Spaceflight Decompression Sickness Contingency Plan

Joe Dervay, M.D.
• 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

Sickness Contingency Plan

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Mission Support

On-orbit Flight Control Room (FCR) Staffing

Surgeon Console - FCR
• **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
    » 12-16 hr stay at 10.2 --- 20 Final PB
    » 16-20 hr stay at 10.2 --- 4
    » 20-24 hr stay at 10.2 --- 12
    » 24 hr > stay at 10.2 ---- 105
    » 75 min
    » 60 min
    » 50 min
    » 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)
DCS Contingency Plan

DCS Disposition Policy

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

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

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

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

Mission Control

Mission Control

Primary Hyperbaric Landing Sites

Cooperative USAF/NASA Programs

Russian EMS Plan

BTA Mods

Hyperbaric Chamber Technology Dev.

Adjunctive Drug Therapy

Russian / ORLAN
### 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 paresthesia. Difficult to distinguish from suit pressure points. <em>-Symptoms do not interfere with performance.</em></td>
<td>Report in post EVA PMC. No future EVA impact.</td>
<td>1-8</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, minimize activity of affected crew member. Perform repress.</td>
<td>3,6 9-10</td>
</tr>
</tbody>
</table>

*Set up PMC post repress.*
# EVA CUFF CLASSIFICATIONS (cont.)

<table>
<thead>
<tr>
<th>Cuff Class</th>
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<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>Serious symptoms – 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>
RATIONALE:

- Spacesuit itself creates pressure points, joint pains, and local paresthesias

- Majority of pain symptoms (86%) in historic database improved or remained the same with time

- Low risk of mild or moderate symptoms progressing to serious

- Worksite safing important for potential Shuttle de-orbit as well as Station operations

- May require 30-45 min. transit to airlock from worksite location

- With serious symptoms, may need to repress affected crewmember ASAP while solo crewmember completes clean-up tasks
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”
Termination of Extravehicular Activity (EVA)

Class 1
- No Rx Required
  - If STS at 10.2 psi
    - Stay in Press Mode
      - 20 Min in Suit
        (10.2 + 4.3 = 14.5 psi)
        - Sx Resolved
          - Block 1
            - Aftercare
              - Medical Check Prior to EVA
                (72 Hr. - 7 Days)
        - No
          - Sx Unresolved, Worse or No Change
            - Additional 160 Min.
              - CMO PE/Neuro Check
                - Hydrate (Isotonic Fluid po, 1 liter/hr)
                - Limit activity
                - PMC
              - RTD 24 Hrs.
              - Reduced Pressure/EVA (Case by Case)
                (72 Hr. - 7 Days)
            - Sx Resolved
              - 20 Min. Extension
                - (+) 2 Hr O₂ by Mask
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                    (72 Hr. - 7 Days)
                - Doff Suit
                  - Aftercare
                    - Periodic Medical Eval.
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            - Doff Suit
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                - Reduced Pressure/EVA
                  (Case by Case)
                    (72 Hr.)
            - RTD 24 Hrs.

If any symptoms remain, check MCC/PMC (Possible Additional O₂, BTA, Orlan Ops.)
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 PMG.

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

If terminating for Cuff Class 3:
   - PMG on AVG 1
   - COMM Mode – HL (A1R)
   - AUD CTR UHF AVG 2 – T/R
   - AVG 1 – OF

4. DO NOT perform POST EMERGENCY REPRESS
   - Abort EVA (Cuff CL. 6) with ingress assist from unaffected crewmember
   - Unaffected crewmember perform PLB salting

If single crewmember abort:
   - Outer hatch equalize #12s (two) – remove
   - Unslow resuscitator from SC2 (MED CL.
   - CPR STATION.
   - OXYGEN SUPPLEMENTAL)

5. Crewmember conscious?
   - YES
   - NO

   18. Can crewmember speak in full sentences with respiratory distress?
      - YES
      - NO

   17. Leave O2 ACT – PRESS for 100 min.
   - CMG report changes in DCS symptoms per DCS exam criteria to Surgeon as requested

6. Cap P < 15.2?
   - YES
   - NO

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

7. DCS signs or symptoms resolved?
   - YES
   - NO

   10. "Leave O2 ACT – PRESS for 100 min.
   - CMG report changes in DCS symptoms per DCS exam criteria to Surgeon as requested

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

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

3. For Cuff Class 3 only, affected crewmember waiting in A/L needs to be in contact with
   Surgeon via PMG due to severity and potential progress of symptoms

4. Cuff Class 4 symptoms may be secondary to Type 2 DCS which is a medical emergency. Unslow the
   resuscitator enables IV crew to be prepared to administer CPR, if reqd. Because it is critical to repress a
   Class 4 quickly, this may result in a one crewmember repress.
**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

### Facial Nerves

<table>
<thead>
<tr>
<th>16</th>
<th>Facial Muscles: Crewmember raises eyebrows, squeezes eyes shut and puffs up cheeks without difficulty.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
</tr>
<tr>
<td></td>
<td>NL</td>
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</table>

### Strength

<table>
<thead>
<tr>
<th>17</th>
<th>Arm Bending Strength: Crewmember bends elbow, with palm towards face and holds for two seconds against examiner resistance. Repeat both sides.</th>
</tr>
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</tr>
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<td>NL</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>18</th>
<th>Leg Bending Strength: Crewmember bends knee and holds for two seconds against examiner resistance. Repeat both sides.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
</tr>
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<td></td>
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</tbody>
</table>

### Coordination Functions

<table>
<thead>
<tr>
<th>19</th>
<th>Finger-to-Finger: Starting with hands wide apart, crewmember easily and accurately touches fingertips together with eyes closed.</th>
</tr>
</thead>
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</table>

### Sensory Function

<table>
<thead>
<tr>
<th>20</th>
<th>Gross Sensation: Examiner squeezes crewmember’s forearms, feet and knees through suit. Crewmember should feel squeezing of the forearms, feet and legs.</th>
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Spaceflight Decompression
Sickness Contingency Plan

Dr. Joe Dervay
Medical Operations

Dr. Joe Dervay

Spaceflight Decompression Sickness Contingency Plan
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
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
Medical Operations
Spaceflight Decompression
Sickness Contingency Plan
Dr. Joe Dervay
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%
- 4 hr

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%
- Simulation
Medical Operations
Spaceflight Decompression
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Mission Support

- Extravehicular Activity (EVA) Monitoring
EVA “CUFF CLASSIFICATION” SYSTEM:

- Simple operational classification of DCS symptoms relevant to EVA crewmember
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- 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)

30K

Time (min) 0 160 200 250 550

V-1

Rest 44 min 2/2: 60%

3 DCS/10 trials = 30%

4 hr EVA

V-2

Rest 34 min 3/2: 60%

0/2 = 0%

Simulation
**Spaceflight Decompression Sickness Contingency Plan**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:15</td>
<td>POST SLEEP 75 min</td>
</tr>
<tr>
<td>2:45</td>
<td>EVA PREP 90 min</td>
</tr>
<tr>
<td>2:57</td>
<td>Purge</td>
</tr>
<tr>
<td>6:5</td>
<td>EMU PREBREATHE 4 hours</td>
</tr>
</tbody>
</table>

**C/L Depress (30 min)**

<table>
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<tr>
<th>Time</th>
<th>Activity</th>
</tr>
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<tbody>
<tr>
<td>7:27</td>
<td>EMU Donning 55 min</td>
</tr>
<tr>
<td>13:57</td>
<td>EVA PET = 6:30 *Metox C/O</td>
</tr>
<tr>
<td>15:1</td>
<td>Rep</td>
</tr>
<tr>
<td></td>
<td>POST EVA w/o H2O</td>
</tr>
</tbody>
</table>

* 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**.

**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)
### CEVIS Exercise Protocol Timeline

**Spaceflight Decompression**

**Sickness Contingency Plan**

Dr. Joe Dervay

<table>
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<th>1:15</th>
<th>4:05</th>
<th>4:17</th>
<th>5:17</th>
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<tr>
<td>POST SLEEP 75 min</td>
<td>EVA PREP 170 min</td>
<td>Purge</td>
<td>EMU Prebreathe (60 min)</td>
</tr>
</tbody>
</table>

- Exercise PB/Prep for Donning - 80 min on mask total
- 50 min on mask prior to start of 10.2 depress
- 10 min exercise for EV1
- 10 min exercise for EV2
- 10.2 psi Airlock Depress (20 mins)
- EMU Donning 55 min
- Purge
- Rep
- C/L Dep (35 min)

**EVA PET = 6:30**

- Rep
- POST EVA w/o H2O

* 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.**

### EVA DAY SUMMARY

- **Post Sleep (1 hour 15 mins)**
- **EVA Prep (Total of 2 hours 50 mins)**
  - Mask Prebreathe (1 hour 20 mins)
  - 10 mins exercise for EV1
  - 10 mins exercise for EV2
  - 10.2 psi Airlock Depress (20 mins)
  - Mask Prebreathe Termination
  - Suit Donning at 10.2 (1 hour)
- **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)**
**Shuttle 10.2 PSI Staged Protocol Timeline**

*Note: Pre-sleep time not shown*

![Shuttle 10.2 PSI Staged Protocol Timeline](image)

**Medical Operations**

Dr. Joe Dervay

**Spaceflight Decompression**

**Sickness Contingency Plan**

1 OR MORE DAYS PRIOR TO EVA DAY

- Mask Prebreathe (1 hour)
- Depress Shuttle Crew Cabin to 10.2 psi (12 hours minimum)

**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 (8 mins)

**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)

Note: Assume depress with AIRLK DEPRESS vlv; 15 min. With 2 hours of Pre-sleep, **STS Crew Day length = 14:17**.
### Table 1

**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% (≤6.5% @ 95% cl)**</td>
<td>1.7% (≤4.0% @ 95% cl) ***</td>
<td>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)</td>
<td>1 / 1372 (1/960 – 1/2402 cl)</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></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</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>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)</td>
<td>1 / 311 (1/217 – 1/549 cl)</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>
</tr>
</tbody>
</table>

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

**cl 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.