Design and Human Factors of Therapeutic Hyperbaric Chambers

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INTRODUCTION: Hyperbaric therapeutic chambers are pressure vessels capable of accommodating one or more persons with the purpose of providing medical treatment. Therapeutic hyperbaric chambers have been in use from the mid-20th century, yet apparently their design has not reached their full potential and they are not compatible with current healthcare facilities design. This paper will present therapeutic hyperbaric chambers from a human-environment-machine perspective in order to highlight their specific problems and requirements, and suggest design concepts that may improve patient satisfaction, quality of treatment, and functionality of the staff. Data were collected from a literature review, a market survey, and personal observations. Main design solutions include personal space and privacy, stress- and anxiety-reducing environments, hazard mitigation, rearrangement of seating, and personalized (user-tailored) entertainment systems. It is suggested that adopting a user-centered design rather than an engineering focus will increase satisfaction and overall 'user experience' of the patients, alleviate psychological issues, and lessen workload and improve functionality of the staff. This study could be applicable and easily adapted to other confined therapeutic environments in which patients are restrained for several hours on a regular basis in receiving treatment, such as dialysis or chemotherapy rooms, and for confined nonmedical situations such as aircrafts and rapid trains.

KEYWORDS: confined atmosphere, healthcare facilities, hyperbaric oxygen therapy, medical design, user-centered design.

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Hyperbaric therapeutic chambers are pressure vessels capable of accommodating one or more persons with the purpose of providing medical treatment[19,23] by breathing high oxygen pressures according to well-structured predetermined protocols.[14] The main indications for hyperbaric oxygen (HBO) treatment are diving and flight causalities [e.g., air or gas embolism, decompression (altitude) sickness], acute indications (e.g., carbon monoxide poisoning, gas gangrene, crush injury, compartment syndrome and traumatic ischemia, central retinal artery occlusion, acute traumatic ischemia), and chronic indications (e.g., healing of selected problem wounds, diabetes, radio necrosis, severe anemia).[8,14,43] While acute treatment characteristics resemble those of intensive care units,[42] chronic treatments are performed in sessions according to fixed protocols at predetermined time intervals for prolonged periods and are similar to treatments given in conventional subspecialty clinics.[17,25]

The two types of therapeutic chambers are monoplace chambers—single-compartment vessels designed for one patient only[18]—and multiplace chambers,[23] having two or more compartments for treating several people simultaneously, which will be the main focus of our study. Therapeutic hyperbaric chambers have been in use from the mid-20th century, yet the design of most chambers does not seem to be compatible with current healthcare facilities design and health promoting environments, human factors principles, and adaptiveness to users' needs and satisfaction.[46]

We decided to examine therapeutic hyperbaric chambers from a human-environment-machine perspective in order to highlight their specific problems and requirements, and suggest design concepts that may improve the patients' experience, quality of treatment and functionality of the staff. This approach could also be applicable to other therapeutic environments in which patients are restrained for several hours on a regular

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basis while receiving treatment such as dialysis or chemotherapy clinics, CPAP (continuous positive airway pressure) treatment for obstructive sleep apnea, and in confined nonmedical situations such as traveling in aircrafts and rapid trains.

METHODS

Data were collected from a literature review and market survey of websites of hyperbaric centers and hyperbaric chamber companies, personal observations, and interviews conducted in numerous hyperbaric chambers. Indexed publications in this area are scarce, and most of the data appearing below were gathered from professional reports and publications.

The information collected was sorted into a table for comparative analysis according to the following categories: morphology, pressure range, number of patients, door type, windows, materials, entertainment options, interior design, in-chamber medical equipment, additional accessories, and breathing equipment. The pictures and information have been used as a "remote" observational study for identifying problems and drawbacks. Based on the findings, different design solutions are presented, including tradeoff considerations between patients and staff requirements.

RESULTS

Hyperbaric chambers, which are pressurized sites having unique physical and psychological specifications and characteristics that may have implications on chamber design, users' needs and performance, are briefly reviewed in the following sections.

Physical Characteristics of Hyperbaric Chambers

Pressure. Therapeutic hyperbaric chambers are compressed to elevated pressures (usually in the range of 1-2.5 MPa) and undergo pressure changes (compression and decompression) performed at a constant rate and according to precise, fixed protocols. Specific in-chamber breathing equipment supplies different gas mixtures at assorted partial pressures to patients and staff. Breathing options include unrestricted breathing (without a mask), which is practical for small volume chambers (monoplace) and for the accompanying staff, intubation, or various types of breathing apparatuses of masks or hoods. The choice of breathing aids depends on patients' clinical status, age, and preferences, as well as on the availability of equipment in each chamber.

Temperature. The pressure changes during compression and decompression cause fluctuations in chamber temperature (in opposite directions) that may cause discomfort to patients at the beginning and end of the treatments.[6] Infants and young children will require special care to maintain their normal body temperature.

Illumination. Natural light is unavailable within hyperbaric chambers; therefore, artificial light is used. Special requirements include pressure-resistant light sources, prevention of glare, and avoiding an increase in heat production.

Isolation. Hyperbaric chambers are isolated units: they are disconnected physically, visually, and acoustically from the external environment. The physical connection with the outside is restricted and the patient and medical and technical staff are unable to enter and exit spontaneously during treatment. All entries and exits are in accordance with compression and decompression rates and bottom-time restrictions. Verbal and visual communications are disturbed and unstable due to voice distortion and the lack of direct visual eye contact, requiring external assistive aids such as microphones and cameras.

Noise. Hyperbaric chambers are relatively noisy environments due to the work of the compressors, although in modern chambers the noise from compressed air pumped into the chamber is muffled.[6] Acoustic problems are frequent, especially during compression and decompression and voice distortion due to increased gas pressures.[6]

Chamber size and morphology. Chamber dimensions and morphology are based on the need to maintain high pressures, frequent pressure changes, restriction in materials selection, and the need for infrastructure, technical support, compressors, and backup systems located next to the hyperbaric chamber. Curved forms (shell structures) are the most appropriate structures that resist high hydrostatic pressure. It is not surprising, therefore, that cylindrical and spherical shapes are the common morphology in undersea habitats and pressure vessels of commercial and military operations. Subsequently, classical therapeutic hyperbaric chambers followed this form and are of cylindrical shape along a horizontal axis.

Using a flat bottom technology, the Ω omega shape (**Fig. 1**, left) increases the horizontal space, supplying a flat and convenient workable platform, but reduces the chamber's overall height. Moreover, the curved walls add constraints on equipment arrangement and seating options for the patients.

Rectangular chambers (Fig. 1, right) have started to gain popularity in recent years as hyperbaric therapy is performed at moderate hydrostatic pressures.[3,30,45] The rectangular shape provides maximal available areas for patients and equipment, a regulated uniform height, the option for wide walk-in doors, vertical walls, and a common appearance of a therapeutic setup. Rectangular chambers are basically designed to be an extension of the hospital's clinical environment, a fact that improves its ease of use and acceptance by the general healthcare community.[3,30]

Chamber materials. Shapes of hyperbaric chambers relate mostly to the materials used. Classical materials of cylindrical hyperbaric chambers are steel for the matrix and glass or acrylic for the windows and viewing area, with a different proportion between the two materials. Concrete and, recently, its advanced version of post-tensioned concrete, enables rectangular chamber morphology and large rectangular doors.[19,45,46] Concrete chambers can be erected by a building contractor and it is easier

Fig. 1. Horizontal cylindrical chamber (left) and rectangular chamber (right).

for a hospital architect to incorporate a concrete HBO facility as another room,[19] saving time and cost of manufacturing. The cost of a concrete chamber is reported to be much lower than a conventional facility structure of steel.[3,30]

As therapeutic hyperbaric chambers are not planned to perform at extreme high pressures, they can be built as light-weight structures using polymer materials, enabling even mobility. Moreover, the use of innovative technologies such as nanotechnology-based materials and extreme textiles[33] (in accordance with fire hazard guidelines and safety regulation)[5,13,24] can help in developing novel structures and revolutionary forms of chambers that are tailored and adapted dynamically to changeable therapeutic needs and varied users' profiles.

Chamber openings. The openings of hyperbaric chambers are determined and modified by their morphology, materials, and pressure restrictions. Doors and windows should be sealed completely, following the vessel contour to maintain the high pressure and avoid a pressure drop. Doors with a wide opening, satisfactory height, and walkthrough passage are needed to enable fast and easy entry and exit for patients walking on their own or supported by wheelchairs or crutches, and for stretchers and beds pushed by staff for patients lying down. These requirements for openings are not met by most cylindrical hyperbaric chambers. Moreover, the cylindrical configuration demands external adaptors such as a set of stairs or a ramp for smooth entry. Rectangular chambers provide much more adaptable opening options: a wide porthole, the possibility of a straight, comfortable walkthrough passage, and the option for a sliding door for easy performance.

The most common windows are sealed windows, usually round, ship-style, port-view windows distributed around the chamber (see Fig. 1), supplying limited visibility by the patients of the outside and by the personnel of the patients inside. Some windows are equipped with views of a television or video screen to allow patients to pass the time.[26]

Interior design. In cylindrical HBO chambers, the patients' seats are arranged in two rows affixed to the walls (**Fig. 2**). In rectangular chambers, the seats are distributed around the walls in a radial configuration, as patients must be connected to breathing systems attached to the chamber boundary. This kind of "fringe" design does not use the entire area of the chamber effectively and forces the patients to face each other for a prolonged period of time, but does not permitting any intimacy. Patients are seated almost knee to knee (Fig. 2), overlapping each other's personal space when stretching out their legs, and possibly blocking staff movement as they walk between patients.

The seating options are usually standard armchairs and benches that are common in diving chambers, in waiting rooms of clinics, or in airplanes in economy class (Fig. 2), lacking special options for supporting and alleviating prolonged sitting while being connected to the compressed gas supply apparatus (mask, hood, etc.), or the monitoring of physiological parameters, infusion, and other equipment. There is an inherently high risk of a flash fire in an oxygen-rich environment under increased atmospheric pressure; therefore, care should be taken in selecting in-chamber furnishings, upholstery, and personal items that are allowed to be taken into the chamber. All materials that support combustion, items that transmit static electricity or may discharge sparks, synthetic rubber, plastic, or metal items are not permitted in or near the HBO chamber.[5,13,26]

Psychological Characteristics of Hyperbaric Chambers

Hyperbaric chambers create a congested, confined ambience detached physically, visually, psychologically, and in an auditory fashion from the external environment. Patients are restricted by masks or hoods worn over their faces and are restrained by a breathing hose with limited length, allowing minimal freedom of movement for periods of about 2 h with a short break in the middle of the HBO session. Breathing through a mask or hood imposes limitations on conversations between patients and even disturbs reading. Patients cannot just walk in and out, and even personal items, including battery-powered toys, radios, hearing aids, or other devices, as well as any metal or "friction" toys that could especially help children to feel at home, are not allowed to be brought into the chamber.[5,26]

Psychological manifestations reported include isolation, claustrophobia and anxiety, insufficiency of control or autonomy, boredom, and lack of personal space and privacy.[6,7,22] Similar psychological sensations are also available in nonpressurized clinical environments such as dialysis or chemotherapy treatment units in which patients are restrained by infusion tubes or blood dialysis lines for several hours on a regular basis at predetermined intervals.[4] Patients with obstructive sleep

Fig. 2. Typical two-row seating configurations in a cylindrical chamber having a shared television screen (left). Patients breathing via a hood (middle) and masks (right).

apnea complain about claustrophobia as they must be connected to a CPAP breathing system over a minimum of 4 h a night.[11]

Users of Hyperbaric Therapeutic Chambers

Therapeutic hyperbaric chambers are shared by three groups of users having different characteristics and needs: the medical staff—physicians and nurses working inside and outside the hyperbaric chamber; the technical team operating the chamber and the equipment, mostly from outside the chamber; and the patients staying inside the chamber, breathing different gas mixtures with various levels of supportive medical treatment given before, during, or after the HBO session(s). Our analysis focuses mostly on the patients, but takes into consideration the needs of the technical and medical teams.

Patients may differ in age, physical, clinical, and mental conditions, fitness, and language knowledge. The majority of nonemergency patients are admitted to the hyperbaric facility for HBO treatments for indications that are unrelated to diving disorders. By and large, these patients are not divers who are familiar with hyperbaric facilities, pressure equilibrium maneuvers, the sound of compressors, compression/decompression temperature changes, and physical isolation. Adherence to HBO treatments is critical for nonemergency patients and is vital for the success of the treatment; patients must attend the facility repetitively for several HBO sessions that are planned according to fixed protocols at predetermined time intervals, which may last for several weeks and even months. Early publications report on negative feelings, anxiety, and even dropout and treatment refusal,[1,7,12] while more recent studies cite low dropout rates and improved patient compliance with HBO therapy (compliance increased with patient education).[22]

Table I summarizes the main characteristics of patients treated in multiple HBO chambers and the possible implications and requirements of the hyperbaric chamber design. As can be seen from the table, patients may be seated or lying down, but all are restricted in their movements and are connected to breathing gas supply apparatus (hood, mask, or intubation), which may eliminate or at least diminish their options for leisure activities (talking, reading, viewing TV, and more). The most significant disruptive issues are lack of privacy, no autonomy or control, being restrained and locked in the hyperbaric environment, disconnection from the outside, poor visibility, communication conditions, and boredom.[6] Some patients may become stressed as a result of this situation accompanied by unfamiliar noise, temperature changes, and claustrophobia. Diversity in patients' profiles calls for tailored design options for seating, entertainment, and privacy.

DISCUSSION

Hyperbaric therapeutic chambers deliver medical treatment, but their design is still following by and large the image and visual language of professional and military underwater facilities, which are characterized by high pressures and extreme environmental conditions. Yet, the therapeutic pressure range is a much lower pressure scale and involves less demanding physical conditions, and the customers and tasks differ. Therefore, a new and modern design should be developed that would be detached from the morphology and visual language of the military and commercial underwater world and be compatible with the therapeutic and healthcare environment.[46]

There is growing evidence of the effect of environmental conditions on people's wellness and the outcome of patients' recovery.[10,36,41] Good design can reduce anxiety, lower blood pressure, reduce the need for pain medication, and shorten hospital stay, while poor design was found to be linked to anxiety, delirium, and more.[31,36,40] Based on patients' needs and the special restrictions and constraints of the hyperbaric environment, we suggest redesigning the ambiance via visual, auditory, olfactory, and tactile manipulations in a personalized and dynamic manner, and spatial reorganization of the chamber space to improve user experience and patient satisfaction, reduce anxiety and claustrophobia, and improve overall adherence and therapeutic outcome.

Visual Manipulations

Amplifying viewing options by placing windows all around the chamber, including on the ceiling, and directing natural light inside will reduce feelings of isolation and claustrophobia and may improve wellness.[39] Windows and exposure to nature serve as positive distractions, reduce stress, and improve wellness and even alleviate pain.[28,31,41] Projection of landscapes and nature through virtual windowing could even further improve

Table I. Patient Characteristics and Possible Implications for Hyperbaric Chamber Design.

PATIENT CHARACTERISTICS	MAIN CATEGORIES	REQUIREMENTS AND IMPLICATIONS OF HYPERBARIC CHAMBER DESIGN
Age	All ages (infants to elderly)	Size adaptable seating and equipment Personalized entertainment options Assistance and guidance
Number of patients	Single patient Several patients and staff	Numerous connections to gas supply breathing systems Separation between patients; need for personal space and privacy Individual treatment protocols
Consciousness level	Conscious Unconscious	Easy and rapid entry and exit by attendants and patients Adequate options for various HBO breathing apparatus (mask, hood, free breathing, intubation) Spacious space for attendant and critical care equipment
Posture	Sitting (+leg support) Lying	Chairs, beds, stretchers Adequate options for various arrangements for breathing equipment Reserved space for wheelchair
Mobility	Walking patients Patients in wheelchairs Critical care patients	Easy walk-in entrance, clear passage Wide opening for stretcher or hospital bed Reserved space for wheelchair Flexibility in number of sitting/lying options
Health status	Generally healthy Sick, impaired	Containment of infections (sterility, separation) In-chamber assistance, supportive equipment Rapid entry and access for medical personnel
Familiarity with facility	Unfamiliar/single (first) treatment – newcomers Customary/repeated sessions – dedicated users	Stress-reducing environment Tutoring, instructions Auditory prewarning about changes (temperature, noise)
Psychological status	Claustrophobia Anxiety Relaxed, calm	Design for reducing claustrophobia Increased transparency (see-through) Relaxing (hidden) design Information and feedback systems
Social needs	Sociable patients Non-social patients	Options for social interaction Personal space and privacy
Interest level	Self-occupied Passive, bored	Tailored, personalized entertainment Support system for reading (e.g., lighting), talking, music (noise, earphones), personal TV, video, etc.

wellness.[39] For example, virtual windows that are installed in isolated and windowless environments such as hyperbaric chambers[37] are used as an artificial substitute for natural light and scenery.

Innovative technologies of currently available smart materials can offer options of reversing the solid opaque outer walls of the hyperbaric chamber, or part of them, into transparent surfaces, thus reducing isolation, claustrophobia, and anxiety. A balance is needed between the need for observing the patients and their privacy inside the chamber by determining the total amount and proportion of transparent and dense surfaces and their distribution. Coloring the chamber's internal walls may affect mood,[47] but based on cultural and personal diversity between people, we suggest using advanced technologies of projected illumination and paintings (virtual painting) in different colors and shades, thus creating a personal dynamic experience according to patients' changeable preferences, instead of using irreversible physical wall coloring. Visual distraction and amusement aids such as personal video or individual VR installation provide distraction and even pain relief[9,21] and should be a complementary system in any hyperbaric chamber.

Olfactory Perception Manipulations

Hyperbaric chambers may suffer from unpleasant odors of ointments, wound secretions, and bodily fluids that may cause discomfort for patients, especially in the confined space of the facility. It is well known that the artificial use of odors may modify mood, physiology, and behavior (aromachology), and even influence wellness by attenuating blood pressure and improving sleep and emotional states.[16,20] Some studies suggest that smell may modulate pain perception (in a gender-specific effect) and could therefore be considered in the process of designing healthcare facilities.[32] We suggest its use in hyperbaric chambers in which odor could be regulated easily using the effective in-chamber ventilation system.

Moreover, therapeutic hyperbaric chambers could even brand themselves by characteristic scents[15] that will reduce the perception of "sickness," generate a calm ambience, and even be of a prestigious unique nature.[27,28] One should not neglect physiological manifestations, such as adaptation to odor, and individual and gender differences in smell sensations.[29] The use of scents could also be effective for confined dialysis and in oncology clinics in which patients complain of unpleasant smells.[4]

Acoustic Manipulations

The hyperbaric chamber is a noisy environment that disrupts communication between people inside the chamber and the outside with control panels and staff, leading to anxiety and restlessness. Solutions for an improved auditory milieu include the selection of personal music via individual systems and earphones, and "Sound Design" ("Soundscape"). Adding acoustic features and elements of the outdoors and landscapes such as water fountains, wind bells, and even trees with typical leaf sounds may have a great impact on ambiance experience, hopefully reflected in reducing stress and improving wellness.[2]

Tactile Manipulations

Tactile communication can be an effective modality for hyperbaric chambers in which visual and auditory communications are disrupted and limited. Tactile information can be perceived simultaneously with visual and auditory signals when using earphones or watching a video or movie, and could deliver personal, discreet, and continuous information to each patient separately. This increases the confidence of the patients, reduces anxiety, improves the feeling of safety, and even allows patients to fall asleep in a relaxed fashion during treatment, knowing that tactile warnings such as a vibration will awaken them in case of an announcement or problem.

Multimodal Sensory Manipulations

Based on the variation between people, their abilities, preferences, and constraints as reflected in Table I, a multimodal sensory design will enable a tailored, personalized platform for each person that is changeable according to environmental conditions (low visibility, noise, silence). Multimodal sensory design can diminish visual and auditory load, and accommodate personal differences and preferences.[34,35] To overcome physical and psychological isolation from the external world, we suggest adding orientation signs such as a clock for time indication, timeline markers, and a progress bar for knowing the stage of treatment and time left until the end of treatment, time until air break, and more.

Redesigning Seating Options

Privacy, lack of personal space, and autonomy are among the main complaints and dissatisfaction expressed by the patients. We suggest reorganizing the seating layout to increase privacy and personal space, and improve staff mobility, access, and visibility to patients in a manner that can be easily performed in cylindrical hyperbaric chambers. **Fig. 3** presents a typical layout of a cylindrical chamber housing 12 seats for patients and a chair for staff arranged side by side whereby a gradual manipulation in seat angles of 30°, 45°, 60°, and 90° has been applied. The 30° arrangement cuts down the number of seats by two (Fig. 3B), yet increases the free space between seats and enables convenient passage and increases privacy since patients are not frontally facing each other, improves the ability of the attendant to observe the patients, and creates a storage space between the seats (Fig. 3C). Any further increase in seat angle expands the attendant's visual contact with the patient, the patients' personal space and privacy, walking convenience and storage space, yet reduces the number of patients to be treated in each HBO session (Fig. 3C, 3D, 3E) and, therefore, is economically less cost effective. Considering the tradeoff, the most convenient options for staff and patients that are still cost effective for operating the chamber seems to be the 30° and 45° seat configurations.

Intermediate dividing walls at about the height of the seats will provide a personal intimate space onto which monitoring devices as well as personal entertainment options could be attached. The panels between patients may be transparent, opaque, or even decorated according to the needs and preferences of each patient and staff member.

For rectangular chambers, we suggest distributing the patients' seats throughout the chamber area by placing docking units supporting the patients' breathing apparatus. The vertical docking stations could be attached to the ceiling (similar to operating room booms) or connected to the chamber floor for the compressed gas supply. This layout will expand the effective utilization of the chamber area, enable placing the breathing equipment as close as possible to the patient, be adaptable both to sitting and lying positions, and enable a 360 degrees of freedom in movement. The docking stations will serve as a fully integrated unit and allow management of the entire process of patient treatment, including connection to information systems, auditory and visual communications, temperature control, lighting management, information panel, hidden storage of private items, and personal entertainment facilities such as flat panels or VC stations that can be lifted up and down at different heights and angles to accommodate both sitting and lying down positions.

Both spatial organizations (swerved seats or seating around docking stations) could also be easily applied in dialysis and chemotherapy treatment units to achieve privacy and personal space.

Redesigning Treatment Seats

Following a reorganization of the seating options at 30° or 45° angles, we propose improving the seating experience based on anthropometric data[38] and users' needs and constraints, which are composed of five elements (**Fig. 4**): a comfortable armchair that can be pushed backward (A); an individual support for each individual leg, allowing stretching each leg independently, and even containing an infrastructure for performing a massage or rehabilitation procedures embedded in the support unit during the HBO session (B); a single-patient armrest (C); a personal headrest and divider (D); and a transparent curved shield with an axis providing a mini personal space (E). A private entertainment system containing music, e-book, video screens, and personal relevant information could be projected onto the shield or connected to the divider.

Based on a demographic perspective, special consideration should be given to elderly people who are likely to become a major group of patients, suffering typically from chronic diseases and a wide array of cognitive and motor disabilities that may significantly disrupt their behavior and treatment outcome. One could even expect that disorientation within the chamber will even be enhanced in the elderly.

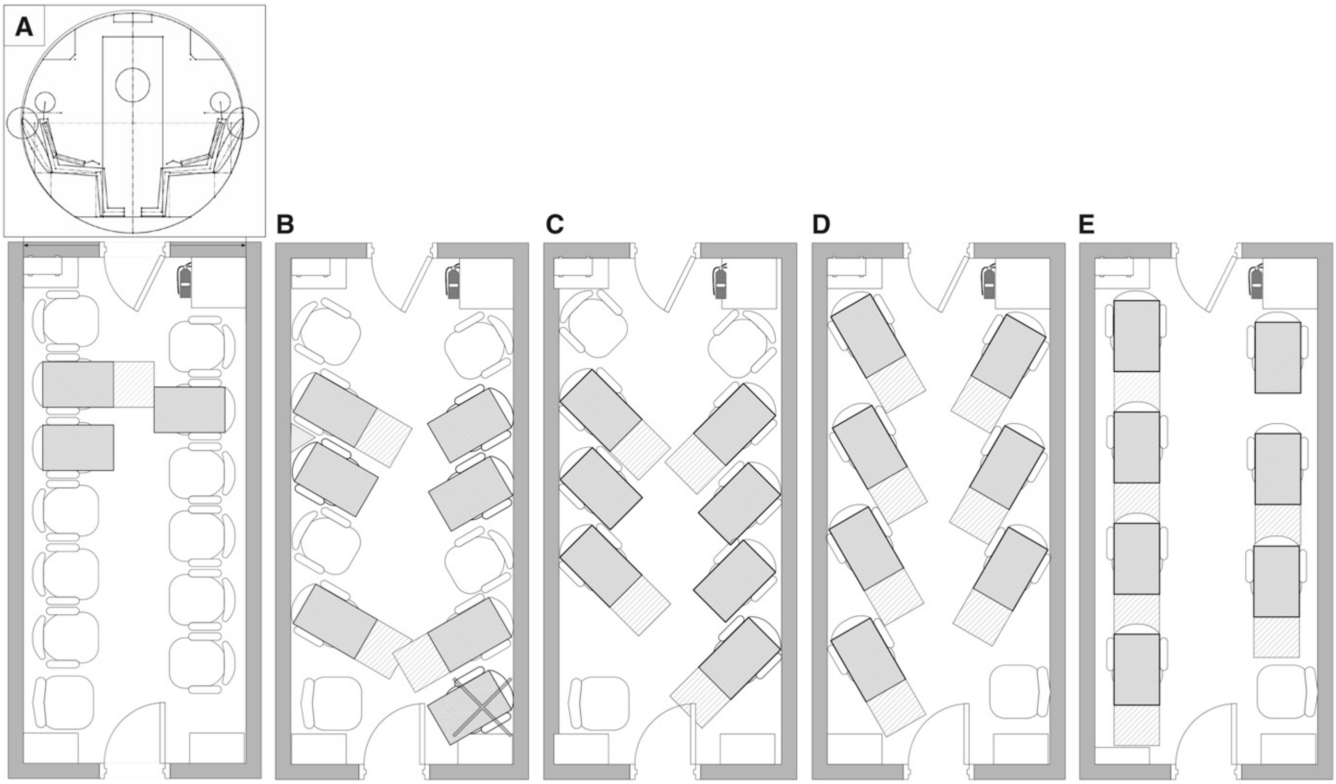

Fig. 3. Typical seating configurations in a cylindrical hyperbaric chamber (cross-section of the chamber - upper figure). A) Current situation of seats arranged side by side; seat deviations at B) 30°, C) 45°, D) 60°, and E) 90°. Gray area denotes the comfort zone for a patient; light gray stripes denote the area for leg stretching.

Conclusions

Hyperbaric oxygen therapy is a well-established therapeutic field with defined indications for treatment, yet it still maintains the spirit and nature of the diving community. The medical hyperbaric community is composed of several clinical specialties, sharing the rationale of using hyperbaric oxygen, similar to using any other drug treatment, without the patients being divers or sea lovers. It is, therefore, time that hyperbaric chambers detach themselves from the visual image of hyperbaric deep-water diving and underwater missions, and integrate with the façade of healthcare facilities and specialties such as plastic surgery, ENT, neurology, dermatology, and more.

Therapeutic hyperbaric chambers should be comfortable, friendly for patients, and serve as a natural extension of the hospital's clinical environment. Close collaboration between engineers, architects, designers, psychologists, and material engineers is needed to produce a novel concept of hyperbaric therapeutic facilities integrated with the healthcare domain, yet taking into consideration the special constraints of the hyperbaric milieu. Special care should be given to following safety regulations in selecting materials and equipment for the hyperbaric chamber, checking specifically with safety regulation sources.[5,13,44] Moreover, based on the current concept of 'personalized medicine,' it is suggested to design small tailored 'personalized hyperbaric chambers' of different configurations as adjuvant therapy for diverse hospital wards and clinics to accommodate a diversity of patients and indications.

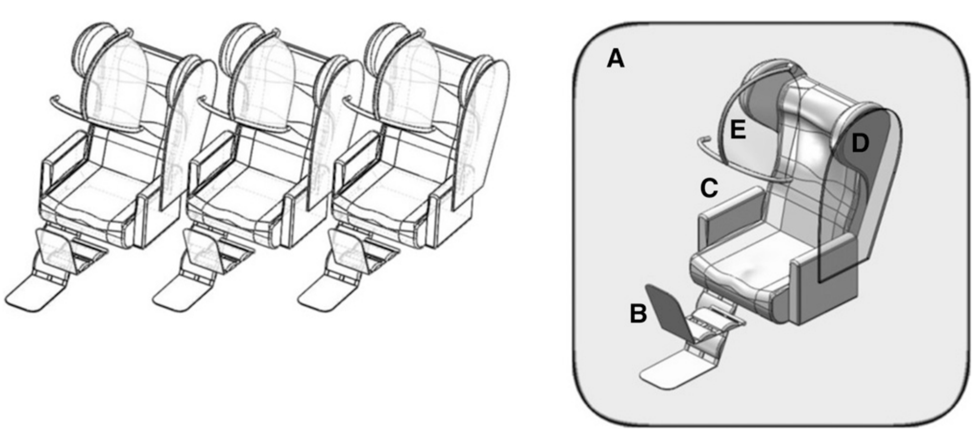

Fig. 4. A design concept for an improved chair: A) ergonomic chair; B) individual support for each leg separately; C) personal armrest; D) personal headrest and divider; and E) plastic transparent shield.

Changing the morphology, materials, and visual image of hyperbaric chambers and their internal design and adopting a user-centered design will hopefully place HBO as an equal subspecialty to others, increase the popularity of this field, and improve patient satisfaction and overall "user experience." Some of these suggestions could be applicable and adapted to other confined environments.

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REFERENCES

1. Allen KD, Danforth JS, Drabman RS. Videotaped modeling and film distraction for fear reduction in adults undergoing hyperbaric oxygen therapy. J Consult Clin Psychol. 1989; 57(4):554–558.
2. Alvarsson JJ, Wiens S, Nilsson ME. Stress recovery during exposure to nature sound and environmental noise. Int J Environ Res Public Health. 2010; 7(3):1036–1046.
3. Balogh A. "Concrete handles the pressure." 1996; [Accessed 2015 Nov 20.] Available from http://www.concreteconstruction.net/Images/Concrete%20Handles%20the%20Pressure_tcm45-343150.pdf.
4. Bouchard L. Patients' satisfaction with the physical environment of an oncology clinic. J Psychosoc Oncol. 1993; 11(1):55–67.
5. Broome J, Colvin AP, Welham JA, Watt S, Gough-Allen R, et al. Health & safety for therapeutic hyperbaric facilities: a code of practice. Norwich (UK): The British Hyperbaric Association; 2000. [Accessed 2015 Nov 20.] Available from http://www.ukhyperbaric.com/documents%5Chealthsafetyfortherapeutichyperbaricfacilities.pdf.
6. Chalmers A, Mitchell C, Rosenthal M, Elliott D. An exploration of patients' memories and experiences of hyperbaric oxygen therapy in a multiplace chamber. J Clin Nurs. 2007; 16(8):1454–1459.
7. Clark C, Rock D, Tackett K. Assessment of the magnitude of anxiety in adults undergoing first oxygen treatment in a hyperbaric chamber. Mil Med. 1994; 159(5):412–415.
8. Davis JC, Dunn JM, Hagood CO, Bassett BE. Hyperbaric medicine in the U.S. Air Force. JAMA. 1973; 224(2):205–209.
9. Diette GB, Lechtzin N, Haponik E, Devrotes A, Rubin HR. Distraction therapy with nature sights and sounds reduces pain during flexible bronchoscopy: a complementary approach to routine analgesia. Chest. 2003; 123:941–948.
10. Dilani A. Psychosocially supportive design: a salutogenic approach to the design of the physical environment. Design and Health Scientific Review. 2008; 1(2):47–55.
11. Edmonds JC, Yang H, King TS, Sawyer DA, Rizzo A, Sawyer AM. Claustrophobic tendencies and continuous positive airway pressure therapy non-adherence in adults with obstructive sleep apnea. Heart Lung. 2015; 44(2):100–106.
12. Ellis ME, Mandal BK. Hyperbaric oxygen treatment; 10 years' experience of regional infectious diseases unit. J Infect. 1983; 6(1): 17–28.
13. European Code of Good Practice for Hyperbaric Oxygen Therapy. [Accessed 2015 Nov 20.] Available from http://www.echm.org/documents/ECGP%20for%20HBO%20-%20May%202004.pdf.
14. Gill AL, Bell CN. Hyperbaric oxygen: its users, mechanisms of action and outcomes. QJM. 2004; 97(7):385–395.
15. Gilbert AN. What the nose knows: the science of scent in everyday life. New York: Crown Publishers; 2008.
16. Goel N, Grasso DJ. Olfactory discrimination and transient mood change in young men and women: variation by season, mood state, and time of day. Chronobiol Int. 2004; 21(4-5):691–719.
17. Guo S, Counte MA, Romeis JC. Hyperbaric oxygen technology: an overview of its applications, efficacy, and cost-effectiveness. Int J Technol Assess Health Care. 2003; 19(2):339–46.
18. Hart GB. The monoplace chamber. In: Kindwall EP, Whelan HT, editors. Hyperbaric medicine practice, 2nd ed. North Palm Beach (FL): Best Publishing Company; 1999:99–126.
19. Haux GFK. History of hyperbaric chambers. North Palm Beach (FL): Best Publishing Company; 2000.
20. Herz RS. Aromatherapy facts and fictions: a scientific analysis of olfactory effects on mood, physiology and behavior. Int J Neurosci. 2009; 119: 263–290.
21. Hoffman HG, Chambers GT, Meyer WJ III, Arceneaux LL, Russell WJ, et al. Virtual reality as an adjunctive non-pharmacologic analgesic for acute burn pain during medical procedures. Ann Behav Med. 2011; 41(2):183–191.
22. Kindwall EP, Whelan HT. Hyperbaric medicine practice. North Palm Beach (FL): Best Publishing Company; 1994.
23. Kindwall EP. The multiplace chamber. In: Kindwall EP, Whelan HT, editors. Hyperbaric medicine practice, 2nd ed. North Palm Beach (FL): Best Publishing Company; 1999:127–142.
24. Kot J, Desola J, Simao AG, Gough-Allen R, Houman R, et al. A European code of good practice for hyperbaric oxygen therapy. Int Marit Health. 2004; 55(1-4):121–130.
25. Leach RM, Rees PJ, Wilmshurst P. ABC of oxygen: hyperbaric oxygen therapy. BMJ: British Medical Journal. 1998; 317(7166): 1140–1143.
26. Leifer G. Hyperbaric oxygen therapy: pre-and posttreatment nursing responsibilities every staff nurse needs to know about. AJN The American Journal of Nursing. 2001; 101(8):26–34.
27. Lindstrom M. Broad sensory branding. Journal of Product & Brand Management. 2005; 14(2):84–87.
28. Lobel T. Sensation: the new science of physical intelligence. New York: Simon and Schuster; 2014.
29. Lundstrom JN, Hummel T. Sex-specific hemispheric differences in cortical activation to a bimodal odor. Behav Brain Res. 2006; 166(2): 197–203.
30. Maison JR. Feasibility of rectangular concrete pressure vessels for human occupancy. San Antonio (TX): Adaptive Computer Technology Inc.; 1990.
31. Malenbaum S, Keefe FJ, Williams ACDC, Ulrich R, Somers TJ. Pain in its environmental context: implications for designing environments to enhance pain control. Pain. 2008; 134(3):241–244.
32. Marchand S, Arsenault P. Odors modulate pain perception: a gender-specific effect. Physiol Behav. 2002; 76:251–256.
33. McQuaid M. Extreme textiles: designing for high performance. New York: Princeton Architectural Press; 2005.
34. Sarter NB. Multimodal information presentation: design guidance and research challenges. Int J Ind Ergon. 2006; 36(5):439–445.
35. Schifferstein HNJ, Desmet PMA. The effects of sensory impairments on product experience and personal wellbeing. Ergonomics. 2007; 50(12): 2026–2048.
36. Schweitzer M, Gilpin L, Frampton S. Healing spaces: elements of environmental design that make an impact on health. J Altern Complement Med. 2004; 10(Suppl. 1):S71-S83.
37. Sky factory. [Accessed 2015 Nov. 20]. Available from http://www.skyfactory.com/.
38. Tilley AR. The measure of man and woman; human factors in design. New York: Wiley; 2013.
39. Ulrich RS. View through a window may influence recovery from surgery. Science. 1984; 224(4647):420-421.
40. Ulrich RS. How design impacts wellness. Healthc Forum J. 1992; 35(5):20–25.

41. Ulrich RS, Zimring C, Zhu X, DuBose J, Seo HB, et al. A review of the research literature on evidence-based healthcare design. HERD: Health Environments Research & Design Journal. 2008; 1(3): 61–125.
42. Weaver LK. Hyperbaric oxygen in the critically ill. Crit Care Med. 2011; 39(7):1784–1791.
43. Weaver LK, editor. Hyperbaric oxygen therapy indications, 13th ed. The Undersea and Hyperbaric Medical Society Hyperbaric Oxygen Therapy Committee Report. North Palm Beach (FL): Best Publishing Company; 2014.
44. Workman WT, editor. Hyperbaric facility safety: a practical guide. Flagstaff (AZ): Best Publishing; 2000.
45. Workman WT, Butler WP. Concrete hyperbaric chambers. Brooks AFB (TX): USAF Hyperbaric Newsletter; January 1997:3.
46. Workman WT. What does the future design of clinical hyperbaric chambers look like? In: Haux GFK, editor. History of hyperbaric chambers. North Palm Beach (FL): Best Publishing Company; 2000:117–130.
47. Yildirim K, Hidayetoglu ML, Capanoglu A. Effects of interior colors on mood and preference: comparisons of two living rooms 1, 2. Percept Mot Skills. 2011; 112(2):509–524.