th>550</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-1</td>
<td>Rest</td>
<td>44 min</td>
<td>3 DCS/10 trials = 30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2/2: 60%</td>
<td>4 hr EVA</td>
<td>Simulation</td>
<td></td>
</tr>
<tr>
<td>V-2</td>
<td>Rest</td>
<td>34 min</td>
<td>0/2 = 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3/2: 60%</td>
<td>Simulation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Spaceflight Decompression
Sickness Contingency Plan
### Spaceflight Decompression Sickness Contingency Plan

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#### 4 hr In-suit Protocol Timeline

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>POST SLEEP 75 min</td>
<td>1:15</td>
</tr>
<tr>
<td>EVA PREP 90 min</td>
<td>2:45</td>
</tr>
<tr>
<td>Purge</td>
<td>2:57</td>
</tr>
<tr>
<td>EMU PREBREATHE 4 hours</td>
<td></td>
</tr>
<tr>
<td>EMU Donning 55 min Ck</td>
<td></td>
</tr>
<tr>
<td>C/L Depress (30 min)</td>
<td>7:27</td>
</tr>
<tr>
<td>EVA PET = 6:30</td>
<td></td>
</tr>
<tr>
<td>Rep</td>
<td>13:57</td>
</tr>
<tr>
<td>POST EVA w/o H2O</td>
<td>15:1</td>
</tr>
<tr>
<td>C/L Depress (30 min)</td>
<td></td>
</tr>
<tr>
<td>*Metox C/O</td>
<td></td>
</tr>
</tbody>
</table>

### EVA DAY SUMMARY

- **Post Sleep** (1 hour 15 mins total)
- **EVA Prep** (1 hour 30 mins)
  - EVA Prep for Donning (30 mins)
  - Suit Donning at 10.2 (1 hour)
- **Suit Purge** (12 mins)
  - Airlock Repress to 14.7
- **In-suit Prebreathe** (4 hours)
- **Crewlock Depress** to vacuum (30 mins)
- **EVA tasks** (6 hours 30 mins)
- **Airlock Repress** (20 mins)
- **Post EVA without EMU H2O Recharge or METOX Regeneration** (1 hour)
- **Pre Sleep** (2 hours)

*It is possible to perform METOX Change-Out (manned) to allow for maximum EVA PET capability. Provided that Crew Day Length violations can be approved, we could support a 6:30 EVA PET.

Note: Assume depress pump and EMERG MPEV & AL VAJ; 30 min C-Lk depress without built in hold at 5psi. With 2 hours of Pre-sleep, STS Crew Day length = 17:17.
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### CEVIS Exercise Protocol Timeline

#### Spaceflight Decompression

#### Sickness Contingency Plan

- **POST SLEEP 75 min**
  - Exercise PB/Prep for Donning - 80 min on mask total
  - 50 min on mask prior to start of 10.2 depress
  - EV1 ex* EV2 ex* Req 45 min mask P/B after exer
  - 45 min reqd before below 11.8 psi

- **EVA PREP 170 min**
  - EMU Donning 55 min
  - Purge
  - EMU Prebreathe (60 min)
  - C/L Dep (35 min)

- **Suit Purge (12 mins)**
  - Airlock Repress to 14.7

- **In-suit Prebreathe (60 mins)**

- **Crewlock Depress to vacuum (35 mins)**

- **EVA tasks (6 hours 30 mins)**

- **Airlock Repress (20 mins)**

- **Post EVA without EMU H2O Recharge or METOX Regeneration (1 hour)**

- **Pre Sleep (2 hours)**

---

* EV1 must start exercise within 10 min after PB initiate, EV2 must start exercise within 25 min after PB initiate to maintain 45 minute of mask time after exercise per FR

Note: Assume depress pump and EMERG MPEV & AL VAJ; 40 min C-Lk depress with built in hold at 5psi PET = 25. With 2 hours of Pre-sleep, **STS Crew Day length = 15:42**.
**Spaceflight Decompression Sickness Contingency Plan**

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**A/L Dep (15 min)**

<table>
<thead>
<tr>
<th>1:15</th>
<th>2:45</th>
<th>2:53</th>
<th>4:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 min Mask PB</td>
<td>*12 HOURS AT 10.2 psi</td>
<td>POST SLEEP 75 min</td>
<td>EVA PREP 90 min</td>
</tr>
<tr>
<td>10.2 Dep</td>
<td>45 min before 12.5</td>
<td>EMU Donning 55 min</td>
<td>Ck</td>
</tr>
<tr>
<td>4:23</td>
<td>10:53</td>
<td>12:12</td>
<td></td>
</tr>
</tbody>
</table>

**EVA PET = 6:30**

**A/L Dep (15 min)**

- *If the EVA is scheduled within 36 hours of 10.2 Dep, this table may be used to calculate the Final EMU PB time.*
- **The less time spent at 10.2, the longer the Final EMU Prebreathe time will be; thus, resulting in an overall longer crew day length. See chart.**
- **If the EVA is scheduled later than 36 hours from 10.2 Dep, the initial PB may be eliminated and the final in-suit PB is 40 mins.**

**Note:** Assume depress with AIRLK DEPRESS vlv; 15 min. With 2 hours of Pre-sleep, **STS Crew Day length = 14:17.**

**EVA DAY SUMMARY (continued)**

- In-suit Prebreathe (40 to 75 mins depending on the time at 10.2 psi)
- Crewlock Depress to vacuum (15 mins)
- EVA tasks (6 hours 30 mins)
- Airlock Repress (20 mins)
- Post EVA without EMU H2O Recharge or METOX Regeneration (1 hour)
- Pre Sleep (2 hours)
### Prebreathe Protocols - Observed and Estimated Risks

<table>
<thead>
<tr>
<th>Prebreathe Protocol</th>
<th>Observed Risk (total DCS) Ground Trials</th>
<th>Flight Experience</th>
<th>Predicted Risk Accounting for Flight Factors* (microgravity, purge, leak check, depressurization rate, etc.)</th>
<th>Predicted Risk (serious Type II DCS) Accounting for Flight Factors*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXERCISE (CEVIS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>45</td>
<td>0 / 34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td>0%</td>
<td>&lt;6.5% @ 95% cl)**</td>
<td>1.7% (≤4.0% @ 95% cl)*** 1 / 4972 (1/3447 – 1/8928 cl)</td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td>6.6% (≤16.3% @ 95% cl)</td>
<td>3.8% (≤12.4% @ 95% cl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0 HOUR (In-suit)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>28</td>
<td>0 / 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td>21% (≤38.0% @ 95% cl)</td>
<td>4.6% (≤9.4% @ 95% cl) 1 / 1372 (1/960 – 1/2402 cl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td>39% (≤56.6% @ 95% cl)</td>
<td>9.9% (≤32.2% @ 95% cl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAMPOUT (ISS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>No direct ground tests</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td>2.8% (≤5.9% @ 95% cl)#</td>
<td>1 / 936 (1/656 – 1/1635 cl)#</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td>5.8% (≤19.0% @ 95% cl)# #</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.2 PSIA STAGED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>35</td>
<td>0 / 141</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td>23% (≤37.5% @ 95% cl)</td>
<td>3.8% (≤7.6% @ 95% cl) 1 / 311 (1/217 – 1/549 cl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td>23% (≤37.5% @ 95% cl)</td>
<td>8.0% (≤26.0% @ 95% cl)</td>
<td></td>
<td></td>
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</tbody>
</table>

*Includes operational margin, microgravity simulation (non ambulation), accounts for exercise with CEVIS protocol. Published/peer-reviewed models.

**ci is upper 95% binomial confidence limit, based on observation of test result.

***ci is the upper part of the 95% confidence interval, based on a statistical regression.