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Legends and Leadership in Hyperbaric Medicine

at the world-renowned Karolinska University Hospital

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Annika Ryberg, MD and Folke Lind, MD with critically ill ICU patient in the multiplace chamber

Legends and Leadership in Hyperbaric Medicine at the world-renowned Karolinska University Hospital

Folke Lind, MD, PhD has been an important international driving force in the development of Hyperbaric Medicine. In 1991 he became Director of Hyperbaric Medicine at Karolinska, and from that time on, he and his colleagues have helped hyperbaric treatment evolve into an established science.

Critical Care News met with Dr Lind, and with Michael Nekludov, MD, who has been working at the institution since 1999 and is the current Director of Hyperbaric Medicine and also with Peter Kronlund, Perfusionist and Technical Manager, who has contributed to the CE registration of products in hyperbaric conditions and is currently the European Chairman of the HBO Safety Committee.

These pioneers have enjoyed a unique collaboration, and they share their experiences of their journey in hyperbaric medicine, their current HBO innovations and future desires for continued development in the field.

Can you describe the current scope of your hyperbaric medicine facilities at Karolinska, and what events led to this?

Folke Lind: I became responsible for the hyperbaric chamber facilities in 1991, and I received sponsoring from Siemens Elema and AGA at that time to establish a hyperbaric chamber facility for intensive care patients. We had two SERVO 900 ventilators at our disposal, and we published our first scientific research article about the use of the SERVO 900 ventilator in HBO therapy. All of these factors led to our starting a good HBO facility for our intensive care patients.

Michael Nekludov: Karolinska Hospital is a world-leading level 1 institution, and this benefits our HBO operations. We are located in close proximity to our central ICU department and helicopter pad, which are important factors. We have a large 4-lock rectangular multiplace chamber, totalling 50 square meters, in which we can treat up to four ICU patients simultaneously. We can take care of up to 9 ventilator patients in our multiplace chamber, in the case of a catastrophic event like a large fire. The chamber was established in 2005 and is equipped with everything an intensive care patient needs. We have another large multiplace chamber that we used primarily as our research chamber; it can be used in hyperbaric as well as hypobaric conditions. Our department also has 3 monoplace chambers.

Folke Lind, MD, PhD at Karolinska has been an important international driving force in the development of Hyperbaric Medicine.

Which types of and numbers of patients have you treated with HBO over the past twelve months?

Michael Nekludov: During 2013 we have conducted 245 HBO treatments with SERVO-i in the multiplace intensive care chamber, with 52 patients in total. In our monoplace chambers we conducted 1956 treatments last year in a total of 88 patients – these patients usually require much longer series of treatments per patient.

Folke Lind: Many people think that we primarily use HBO to treat decompression sickness, also known as divers' disease, but this is a minority patient category for us. Our most common acute patient indication is necrotizing faciitis. These serious soft tissue bacterial infections are the largest patient category we treat with HBO, particularly in the multiplace chamber, since most of them are deeply sedated, and requiring intensive care. Air embolism, decompression sickness and carbon-monoxide intoxication are other acute patient categories.

We also have elective HBO therapy with different patient categories, such as diabetes patients with foot ulcers, patients with radiation damaged tissue, chronic infections, neurosurgical infections and patients with infected implants.

Michael Nekludov: If you look at our statistics from last year, of the 245 treatments in the multiplace chamber; 24 of these were carbon monoxide cases, necrotizing fasciitis were a total of 167 treatments, 30 treatments of tissue ischemia - for example crush injuries leading to possible amputation, and 5 decompression sickness patients.

For treatments in our monoplace chamber last year, we treated primarily radiation tissue damaged patients, patients with osteomyelitis, infected implants and hypoxic ulcers, and lastly decompression sickness.

What is the current staffing situation within your department for supporting hyperbaric medical treatments?

Michael Nekludov: Currently we have 14 doctors that work for HBO on-call. Chamber operators consist of both nurses and physicians, and we have 16 staff members currently, with another 2 in training. We have a total of 27 intensive care nurses who are qualified to work in the HBO chamber. We have 4 permanent staff members in our monoplace department consisting of 2 registered nurses and 2 practical nurses.

What are the requirements for a ventilator used for HBO?

Folke Lind: It must be safe from an electrical standpoint as fire is a devastating occurrence in the chamber. For the SERVO-i we have the possibility to use the ventilator in the ICU and use batteries during transport to the hyperbaric chamber. We run on batteries until we enter the chamber, where we connect to external 12V power and remove the batteries, thus ensuring a smooth process without interruption of ventilation. Besides the pure safety aspects of operation, the ventilator must compensate for the hyperbaric environment and of course deliver what is set, and report monitored values correctly. $EtCO_2$ is mandatory and the SERVO-i curves are efficient in detecting problems like increasing intrinsic PEEP. As we have PDMS system in the chamber a connection to the ventilator is a must to generate proper documentation of the procedure.

What were the primary factors leading to the decision to initiate and test the SERVO-i ventilator for HBO treatment?

Folke Lind: I think our longstanding collaboration with SERVO ventilator developers, first with Siemens and later with MAQUET, as well as our history of use of the SERVO 900 ventilator in the HBO environment made it quite natural for us to want to help develop and upgrade to HBO with SERVO-i .

Peter Kronlund: To enable collaboration and development, you need a partner company with enough curiosity and power to drive these types of large scale development projects. By power, I mean that powerful financial and technical resources are needed. MAQUET and the former SERVO owner Siemens-Elema have always worked closely together with the Karolinska Institute.

When it came to SERVO-i, our collaboration started one evening in 2006, when Folke, I and members of the MAQUET development department started to look at prototypes which subsequently lead to the final approved HBO application in SERVO-i. We worked together in the evenings after our normal daytime HBO operations were finished, and on weekends as well with evaluation of the new application. Evaluation is a continuing process: what works, what doesn't work, and back to the developers to redefine, modify, return and validate again.

Michael Nekludov: It is also important to note that with SERVO-i we have an intensive care ventilator that works in the HBO environment. This is valuable to us as we place continuing requirements in regard to our standard ICU equipment and treatment performance wherever we are with the patient – either in the intensive care unit or in the HBO chamber. We need to guarantee the same quality of ventilation treatment performance in both settings. No matter where you are with the intensive care patient, you want to have access to and adjust the same respiratory parameters on the ventilator in the same manner. We want to provide a modern intensive care without any interruptions in ventilatory treatment.

With SERVO-i we also have the benefit of standardizing so that all ICU staff members can be educated and trained on the same ventilator platform.

What work and processes were requirements to receive hospital approval for use of the SERVO-i ventilator in the chambers?

Peter Kronlund: In very simple practical terms, what we do is take one medical device such as SERVO-i, and connect another medical device to it – the HBO module. It is the original device which regulates how to go forward with requirements and approval for the

Michael Nekludov, MD, is the current Director of Hyperbaric Mediciine at Karolinska

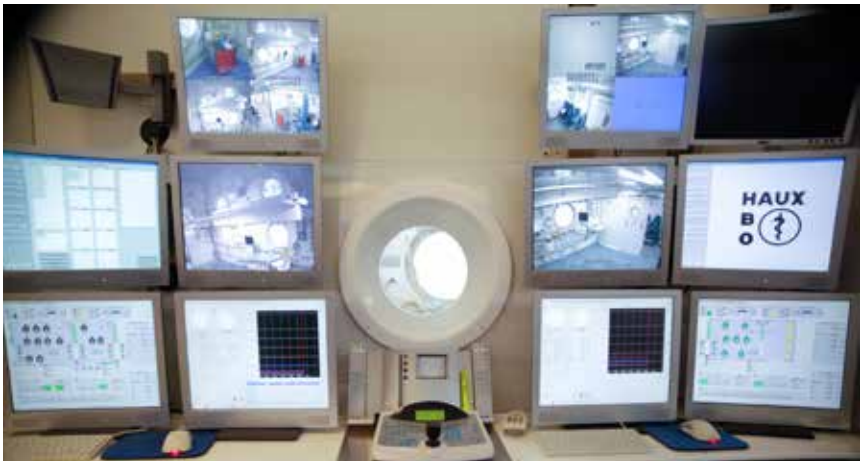
Technical manager Peter Kronlund has contributed to the CE approvals of several devices in the HBO environment

connecting device. The manufacturer of the HBO multiplace chamber, Haux Life Support in Germany, together with an independent institution that certifies their products called Germanischer Lloyd, who in turn is an expert on HBO chambers and different types of underwater installations. They have collaborated on a guide called "Enclosures for electrical devices in hyperbaric facilities", which gives an understanding of the requirements before the risk analysis is made and the devices are being developed. I am currently Chairman of the European Safety Committee, so I know there is an ongoing dialogue between organizations. For SERVO-i and HBO, it was a long development and approval process but very valuable for everyone that was involved during each step of the way.

How often and for how long are the patients on mechanical ventilation in the chamber?

Folke Lind: The patient should be prepared before going to the chamber with appropriate ventilator, syringe pumps, and intensive care monitoring for the hyperbaric chamber. We use the SERVO-i and if the patient is given multiple treatments he can use the same ventilator in the ICU and in the chamber. In patients who need repeated HBO treatment, this allows easier and more practical handling of the routine in the ICU and chamber, as well as transport to and from the chamber. We have the philosophy of slowly increasing and decreasing pressure in the chamber. Hence, pressure is ramped up in a curvilinear fashion during 11-13 minutes until the therapeutic target pressure level, 2,8 ATA corresponding to18 meters below water surface, is obtained. After 70 minutes, during which time we provide two 5 minute periods of air breathing in order to avoid oxygen toxicity, we begin a slow decompression. Pressure is

Birgitta Johansson, LPN and Carola Lenbäck, LPN (chatting with a patient in a monoplace chamber).



The technical control center outside of the multiplace chamber

then gradually stepped down until a threshold of 1.9 ATA were we remain stationary for 10 minutes, then continue the decrement in pressure down to 1.3 ATA where another 10 minutes pause is administered. Pressure is then tapered off to sea level. The total time for a session is set to 113 minutes. We expand the time to 3 hours or more if we treat severe cases, divers or gas embolism.

How do you monitor mechanical ventilation in the chamber?

Folke Lind: We have a long tradition of using etCO_2 monitoring in the chamber. This started as a collaborative project with Siemens Elema using the SERVO 900 C and accompanying CO_2 analyzer 930. We found that by using compensation factors for the hyperbaric environment we could achieve breath-by-breath control of ventilation. By comparing the Arterial CO_2 level to the end tidal, assuming parallel development, we have found that etCO_2 monitoring has been our most important source to guarantee proper ventilation and bringing immediate attention to mechanical problems like endotracheal tube patency. We routinely obtain a blood gas 20 minutes after reaching target pressure and then adjust the ventilator according to the arterial PCO_2. With the SERVO-i we are able to control pressure and volumes both delivered and exhaled routinely and we use the flow curve to detect intrinsic PEEP. An important effect of the hyperbaric environment is the increase in the respiratory time constant, increasing the tendency for auto PEEP. The situation is easily detectable as flow does not return to zero during expiration.

We have treated a full range of patient categories, from an infant of 2.5 kilos up to patients weighing 130 kilos

The density of Oxygen increases linearly with increasing barometric pressure. How does this affect the gradient between Peak Inspiratory Pressure and Plateau Pressure?

Folke Lind: We have used pressure controlled ventilation routinely for several years and flow resistance increases with the square root out of the density increase. At 18 meters corresponding to 2,8 ATA and 2,8 times increased gas density there is therefore a 1,7 times increased flow resistance. Since the endotracheal tube gives the highest flow resistance most of the peak pressure is just a reflection of the flow resistance in the tube as can be seen by the lower plateau pressure. If we cannot achieve normoventilation, we increase pressure and the inspiratory time thus decreasing the impact of the increased resistance. We also try to avoid dead space ventilation as much as possible.

Can you share some of your patient experiences during the past year for the use of SERVO-i ventilator to provide HBO treatment?

Folke Lind: We calculate that we have conducted 105 patient treatments with SERVO-i with HBO in 2012, and over 200 patient treatments with SERVO-i and HBO in 2013, so we are well over 300 patient treatments in total for the product by now. We have treated a full range of patient categories, from an infant of 2.5 kilos up to patients weighing 130 kilograms. The 2.5 kilo baby was a difficult to ventilate patient, and we were happy to have SERVO-i to help us with this particular case. The child had undergone abdominal surgery and fasciitis had developed in the surgical incision area.

Michael Nekludov: A wide range of patients, and as we mentioned earlier, very critically ill patients and patients with sepsis and multi-organ failure. Again, it is an advantage to have a standardized ventilator solution in all the intensive care units, including the neonatal and pediatric patients. Introducing the SERVO-i with HBO went very smoothly, almost without any problems at all. I am impressed with the product development process at MAQUET. With many other types of medical devices, we sometimes get the impression that a device has been generated in product development for direct sales, with no understanding of the customer need or requirement. Those types of companies have a difficult time making innovative products without understanding the true need of the customer. In the case of SERVO-i with HBO, MAQUET as a manufacturer responded to customer needs and requirements, a tradition that has always been associated with development of the SERVO ventilator product line.

Teamwork in the multiplace chamber with intensive care staff members Folke Lind, MD, Annika Rydberg, MD and Karin Andersson, critical care nurse

What are some of the primary differences in providing ventilation to HBO patients with the SERVO-i ventilator, compared to the SERVO 900 ventilator?

Folke Lind: The SERVO 900 ventilator was a valuable cornerstone here for more than two decades. The SERVO-i provides us with flow and pressure curves, in order to see how the lungs are functioning and how the body is responding to expiration and inspiration. This is especially important with very critically ill patients, who are difficult to ventilate.
Michael Nekludov: We also have an unbroken chain of care for the patient, as they are being treated with SERVO-i in the central ICU departments.

What are some of the primary differences compared to other HBO ventilators?

Folke Lind: We have not had so many other solutions to compare to. When I took over the responsibility for the HBO facilities in 1991, we had a hyperbaric Dräger Oxylog, and we have had transport ventilators in the early years, but these disappeared fairly quickly in time. We also did hand ventilation in the very beginning.

Peter Kronlund: It is important to note that we were unwilling to introduce other solutions from other manufacturers in the Karolinska Hospital. There has been a focus on standardizing whenever possible to reduce the numbers of devices from different manufacturers, as part of our safety and security processes.

The SERVO-i ventilator with HBO may also be used in the general ICU. Can you describe the patient or clinical advantages in this respect?

Michael Nekludov: It is important to maintain continuity in the patient treatment, and avoiding breaking the ventilatory circuit with disconnecting and re-connection in these severely ill intensive care patients. When we bring the patient to the HBO chamber we frequently see that O_2 saturation deteriorates a little after HBO therapy. We usually increase the oxygen concentration a bit and recruit the lungs. If you are at a level of 70-80% prior to HBO, it may be a bit problematic afterwards. For example, in septic patients or patients with severe fasciitis it is very important to avoid atelectasis by means of maintaining PEEP and avoiding breaking the patient circuit.

The patient being treated in the chamber today is a female that has a severe fasciitis that generated in her throat after an infection, and has spread from the throat to the mediastinum. She has had complex infection processes which have been treated with ORN-surgery and thorax surgery. There are open drains in her throat and thorax and her current oxygen requirement is 60%. This type of critically ill patient is not one that you want to expose to further potential risks, such as atelectasis.

Action at 11,52 m depth in the multiplace chamber

This is about the most severe patient category to be found in the ICU, where we need to optimize ventilation during a number of other ongoing treatments and interventions.

Folke Lind: It is also important to note that SERVO-i HBO ventilator is connected to the PDMS system for continuous data collection in the central ICU departments, so there is no interruption in data collection for HBO treatments. This is just one more detail that makes HBO therapy an integral portion of the entire intensive care treatment.

What do you see as development areas for hyperbaric treatments and technology in the future?

Michael Nekludov: Perhaps an even broader scale of pressure tolerances in future. Right now we are currently treating at a maximum of 18-19 meters depth. But we do have types of treatment we would like to conduct at 30 meters depth with the ventilator.

If we are really visionary, in future we would like to deliver dialysis during the course of HBO treatment. Quite recently, we have conducted a technical test of a dialysis system in the HBO chamber, but we have not tested with patients yet.

You are currently involved in a range of ongoing HBO studies in different areas: assessing symptom relief in radiation induced cystitis with HBO, HBO in lower leg trauma, HBO as a treatment component in necrotizing soft tissue infections, and HBO to reduce post-op complications in diabetic patients. Although these are all significant areas for research, can you share which area you feel has the biggest priority at present?

Folke Lind: The European research project where we are participating with the largest 5 year financing is both pre-clinical and clinical, and the project is called Infect. The purpose is to learn more about these flesh-eating bacteria. HBO is a small part of this project. But in Scandinavia, we see several hundred of these patients with these conditions and treat them with HBO in several centers in Sweden, Denmark and Norway.

Another international research study is the Hyperbaric Oxygen in Lower Leg Trauma, or HOLLT study, which we are about to summarize after almost 10 years of faithful study and research. We have studied 107 patients so far, so we are near our objective of 120 patients. About one patient every second month may appear in Stockholm or Melbourne, or the Czech Republic.

We also have an ongoing Scandinavian randomized controlled trial to investigate treating radiation induced cystitis with hyperbaric oxygen. Sahlgrenska University Hospital in Göteborg is sponsoring this study, and we are participating together with Rigshospitalet in Copenhagen and the Haukeland University Hospital in Bergen, Norway. We have very good research collaboration in Scandinavia in the area of hyperbaric medicine.

Michael Nekludov: We are also conducting research in the area of post-operative hyperbaric oxygen treatments to reduce complications for diabetics undergoing vascular surgery. Another interesting potential research area is within neuro ICU. There are a few publications about skull injuries and HBO therapy

Folke Lind: For example, there are head injuries too severe to operate, and there aren't many other alternative treatments available. There is a theory that it might be beneficial to give HBO intermittently with oxygen therapy to these patients. There have been some results in this area in a randomized study in the US.

At Karolinska you have become pioneers as well as ambassadors or missionaries for HBO throughout the world. What types of educational activities do you conduct here?

Folke Lind: Yes, this spring we have planned visits from Moscow and intensivists from St Petersburg for whom we will hold some training courses. We will also conduct a study visit for 2 intensivists from the Netherlands in the next few weeks. We have conducted several international meetings in Stockholm and we offer a free educational website with lectures from meetings and symposiums, which is located at www.hyperbaricoxygen.se. We have a well-established collaboration with the Mayo Clinic in the US, and they will be visiting us next year. They will be conducting a symposium on HBO in 2015, where I've been invited as a speaker. Sydney is the site of another investment in a multi-place chamber, where Karolinska has been a forerunner. We are definitely at the forefront in driving development in HBO.

Michael Nekludov: The US has historically used monoplace chambers more frequently, and there have been attempts there to install all equipment in a monoplace chamber, but the disadvantage to this is that the physician has no access to the patient during treatment, a clear limitation during a long treatment process as we see it. We believe that the best way to treat intensive care patients with hyperbaric medicine is to incorporate all aspects of intensive care, including caregivers, within the HBO chamber.

Peter Kronlund: We share our various experiences in different forums, such as lectures, presentations and meetings with different groups such as technicians, nurses and physicians from different countries.

Folke Lind: That is why we have been doing this, ever since 1977 when we began our research. At my first congress in 1980, we were already pioneers for other sites who were interested in starting up HBO. There is a university hospital in Okinawa in Japan that has been here for an educational visit. They have copied our HBO facilities and treatment methods, as has a center in Singapore. But with reference to Asia, China is the land with the most HBO chambers per capita in the world! They are treating more indications with hyperbaric medicine than any of us are today.

Michael Nekludov monitors and helps to prepare another patient for treatment in the hyperbaric multiplace chamber

Biography

Folke Lind, MD PhD has been an important driving force for the development of Hyperbaric medicine. With a life-long interest in diving, it was a natural development to become involved in baromedical research even before his MD in 1980. Baromedicine was at this time a part of the physiology institution at the Karolinska institute and Dr. Linds Ph.D thesis on "Respiratory drive and breathing pattern during exercise in man" in many ways reflected the ground breaking work on respiratory physiology of the institution at the time. During his residency for specialization in Anesthesia and Intensive Care he continued his postdoctoral research at the Karolinska Institute with more emphasis on Hyperbaric Medicine. In 1991 Dr. Lind became Director of Hyperbaric Medicine, a position he held for 17 years. During these years Hyperbaric medicine and treatment has evolved into an established science, with proven effects of beneficial actions on host infectious defense systems, antibiotic potency, angiogenesis and wound healing. During Dr. Linds leadership, the Institution for Hyperbaric Medicine has become leading in the world. The functionality of the current multiplace chamber is very much due to the work by Dr. Lind, first during the planning phase by providing a detailed specification of the unit and secondly by his long time collaboration with the industry, resulting in registration of infusion pumps, monitors, data collections systems, defibrillators and the SERVO ventilators for hyperbaric conditions. Dr. Lind is currently dividing his clinical obligations with research efforts associated with clinical aspects of hyperbaric therapy. He is an avid lecturer on the many different aspects of Hyperbaric medicine from chamber construction to cell-mediated patient responses. He is currently involved in several multi center trials concerned with effects of Hyperbaric therapy.

Michael Nekludov, MD, studied medicine at Saratov University, in the Russian Federation, where he graduated in 1990. He received his Swedish MD diploma in 1993 from the Karolinska Institute, followed by internship during the years of 1995-1997 at Danderyds Hospital in Stockholm. He also practiced in several other Scandinavian hospitals such as in Göteborg, Motala, Västerås, Gällivare and Tromsö in Norway.

In 1997, Michael Nekludov pursued his studies and work within the area of anesthesiology, obtaining a specialist degree in 2002.

Michael Nekludov has been employed at the Anesthesiology Department of Karolinska University Hospital since 1998, and has been active as an HBO on-call physician since 1999. He has experience within general anesthesiology and intensive care, as well as HBO and neurosurgical intensive care.

Michael Nekludov, MD is currently involved in several ongoing research projects in the areas of HBO and neurotrauma. He has been Medical Director for the HBO operations at Karolinska University Hospital since 2013.

Peter Kronlund, RN, Perfusionist CCP received his initial nursing degree in Sweden in 1974, and qualified as specialty nurse in 1981 and as a military ICU nurse in 1984. He was a team member of the Karolinska Heart Transplant and Total Artificial Heart Project for the years of 1985-1987, with team members Professor B Semb, Dr B Koul, Dr J Liska and perfusionist J Svensson. Peter Kronlund obtained his degree as Perfusionist CCP in 1988, with special projects in Hypthermia survival in cold water and ECMO with heparin-coated blood circuitry under Professor B Olsson.

Peter Kronlund started working in the Karolinska Hyperbaric Medicine Department in 2005, with the assignment to develop work with intensive care applications in hyperbaric environment in collaboration with the biomedical engineering team at Karolinska.

Peter Kronlund acted as Chairman and General Secretary of the Swedish and Scandinavian Perfusionist Organisations 2001-2003. He has presented numerous scientific abstracts, oral presentations and published articles from 1990 to the present time. He is currently Technical Manager of the Hyperbaric Medicine Department at Karolinska Institute, and is Board Member and Chairman of the Safety Committee of the European Baromedical Association for Chamber Operators, Nurses and Technicians.

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