Optimal Use of Hyperbaric Oxygen Therapy in Military Medical Setting

(Utilisation optimale de l’oxygénothérapie hyperbare dans le contexte militaire)

The Task Group on Hyperbaric Oxygen Therapy in military medical setting explored the usefulness of hyperbaric oxygenation for medical conditions encountered in operational military settings; taking into account the technical specificities and constraints of hyperbaric oxygen therapy administration, recommendations are made as to the optimal implementation of this treatment.

Published February 2016
Optimal Use of Hyperbaric Oxygen Therapy in Military Medical Setting

(Utilisation optimale de l’oxygénothérapie hyperbare dans le contexte militaire)

The Task Group on Hyperbaric Oxygen Therapy in military medical setting explored the usefulness of hyperbaric oxygenation for medical conditions encountered in operational military settings; taking into account the technical specificities and constraints of hyperbaric oxygen therapy administration, recommendations are made as to the optimal implementation of this treatment.
The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations’ and NATO’s S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO’s ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT  Applied Vehicle Technology Panel
- HFM  Human Factors and Medicine Panel
- IST  Information Systems Technology Panel
- NMSG  NATO Modelling and Simulation Group
- SAS  System Analysis and Studies Panel
- SCI  Systems Concepts and Integration Panel
- SET  Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists’ Meetings, Lecture Series and Technical Courses.

The content of this publication has been reproduced directly from material supplied by STO or the authors.

Published February 2016

Copyright © STO/NATO 2016
All Rights Reserved


Single copies of this publication or of a part of it may be made for individual use only by those organisations or individuals in NATO Nations defined by the limitation notice printed on the front cover. The approval of the STO Information Management Systems Branch is required for more than one copy to be made or an extract included in another publication. Requests to do so should be sent to the address on the back cover.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>vi</td>
</tr>
<tr>
<td>HFM-192 Membership List</td>
<td>vii</td>
</tr>
<tr>
<td><strong>Executive Summary and Synthèse</strong></td>
<td>ES-1</td>
</tr>
<tr>
<td><strong>Chapter 1 – Background and Justification</strong></td>
<td>1-1</td>
</tr>
<tr>
<td>1.1 Hyperbaric Oxygen Therapy</td>
<td>1-1</td>
</tr>
<tr>
<td>1.2 Accepted Indications for HBO</td>
<td>1-1</td>
</tr>
<tr>
<td>1.3 Specific Military Indications</td>
<td>1-3</td>
</tr>
<tr>
<td>1.4 Complexity of HBO in Military Settings</td>
<td>1-3</td>
</tr>
<tr>
<td><strong>Chapter 2 – Objectives of this Report</strong></td>
<td>2-1</td>
</tr>
<tr>
<td>2.1 Define Military Indications for HBO</td>
<td>2-1</td>
</tr>
<tr>
<td>2.2 Define “Conditions for Use”</td>
<td>2-1</td>
</tr>
<tr>
<td>2.3 Propose Procedure for Treatment of Military Injuries</td>
<td>2-1</td>
</tr>
<tr>
<td><strong>Chapter 3 – Military Indications</strong></td>
<td>3-1</td>
</tr>
<tr>
<td>Definitions Used in this Summary</td>
<td>3-1</td>
</tr>
<tr>
<td>3.1 Acoustic Trauma</td>
<td>3-3</td>
</tr>
<tr>
<td>3.2 (Iatrogenic) Arterial Gas Embolism</td>
<td>3-4</td>
</tr>
<tr>
<td>3.3 Burn Injury – Life-Threatening (High TBSA or Respiratory Burns)</td>
<td>3-5</td>
</tr>
<tr>
<td>3.4 Burn Injury – Non-Life-Threatening</td>
<td>3-6</td>
</tr>
<tr>
<td>3.5 Carbon Monoxide Poisoning</td>
<td>3-7</td>
</tr>
<tr>
<td>3.6 Crush Injury (Combined Trauma to Bones, Soft Tissue, Vessels, or Nerves)</td>
<td>3-8</td>
</tr>
<tr>
<td>3.7 Decompression Sickness – Life-Threatening</td>
<td>3-9</td>
</tr>
<tr>
<td>3.8 Decompression Sickness – Non-Life-Threatening</td>
<td>3-10</td>
</tr>
<tr>
<td>3.9 Frostbite</td>
<td>3-11</td>
</tr>
<tr>
<td>3.10 Soft Tissue Infections – Life-Threatening</td>
<td>3-12</td>
</tr>
<tr>
<td><strong>Chapter 4 – Conditions for Optimal Use</strong></td>
<td>4-1</td>
</tr>
<tr>
<td><strong>Chapter 5 – Recommendations</strong></td>
<td>5-1</td>
</tr>
<tr>
<td>5.1 Planning</td>
<td>5-1</td>
</tr>
<tr>
<td>5.2 Routing</td>
<td>5-1</td>
</tr>
<tr>
<td>5.3 Practical Issues to be Resolved</td>
<td>5-1</td>
</tr>
<tr>
<td>5.3.1 Evacuation Routing</td>
<td>5-1</td>
</tr>
<tr>
<td>5.3.2 Financial Agreements</td>
<td>5-2</td>
</tr>
<tr>
<td>5.3.3 Evaluation of Efficacy</td>
<td>5-2</td>
</tr>
</tbody>
</table>
Annex A – Scientific Background and Rationale for the Use of Hyperbaric Oxygen Therapy in Discussed Diseases and Conditions

A.1 Acoustic Trauma
  A.1.1 Pathophysiology of the Condition
  A.1.2 Rationale for HBO Therapy
    A.1.2.1 Theoretical Benefit of HBO Therapy
    A.1.2.2 Animal Experiments
    A.1.2.3 Human Data

A.2 Arterial Gas Embolism
  A.2.1 Pathophysiology of the Condition
  A.2.2 Theoretical Benefit of HBO
  A.2.3 Clinical Scientific Evidence

A.3 Burn Injury – Life-Threatening (High TBSA or Respiratory Burns)

A.4 Burn Injury – Non-Life-Threatening
  A.4.1 Introduction
  A.4.2 Pathophysiology of the Condition
  A.4.3 Theoretical Benefit of HBO
    A.4.3.1 In Vitro Studies
    A.4.3.2 In Vivo (Animal – Human)
  A.4.4 Clinical Scientific Evidence

A.5 Carbon Monoxide Poisoning
  A.5.1 Introduction
  A.5.2 Pathophysiology of the Condition
    A.5.2.1 Hypoxia
    A.5.2.2 Perivascular Injury
    A.5.2.3 Excitotoxicity
  A.5.3 Theoretical Benefit of HBO
  A.5.4 Literature

A.6 Crush Injury (Combined Trauma to Bones, Soft Tissue, Vessels, or Nerves)
  A.6.1 Pathophysiology
  A.6.2 Theoretical Benefit of HBO
    A.6.2.1 In Vivo
    A.6.2.2 In Vitro
  A.6.3 Clinical Scientific Evidence

A.7 Decompression Sickness – Life-Threatening

A.8 Decompression Sickness – Non-Life-Threatening
  A.8.1 Introduction
  A.8.2 Theoretical Benefit of HBO
  A.8.3 Scientific Evidence

A.9 Frostbite
  A.9.1 Introduction
  A.9.2 Literature Review
A.9.3 Mechanism of Action of HBO
A.9.4 Clinical Experience
A.10 Soft Tissue Infections – Life-Threatening
   A.10.1 Gas Gangrene
      A.10.1.1 Benefit of HBO
      A.10.1.2 Clinical Scientific Evidence
   A.10.2 Soft Tissue Infections and HBO
      A.10.2.1 Theoretical Benefit of HBO
      A.10.2.2 Clinical Scientific Evidence
A.11 References

Annex B – Hyperbaric Centres Identified as “Suitable” for Treatment of Military HBO Indications
   B.1 Definitions and Methods
   B.2 Other Sources
      B.2.1 Europe
      B.2.2 United States
   B.3 Hyperbaric Facilities

Annex C – Hyperbaric Reference Persons for Military HBO
# List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1-1</td>
<td>Accepted Indications for HBO According to ECHM</td>
<td>1-2</td>
</tr>
<tr>
<td>Table 1-2</td>
<td>“Accepted Indications” for HBO According to UHMS</td>
<td>1-3</td>
</tr>
<tr>
<td>Table 4-1</td>
<td>Required Hospital Capabilities for Treatment of Military HBO Indications</td>
<td>4-2</td>
</tr>
<tr>
<td>Table A-1</td>
<td>Patient Assessment and Recommendations for HBO</td>
<td>A-12</td>
</tr>
<tr>
<td>Table A-2</td>
<td>Gustilo Classification and Recommendations for HBO</td>
<td>A-12</td>
</tr>
<tr>
<td>Table B-1</td>
<td>Hyperbaric Facilities and Hospitals</td>
<td>B-2</td>
</tr>
</tbody>
</table>
HFM-192 Membership List

LtCol MC Dietmar M. FISCHER, MD
Dept of Anesthesiology and Intensive Care Medicine
Federal Armed Forces Hospital Ulm
Oberer Eselsberg 40
89081 Ulm
GERMANY
Email: mail@decodoc.de / dietmar.fischer@extern.uni-ulm.de / dietmarmanfredfischer@bundeswehr.org

LtCol Peter GERMONPRE, MD (Chair)
Centre for Hyperbaric Oxygen Therapy
Military Hospital Brussels
Rue Bruyn, 1
B-1120 Brussels
BELGIUM
Email: peter.germonpre@mil.be / p.germonpre@gmail.com

CFR MN Francisco GUERREIRO, MD
Hospital das Forças Armadas
Azinhaga Ulmeiros
1620-060 Lisboa
PORTUGAL
Email: quaresma.guerreiro@marinha.pt / franciscogamitoguerreiro@gmail.com / franciscoguerreiro@iol.pt

ADC Robert HOUMAN, CHT
(Retired from RTG-192 as of January 2012)
Centre for Hyperbaric Oxygen Therapy
Military Hospital Brussels
Rue Bruyn, 1
B-1120 Brussels
BELGIUM
Email: rob.houman@mil.be

Dr. Igor MEKJAVIC
(Until 2012 – not replaced)
Institute Jozef Stefan
Jamova 39
1000 Ljubljana
SLOVENIA
Email: igor.mekjavic@ijs.si

Capt Mark E. MICHAUD
(As from 2012)
Bureau of Medicine and Surgery
Head, Undersea Medicine and Radiation Health (M3B3)
2300 E Street, NW
Washington, DC
UNITED STATES
Email: Mark.Michaud@med.navy.mil

Mesut MUTLUOGLU, MD
(As from 2013)
Department of Underwater and Hyperbaric Medicine
Gulhane Military Medical Academy
Haydarpasa Teaching Hospital
34668, Uskudar, Istanbul
TURKEY
Email: drmutluoglu@gmail.com

Milos SAZEL, MD, PhD, LtCol. ret.
Institute of Aviation Medicine Prague
Gen. Piky 1
P.O. Box 19
160 60 Prague 6
CZECH REPUBLIC
Email: sazel@ulz.cz / sazel@centrum.cz

LT(N) Gunalp UZUN, MD
Assistant Professor
Department of Underwater and Hyperbaric Medicine
Gulhane Military Medical Academy
Haydarpasa Teaching Hospital
34668, Uskudar, Istanbul
TURKEY
Email: gunalpuzun@gmail.com

Edward (Andy) WOODS Captain MC, USN
BUMED M3/5 Director Fleet Programs
Specialty Leader Undersea Medicine and Radiation Health
2300 E Street NW
Washington, DC 20372-5300
UNITED STATES
Email: edward.woods@med.navy.mil
REPORT DOCUMENTATION PAGE

1. Recipient’s Reference  
   STO-TR-HFM-192
   AC/323(HFM-192)TP/664

2. Originator’s References  
   ISBN  
   978-92-837-2026-3
   PUBLIC RELEASE

5. Originator  
   Science and Technology Organization  
   North Atlantic Treaty Organization  
   BP 25, F-92201 Neuilly-sur-Seine Cedex, France

6. Title  
   Optimal Use of Hyperbaric Oxygen Therapy in Military Medical Setting

7. Presented at/Sponsored by  
   The Task Group on Hyperbaric Oxygen Therapy in military medical setting  
   explored the usefulness of hyperbaric oxygenation for medical conditions  
   encountered in operational military settings; taking into account the technical  
   specificities and constraints of hyperbaric oxygen therapy administration,  
   recommendations are made as to the optimal implementation of this treatment.

8. Author(s)/Editor(s)  
   Multiple

9. Date  
   February 2016

10. Author’s/Editor’s Address  
    Multiple

11. Pages  
    84

12. Distribution Statement  
    There are no restrictions on the distribution of this document.  
    Information about the availability of this and other STO unclassified publications is given on the back cover.

13. Keywords/Descriptors  
    Acoustic trauma  
    Anaerobic infections  
    Complex trauma  
    Diving accident treatment  
    Hyperbaric medicine  
    Hyperbaric Oxygen Therapy  
    Medevac  
    Strategic evacuation planning  
    Submarine rescue planning  
    Treatment of battle wounds

14. Abstract  
   Hyperbaric Oxygen Therapy (HBO) is a treatment based on the respiration of high concentrations  
   (up to 100%) of oxygen, while patients are exposed to high environmental pressures in a “hyperbaric  
   chamber”. This treatment has been shown to be beneficial in a number of conditions/injuries, some  
   of which are pertinent to military-type injuries.

   When administered timely and in a correct way, HBO improves the evolution and final outcome;  
   however, because of the technical limitations of the treatment (necessity of a hyperbaric chamber,  
   adequate oxygen and compressed air supplies, competent medical and paramedical personnel), HBO  
   centers are not common, even in non-military setting.

   The RTG-192 examined the possible military applications of HBO, and defined the conditions for its  
   use. While not realistic to suggest the placement of HBO centers close to operations theatres, it may  
   be possible to organize the medical evacuation routes in such a way that military patients can be  
   treated in a (civilian or military) hyperbaric center “along the route”, for a short period, before being  
   further evacuated to their final destination.

   Conditions and modalities for efficient use have been formulated, and recommendations have been  
   made as to medical planning and education of military medical personnel.
Les publications de l’AGARD, de la RTO et de la STO peuvent parfois être obtenues auprès des centres nationaux de distribution indiqués ci-dessous.


**CENTRES DE DIFFUSION NATIONAUX**

**BELGIQUE**
Royal High Institute for Defence – KHID/IRSD/RHID Management of Scientific & Technological Research for Defence, National STO Coordinator Royal Military Academy – Campus Renaissance Renaissancelaan 30, 1000 Bruxelles

**CANADA**
DGSIST Recherche et développement pour la défense Canada 101 Colonel By Drive, 6 CBS Ottawa, Ontario K1A 0K2

**DNEMARK**
Danish Acquisition and Logistics Organization (DALO) Lautrupbjerg 1-5 2750 Ballerup

**ESPAGNE**
SDGTECIN (DGAM) C/ Arturo Soria 289 Madrid 28033

**ESTONIE**
Estonian National Defence College Centre for Applied Research Riia str 12 Tartu 51013

**ETATS-UNIS**
Defense Technical Information Center 8725 John J. Kingman Road Fort Belvoir, VA 22060-6218

**FRANCE**
O.N.E.R.A. (ISP) 29, Avenue de la Division Leclerc BP 72 92322 Châtillon Cedex

**GRECE (Correspondant)**
Ministry of Defence “Prof. Tsvetan Lazarov” “Tsvetan Lazarov” bul no.2 1592 Sofia

**HONGRIE**

**ITALIE**
Centro Gestione Conoscenza Secretariat General of Defence Via XX Settembre 123/A 00187 Roma

**LUXEMBOURG**
Ministry of Defence ‘Your Belgique’

**NORVEGE**
Norwegian Defence Research Establishment Attn: Biblioteke P.O. Box 25 NO-2007 Kjeller

**PAYS-BAS**
Royal Netherlands Military Academy Library P.O. Box 90.002 4800 PA Breda

**POLOGNE**
Centralna Biblioteka Wojskowa ul. Ostrobramska 109 04-041 Warszawa

**PORTUGAL**
Estado Maior da Força Aérea SDF/ Centro de Documentação Alfragide P-2720 Amadora

**REPUBLIQUE TCHÉQUE**
Vojenský technický ústav s.p. CZ Distribution Information Centre Mladoboleslavská 944 PO Box 18 197 06 Praha 9

**ROUMANIE**
Romanian National Distribution Centre Armaments Department 9-11, Drumul Taberei Street Sector 6 061353 Bucharest

**ROYAUME-UNI**
Dstl Records Centre Rm G02, ISAT F, Building 5 Dstl Porton Down Salisbury SP4 0JQ

**SLOVAQUIE**
Akadémia ozbrojených sil gen. M.R. Štefnik, Distribučné a informačné stredisko STO Demiánová 393 031 06 Liptovský Mikuláš 6

**SLOVÉNIE**
Ministry of Defence Central Registry for EU & NATO Vojkova 55 1000 Ljubljana

**TURQUIE**
Millî Savunma Bakanlığı (MSB) ARGE ve Teknoloji Dairesi Başkanlığı 06650 Bakanlıklar Ankara

**AGENCES DE VENTE**

The British Library Document Supply Centre
Boston Spa, Wetherby West Yorkshire LS23 7BQ

Canada Institute for Scientific and Technical Information (CISTI)
National Research Council Acquisitions
Montreal Road, Building M-55 Ottawa, Ontario K1A 0S2

AGARD, RTO & STO publications are sometimes available from the National Distribution Centres listed below. If you wish to receive all STO reports, or just those relating to one or more specific STO Panels, they may be willing to include you (or your Organisation) in their distribution. STO, RTO and AGARD reports may also be purchased from the Sales Agencies listed below.

Requests for STO, RTO or AGARD documents should include the word ‘STO’, ‘RTO’ or ‘AGARD’, as appropriate, followed by the serial number. Collateral information such as title and publication date is desirable. Full bibliographical references and abstracts of STO, RTO and AGARD publications are given in “NTIS Publications Database” (http://www.ntis.gov).

**NATIONAL DISTRIBUTION CENTRES**

**BELGIUM**  
Royal High Institute for Defence – KHID/IRSD/ RHID  
Management of Scientific & Technological Research for Defence, National STO Coordinator  
Royal Military Academy – Campus Renaissance  
Renaissancelaan 30  
1000 Brussels

**BULGARIA**  
Ministry of Defence  
Defence Institute “Prof. Tsvetan Lazarov”  
“Tsvetan Lazarov” bul no.2  
1592 Sofia

**CANADA**  
DSTKIM  
Defence Research and Development Canada  
101 Colonel By Drive, 6 CBS  
Ottawa, Ontario K1A 0K2

**CZECH REPUBLIC**  
Vojenský technický ústav s.p.  
CZ Distribution Information Centre  
Mladoboleslavská 944  
PO Box 18  
197 06 Praha 9

**DENMARK**  
Danish Acquisition and Logistics Organization (DALO)  
Lautrupbjerg 1-5  
2750 Ballerup

**ESTONIA**  
Estonian National Defence College  
Centre for Applied Research  
Riia str 12  
Tartu 51013

**FRANCE**  
O.N.E.R.A. (ISP)  
29, Avenue de la Division Leclerc – BP 72  
92322 Châtillon Cedex

**GERMANY**  
Streitkräfteamt / Abteilung III  
Fachinformationszentrum der Bundeswehr (FIZBw)  
Gorch-Fock-Straße 7  
D-53229 Bonn

**GREECE (Point of Contact)**  
Defence Industry & Research General Directorate, Research Directorate  
Fakinos Base Camp, S.T.G. 1020  
Holaragos, Athens

**HUNGARY**  
Hungarian Ministry of Defence  
Development and Logistics Agency  
P.O.B. 25  
H-1885 Budapest

**ITALY**  
Centro Gestione Conoscenza  
Secretariat General of Defence  
National Armaments Directorate  
Via XX Settembre 123/A  
00187 Roma

**LUXEMBOURG**  
Soe Belgium

**NETHERLANDS**  
Royal Netherlands Military Academy Library  
P.O. Box 90.002  
4800 PA Breda

**NORWAY**  
Norwegian Defence Research Establishment, Attn: Biblioteket  
P.O. Box 25  
NO-2007 Kjeller

**POLAND**  
Centralna Biblioteka Wojskowa  
ul. Ostrobramska 109  
04-041 Warszawa

**PORTUGAL**  
Estado Maior da Força Aérea  
SDFA – Centro de Documentação  
Alfragide  
P-2720 Amadora

**ROMANIA**  
Romanian National Distribution Centre  
Armaments Department  
9-11, Drumul Taberei Street  
Sector 6  
061353 Bucharest

**SLOVAKIA**  
Akadémia ozbrojených sil gen  
M.R. Štefánika, Distribučné a informačné stredisko STO  
Demáróna 393  
031 06 Liptovský Mikuláš 6

**SLOVENIA**  
Ministry of Defence  
Central Registry for EU & NATO  
Vojkova 55  
1000 Ljubljana

**SPAIN**  
SDGTECIN (DGAM)  
C/ Arturo Soria 289  
Madrid 28033

**TURKEY**  
Milli Savunma Bakanlığı (MSB)  
ARGE ve Teknoloji Dairesi Başkanlığı  
06650 Bakanlıklar – Ankara

**UNITED KINGDOM**  
Dstl Records Centre  
Rm G02, ISAT F, Building 5  
Dstl Porton Down, Salisbury SP4 0JQ

**UNITED STATES**  
Defense Technical Information Center  
8725 John J. Kingman Road  
Fort Belvoir, VA 22060-6218

**SALES AGENCIES**

The British Library Document Supply Centre  
Boston Spa, Wetherby  
West Yorkshire LS23 7BQ  
UNITED KINGDOM

Canada Institute for Scientific and Technical Information (CISTI)  
National Research Council Acquisitions  
Montreal Road, Building M-55  
Ottawa, Ontario K1A 0S2  
CANADA