UHMS Best Practice Guidelines

Prevention and Treatment of Decompression Sickness and Arterial Gas Embolism

28 April 2011

Based in part on:
USN Diving Manual Revision 6; April 2008
With Advance Change Notices 15-102
and
Manual of the Medical Department (ManMed)
Change 126 - August 2005
and
U.S. Air Force Guidelines for Treating Altitude Decompression Sickness (USAF Instruction 48-112)
and
Association of Diving Contractors International (ADCI)
Return to Diving Guidelines after DCS - 2011

Introduction

The UHMS was funded by the U.S. Air Force in 2010 to develop a set of best practice guidelines for the prevention and management of decompression sickness and arterial gas embolism. Although this topic has been addressed by previous UHMS workshops[1-3], this document represents the most comprehensive effort to date.

The committee carefully reviewed evidence that was available. However, for many of the issues, there was little or no published scientific evidence upon which to base recommendations. Therefore, evidence for the current recommendations is based mainly on expert opinion (American Heart Association Class II, level of evidence C).

Notes:
1. The best practice guidelines are derived in part from the documents above. Changes approved by the Undersea and Hyperbaric Medical Society Committee on Decompression Sickness and Arterial Gas Embolism are denoted in red text.

2. The guidelines not denoted by red text are derived from the above documents and were reviewed by the UHMS DCS and AGE Committee without any recommendations for changes at this time.

3. Decompression sickness (DCS) refers to the clinical syndrome of neurological deficits, pain, or other clinical disorders resulting from the body tissues being supersaturated with inert gas after a reduction in the ambient pressure. Arterial Gas Embolism (AGE) refers to gas bubbles in the systemic arterial system resulting from pulmonary barotrauma, iatrogenic entry of gas into the arterial system, or arterialized venous gas emboli. Decompression illness (DCI) is an inclusive term that encompasses either or both DCS and AGE.

Decompression Sickness (DCS) in Divers

DCS Prevention

1. Diver Selection (ManMed Change 126 Aug 2005)

Screening for Patent Foramen Ovale (PFO)

While PFO testing of individuals with repetitive DCS incidents may be useful for advising on future exposures, there is as yet insufficient evidence to support pre-screening for a PFO in divers, pilots, or astronauts.

History of DCS

Disqualifying for diving duty

Deselection of divers for repeated episodes of DCS

Not recommended

2. Pre-Dive DCS Prevention (USN Dive Manual Chap 9 – Air Decompression)

Pre-dive exercise:

No recommendation

Table modifications based on water temp:

No recommendation

Hydration (in warm water diving):

Immersion in water induces a diuresis which, in addition to pre-existing dehydration due to hot weather or exertion, could impair inert gas elimination during and after decompression. Maintenance of a normal degree of hydration before and after a dive is recommended. Anecdotal evidence suggests that over-aggressive hydration may predispose to immersion pulmonary edema after long distance surface swimming.

Dive depth limits:

For SCUBA dives – maximum depth of 130 ft (on-site chamber recommended for military diving if dive depth is greater than100 ft)

"Clean" times:

Surface interval required for the diver to be considered "clean" for the next dive:

2 hours 20 minutes for repetitive group Alpha

15 hours 50 minutes for repetitive group Zulu

3. DCS Prevention (During the Dive)

Ascent Rate

30 feet per minute

4. DCS Prevention (Post-Dive)

Exercise restrictions

Both aerobic (e.g. running) and anaerobic (e.g. weight lifting) exercise performed within 4 hours after a compressed gas dive with significant decompression stress may be associated with an increased risk of DCS. It is recommended that strenuous exercise be avoided during this 4-hour period unless required by operational necessity.

Ascent to altitude restrictions (Up to 10,000 ft)

Time/ascent Table - up to 29:15 for Repet Group Zulu

48 hours for Exceptional Exposure Dives

Treatment of Decompression Sickness
USN Diving Manual Revision 6; April 2008

5. Pre-Recompression

Oxygen

15 L/M with reservoir mask or demand valve

Patient in supine position (not head down)

Continuous monitoring

Air transport

As low as safely possible

Preferably lower than 1000 ft

Pressurize aircraft cabin to 1 ATA if possible

Consider Emergency Evacuation Hyperbaric Stretcher

Recompress even if signs/symptoms resolve prior to recompression

6. Initial Recompression for DCS

- The USN Diving Manual treatment algorithms remain the gold standard for initial recompression of diving-related DCI. The use of alternate tables should be reserved for trained personnel at facilities with the expertise and hardware to deal with untoward/unexpected responses to therapy.

- Surface oxygen is not a substitute for hyperbaric therapy in diving-related DCI. However, surface oxygen alone can be considered if symptoms are mild and have been stable for 24 hours, neurological

examination is normal, and evacuation of the patient cannot readily be achieved or is associated with some risk (3).

Type I – Treatment Table 5 (TT5)
- Musculoskeletal pain
- Skin bends
- Lymphatic bends

Type II – Treatment Table 6 (TT6)
- Includes all other manifestations of DCS
- Recompress to 60 FSW on 100% O2 and begin TT6
- Diving Medical Officer (DMO) has option to go to 165 early if patient has unsatisfactory response at 60 FSW

*Note: Severe Type II signs/symptoms warrant full extensions of 60 FSW oxygen breathing periods even if S/S resolve during the first oxygen breathing period

Deep Uncontrolled Ascents – (Treatment Table 8 (TT8)
- 225 FSW table for treating deep, uncontrolled ascents when more than 60 minutes of decompression have been missed.

7. Unchanged or Worsening Severe Signs/Symptoms after Initial Recompression to 60 FSW

* Note: "Severe" Implies neurological or cardiopulmonary S/S but this is not explicitly stated.

Go to 165 FSW – if good resolution of signs/symptoms in 30 min - do a TT6A

If need to stay at 165 FSW for up to 2 hrs – come to 60 FSW on TT4

If doing well after 60 FSW stay – come to the surface on TT4

8. Persistent Symptoms at 60 FSW

Extend TT6 for two 25-minute periods at 60 FSW

Extend TT6 for two 75-minute periods at 30 FSW

DMO may recommend customized treatment

Stay at 60 FSW for 12 hours or longer – come out on TT7

9. Recurrence of Serious Symptoms during Decompression

If shallower than 60 FSW – go to 60 FSW

If deeper than 60 FSW – go to 165 FSW

10. In-Water Recompression

Only when:
- No recompression facility on site

Significant signs/symptoms
No prospect of reaching chamber in 12-24 hrs
No improvement after 30 min of 100% oxygen on surface
Thermal conditions are favorable

Not for unconsciousness, paralysis, respiratory distress, or shock
Keep these individuals on the surface with 100% O2

In-Water Recompression with oxygen preferred
Purge rebreather 3 times with oxygen
30 FSW with stand-by diver
60 min at rest for Type 1
90 min at rest for Type II
20 FSW for 60 min
10 FSW for 60 min
100% O2 for additional 3 hours on the surface

In-Water Recompression with air (if no oxygen available)
Follow TT1A
Full face mask or surface-supplied helmet preferred
SCUBA used only as last resort
Stand-by diver required

* Note: “In divers with severe Type II symptoms or symptoms of arterial gas embolism (e.g. unconsciousness, paralysis, vertigo, respiratory distress (chokes), shock, etc), the risk of increased harm to the diver from in-water recompression probably outweighs any anticipated benefit.”

11. Adjunctive Therapy - Fluids

1-2 liters of water, juice, or non-carbonated drink over the course of
TT5 or TT6

If not able to take oral fluids: isotonic crystalloid or colloid

Avoid dextrose-containing fluids

Titrate to adequate blood pressure and 1-2 cc/kg/hr urine output or to clear urine

Avoid fluid overload

12. Adjunctive Therapy – Medications

Low molecular weight heparin for paraplegia – enoxaparin 30 mg q12h or or dalteparin 5000 IU SQ q24h

No aspirin

No corticosteroids

No lidocaine

14. Environmental Control during Recompression

Avoid hyperthermia during treatment

15. Post-Recompression Management of DCS

Remain within 30 minutes of a recompression facility for a period of 6 hours

Chamber Proximity

Remain within 60 min travel time of chamber for 24 hrs

Be accompanied during that period

Hospital admission

Consider after TT6, TT6A, TT4, TT7, TT8

Flying after Treatment

72 hours if no residual S/S

When cleared by DMO if residual signs/symptoms

16. Post-Recompression Evaluation of DCS Patients (NAVSEA Advance Change Notice 15-102)

Divers with any DCS (including joint pain or skin changes shall have an Undersea Medical Officer (UMO) entry in their record describing the condition and treatment

Magnetic resonance imaging (MRI) is not required for DCS Type II unless symptoms do not resolve completely with initial recompression.

Magnetic resonance imaging (MRI) of the brain with or without spinal cord (as indicated clinically) shall be obtained within 1 week of the time of injury for divers with neurologic deficits persisting beyond initial treatment.

If the initial MRI reveals abnormalities or if the diver has continued residual symptoms, a repeat MRI should be done at 1 month and neurology consultation obtained.

Patent Foramen Ovale (PFO) Evaluation

- There is an association between PFO and early onset/severe DCS.

- While the likely mechanism for the association is inter-atrial transcardiac passage of venous gas emboli (VGE), other mechanisms are possible.

- The presence of a PFO is unlikely to increase the risk of DCS after dives with minimal decompression stress. Neurological DCI cases after "trivial" exposures are much more likely to be linked to other causes, such as pulmonary barotrauma.

- The presence of a PFO does not increase the risk of pain-only DCS.

- A specific DCS incident cannot be linked to the presence of a PFO with any degree of certainty.

- Testing for a PFO is not indicated for the evaluation of pain-only DCS.

- Evaluation for PFO may be considered in selected patients with severe or repetitive neurological DCS.

- The sensitivity of bubble contrast transthoracic echocardiogram and transcranial doppler is adequate for the detection of a PFO likely to be important in the pathophysiology of DCS.

- Data to suggest that PFO closure prevents DCS are incomplete.

- If it is suspected that a diver's repetitive DCS incidents are related to a PFO, reduction of decompression stress in future diving activities by more conservative diving practice is probably a better approach than PFO closure.

17. Management of Residual DCS Symptoms

Should be treated with follow-up HBO treatments

Supervised by DMO

May be no improvement with first treatment

Note that improvement may be seen after delays to follow-up HBO treatments of up to 1 week

Continue until no improvement on 2 consecutive treatments

Treatment may be daily TT6 or twice-daily TT5/TT9. For follow-up ("tailing") treatments there are no definitive data comparing USN tables 5, 6, or 9 to other tables.

18. Return to Diving after DCS

Magnetic Resonance Imaging (MRI) and Return to Diving

The presence of small hyperintense white matter lesions on brain MRI following cerebral DCS in an otherwise completely recovered ("completely recovered" implies the absence of relevant symptoms or signs and the absence of any significant deterioration on neurocognitive testing conducted by a specialist neuropsychologist) diver is of uncertain significance, particularly in the absence of a baseline MRI. Such lesions may be found in subjects who have no significant history of brain injury. There is currently insufficient evidence that the appearance of such lesions, even in association with an episode of DCS, has any definitive prognostic significance in relation to development of post injury complications such as seizures. The committee recommends that return to diving decisions be made on the basis of clinical assessment. However, MRI scans should continue to be taken to exclude unanticipated significant lesions that might affect fitness for diving and, potentially, to inform future debate about the significance of small hyperintense white matter lesions.

There is no compelling evidence at present to support any specific waiting period for return to diving after treatment of DCS. The following recommendations from the U.S. Navy Diving Manual and the Association of Diving Contractors International are offered for DMO consideration.

Note: there are no studies examining the safety of return to diving with or without lesions detectible by MRI. In addition, MRI has improved dramatically over the last 30 years, and improvements are expected in the future. Thus, whether a

lesion can be detected or not using MRI is not an absolute, but is likely to vary with technique and stage of development of the technology.

U.S. Navy Return to Diving Guidelines after DCS

1. In diving duty candidates, any prior history of DCS or AGE is disqualifying.

2. DCS Type I - Divers with DCS Type I which resolves on initial treatment and who remain asymptomatic may be cleared by a UMO for return to diving 7 days following treatment. (Pending Advance Change Notice)

3. DCS Type II - Divers with DCS Type II which resolves on initial treatment and who remain asymptomatic may be cleared by a UMO for return to diving 30 days following treatment.

4. Neurologic deficits persisting beyond initial treatment are disqualifying. Waiver may be considered with the following provisions:

a. Magnetic resonance imaging (MRI) of the brain with or without spinal cord (as indicated clinically) shall be obtained within 1 week of the time of injury.

b. If initial MRI is negative and symptoms are resolved, the diver may be returned to diving 30 days post-incident following documentation in the health record and interim waiver for return to diving from by Bureau of Medicine and Surgery, Undersea Medicine and Radiation Health (BUMED).

c. If initial MRI reveals abnormalities or the diver has continued residual symptoms, the diver will remain not physically qualified (NPQ) for diving duty until a waiver is obtained from the Bureau of Naval Personnel for resumption of diving duty. The work-up shall include at minimum:

1. Initial MRI (within 1 week)
2. Follow-up MRI at 1 month
3. Neurology consult

5. Divers experiencing DCS Type II after a no-decompression dive (an “undeserved hit” or who have experienced more than one episode of DCS Type II shall be evaluated for the presence of a PFO. In these cases, the presence of a PFO is disqualifying. Waiver may be granted on a case-by-case basis. PFOs diagnosed incidentally (for example, in the course of evaluating an asymptomatic murmur) are not disqualifying.

Association of Diving Contractors International (ADCI) Return to Diving Guidelines after DCS

Residual symptoms

Return to diving is not recommended

Type II DCS with an Abnormal MRI of the Brain

Return to diving is not recommended

The following return to diving intervals are recommended only if the diver's signs and symptoms of DCS have completely resolved.

Pain-only DCS resolving with 1 Treatment Table:	24 hours
Pain-only DCS resolving with serial Treatment Tables:	7 days
Sensory DCS resolving with 1 Treatment Table:	7 days
Motor DCS resolving with 1 Treatment Table:	20 days
Motor DCS resolving with serial Treatment Tables:	6 months

20. Altitude DCS Management (AFI 48-112)

Ground level oxygen (GLO2) can be use for altitude exposure (not diving related) induced DCS if the following principles are followed:

A. Used for joint pain only
B. Presentation for treatment must occur no later than 2 hours after hypobaric exposure.
C. Not for paresthesias, chokes, cutis marmorata, or neurological DCS
D. Administer 100% O2 by tight fitting aviator's mask, hood, or reservoir System.
E. Pain resolution must occur within two hours of treatment.
F. If pain resolves on descent, or at exiting of chamber, 2 hours of GLO2 is still required. If is pain present on reaching ground level then:
G. Some resolution of pain must begin within 30 minutes of initiation of GLO2
H. Must have one hour on GLO2 following complete resolution of pain
I. Maximum of three hours of oxygen can be used
J. If above criteria are not met, patient must undergo recompression therapy.
K. If symptoms worsen or recur after GLO2, recompression therapy must be used.
L. Consultation with USFSAM/FEEH is required on all cases of suspected or diagnosed DCS cases

In rare cases of DCS or AGE where security considerations or remoteness of the deployed location make rapid transport not feasible or impossible, surface-level oxygen may be used until such transportation is available. Consultation with USAFSAM/FEEH is required.

If recompression therapy is undertaken, follow USN decision algorithm for therapy. Note: To reduce recurrence of neurological DCS, a USAF or USN Treatment Table 6 with two extensions at 60 feet of sea water (FSW) is recommended

Arterial Gas Embolism

Prevention

21. Diver Selection (ManMed Change 126 Aug 2005)

- Screening of all divers for PFO
  - Not recommended
- Most serious pulmonary disorders are disqualifying (DQ) for Naval Service
  - Includes asthma and history of asthma after age 13
- Diving Duty Specific Disqualifiers
  - Pulmonary barotrauma in candidates
  - Spontaneous pneumothorax
  - Traumatic pneumothorax (waiverable)
  - Chronic obstructive pulmonary disease
  - Chronic restrictive lung disease
  - Diving related pulmonary barotraumas
    - Waiverable in established divers if:
      - a. Due to violation in procedure
        - and
      - b. First episode

22. Prevention during the Dive (USN Dive Manual)

- Cautions against breath-holding on ascent

Treatment of Arterial Gas Embolism
USN Diving Manual Revision 6; April 2008

23. Pre-Recompression

- Oxygen
  - 15 L/M with reservoir mask or demand valve
- Supine position (not head down)
- Continuously monitoring
- Air transport
  - As low as safely possible
  - Preferably lower than 1000 ft
  - Pressurize aircraft cabin to 1 ATA if possible
  - Consider Emergency Evacuation Hyperbaric Stretcher

Recompress even if signs/symptoms resolve

24. Initial Recompression

- The USN Diving Manual treatment algorithms remain the gold standard for initial recompression of diving-related DCI.

- Surface oxygen is not a substitute for hyperbaric therapy in diving-related DCI.

- The use of alternate tables should be reserved for trained personnel at facilities with the expertise and hardware to deal with untoward/unexpected responses to therapy.

To 60 FSW on 100% O2 and begin TT6
DMO has option to go to 165 FSW early if patient not doing well
*Note: Severe signs/symptoms warrant full extensions of 60 FSW oxygen breathing periods even if S/S resolve during the first oxygen breathing period

25. Unchanged or Worsening Severe Signs/Symptoms after Initial Recompression to 60 FSW

Go to 165 FSW – if good resolution of signs/symptoms in 30 minutes – use TT6A
If need to stay at 165 FSW for up to 2 hrs – come to 60 FSW on TT4
If doing well at 60 FSW – come to the surface on TT4

26. Persistent Symptoms at 60 FSW

Extend TT6 x two 25-minute periods at 60 FSW
Extend TT6 x two 75-minute periods at 30 FSW
DMO may recommend customized treatment
Stay at 60 FSW for 12 h or longer – come out on TT7

27. Recurrence of Serious Symptoms during Decompression

If shallower than 60 FSW – go to 60 FSW
If deeper than 60 FSW – go to 165 FSW

28. In-Water Recompression

"In divers with severe Type II symptoms or symptoms of arterial gas embolism (e.g. unconsciousness, paralysis, vertigo, respiratory distress (chokes), shock, etc), the risk of increased harm to the diver from in-water recompression probably outweighs any anticipated benefit."

29. Adjunctive Therapy - Fluids

Differs from those for DCS

1) Divers with isolated AGE (without DCS) may be less dehydrated
2) Fluids may worsen cerebral edema

Crystalloids probably best choice if fluids are needed

Do not overhydrate

For isolated AGE, fluids should be administered at maintenance rates; otherwise titrate to 1-2 cc/kg/hr urine output

30. Adjunctive Therapy – Medications

Enoxaparin 30 mg SQ q12h or dalteparin 5000 IU SQ q24h for paralysis

Full anticoagulation not routinely used

If lidocaine is used, 1 mg/kg bolus then 2-4 mg/min infusion to maintain a plasma concentration of 2-6 micrograms/mL (8.5-25.6 micromoles/L)

No aspirin

No corticosteroids

31. Environmental Control during Recompression

Avoid hyperthermia during treatment

32. Post-Recompression Management

Remain within 30 minutes of a recompression facility for a period of 6 hours

Chamber Proximity

- Remain within 60 min travel time of chamber for 24 hrs
- Be accompanied during that period

Hospital admission

- Consider after TT6, TT6A, TT4, or TT7

Flying after Treatment

- 72 hours if no residual S/S
- When cleared by DMO if residual signs/symptoms

33. Post-Recompression Evaluation (ManMed Change 126 Aug 2005)

MRI of brain within 1 week

Non-contrast chest CT

Not required

- PFO evaluation
- CPK

34. Management of Residual Symptoms

Follow-Up HBO Treatments
Supervised by DMO
May be no improvement with first treatment
Improvement seen after delays to follow-up HBO therapy of up to 1 wk
Continue until no improvement on 2 consecutive treatments
May be daily TT6 or twice-daily TT5/TT9

35. Return to Diving after AGE

Magnetic Resonance Imaging (MRI) and Return to Diving

The presence of small hyperintense white matter lesions on brain MRI following cerebral DCI in an otherwise completely recovered (*completely recovered implies the absence of relevant symptoms or signs and the absence of any significant deterioration on neurocognitive testing conducted by a specialist neuropsychologist) diver is of uncertain significance, particularly in the absence of a baseline MRI. Such lesions may be found in subjects who have no significant history of brain injury. There is currently insufficient evidence that the appearance of such lesions, even in association with an episode of DCI, has any definitive prognostic significance in relation to development of post injury complications such as seizures. The committee recommends that return to diving decisions be made on the basis of clinical assessment. However, MRI scans should continue to be taken to exclude unanticipated significant lesions that might affect fitness for diving, and potentially, to inform future debate about the significance of small hyperintense white matter lesions.

There is no compelling evidence at present to support any specific waiting period for return to diving after treatment of AGE, although pulmonary pathology can be a cause of AGE, and it is prudent to first exclude pulmonary pathology as a precipitating factor. The following recommendations from the U.S. Navy Diving Manual and the Association of Diving Contractors International are offered for DMO consideration.

Note: there are no studies examining the safety of return to diving with or without lesions detectible by MRI. In addition, MRI has improved dramatically over the last 30 years, and improvements are expected in the future. Thus, whether a lesion can be detected or not using MRI is not an absolute, but is likely to vary with technique and stage of development of the technology.

<u>U.S. Navy Return to Diving Guidelines after AGE</u>

1. In diving duty candidates, any prior history of DCS or AGE is disqualifying.

2. Neurologic deficits persisting beyond initial treatment are disqualifying. Waiver may be considered with the following provisions:

a. Magnetic resonance imaging (MRI) of the brain (as indicated clinically) shall be obtained within 1 week of the time of injury.

b. Return to diving may be considered after 1 month if the following conditions have been met:

- No residual Signs/Symptoms
- Normal MRI
- Non-contrast chest CT performed
- Normal Pulmonary Function Tests
- Favorable recommendation from a pulmonologist
- Recommended for return to diving by a UMO

c. If initial MRI is abnormal or the diver has continued residual signs/symptoms, the diver will remain not physically qualified (NPQ) for diving duty until a waiver is obtained from the Bureau of Naval Personnel for resumption of diving duty. The work-up shall include at minimum:

1. Initial MRI (within 1 week)
2. Follow-up MRI at 1 month
3. Neurology consult
4. Pulmonary consult

3. The diver will be permanently disqualified for pulmonary barotrauma if no procedural violations occurred during the dive or for a second episode.

4. Divers experiencing DCS Type II/AGE after a no-decompression dive (an “undeserved hit” or who have experienced more than one episode of DCS Type II/AGE shall be evaluated for the presence of a PFO. In these cases, the presence of a PFO is disqualifying. Waiver may be granted on a case-by-case basis. PFOs diagnosed incidentally (for example, in the course of evaluating an asymptomatic murmur) are not disqualifying.

<u>Association of Diving Contractors International Return to Diving Guidelines after AGE</u>

Residual symptoms

Return to diving is not recommended

The following return to diving interval is recommended <u>only if</u> the diver’s signs and symptoms of AGE have completely resolved:

Pulmonary Barotrauma: 3 months

References

(1). Moon RE, Sheffield PJ. Guidelines for treatment of decompression illness. Aviat Space Environ Med 1997;68:234-43.

(2). Moon RE, Ed. Adjunctive Therapy for Decompression Illness. Kensington, MD: Undersea and Hyperbaric Medical Society; 2003.

(3). Mitchell SJ, Doolette DJ, Wachholz CJ, Vann RD, Eds. Management of Mild or Marginal Decompression Illness in Remote Locations. Durham, NC: Divers Alert Network; 2005.