Commander Military Personnel Command

Dysbaric Osteonecrosis in the CAF

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Background

General

1. This Instruction supersedes CF H Svcs Gp Instruction 9000-35, Dysbaric Osteonecrosis - Radiological Survey of Personnel Exposed to Dysbaric Environments.

Application

2. This Instruction applies to all CAF personnel, Department of National Defence (DND) Public Servants, contractors and sub-contractors who provide health services to CAF members. In particular, it applies to all personnel (CAF, DND Servants, contractors, and sub-contractors) who provide health services to CAF members who are divers as described below.

Purpose

3. The purpose of this Instruction is to outline the requirements and recommendations for performing long bone surveys.

Abbreviations

4. The following table contains abbreviations used in this Instruction.

Abbreviation	Term or Title in Full
ADMO	Advanced Diving Medical Officer
ADMT	Advanced Diving Medical Technician
AGE	Arterial Gas Embolism
AUMB	Aerospace and Undersea Medical Board
BAvMed	Basic Aviation Medicine
BDMT	Basic Diving Medical Technician
BDMO	Basic Diving Medical Officer
CD	Clearance Diver
CDM	Consultant in Diving Medicine
CDHM	Consultant in Diving and Hyperbaric Medicine (CFEME Toronto)
CDSM	Consultant in Diving and Submarine Medicine
CAF	Canadian Armed Forces

CFDPC	Canadian Forces Diving Policy Committee
CFEME	Canadian Forces Environmental Medicine Establishment
CFHIS	Canadian Forces Health Information System
CF H Svcs	Canadian Forces Health Services
CF H Svcs C	Canadian Forces Health Services Centre
CF H Svcs Gp	Canadian Forces Health Services Group
CFB	Canadian Forces Base
CSN	Canadian Switchboard Network
D Med Pol	Director – Medical Policy
DCS/DCI	Decompression Sickness / Decompression Illness
DWD	Deep Water Diver
DMO	Diving Medical Officer
DON	Dysbaric Osteonecrosis
DRDC	Defence Research & Development Canada
ECG	Electrocardiogram
FSMO	Fleet Support Medical Officer
HCP	Health Care Provider
IAW	In accordance with
In Att	Inside Attendant
ION	Ischemic osteonecrosis
JTF	Joint Task Force
LBS	Long Bone Series
MEL	Medical Employment Limitation

MOC	Military Occupation Code
MOSID	Military Occupational Structure Identification
MRI	Magnetic Resonance Imaging
OT	Occupational Transfer
PA	Physician Assistant
PFT	Pulmonary Function Test
PHA	Periodic Health Assessment
PID	Pressure tolerance testing / training
PTT	Pressure tolerance testing / training
SAR	Search and Rescue
SWD	Shallow Water Divers
US-AUMB	Undersea Subcommittee of Aerospace & Undersea Medical Board

Definitions

Note1: Definitions are for the purpose of this Instruction.

ADMO

5. A medical officer trained in diving medicine, and who is qualified to conduct all diver PHAs and to treat diving casualties in a hyperbaric (recompression) chamber.

ADMT

6. A Physician Assistant trained in diving medicine, and who is qualified to do annual diver PHAs (which are reviewed by an ADMO) and to work as the inside tender in a hyperbaric chamber during treatments.

AGE

7. A severe diving-related pathologic condition occurring in the body when gas bubbles gain access to the arterial system, causing blockage of blood flow and leading to local hypoxia and cellular death.

AUMB / US-AUMB

8. The Aerospace and Undersea Medical Board (AUMB) is the CAF's advisory board in these areas (Terms of Reference are as promulgated at Ref E). It resides at CFEME, DRDC Toronto. While all CDMs plus RCN Surg are also members of the plenary AUMB, by themselves they comprise the Undersea Subcommittee of AUMB (US-AUMB).

BDMT

9. A Physician Assistant trained in diving medicine, and who is qualified to do annual diver PHAs (which are reviewed by an ADMO).

Clearance Diver

10. The CAF Regular Force DWD occupation (MOC 341, MOSID 00127) whose members are trained to dive to depths up to 100m (330 feet) on various gas mixtures using a range of scuba, surface-supplied, and re-breather apparatus. Duties may include mine countermeasures, explosive ordnance disposal, demolition, seabed search and salvage, underwater construction and experimental diving.

CDM /CDHM

11. As defined Ref A, a CDM is an ADMO who has undergone additional post-graduate training in diving and hyperbaric medicine. The CDM residing at CFEME/DRDC Toronto is designated ‘CDHM’ IAW vols 2 & 5 Ref A. On behalf of US-AUMB, CDHM provides expert opinion and medical support to all operational diving organizations within the CAF and to D Dive S and the CFDPC.

CDSM

12. A term used to refer to CDMs who are also qualified in submarine medicine. The RCN Surg may appoint one of these CDSMs as PoC for submarine medicine issues on each coast, and/or as practice leader for CAF Submarine Medicine.

CFEME

13. A CF H Svcs Gp unit located at DRDC in Toronto. It represents the center of Aerospace & Undersea medical expertise for the CAF.

DCS

14. A *pathophysiological* term for a condition resulting from a decrease in ambient pressure acting on tissues with absorbed inert gas (N2, He, Ar), whereby the dissolved inert gas in the tissues and circulatory system evolve from solution to form bubbles that interfere with normal tissue function. Symptoms may be mild (‘Type I’; e.g., joint only) or serious (‘Type II’ e.g. involving the central nervous system).

DCI

15. A *descriptive* term used in Ref A that refers to the whole spectrum of bubble-related illness ranging from AGE to DCS.

DMO

16. A medical officer trained in diving medicine, and who is qualified to do all diver PHAs (which are then reviewed by an ADMO).

DON

17. A delayed manifestation or long-term effect of DCS thought to be due to inadequate decompression resulting in blockage of blood vessels in the long bones, and leading to bony necrosis.

PID

18. The CAF Reservist DWD occupation (MOC R345, MOSID 00225). PIDs are qualified to descend to depths of 45m (150 feet); their primary occupation is that of diver. They sometimes employ staged decompression and certain breathing apparatus not used by SWDs. These Reserve Force divers frequently work on Class B and C Service contracts with the Regular Force. There are 4 classes of PID. Class 1 (QL1) are designated SWDs, whilst Class 2, 3 and 4 (QL2, 3 and 4) divers are designated DWDs, and dive to a maximum depth of 45m (150 feet).

SWDs

19. Divers who rarely dive greater than a depth of 15m (50 feet), who never exceed 30m (100 feet), and who are required to dive within no-decompression limits (this entails all CAF divers except DWDs - i.e. Class 2, 3 and 4 PID and Clearance Divers).

Introduction and Description

20. ION is linked to both traumatic and non-traumatic aetiologies. Over 75 aetiological factors have been associated with non-traumatic osteonecrosis, one of which is the change in ambient pressure encountered by divers. This latter species of ION is referred to as DON. DON involves the death of osteocytes in bones bearing yellow (fatty) marrow, but not in those containing red (haematopoietic) marrow. Specifically, the involved bones are the proximal humerus, proximal and distal femur, and proximal tibia. DON lesions are categorized as being either juxta-articular (‘A’) or shaft (‘B’) depending on where they are located.

Pathophysiology

21. The underlying cause of DON is still open to debate, with a number of competing theories proposed in the literature. A common theme behind these theories (with the exception of oxygen toxicity) is the presence of inadequate decompression. Current medical evidence is not adequate to determine which of the various pathophysiologic mechanisms is of primary significance, and it may be that a number of factors operate concurrently. As a starting point, however, we do know that the regions in which DON occurs are susceptible to vascular compromise owing to poorly developed collateral circulation. We also know that blood flow to yellow marrow is relatively diminished with prolonged wash-in and wash-out times. And further, we know that nitrogen is 5 times more soluble in marrow fat than in blood. The etiological theories most prominent in the literature are the following:

a. Autochthonous bubbles arising in both intra and extra-cellular marrow compartments directly compress vascular walls leading to a reduction in blood flow;
b. Intra-medullary pressure (IMP) is increased owing to bubble accumulation, venous infarction, or osmotic fluid shifts arising from gas differentials. The IMP rises to exceed perfusion pressure, producing relative ischemia;
c. Arterial gas emboli produce an occlusive ischemia;
d. Lipid emboli are mobilized from adipocytes which rupture owing to expanding intra-cellular bubbles. The lipid emboli travel to marrow sinusoids and produce a compressive ischaemia. Lipid emboli also act as precipitators of inflammatory and thrombogenic cascades, processes which cause further vascular compromise and tissue damage;
e. Gas bubbles initiate inflammatory and thrombogenic cascades via stimulation of microparticle production. Thrombosis leads to ischemic damage while inflammatory processes result in osteocyte destruction; and
f. Increased partial pressures of oxygen produce free radical production which is directly cytotoxic to osteocytes.

Diagnosis

22. Diagnosis is based on imaging studies. MRI is the preferred method as it is both more sensitive and specific than plain radiography. Changes on plain radiography may not be observed until many months, or even years, after a DON lesion begins to develop. MRI is able to detect the presence of DON as early as 2 weeks, and by 2 months virtually all lesions are demonstrable.

23. The differential diagnosis includes: bone cysts and pseudocysts, bone islands, enostoses, enchondromas, fibrous cortical defects, non-ossifying fibromas, and fibrous dysplasia.

Staging and Classification

24. There is a well described set of progressive pathologic changes that occur in DON lesions. These changes have been classified by Ficat using MRI as per Annex B. An alternate

classification system is that used by the UK Medical Research Council. This system is based on the appearance of lesions as demonstrated by plain radiography, and is organized as per Annex C. The Ficat classification system is more commonly used as MRI is now the diagnostic tool of choice.

Risk Factors

25. DON is seen to occur in divers whose depth exposures are in excess of 30 msw, or whose dive durations at depths less than 30 msw exceed 4 hours. It does not occur in relation to dive exposures less than this minimum, except in circumstances where there has been an incidence of DCS. Saturation diving appears to increase the risk of developing DON beyond that of deep bounce diving. The occurrence of Decompression Sickness (DCS) is also a strong risk factor for DON and is (as determined by multivariate analysis) independent of the risk for depth/duration exposures. In other words, a diver never having suffered DCS may develop DON if his depth/duration exposures exceed the minimum values stated above, and a diver never exceeding those minimums may develop DON if he has suffered from DCS. Missed or omitted decompression also represents a dysbaric risk in relation to DON; however, the threshold of significant omission has not been determined. DON has been diagnosed in submariners after a single provocative decompression exposure (i.e. submarine escape) even in the absence of DCS.

26. Approximately 60% of DON sufferers report an episode of probable limb bends, but this number is likely to be influenced by recall bias. For those individuals who suffer a DCS event, the number who will go on to develop DON has not been determined.

27. Factors which augment the risk for DON in divers with dysbaric exposures include:

a. Age greater than 40 years;
b. Obesity;
c. Alcoholism;
d. Fatty liver; and
e. Hyperlipidaemia

Epidemiology

28. Amongst commercial divers who operate at depths less than 50 msw, the incidence of DON is 0.4%. For those diving between 50 and 150 msw, the incidence is 2.7%. The incidence of DON in military divers has not been adequately determined, with estimates varying between 0 and 4%. A reasonable figure for the CAF is approximately 0.2 to 1%.

Presentation

29. DON lesions may develop 10 years or more after the cessation of hyperbaric exposure. Shaft

lesions generally remain asymptomatic, while juxta-articular lesions generally progress to produce pain and limited range of motion. Juxta-articular lesions in bounce divers are most commonly seen in the humeral head, while those occurring in saturation divers and caisson workers are most commonly seen in the femoral head. While juxta-articular lesions in any of these populations may occur in the distal femur or proximal tibia, they are distinctly unusual.

30. When a DON lesion is identified, a concurrent lesion at a different location will be identified by x-ray in approximately 50% of cases and by MRI in approximately 90% of cases. The second lesion may be either of the ‘A’ or ‘B’ varieties, regardless of the nature of the first lesion.

Prognosis

31. Early DON lesions identified on either plain film or MRI may remain quiescent for many years before progressing to end-stage joint disease. On the other hand, quiescent lesions may never become progressive. The percentage of early lesions which will follow the progressive or benign pathway is not known. It is known, however, that once a lesion develops cortical collapse it will inevitably proceed to advanced degenerative arthropathy. For avascular osteonecrosis of other origins, cortical collapse occurs by 3 years in 70 to 80% of cases.

32. There is general agreement that timely treatment of DCS with hyperbaric oxygen is likely to reduce the incidence of subsequent DON, but there are reports of DON developing after a single DCS event despite adequate recompression therapy.

Screening Recommendations

33. All CAF diving candidates and diving medical personnel (ADMO/ADMT) shall complete a questionnaire (Annex A – ‘DON Screening Instrument’) at the time of their initial diving medical evaluation to determine their pre-existing risk for DON.

34. All qualified CAF divers, be they Ship’s Team Divers (STD), Port Inspection Divers (PID), Clearance Divers (CD), Search and Rescue Technicians (SAR Techs), or Combat Divers, shall complete this same questionnaire at the time of every PHA (Type I and II) for the duration of their diving careers.

35. Shallow water diving candidates (depths < 30 msw / no-decompression limits) whose response to the questionnaire indicates an increased risk for DON shall undergo a Long Bone Survey (LBS). Should there be no positive responses on the questionnaire, no LBS is required. The LBS, when indicated, shall take place within one month of the candidate having successfully completed the qualifying course.

36. All deep water diving candidates (CD and PID) shall undergo LBS when they have been selected for training, whether or not they have responded positively to the questionnaire.

37. For previously qualified divers who, at the time of a PHA, provide a newly positive response that indicates an increased risk for DON, a LBS shall take place within one month of the

questionnaire having been completed. For divers with ongoing exposure to DON risk factors (as identified by the questionnaire), LBS shall be performed every five years (though not more frequently than once every five years). Where no new or ongoing exposure to DON risk factors is identified by the questionnaire, no further imaging is required until the termination of active diving duties.

38. Should a diver have a LBS performed at any point, they shall also undergo LBS at 5 years following the initial LBS. All deep water divers and any shallow water divers who have had a prior LBS shall undergo LBS at the termination of their active diving careers. Shallow water divers who have not previously had a LBS, do not require screening at the termination of their active diving careers.

39. For the purposes of this direction on approach to screening of DON in divers, diving medical personnel shall be considered equivalent to shallow water divers.

40. Any diver who is diagnosed with DCS (Type I or Type II) or who significantly violates decompression schedules (see para 40 immediately below) shall undergo LBS within one week post-event, followed by MRI screening at two months post-event. The MRI shall assess bilateral shoulders, hips and knees (regardless of the location of a limb bend). Should no lesions suspicious for DON be identified by MRI, the diver shall undergo LBS screening every five years for the duration of their diving careers and at the termination of active diving/submariner duties.

41. For the purposes of DON screening, significant omitted decompression is defined as missed decompression of greater than 10 minutes from depths of 30 msw or less, or any missed decompression from depths in excess of 30 msw.

42. Submariners who have sustained decompression exposures as a result of escape shall undergo LBS within one week post-event, followed by MRI screening at two months post-event. The MRI shall assess bilateral shoulders, hips and knees. This screening shall occur whether or not the submariner presented with symptoms or signs of DCS.

Management

43. All instances of DCS, significant omitted decompression, submarine escape, or lesions of DON require consultation with a Consultant in Diving Medicine (CDM). The following points describe the standard CAF approach to DON lesions, but a CDM may alter this protocol at their discretion.

44. When a juxta-articular lesion is identified by plain radiography, it shall be further characterized by MRI and staged according to the Ficat classification (Appendix I – ‘Classifying DON Lesions).

45. When a juxta-articular lesion is identified, whether by plain radiography or MRI, MRI evaluation shall be performed of bilateral shoulders, hips and knees in order to rule out the presence of other DON lesions.

46. When a juxta-articular lesion is identified, it shall be followed by plain radiography every 6

months for the first two years, then annually until such time as the lesion shows no further interval change.

47. Any diver diagnosed with a juxta-articular lesion shall be referred to an orthopaedic surgeon for confirmation of the diagnosis, opinion regarding aetiology, and treatment recommendations.

48. Any diver with a juxta-articular lesion is to be declared, ‘unfit CAF diving / unfit hyperbaric environment’. Such members should be strongly advised to discontinue any future civilian diving in excess of 30 msw. They should also be advised to avoid activities that impose load-bearing on the involved joint.

49. When a shaft lesion is identified, MRI evaluation shall be performed of bilateral shoulders, hips and knees in order to rule out the presence of juxta-articular lesions. Thereafter, divers with shaft-only lesions shall be screened by LBS every five years until the termination of their active diving careers, at which time an exit LBS shall be performed. Divers with shaft-only lesions may continue diving as per their qualifications.

Responsibility

Responsibility Table

50. The table below describes responsibilities associated with Dysbaric Osetonecrosis Screening.

The...	Is responsible for...
CDHM (CFEME Toronto)	• Providing support and clinical guidance regarding any suspected cases of DON • Ensuring that Basic and Advanced Dive Medicine Courses provide instruction on DON
Other CDMs	• Providing support and clinical guidance regarding any suspected cases of DON
Formation ADMO (Fleet Support MO) and other Approval Authorities	• Performing quality assurance on the completion of Dive medical exams to see that DON screening is occurring as required
ADMO	• Reviewing Diver PHAs conducted by a BDMT, ADMT, DMO or a BAvMed provider • Staying current with this DON policy

DMO, BDMT, ADMT	Conducting annual PHAs (Note: The results will be reviewed by an ADMO) • Staying current with this DON policy
Divers	• Ensuring they maintain current medical certification by scheduling appropriate annual PHAs • Notifying their DMO and CoC immediately of any MELs or interim health issues that may temporarily or permanently affect their ability to perform diving functions safely • Completing the Annex A DON Risk Questionnaire at their initial dive medical examination and at all subsequent PHAs, both Type I and II

References:

A. B-GG-380-000, Canadian Forces Diving Manual
B. DAOD 8009-1, Canadian Forces Diving – Organization and Operating Principles
C. Clearance Diver Prelim and Selection one-pager
D. Terms of Reference – AUMB
E. RCN Surg 'One-Pager': SWD Medical Checklist
F. Diving General Memorandum 2010/13/A
G. RCN Surg 'One-Pager': CDM Consultation Service
H. Ficat RP. Idiopathic bone necrosis of the femoral head: early diagnosis and treatment. J Bone Joint Surg Br. 1985;67:3–9.

Annexes:

A. Annex A (PDF, 10 Kb) - Dysbaric Osteonecrosis Screening Instrument
B. Annex B - Ficat Staging and Classification of Dysbaric Osteonecrosis
C. Annex C – UK Medical Research Council Classification of Dysbaric Osteonecrosis

Annex B to CF H Svcs Gp Inst 4000-24

Ficat Staging and Classification of Dysbaric Osteonecrosis

The well described set of progressive pathologic changes that occur in DON lesions have been

classified by Ficat as follows:

0 - Ischemia / intravascular coagulation: This stage is asymptomatic and shows no radiographic changes.

1 - Dead bone without repair: This stage is also asymptomatic. Plain radiography is normal. MRI will demonstrate marrow edema by 4 weeks post onset. Necrotic zones will appear as low signal intensity on T1-weighted images.

2 - Dead bone with repair, but without collapse: Symptoms are generally absent in this stage. Lesions may not appear on plain radiography until 4 months after this stage begins. When lesions do appear on x-ray, they include sclerotic areas with irregular margins, spherical opaque areas (‘snowcap’), and linear opacities. MRI may demonstrate rings of low signal intensity surrounding a necrotic centre. The rings represent a reactive front of revascularization and re-ossification.

3 - Dead bone with repair and collapse: Once the process of collapse begins, symptoms become evident. These usually consist of pain associated with joint motion or weight-bearing, along with some degree of tenderness. Plain radiography will demonstrate subchondral fracture, evident as a radiolucent ‘crescent’ line. MRI will demonstrate a necrotic centre, a reactive front, and collapse of the articular surface.

4 – Secondary degenerative arthropathy: This stage may progress to complete destruction of involved joints.

Annex C to CF H Svcs Gp Inst 4000-24

UK Medical Research Council Classification of Dysbaric Osteonecrosis

An alternate classification system is that used by the UK Medical Research Council. This system is based on the appearance of lesions as demonstrated by plain radiography, and is organized as follows:

a. Juxta-articular Lesions:
   - A1 – Dense areas with intact articular cortex.
   - A2 – Spherical opacities.
   - A3 – Linear opacities.
   - A4 – Structural failures: translucent cortical bands, collapse of articular cortex, sequestration of cortex.
   - A5 – Secondary degenerative arthritis.

b. Shaft Lesions:
   - B1 – Dense areas.

     B2 – Irregular calcified areas.

     B3 – Translucent and cystic areas.