WCHM

WOUND CARE AND HYPERBARIC MEDICINE

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INSIDE THIS ISSUE

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CONTENTS

WCHM
WOUND CARE AND HYPERBARIC MEDICINE

EDITORIAL STAFF
Best Publishing Company
Jaclyn Mackey, Publisher
jmackey@bestpub.com

MAGAZINE PRODUCTION
Lorraine Fico-White
lorraine@bestpub.com
Diana Robinson
diana@bestpub.com

ADVERTISING/SPONSORSHIPS
info@bestpub.com

LETTERS
Send your questions, comments, suggestions, news, or information to *info@bestpub.com*

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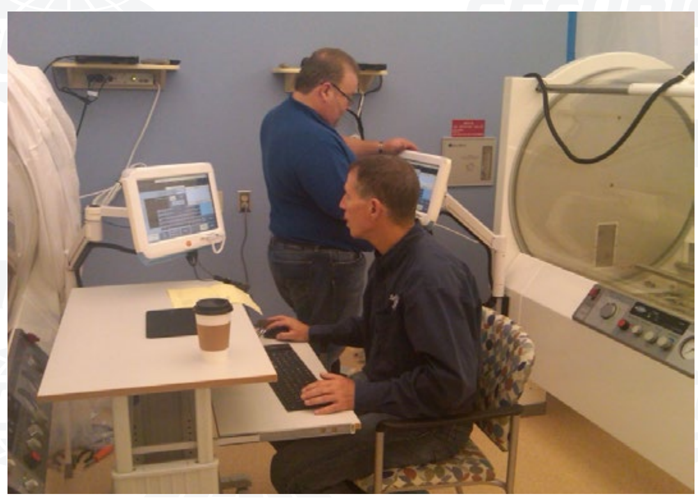

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NOTE FROM THE EDITOR

As *WCHM* begins its eighth year of publication, we would like to extend a special thank you to our elite sponsor Matrix as the company goes on sabbatical. Matrix has provided peace of mind to ensure success for wound-care programs since 2003. You will find a special tribute to Matrix and its founders in this issue.

The hyperbaric medicine section of *WCHM* includes the following:

- discussion by Laura Josefsen and Janet Bellow concerning the advantages of having nurses in hyperbaric facilities
- press release from UHMS as it welcomes Italian Medical Society SIMSI as an affiliate
- case study by Dr. Joseph White on carbon monoxide poisoning and the issues surrounding it
- synopsis of the fourth edition of *Hyperbaric Medicine Practice*, to be published in 2017

Darren Mazza returns to discuss privacy issues for hyperbaric patients in the safety section of *WCHM*. This month *WCHM* brings back its popular diving medicine section with an article by Dr. Strauss and Lientru Lu titled "The Younger-Aged Diver: Thriving in the aquatic environment."

The wound-care section of *WCHM* includes the following:

- part 4(a) of 5 in Diabetic Wound Prevention Series by Dr. Michael Strauss, Anna Tan, and Lientra Lu discussing protective footwear in depth
- chapter excerpt written by Dr. Bert Slade from the upcoming *Textbook of Chronic Wound Care: An Evidence-Based Approach to Diagnosis and Treatment* by Drs. Jayesh Shah, Paul Sheffield and Caroline Fife.

If you've ever wanted to get an article you authored published to an audience of thousands of wound-care and hyperbaric medicine practitioners, 2017 is the year for you to make this happen. Please submit your articles to info@bestpub.com or call 561.776.6066. We also invite you to join our elite group of *WCHM* advertisers and reach your target audience.

We look forward to hearing from you.

Lorraine Fico-White
Managing Editor, *WCHM*

The Advantage to Having Registered Nurses in Hyperbaric Facilities

By Janet Bello, RN, ACHRN, and Laura Josefsen, RN, ACHRN

The clinical world of hyperbaric medicine is truly a team concept with each member (physicians, nurses, and technicians) bringing the best of each respective scope of practice. The Undersea and Hyperbaric Medical Society (UHMS) accreditation process utilizes physicians, registered nurses (CHRNs) and technicians (CHTs) to evaluate hyperbaric facilities as each professional brings his or her own perspective to the comprehensive care that patients receive.

The specialty of nursing is a multifunctional part in the medical model. Nursing is the profession representing patient rights. According to the American Nurses Association, "Nurses use theoretical and evidence-based knowledge of human experiences and responses to collaborate with health-care consumers to assess, diagnose, and identify outcomes, and plan, implement, and evaluate care."[1]

WOUND CARE CERTIFICATION STUDY GUIDE
SECOND EDITION

DR. JAYESH SHAH, in partnership with **DR. PAUL SHEFFIELD** of International ATMO and **DR. CAROLINE FIFE** of Intellicure, has created the perfect tool for anyone studying to take a wound certification exam — AAWM, APWCA, CWCN, NAWC, and more.

Now in its second edition, the *Wound Care Certification Study Guide* is fully updated with the latest clinical practices and regulatory and reimbursement information. Drs. Shah, Sheffield, and Fife, along with numerous contributing authors who are considered experts in the field of wound care, have collaborated to create the best possible study resource for these important examinations. The content focuses on key information that wound care certifying agencies consider important in their examinations, with self-assessment questions at the conclusion of each chapter to help participants identify areas of comprehension and concepts that require further study.

This all-inclusive study guide includes:

- Thirty-three informative chapters that review the core principles candidates need to know to obtain wound care certification
- New chapter on hyperbaric oxygen therapy by Yvette Hall, Patricia Rios, and Jay Shah
- Added section on PQRS and quality reporting by Dr. Caroline Fife
- A full-length post-course exam complete with answers and explanations
- Comprehension questions with detailed answers at the end of each chapter
- More than 200 color photos, tables, and diagrams
- Clinical pathways with best practice recommendations for the practitioner
- New chapter on hyperbaric oxygen therapy and added section on PQRS and quality reporting
- Guidance on how to choose the certification

"It was my pleasure to review the second edition of the Wound Care Certification Guide. I found the chapters to be well written and organized, building upon the science of wound healing while including practical clinical applications and sample questions. This text should be useful to all wound care professionals, including the novice and expert alike. It will certainly be an important adjunct for anyone preparing for board examinations."

— Robert J. Snyder, DPM, MSc, CWS; Professor and Director of Clinical Research, Barry University SPM; Past President, Association for the Advancement of Wound Care; Past President, American Board of Wound Management

"The manuscript is the result of a monumental amount of work. I congratulate all involved."

— Terry Treadwell, MD, FACS; Medical Director, Institute for Advanced Wound Care

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"Nurses provide management for quality improvement, documentation, infection control, patient education, and intervention as well as initial and ongoing nursing assessment of patient care," notes HG Vincent in *Hyperbaric Nursing*.[2,3]

The perception is that the quality of documentation equates to the quality of care. Documentation is an essential aspect of the nursing process, which includes chart reviews for accurate, comprehensive charting to meet regulatory and reimbursement guidelines for patient care, patient safety, and billing/reimbursement.[4]

Patients receiving hyperbaric oxygen treatments benefit from having the hyperbaric-trained RNs as part of their initial and ongoing nursing evaluations. The trained hyperbaric nurse uses critical thinking skills in the areas of quality improvement by gathering, assessing and evaluating data for patients going into the altered environment of 100% oxygen under increased atmospheric pressure. This data includes the following:

- physical and psychosocial assessments, patient attitude
- education, how patients learn, barriers to learning
- patient compliance, ability to deal with health-care issues
- baseline functional status, social environment, cultural environment, emotional states, and safety issues to identify initial and ongoing nursing interventions and revisions[2,3]

To further assess the potential for patient issues going into the hyperbaric chamber, including the goal/rationale and actions for each issue, the Baromedical Nurses Association (BNA) Guidelines for Standard of Care for the Patient Receiving Oxygen Therapy (HBO_2) are available on the BNA website at *hyperbaricnurses.org/about-us/standards-of-care/*. ■

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2. Vincent HG. Documentation. In: Larson-Lohr V, Norvell H, eds. Hyperbaric Nursing. Flagstaff, AZ: Best Publishing Company; 2002. p. 5-78.
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About the Authors

JANET H. BELLO, RN, BSN, ACHRN, is an independent consultant for hyperbaric medicine. As an Associate member of the Undersea and Hyperbaric Medical Society (UHMS), she serves as secretary for the Associates Council, is a nursing representative on the UHMS Accreditation Council, a nurse surveyor for the UHMS Accreditation Team and on the Membership Committee. Janet has also served as an officer and board member for the UHMS NE Chapter and the Baromedical Nurses Association. Her past experience includes hyperbaric programs supervisor for the Wound Recovery and Hyperbaric Medicine Center at Kent Hospital in Warwick, RI, and program manager for Praxis Clinical Services at Our Lady of Fatima Hospital, Hyperbaric Medicine Unit, in North Providence, RI. Both facilities provide hyperbaric emergency and critical care 24/7 for patients in monoplace chambers. Other nursing experience includes critical care and cardiovascular services, critical care educator and clinical manager for cardiovascular stepdown units at Piedmont Hospital in Atlanta, GA. She is licensed in the Commonwealth of Massachusetts. She received her bachelor of science degree in nursing at the University of Virginia.

LAURA JOSEFSEN, RN, ACHRN, has been involved in hyperbaric nursing since 1982. A founding member of the Baromedical Nurses Association (BNA) in 1985, she served as BNA president from 1996 to 1998 and as a board member in several positions throughout the years. She served on the Undersea and Hyperbaric Medical Society (UHMS) Associates Council for six years, with two of those years as Nurse Representative on the UHMS Board of Directors. She has been a member of the UHMS Accreditation Team as a nurse surveyor, served for many years as an executive board member of the National Board of Diving and Hyperbaric Medical Technology and is a previous chairman of the BNA Certification Board. She is a member of the UHMS Associates, former member of Divers Alert Network, and former member of the Hyperbaric Technologists and Nurses Association (HTNA) of Australia. She has numerous publications and is an internationally recognized speaker in the field of hyperbaric medicine. Her passions are quality improvement and education to promote hyperbaric nursing, safety, and optimal standards of care and practice for patients and the community.

Thank You, MATRIX

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WCHM magazine would like to thank our long-term sponsor MATRIX, who has provided peace of mind to ensure success for wound-care programs around the country.

Mary Hirsch and Becky Evenson started the company in 2003 with the goal to be an advocate for hospital partners who wanted to develop comprehensive outpatient wound-care centers. Over the years, MATRIX worked with multiple facilities in various capacities, from consulting to complete management.

Mary Hirsch and Becky Evenson

In June 2015, Becky took over management of the company, and Mary remained on as a consultant. Becky is currently putting the company on "sabbatical" due to health issues.

"Matrix has been privileged to work with some amazing administrators, clinicians and physicians over the years and developed programs that have provided exceptional care to wound care and hyperbaric patients. We have been active in UHMS committees including UHMS surveyors, education committee, and accreditation counsel and also have held board positions on the BNA. We have also been chapter organizers and board members of Save a Leg, Save a Life, have lectured around the country and have educated many through our comprehensive introductory hyperbaric and wound-care course."

UHMS Welcomes Italian Medical Society SIMSI as Affiliate

By Renée Duncan, Communications Coordinator,
Undersea and Hyperbaric Medical Society

The Italian Diving and Hyperbaric Medicine Society, Società Italiana di Medicina Subacquea e Iperbarica (SIMSI), has joined the Undersea and Hyperbaric Medical Society (UHMS) as an affiliate organization.

Founded in 1997, SIMSI is affiliated with the European Underwater and Baromedical Society (EUBS). Its mission is to be the "beating heart" of knowledge for diving and hyperbaric medicine in Italy.

"Our founding principles are based on respect for the culture of the Society and for the stakeholders — the institutions, physicians, patients and divers — associated with it," noted Pasquale Longobardi, MD, SIMSI president.

SIMSI advocates authenticity, truth in every action, behavior and information, with the passion to be the leading and authoritative reference in the field. Its motto is "Oxygen is Energy, Water is Life: SIMSI O_2 and Water 4U."

SIMSI activities for 2017 include the following:

- organization and participation in several events: 25th European Diving Show (EUDI), *http://www.eudishow.eu/site/en/*; SIMSI in Tours (five workshops for the dissemination of the message "Look Good, Dive Better"); International Meetings on HBO_2 therapy (Salsomaggiore-Parma, May 5-7) and on technical diving (Ponza Island, May 4-7); SIMSI Convention 2017, a dive cruise in Maldives, (August 3-11); EUBS Annual Meeting in Ravenna (September 12-17)
- participation in legislative initiatives; Health Ministry accreditation of the SIMSI guidelines for the appropriate HBO_2 therapy indications
- training: Medical Examiner of Diver (MED) course DMAC / EDTCmed Level 1, which enables registration in the European Diving Medicine Databank, *http://www.edmd.eu/*; wound care related to HBO_2 therapy patients

"SIMSI is devoted to implementing connections with associations, sister scientific societies, universities, research institutes, promoting the scientific publication in peer-reviewed journals, updating on a regular basis information on the website (*www.simsi.it*) and publishing its bulletin, three times a year," Longobardi said. "SIMSI is very proud to join the UHMS International Affiliate Program thanks to the valuable efforts of UHMS Vice President Professor Gerardo Bosco. It is an opportunity for a global collaboration in diving and hyperbaric medicine aiming to harmonize, together with other countries, the standard of care for the approved indications of HBO_2 therapy and the diving medicine procedures as well as the education and training of doctors and associated baromedical professionals.

"Italy has a long tradition in this field and many talented experts. SIMSI will surely contribute to the success of several UHMS initiatives," Longobardi concluded.

All approved Affiliate society members receive a 50% discount on UHMS dues while retaining full privileges within the Society.

Please contact John Peters for specific information.

For more information about the UHMS Affiliate program, write to UHMS Executive Director John Peters at *jpeters@uhms.org* or call toll-free 877-533-8467 (UHMS) ext. 100. ■

CO: It's Not Just About the Gas

By Joseph C. White, MD

The Hyperbaric Oxygen Therapy Unit at John T. Mather Memorial Hospital in Port Jefferson, NY, is one of the few units still providing 24/7 care. It has effectively dealt with many dramatic situations. To illustrate the ongoing issues surrounding carbon monoxide (CO) as well as the global issues it raises, I present here a case of CO poisoning the unit encountered.

Six people with potential CO poisoning were transported to the Mather Hospital emergency room (ER) and its 24/7 hyperbaric unit. A power outage had been reported secondary to weather conditions, so the victims had borrowed a generator from a friend.

They were aware of the potential dangers of CO, so to mitigate the issue, they left open the windows in the house but made the mistake of putting the generator in the basement.

Despite their precautions, one victim was awoken when she heard her husband moaning in his sleep. Immediately upon waking, she had a tremendous headache and realized the problem could be CO. She had difficulty arousing her husband but was finally able to get him up. He also had a tremendous headache as well as dizziness and confusion.

She was also able to wake her two children, two other family members in different areas of the house, and call 911.

The victims were transported on 100% oxygen to the ER, where three adults had levels between 20 and 28, the children (ages 5 and 10) had levels of 9 and 12, while the fourth adult had a level of 11.

After evaluation, three of the four adults were offered hyperbaric oxygen (HBO) treatment on Dr. Lindell Weaver's protocol. The fourth adult, who had the level of 11, had a significant heart issue with an ejection fraction of 20% and had been on a life vest. Our hyperbaric cardiologist's evaluation recommended he not be put into the chamber but to remain on 100% oxygen. One child refused to stay in the chamber.

All patients were doing better after treatment, but they declined completion of the Weaver protocol.

I will discuss a few of the issues this case of CO highlights.

First, no matter how you try to mitigate it, machinery that can produce CO, a generator in this case, should not operate in an inhabited space. It is difficult to track the path of air currents throughout the space, and the locations of the victims during the intoxication can cause a significant variation in both CO levels as well as resultant symptoms.

These patients actually knew CO could cause harm and left all the windows open, believing it would prevent the problem. Consider what the results might have been if they had closed the fresh-air source.

A second point is the need for CO detectors. Despite all the information about CO, there are still many homes and other inhabited spaces, including work areas, that go without detectors. Our patients had detectors but had removed them and placed them in the moving van on the driveway since they were relocating in a few days. Continued education and legal requirements remain the mainstays of evoking the change needed for CO monitoring.

An issue we have experienced is the resistance of patients to accept a three-course HBO treatment protocol despite a maximal educational effort by the HBO staff, focusing on the possible long-term sequelae CO may cause.

Those reading this magazine are probably already woefully aware of the issue regarding the availability of acute hyperbaric access as discussed in this case and raised in the article "Emergency and Critical Care Hyperbaric Medicine in the United States" by Enoch Huang, MD, in the Fall 2016 issue of *WCHM*. Thankfully, 22 years ago our hospital agreed to establish a hyperbaric program,

> "There is, in my opinion, an absolute need for access to immediate HBOT for certain medical issues such as dive injuries, gas gangrene, certain CO accidents, some necrotizing infections and some acute ischemic perfusions cases. If the exodus continues, there will be even less opportunity to treat these patients."

which has served our community with 24/7 coverage since its inception.

There has been a massive exodus of 24/7 hyperbaric units in the country for various reasons, but I would postulate a lot of it is directly related to the cost of maintaining a unit, staffing and lack of appropriate insurance reimbursement. There is, in my opinion, an absolute need for access to immediate HBOT for certain medical issues such as dive injuries, gas gangrene, certain CO accidents, some necrotizing infections and some acute ischemic perfusions cases. If the exodus continues, there will be even less opportunity to treat these patients.

If indeed there is a difference between levels of hyperbaric unit care (levels 1–3), cost is probably the overwhelming factor leading to closure of 24/7 units, and then the payers should reimburse on standards based on these levels. Perhaps if this occurred, it would encourage centers to remain available, and others who are considering initiating a program may opt into a more encompassing level of service.

The constant battle that occurs between providers and payers continually grows. Part of the responsibility, in my opinion, belongs to the hyperbaric community. There have been many hyperbaric treatments and reports of units that will treat disease processes not amenable to hyperbaric treatments and bill erroneous codes. This can lead to such scrutiny that it becomes very difficult to get payment for appropriate HBO care.

I am sorry to say that after 22 years and more than 35,000 treatments, even our unit is struggling with the concept of changing to a 9-to-5 outpatient radiation and wound-care only facility. That will leave our county without any HBO 24/7 unit, and any acute HBO case will now have to travel about 20-50 miles to get to one. In other areas of the country, patients need to travel hundreds of miles, which in many cases can lead to no access to HBO treatments.

The hyperbaric medical communities have been championing the need to keep these important centers and chambers viable, but it is a relatively small community of providers. Until there is a strong medical, patient and politically supported movement to halt the loss, we will soon cease to exist in any meaningful quantity. Some will argue we are there already.

I strongly encourage everyone to bring this issue to the forefront to those who can help ensure the viability of hyperbaric medicine in our country. ■

About the Author

JOSEPH C. WHITE, MD, is director and cofounder of the Hyperbaric Medicine Unit at John T. Mather Memorial Hospital in Port Jefferson, NY. A graduate of the Georgetown School of Medicine, he has been practicing hyperbaric medicine since 1994. He is UHMS board certified and is board certified and a Fellow in the American Academy of Family Physicians (AAFP), practicing family practice for more than 30 years. He oversees a three-chamber monoplace unit at Mather Memorial and was involved in assisting with dive and identification operations during the 1996 TWA Flight 800 incident in New York. He coauthored an article related to thermal decompression stresses in heated dive suits from that operation.

What We Can Expect from *Hyperbaric Medicine Practice*, 4th Edition

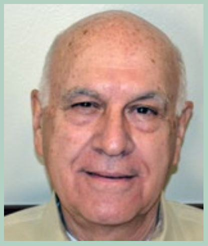
By Henry J.C. Schwartz, MD, FACP

A textbook may sometimes gain the unusual trait of longevity beyond all other books — it can be revised and remain a primary source of information for generations of students. *Hyperbaric Medicine Practice* by Eric P. Kindwall seems destined to become such a book. The 4th edition, to be published by Best Publishing Company in 2017, is edited by Harry T. Whelan et al. and pays tribute to its original author, Dr. Kindwall, who died in 2012. It also adds new information of interest to all in the field of in-water diving and clinical hyperbaric medicine.

Most chapters have been written or revised by new authors, and several have the same author or authors but are updated. New chapters include indications for hyperbaric oxygen treatment subjects recently approved for treatment such as idiopathic sudden sensorineural hearing loss and central retinal vein occlusion. There are also chapters dealing with submarine rescue and problems that pertain to technical and rebreather diving. A chapter supporting the use of a ketogenic diet to reduce the risk of central nervous system oxygen toxicity is supported by considerable technical data but will likely elicit discussion among the scientific community until this modality is backed by human evidence of effectiveness.

Several chapters in the 3rd edition do not appear in this one. These chapters include physics of diving and hyperbaric pressure; hyperbaric oxygen therapy and the quality payment system; sternal wound infection, dehiscence, and sternal osteomyelitis; ileus associated with abdominal surgery and acute myocardial infarction in animals and man. The omission of chapters dealing with payments and regulations recognize that these issues do not belong in medical textbooks. The other deletions reflect the minimal value and lack of effectiveness of hyperbaric oxygen therapy in those conditions or are more appropriately addressed elsewhere. ■

About the Author



HENRY J.C. SCHWARTZ, MD, FACP, is retired from the US Navy as a captain in the Medical Corps. He received a bachelor of science degree in zoology and his MD from the University of Wisconsin-Madison. After interning at the Philadelphia General Hospital, he entered the US Navy, where he served for a total of 25 years and also had a private practice of internal medicine in between navy stints. After retiring from the Navy, he was a physician at the Hyperbaric Treatment Center at the John A. Burns School of Medicine of the University of Hawaii, where he was also appointed as an associate clinical professor. He is board certified in internal medicine and in undersea and hyperbaric medicine. He is a private pilot, a navy saturation diving medical officer and is qualified in submarines.

Protecting Patient Privacy

By Darren Mazza EMT, CHT

While trying to provide good patient care, the clinical environment can be chaotic at times due to time constraints. Many patients treated in the hyperbaric department are also treated in the wound center, requiring collaborative efforts between both departments.

With the Health Insurance Portability and Accountability Act of 1996 (HIPAA), providing patient privacy is not only the law but is also sometimes difficult to ensure in the monoplace environment. Although my department has two patient-changing rooms and several privacy curtains, including a curtain between both chambers, patients occasionally pass each other when either coming from the changing room, to and from the bathroom, or entering or leaving the department. Occasionally, patients will speak to each other in passing and will share both their medical and treatment information with one another.

Hyperbaric patients receive daily treatments, and because of this we, as certified hyperbaric technologists (CHTs), spend a great deal of time with them. We develop a comfort zone and a friendship with each patient. This is good because sometimes patients seek comfort from those they trust. We value and respect each patient's right to privacy. I want patients to have trust and confidence not only in my competencies relating to the job but also that they can depend on me to protect their privacy during their treatments.

On one occasion, the biomedical tech came into the chamber room to speak with me regarding a problem with one of the chambers, but I was prepping a patient for treatment. The biomed tech attempted to come through the privacy curtain, but I quickly stopped him. Although a patient seems amiable with other staff members coming in, it's not OK.

On another occasion, an employee from another department in the hospital came in to speak with me, and the patient was clearly uncomfortable. So I now make every effort to obtain patient permission before introducing them to another staff member. I myself have been hospitalized and can recall how compromised I felt. As a patient, you tend to feel at the mercy of those around you. Having to wear a hospital gown makes one feel compromised and vulnerable. It's absolutely crucial for the CHT to recognize when this occurs and to do everything possible to prevent it through protecting the patient's privacy.

Take home message: Stay vigilant in your efforts to ensure patient privacy at all times. A good CHT first needs to be a good patient-care provider, one who makes it a priority to protect and maintain patient privacy. ■

About the Author

DARREN MAZZA has been the CHT and safety director at the Center for Wound Healing and Hyperbarics at Swedish Edmonds in Washington since 2008. He began his health-care career working as both an EMT and an emergency room preceptor in Sacramento, California. In 2005, he moved his family to Idaho, where he was department head of the hospital's outpatient wound-care and hyperbaric center. With more than 28 years in health care, he has been able to apply his past to his current role in the hyperbaric industry, making him a more responsible CHT and safety director.

The Younger-Aged Diver

Thriving in the aquatic environment

By Lientra Q. Lu, BS, and Michael B. Strauss, MD

Diving in the younger age group is a gray area, especially with respect to scuba diving. Little data exist, and most information deals with divers in their teens. Diving activities can range from swimming/snorkeling on the surface, to breath-hold diving, to scuba diving. There are many anecdotal reports of divers who have not yet attained adulthood who scuba dive successfully. No studies exist on this subject, however, and all the recommendations seem to be opinions with little scientific basis.[1-4]

There are many challenges in diving — physical, physiological and psychological — that need to be considered when making decisions about diving in the younger age groups. Water skills are another essential criterion for safe and enjoyable diving, and, of course, these apply to adults as well as youthful divers. Age is also an important consideration. Diving activities that may be appropriate for the late teenager may be inappropriate for younger-aged divers. We will discuss these subjects and provide recommendations for "safe and sane" diving in the youthful population based on physical, physiological and psychological considerations.

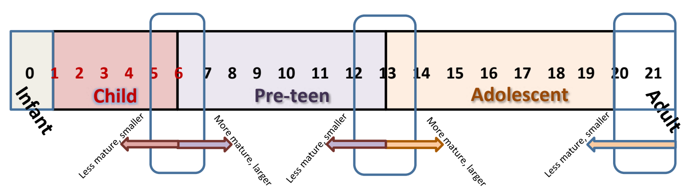
Age Considerations

Age is a crucial variable for making appropriate recommendations for diving in the youthful population. The activity level applied to a teenager would likely be inappropriate for the child. For classification purposes, we divide the youthful diver into three age categories (Figure 1): childhood, ages 1-5; preteen, ages 6-12; and adolescence, ages 13-19. Remember age is relative and reflects a continuum of growth and maturation.

Age considerations are arbitrary. Chronological age must be paired with physiological age, which is the age physical and cognitive functions are equivalent to populations of different ages. At the transition points, the youth may be on either side of the specified ages we suggest. Many milestones exist for chronological ages, some absolute, others relative (Figure 2).

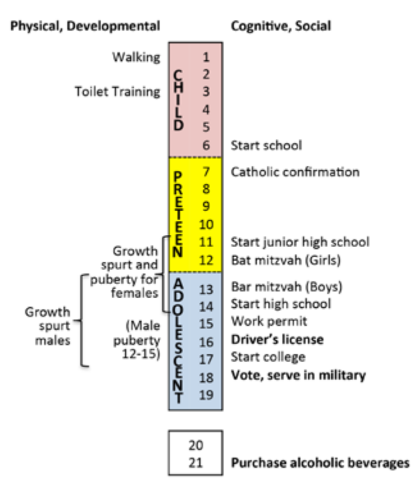
> Age considerations in diving are arbitrary, albeit they were more conservative in the past. In 1999, with the intention of promoting diving as a sport to a larger audience, the World Recreational Scuba Training Council, whose main purpose was to create a standardized recreational diving guideline, removed its recommendation that one should be at least 15 years old before seeking junior-level certification.[5] Without age-limit restrictions, several major training agencies began developing their own age-specific programs for children as young as 10 years old.

FIGURE 1. The continuation of age considerations in youth



Legend: Chronological age groupings are used to categorize growing older in youth. The groupings are arbitrary, and at the transitions the physiological age — i.e., what activities a person of a corresponding age would be doing better— define the category. For diving, physiological age is a better criterion than chronological age for making decisions as to what type a young diver should do. Maturation and size are criteria that can help ascertain physiological age.

FIGURE 2. Chronological milestones



For each age category, we offer specific recommendations for diving activities, as we will show later in this article.

Water Skills

This term is laden with emotional connotations. One can imagine a parent boasting about their 1-year-old child being able to swim the width of a backyard pool. While a notable accomplishment, it does not equate to water safeness. Imagine what would happen if the child fell into the pool clothed; undoubtedly, he/she would require rescue. Likewise, for a grandparent bragging about their 10-year-old grandchild being able to swim a mile in a swimming pool. These conditions are far different from swimming in open water without walls for turns every 25 yards, currents and swells. Water safeness needs to be paired with age and situations (Table 1). For the child, we suggest that being able to swim easily 100 yards or more at a slow rate with swim gear or come to the surface and remain in place for five minutes if clothed is a reasonable measure of water safeness for this age, while for the preteen, swimming a quarter mile with swim gear and almost unlimited ability to stay on the surface if clothed. For the adolescent, and potential scuba diver, swimming ability sufficient to swim a quarter mile and/or be able to meet requirements for a Boy Scout Lifesaving merit badge or Red Cross Swimming Level 7 are reasonable criteria (Table 2).[6] Consequently, water skills must be considered in light of not only swimming ability, but also the situation in which the young person is placed.

The American Red Cross has been active in water-safety training. Old designations such as Beginner, Intermediate, Swimmer, Junior Life Saver and Senior Life Saver designations have been replaced with Red Cross swim levels. For example, a Level 1 requirement is to establish comfort in the water and be able to swim 5 feet, whereas a Level 7 qualification requires swimming and skill proficiency, a quarter-mile swim, survival floating and the ability to retrieve an object from 7 feet of water.

The Red Cross Water Safety Instructor designation remains. Goals are to teach water safety and swimming skills. To qualify for this certification, the applicant must be at least 16 years old and have swimming skills equivalent to Red Cross Level 4 qualifications, which include being able to swim 25-yard segments with four different strokes (crawl, elementary backstroke, sidestroke and breaststroke) totaling 100 yards and 15 yards with the butterfly stroke, treading water on the surface for one minute and backfloat on the surface for one minute.

Fitness is another consideration in diving. It equates to the ability to meet exercise and activity challenges under ordinary conditions as well as to muster increased efforts to meet emergencies. While youngsters in land-based competitive sports may have superb fitness for their activities, this may not extend to water-related activities. Kenneth Cooper generated "The 12-Minute Swim Test for Assessing Cardiorespiratory Endurance."[7] The test consists of measuring the swimming distance covered in 12 minutes and rates it in five categories from very poor to excellent, in six age categories (from 12-19 up to 60 and over) and whether male or female.

The International Association of Dive Rescue Specialists (IARDS) watermanship test is another approach to measuring fitness in the aquatic environment.[8,9] It consists of five exercises including timed-surface swim, snorkel swim with fins, treading water, rescue tow with fins, and object retrieval from 9 feet of water. The first four items are timed and graded from incomplete (equivalent to 0 points) to five points. A score of 12 points (of a maximum of 20 points) and object retrieval are required to meet IARDS standards. Whereas, a teenage competitive swimmer would be easily

TABLE 1. Quantifying water skills in youngsters

Age Groupings	Water Safe Skills: Inadequate	Water Safe Skills: Minimal (optimal swim conditions*)	Water Safe Skills: Optimal	Comment: Inadequate water skills is a reason to defer diving and a reason for further training
Child 1-5 years	Nonswimmer	Comfort in water; able to swim 25 yards and surface dive** to 3 feet	Able to swim almost unlimited distances	Additional recommendation: ability to come to surface and remain there while fully clothed
Preteen 6-12 years	Marginal swimmer, tends to panic in the water	Able to swim 100 yards and surface dive to 6 feet	Equivalent to a Boy Scout Lifesaving Merit Badge, easily swim ¼ mile or more	Enjoy water activities recreationally
Adolescent 13-19 years	Only minimal ability to swim with no form or finesse with swimming strokes	Easily able to swim ¼ mile and surface dive to 10 feet, equivalent to Red Cross Swimming Level 7	Competitive swimmer, water polo player or synchronized swimmer	By 16 to 17, much of growth has been achieved and fitting of diving equipment is easier

*Optimal swim conditions (calm, clear and warm open water without currents or waves; pool swimming)

**Surface dive — i.e., pick up object off bottom

TABLE 2. Boy Scout Lifesaving Merit Badge requirements (highlights)

Requirement	Comment
1. Continuous 400-yard swim in a "strong" manner using 4 stroke types (crawl, side, back and breast)	Satisfactorily complete Second Class and First Class rank requirements that include shorter swim distances, turns in the water and elementary forms of lifesaving
2. Knowledge of Boy Scout "Safe Swim Defense"	These include recognition of persons in the water who need assistance, options for rescue and situations where in-water rescue should not be done
3. Demonstration of elementary forms of lifesaving	These include the mnemonic of TOW (i.e., reach with arm, towel, pole, paddle, etc.), THROW (a lifebuoy), ROW and as a last resort GO and how to do these techniques
4. Awareness of "go" flotation devices	Demonstrate how to use flotation devices for simulated rescues
5. Considerations for a swimming rescue	Preparations for water entry (i.e., clothing/shoe removal), maintaining visual contact but avoiding physical contact with victim, calming the victim, towing victim using an aid
6. Perform lifesaving tows	These include back underarm tow and cross chest tow
7. Demonstrate rescues for an unconscious victim	With or without equipment aids; using front and rear approach
8. Demonstrate releases	Include wrist hold, rear hold and front hold
9. Retrieve 10-pound objects in 10 feet of water	Use feet-first and head-first surface dives
10. Demonstrate cardiopulmonary resuscitation skills	
11. Recognition and first-response management of spinal cord injury	
12. Recognition of other possible aquatic-related injuries	These include hypothermia, sunburn, marine animal injuries, hyperventilation-panic and traumatic

Note: Bold font is knowledge and skills particularly apropos for teenage scuba divers able to exceed this requirement, a fit basketball player without good water skills may fail.

What Does the Literature Show?

Our literature review located more than 20 articles pertaining to younger-aged divers and topics ranging from physical and cognitive challenges to preexisting conditions and common illnesses from diving. Most of the studies, however, were conducted in the 1980s and '90s — more than 20 years ago. The information from previous reports describes potential problems the younger diver may encounter when diving.

- *Barotitis and barotraumas* are caused by pressure changes during descent.[10,11] Although the study was conducted for pressure changes in aviation, the pathophysiology is the same in flying and diving. The younger the child, the harder it is for him/her to successfully learn and complete a Valsalva maneuver to normalize middle-ear pressure.
- *Adolescents* who enter puberty earlier than their peers are at risk for lower levels of cognitive complexity and propensity to engage in health risk behaviors.[12] Some kids are still in the "concrete thinking" stage in which they can function well with specific instructions but are unable to solve unanticipated problems.
- *Reactive oxygen species*, powerful mutagens that alter the body metabolism, generate more in oxygen-enriched diving tanks than in compressed-air tanks.[13] Its effects on development are still unknown.
- *Patent foramen ovale* (PFO), a small opening between the right and left atria of the heart, can remain open in some children until the age of 20. With diving and equalization techniques, people with open PFO can develop an embolism or decompression sickness.[14,15]
- *Bone growth retardation* under hyperbaric pressure was raised as a possible concern but was not shown to occur in juvenile rats subject to decompressions stresses.[16] This could be a concern in a growing child if nitrogen bubbles occur in the growth plates of long bones and hinder growth.

MEDICAL CONSIDERATIONS FOR YOUTHFUL DIVERS

Childhood Divers

Childhood divers include youth in the 1- to 5-year age group. Little consideration is given in the literature to this segment of the possible diver population.

Physical challenges: Six physical challenges can occur in the childhood diver. Size is a major physical challenge concern.

Ramifications are small stature and lack of muscle strength and coordination. These could make water entry in the presence of waves or surges, steep beach inclines or rocky shorelines challenging encounters. A corollary to this is that a current, even if almost imperceptible, may be stronger than the child's ability to swim against it. Second, the large surface-area-to-mass ratio of the child predisposes this age group to hypothermia when immersed in water below body temperature. With rapid growth of the child, it would be impractical to continually obtain new wetsuits to fit the child appropriately.

A third physical challenge not to be discounted is sunburn. It is expected the diving activities in this age group would primarily be surface swimming with a mask to visualize the wonders of the underwater environment. A few minutes of surface swimming in a sunny environment could lead to sunburn to the back and backs of the neck and thighs. A fourth physical stress is middle-ear barotrauma with surface dives to inspect the bottom. Although this diver age group would not be expected to make surface dives to more than 5- to 6-foot depths, the pressure differentials are still sufficient to generate ear squeezes. The smaller-sized Eustachian tubes and/or hypertrophic tonsils could interfere with middle-ear space pressure equilibration.

An article in *Undercurrent* magazine details cognitive challenges that a growing child might encounter while diving.[17] Most escape a parent's consideration.

On a cognitive level, Jean Piaget's three developmental stages help set the boundaries for each age group: preoperational period from ages 2-7, concrete operational period from ages 7-11, and formal operational period from ages 11-15.[18] A 10-year-old wanting to obtain a junior diving certification can appreciate objects present and logical sequences but still lack abstract thinking. This cognitive deficit will prevent the child from finding solutions to hypothetical situations as well as facing a real diving emergency.

The Child Development Institute, LLC, has issued information about scuba diving instruction for kids, most of which advise on the child's personality, the instructor's experience, and the teacher-to-student ratio for a class.[19] Most of the concerns about diving for children are posted and addressed on the forum *scubaboard.com*.[20] All the information provided in this text box, however, is more often than not personal experience and anecdotal.

The coauthor's experiences treating children in the hyperbaric oxygen chamber indicate that as a group children clear their ears better than adults. Only in the rarest situations when pathology from tumor or infection is present adjacent to the Eustachian tube openings are ear tubes needed for ear clearing in this age group.

Comment: Middle-ear space pressure equilibration in the child diver is probably a "never" problem. If pain is experienced during descent after a surface dive, the child will probably stop the descent. It appears that with repetitive breath-hold dives over a few days, ear clearing becomes easier and easier and is a natural adaptive mechanism to this physical stress.

A fifth stress is infection of the external auditory canal, commonly referred to as swimmer's ear. Water retention in the external auditory canal coupled with a warm environment and commensal bacteria in the canal is the precursor for infection.[21] It is likely that the childhood diver will be engaging in "diving" activities only in warm, clear water, so the warmth plus water retention precursors can alter the ear canal environment enough that infection is able to develop in the canal.

The sixth and final physical challenge is injuries from marine animals. This is probably the greatest of the physical risks because penetrating injuries from sea urchin spines and stingrays are possible when entering water from the beach. The other marine animal injury risk is from jellyfish stingers. Bite injuries from sharks are possible but, compared to the likelihood of spine and jellyfish injuries, much less likely.

Physiological challenges: These are probably the least of the challenges in this age group because it is unlikely that the childhood diver would be using scuba gear and experiencing the physiological stresses (e.g., ongassing and offgassing) that it imposes. Near-drowning and drowning, however, are important considerations in this age group. Because of their young age, children may not have learned to generate anxieties/fears about water. The younger the child, the less likely he or she will have an aversion to aspirating water. Struggling may not be apparent.

Even though children are purported to be water safe, there are 3,000 drownings each year in the USA in youth from birth to 19 and probably 1,000 or more times that of near-drownings.[22] This makes near-drownings the leading cause of accidental deaths in the USA, even higher than automobile accidents.[23] Since drownings without anoxic encephalopathy range from a momentary submersion to brief anoxia periods that do not require cardiopulmonary resuscitation, there is no requirement to report such. Consequently, the incidence of near-drownings with sequelae is probably 1000-fold more than for drowning deaths. Most drownings and near-drownings occur in backyard swimming pools when the child enters the water unsupervised. While this information seems remote to diving, it emphasizes the importance of adult supervision for "divers" in this age group.

Psychological challenges: In contrast to the older age groups of youthful divers, anxieties about the aquatic environment are likely not to be present in the childhood diver. Consequently, the lack of psychological responses to stresses of the aquatic environment may place the child in jeopardy. It is unlikely that the child will have full or even any appreciation for the six physical stresses described previously. Conversely, an unpleasant water-related event such as aspiration, hypothermia, a jellyfish sting, etc., especially as the child approaches the preteen years, may cause such profound anxieties that the child remains fearful of the water.

Clinical Scenario: A 4-year-old child jumps off a diving board into a 10-foot-deep diving pool. Somewhat mysteriously, he slowly makes what appear to be purposeful swimming movements below the surface of the water with no attempt to come to the surface, and there's no evidence of any struggling or desire to breathe. After what seemed an eternity to the lifeguard, but probably less than 30 seconds, the lifeguard brought the child to the surface and then onto the pool deck. After a couple of burps the child said he was OK, did not show any signs of anxiety or distress and was able to stand and walk normally. He was instructed to continue his water activities in the shallow end of the pool.

Comment: The child, not knowing otherwise, did not show panic or anxiety symptoms in the ideal environment of a warm swimming pool. Obviously, the above scenario demonstrates that comfort in the water does not equate to water safeness. Had the lifeguard not appreciated that something was wrong with the child appearing to swim underwater as a bird flies through the air, a near-drowning or drowning could have resulted. Probably some breathing efforts were done while the child was submerged because of the initial burps. Again, the child showed no signs of panic.

Preteen Divers

The years between ages 6 and 12 are ones in which phenomenal growth and physiological (metabolical, endocrinological/hormonal, neurological/brain-related and musculoskeletal) changes take place. Strength, coordination and endurance increase sufficiently that this age group can become actively engaged in aquatic activities.

Physical challenges: The physical challenges described for childhood are even more applicable to preteen divers because they are gaining the size and strength to spend longer times at the aquatic activity and may have so much confidence that they can do so without adult supervision. While fitting of diving equipment may not be optimal for the preteen, options are increasingly available and easily located on the Internet.[24] The major equipment challenge in this age category is proper fitting of a buoyancy compensator. Smaller-capacity scuba tanks and smaller-sized second-stage scuba regulators mitigate these equipment considerations. Swimming fins and appropriately sized dive masks for youngsters are available. Exposure suits can be custom made but can be expensive. A better choice for this age group and size of diver is to dive in warm, tropical waters where only minimal protective clothing — for example, surfing trunks and long-sleeved T-shirts — is used.

Physiological challenges: Although scuba diving is generally not an activity promoted for this age group, parents often boast of their youngsters' ability to breathe with a scuba regulator and participate in diving activities (Figure 3).[25] In actuality, it is probably no more difficult to breath with a scuba regulator than using an inhaler for managing asthma. Since depths of dives are so closely controlled by parents or dive guides, decompression sickness is an unlikely occurrence. In fact, the authors are not aware of any reports of decompression sickness occurring in a preteen. A more serious concern is that a panic-provoking situation will cause the preteen to dart to the surface while breath-holding and cause an arterial gas embolism. Air embolism has been described in this age group.[26] Air embolism can occur with breath-holding of compressed air from depths as shallow as 7 feet (2 meters).

FIGURE 3. Scuba in a childhood diver

Legend: Breathing with a regulator is no more difficult than using an inhaler. More skills and equipment challenges are required for buoyancy control (e.g., proper fit of a buoyancy compensator). Finally, judgment will be fully dependent on adult supervision.

A more serious physiological concern in the preteen diver is blackout. Through networking, young breath-hold divers may learn that they can extend their breath-hold times by hyperventilation, which effectively removes carbon dioxide from body tissues and delays accumulation of this waste product, which normally causes almost irrepressible desires to breathe.[27] Since oxygen stores are not increased with hyperventilation, the breath-hold diver may blackout from hypoxemia before he or she develops a desire to breathe from carbon dioxide reaching the breath-hold

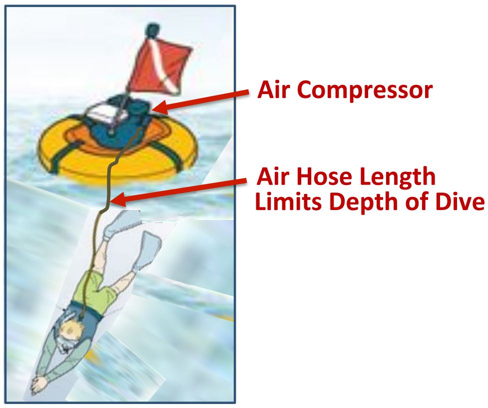
The authors are aware of a surface-supplied hookah-like rig that has been mentioned for compressed-air diving in older children (Figure 4). A small air compressor sitting in an innertube-like floatation device has hoses attached to it. The divers breathe through a second-stage scuba regulator. By limiting the length of the hose, the childhood diver can go no deeper than the hose length, which may be 20 feet or so. While decompression sickness is unlikely at such shallow depths, air embolism is a possibility if something goes wrong and the diver holds his or her breath while making an emergency ascent.

Clinical scenario: Several youngsters were playing in a backyard swimming pool. They decided to tie weights to a bucket handle and let the bucket filled with air sink to the bottom. After almost exhausting the air from the bucket, one of the kids swam to the surface holding his breath. Upon surfacing, the kid sighed and immediately lost consciousness. Resuscitation efforts by paramedics were futile.

Comment: The diagnosis was arterial gas embolism. Calculations from diving physics show that an ascent from as little as a 3-foot (about 1 meter) depth after a full inhalation of air into the lungs will theoretically result in a 10 percent overexpansion of the lungs upon reaching the surface. This differential pressure may be sufficient to rupture alveoli and cause an arterial gas embolism.

Dictum: Breath-holding while ascending after breathing compressed gas must be avoided. In the above scenario, it is unlikely the kids were aware that it was dangerous to ascend while breath-holding after taking a deep breath from air in the submerged bucket.

FIGURE 4. Surface-supplied gas-supply diving



Legend: Surface-supplied air system (e.g., Brownie's Third Lung Hookah) is an alternative to scuba (self-contained underwater breathing apparatus diving). The hose length prevents enough ongassing to cause decompression sickness after surfacing. If the diver panics, however, and and has an uncontrolled ascent to the surface, arterial gas embolism can occur.

breakpoint. For "macho" reasons of wanting to set new depth or underwater swim distance records for themselves, the uninformed diver (or swimmer) may hyperventilate enough to delay the desire to breathe and blackout without a desire to breathe while underwater. Since snorkeling and breath-hold dives from the surface to explore the bottom are likely to be the main diving activities of the preteen, it behooves anyone responsible for the diving and swimming activities in this age group (e.g., parents, lifeguards, coaches, trainers, dive supervisors, boat operators, etc.) to not permit hyperventilation before engaging in underwater activities.

A remote, theoretical concern for diving in this age group is bubble formation with ascent in areas of slow blood flow, such as sinusoids, bone marrow, venous plexuses (Babson) in the spinal canal, and growth plates. Whereas, bubble formation in sinusoids and bone marrow may remain silent, it could have ramifications if it occurred around the spinal cord or in the growth plates of the rapidly elongating preteens' long bones. Generation of angular deformities if the bubbles occluded circulation on the medial or lateral edges of the growth plate or total arrest of growth if the entire growth plate was involved. These problems remain theoretical possibilities, and again we are unaware of any reported cases of them occurring. Peter Walker's study of growth plates in rats after decompression stresses showed no abnormalities.[16]

Psychological challenges: For the preteen diver, this is probably the biggest concern of the three categories of challenges. The physical challenges, which predominate activities for the childhood diver, are gradually being mitigated by growth. Participation in competitive sports activities, which is often started in the preteens, rapidly builds strength, stamina, coordination and confidence in this age category. What is lacking are judgment and experience. Consequently, while the physical challenges as described for the childhood diver still exist, they are no longer such an impediment to aquatic activities in the preteen. Whereas, the childhood diver may not engage in water activities without one-to-one adult supervision, the preteen diver may do such with his or her buddies. Dares and goading can likely exceed judgment, leading to unsafe aquatic-related activities — in particular, as mentioned above, is using the hyperventilation technique to increase underwater swimming distance, breath-hold dive durations or depth excursions.

Scuba diving in this age group raises the same judgment and experience concerns as described in the childhood diver. The newfound ability to "breathe" underwater may give the preteen diver confidence that there are no limits as to what he or she can do underwater. This age group may not yet have the capacity to fully appreciate the challenges of diving and the medical problems that can arise from them.

MEDICAL CONSIDERATIONS FOR THE TEENAGE DIVER

Physical challenges: Teenage divers exhibit extremes in their ability to dive. In terms of physical challenges, they are probably as fit and strong as any times in their lives. This is understandable because of the high probability of participation in competitive sports, dancing, martial arts or other physical fitness activities. Conversely, in terms of judgment and daredevil activities, this age category exceeds that of the preteen diver. With growth, increased size and strength, and an attitude, there is no obstacle too great to surmount. The likelihood of risk-taking behavior increases proportionately and may be exacerbated by the use of alcohol and street drugs. Most of the physical challenges of diving as summarized in the childhood section are easily overcome because of maturation of their musculoskeletal system. At this point in development, fitting of diving equipment is not a problem except for the extremes of size.

Physiological challenges: With approaching adulthood, the physiological challenges for the teenager are probably little different than that for adults. Because of longer and deeper scuba dives, decompression sickness and nitrogen narcosis become a possibility but are probably no more likely than in the adult diver. In addition, motivation, spearfishing and possibly competition place the breath-hold diver at risks for hypoxic blackouts. Breath-holding hypoxic blackouts are not only associated with hyperventilation (i.e., breath-holding after hyperventilation)[27] but also distractional (i.e., subjugating the breath-hold breakpoint due to fixation on an underwater goal) and diffusional causes associated with deep breath-hold dives in which the diver remains on the bottom until his or her blood oxygen content approaches the point of losing consciousness. During ascent with decreases in ambient pressure, blood oxygen contents decline as quantified by Dalton's law and can reach levels at which consciousness is lost. Blackouts may also arise from arrhythmias, which may be precipitated by cold-water immersion coupled with breath-holding, both components of the diving reflex.

Pathophysiology associated with chronic medical conditions becomes a consideration in the adolescent scuba diver. Diabetes, asthma and seizure disorders are the three most commonly encountered problems. Typical diabetics in the adolescent age range are of the type-1 variety in which the pancreas has lost the ability to produce insulin. Without insulin to act as an enzyme to carry blood glucose across the cell membrane and then be used as the substrate (fuel) for metabolism, cell function ceases. If blood sugars are too low, consciousness can be lost; if profound enough, death of brain cells occur; if too high, metabolic derangements termed ketoacidosis can be life-threatening. Consequently, decisions regarding scuba diving require careful medical consideration. If blood sugars are stable, and the adolescent patient is compliant with insulin use and monitoring, diving under controlled circumstances is a reasonable decision. Controlled conditions include diving to minimize stresses such as in warm, clear water, minimizing swimming required by diving off of boats with descending lines, utilizing finger-stick tests of blood glucose before entering the water and after surfacing, diving with a buddy aware of the adolescent's diabetes condition, and carrying an emergency sugar source to take if symptoms of hypoglycemia are noted.

Recommendations for diving in adolescent asthmatics require similar decision-making and diligence. If wheezing requires use of inhalers more frequently than several times a year, scuba diving is not recommended. The breathing of dry, dehumidified air in the scuba tank cooled to the ambient water temperature may precipitate an asthma attack. With bronchospasm, air may be retained in the alveoli during ascent and lead to extra-alveolar air problems such as arterial gas embolism, pneumothorax and/or mediastinal emphysema. Conversely, if the patient with an asthmatic history is generally asymptomatic and is asymptomatic at the time of the dive, diving under the controlled conditions described above for the diabetic is a reasonable decision.

A history of seizures is an absolute contraindication for the adolescent scuba diver. Adult scuba divers with a seizure history might dive, but this is generally done against medical advice. The adolescent scuba diver does not have as much independence as the adult in obtaining equipment, selecting diving sites and diving without supervision. Seizures are an absolute contraindication in scuba diving for several reasons. First, increased partial pressures of oxygen are known to cause seizures. Scuba diving increases oxygen partial pressures, as explained by Dalton's law. For example, at a 33-foot (10-meter) depth, which is equivalent to 2 atmospheres absolute, the oxygen partial pressure doubles. Second, a seizure while underwater with associated loss of consciousness is tantamount to a near-drowning/drowning incident. If the dive buddy is skilled enough to bring the submerged, unconscious victim to the surface, retention of air in the lungs and expansion with ascent may lead to an arterial gas embolism. Third, if the diver with a seizure disorder requires recompression in a hyperbaric chamber because of decompression sickness, the breathing of pure oxygen under hyperbaric conditions may precipitate a seizure. Fortunately, this latter risk can be substantially reduced by giving anticonvulsant medications intravenously to the victim before and during the treatment.

A patent foramen ovale (PFO) is another physiological problem that occurs in divers, and since the condition is present from birth, it can occur in teenage divers as well. The foramen ovale is an opening in the septum of the

Clinical scenario: A newly certified 19-year-old male has begun scuba diving as an outlet for a behavior disorder. After an unremarkable dive to 50 feet (15 meters) for less than hour, his fifth open-water scuba dive, he was asymptomatic on the surface. While talking with other divers, one of them tells a joke. The diver in question begins laughing hysterically (possibly a side effect of his behavior problem) and immediately collapses unconscious and unresponsive.

Fortunately, a recompression chamber was nearby, and after hyperbaric oxygen recompression, the patient recovered without any residual problems. Before being allowed to resume diving, he required a medical clearance. A heart bubble study demonstrated a patent foramen ovale (PFO). The patient was intent on resuming scuba diving but was advised to not do such until the problem was repaired.

Comment: Although the diver had a few previous uneventful scuba dives, the hysterical laughter and consequential increased intrathoracic pressure apparently forced silent bubbles in the venous circulation to pass from the right ventricle through the PFO to the left ventricle and into the arterial circulation. The collapse symptoms resulted from bubbles blocking the brain circulation.

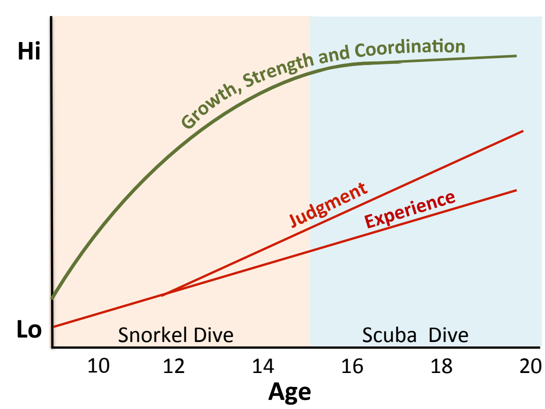
With current technology, invasive cardiologists are able to close the PFO using percutaneous techniques, thereby minimizing the morbidity associated with open-heart surgery. Once the PFO is closed, divers are cleared to resume scuba diving.

ventricles that allows blood in the fetus to bypass the lungs. At birth, it typically closes with the first breath of air taken by the newborn baby. If it remains open or partially open, which occurs in about 25 percent of humans, silent bubbles (which almost always occur with ascent from a scuba dive and are usually harmlessly filtered out through the lungs) moves from the right ventricle to the left ventricle. This allows bubbles to enter the arterial bloodstream and cause stroke-like symptoms if they lodge in the brain.

Psychological challenges: Judgment has to be paired with experience for the teenage diver (Figure 5). Also, water skills must be considered. If the teen is not comfortable in the water, scuba diving training should not be encouraged. Loss of control accompanied by panic is a leading cause of death in scuba divers and most frequently occurs in the inexperienced divers.[28] The same attitudes and feelings of immortality that had their origins in the preteen years is likely to be carried over and even magnified in the adolescent diver. In diving, there can be no substitute for judgment, and judgment comes with experience and maturity. Society has set some norms for judgment, which is reflected in setting the voting age at 18 and the obtaining of driver's licenses after age 16 (Figure 2). These requisites are reasonable criteria for scuba diving as well.

Behavior problems and scuba diving is a subject that deserves further research (see previous clinical scenario). With the risk of reckless behaviors and inability to follow directions, adolescents with attention deficit hyperactivity disorder (ADHD) need to be carefully scrutinized before allowing snorkel and scuba diving. One criterion is if they can obtain a driver's license, they can follow directions well enough to scuba dive. Patients with more serious problems such as Asperger's syndrome, neuroses, dyslexia or cognitive

FIGURE 5. Growth vs. maturity in preteens and adolescents



Legend: Judgment and experience lag behind growth and development. This has important ramifications for making decisions when to begin scuba diving.

What diving activities should be encouraged in the teenage diver? The coauthor's sons did not obtain their scuba diving certifications until after they obtained their driver's licenses. Both were competent swimmers, being on swimming and water polo teams since their early teens and having their Boy Scout Lifesaving merit badges.

During family outings at diving programs, they would snorkel dive. Both enjoyed the freedom of this activity and easily could breath-hold more than a minute and submerge to greater than 30-foot (10-meter) depths. Even today on scuba diving trips they spend their time between scuba dives with snorkeling or in lieu of doing repetitive scuba dives.

function impairment may find scuba diving and being able to visualize the aquatic environment so fulfilling that it mitigates their neurological problems. Diving with these conditions requires one-to-one competent adult supervision and diving with optimal conditions (described in the childhood diver section). Similar benefits of scuba diving and requirements to do such apply to patients with paralyzed extremities, cerebral palsy and single-limb amputations.

Certifications for the Younger-Aged Diver

In their goals to expand and promote scuba diving, diving certification organizations have designed programs for younger-aged divers. Most provide certifications and have catchy names. For teenagers, it is advisable that scuba classes be limited to students their own ages. Consider the following:

The **National Association of Underwater Instructors (NAUI)** features the Skin Diver program for kids 8 years old and older for snorkeling and breath-hold surface diving to a 5-foot depth.[29] Next, at age 10 and above, they can take beginner scuba diving courses and earn their Junior Scuba Diver certificate. At 15 years of age and with 25 scuba dives, they can earn the Experienced Scuba Diver certificate.

The **Professional Association of Diving Instructors (PADI)** provides the Supplied Air Snorkeling for Youth (SASY) for children ages 5 to 7.[30] It also has the Bubblemaker Diving Program, in which kids as young as 8 years old can blow bubbles underwater by scuba diving in a pool or shallow water. The PADI Seal Team offers formal lessons for kids from 8 years old and up to complete AquaMissions toward earning a certificate. From 10 years old and above, kids can get schooled and certified in the official PADI Open-Water Diver Course for scuba diving.

Scuba Educators International (SEI) took over the Y-SCUBA programs from the Young Men's Christian Association (YMCA) in 2008.[31] SEI now offers the Open-Water Diver Course for both adults and children 12 years and older.[32] Upon completing the course, however, children ages 12-15 years are awarded the Junior Open-Water Diver certification.

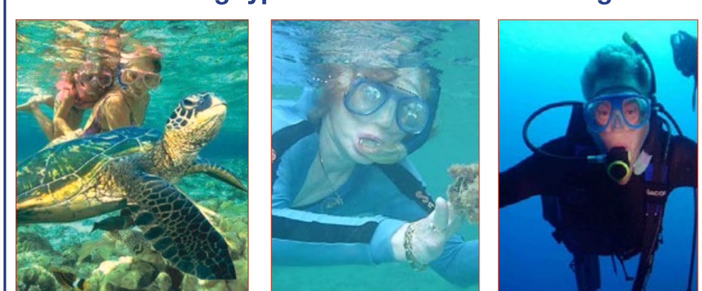
Scuba Schools Internationals (SSI), which merged with the National Association of Scuba Diving Schools (NASDS) in 1999, designs the Scuba Rangers program for children ages 7-12 and the Junior Scuba Program for adolescents ages 10-14 with a variety of special names, including Junior Scuba Diver, Junior Open-Water Diver, Junior Advanced Adventurer, Junior Rescue Diver, etc.[33,34]

Our Recommendations

With the above information, logical recommendations can be made for younger-aged divers (Table 3, Figure 6). A few maxims need to be mentioned, however, in conjunction with making decisions who, when, where and with what equipment a youngster should dive. They include the following:

1. Water skills are both a function of swimming skills and the environment in which the young swimmer/diver is placed.
2. Three age categories — childhood, preteens and adolescents — are useful for making recommendations about diving activities in youth.
3. Physical challenges of the aquatic environment by and large pertain to how the external environment influences the diver.
4. Physiological challenges are those that reflect how the diver's body responds to these challenges.
5. Psychological challenges are how the human mind responds to the combination of the physical and physiological challenges.
6. Younger-aged individuals should not be forced into water-related activities they do not enjoy; obviously not every young person wants to become a diver.
7. Diving certification agencies have developed programs for younger-aged divers with specifications for equipment used and depths of diving.

FIGURE 6. Diving type recommendations vs. age



Childhood **Preteen** **Adolescent**

Legend: Each age category deserves special recommendations. For the childhood diver, it should be surface swimming with one-to-one adult supervision. For the preteen, snorkel diving with shallow breath-hold dives with buddies is OK. Scuba diving becomes appropriate for the mid- and late-adolescent.

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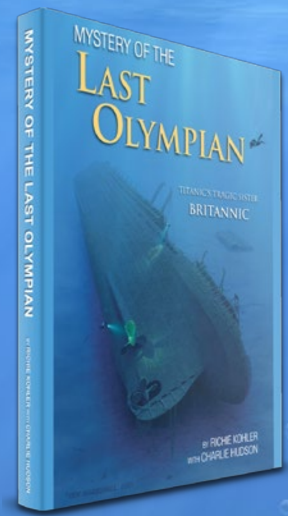

MYSTERY OF THE LAST OLYMPIAN: *Titanic*'s Tragic Sister *Britannic*

by Richie Kohler with Charlie Hudson

For 100 years the mystery surrounding the sinking of *Titanic*'s tragic sister *Britannic* was a riddle waiting to be solved. This book gives you a firsthand account as Richie Kohler takes readers on the intriguing journey from the rise of the magnificent Olympians to the ship's fateful sinking in 1916. He then moves forward in time through multiple expeditions, beginning with the great Jacques Cousteau, who located the wreck of the ocean liner in 1975. Each successive team of divers who risked their lives uncovered new clues, but it was not until 2009 that Kohler and his dive partner definitively pinpointed the secret that had eluded everyone before then.

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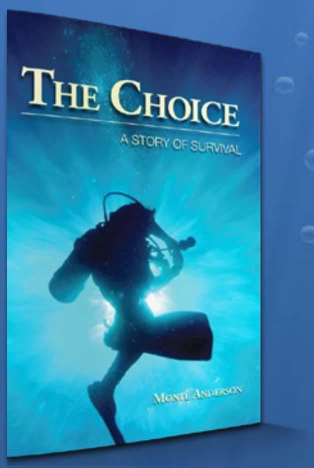
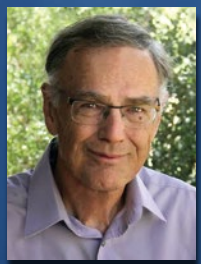


THE CHOICE: *A Story of Survival*

by Monte Anderson

As three friends drove across the Navajo Reservation in northern Arizona after backcountry skiing in Colorado, they talked about their lives. Then one said, "I really shouldn't be alive today."

David Scalia's astounding story occurred in 1982, when a scuba equipment failure caused a devastating accident, but he had a scrapbook documenting everything that happened. He suffered incalculable damage to his body for more than 12 grueling hours. Days later, he was given a profound choice — to live or to die. Almost unbelievable, this is his true story — and it involves some friends and colleagues you may know, including Dr. Gregory Adkisson, Dr. Tom Neuman, and Dr. Paul Phillips.



About the Author: Monte Anderson completed a medical residency at Creighton University and continued his studies with subspecialty training in gastroenterology and hepatology as an army officer at Fort Sam Houston in San Antonio, Texas. After his discharge from the military, most of his career was happily devoted to the Mayo Clinic in Arizona. Feeling that true tales tend to be more compelling than fiction, he has always preferred reading nonfiction, especially since something is always learned in the process. *The Choice: A Story of Survival*, his first effort outside of scientific writing, is nonfiction.

"Dr. Monte Anderson makes his debut in nonmedical writing with The Choice: A Story of Survival and does so with a splash. The nonfiction book relates the fascinating story of his friend's 1982 diving accident near a remote island in Mexico. Dr. Anderson's recounting of the details reflects his tremendous investigative ability, as well as the diver's will to survive."

~ Neil B. Hampson, MD, author of *Cherry Red*

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8. Scuba diving training is best deferred until judgment becomes equivalent to that required to obtain a driver's license and swimming skills are equivalent to those required for a Boy Scouts Lifesaving merit badge (Table 2) or being able to pass the IARDS watermanship test.
9. While decompression sickness is not likely to occur at shallow depths (e.g., using a hookah rig), air embolism is possible, especially if the diver panics and breath-holds while making an uncontrolled ascent.
10. While breathing compressed gas through a regulator is almost as easy as breathing itself, before doing such the younger-aged diver must be aware of the limitations and hazards when using this equipment for diving.

Conclusions

The pleasure and educational value of diving for younger age groups must be weighed against the risks involved. By categorizing younger-aged divers as childhood, preteen and adolescent, the first step in making appropriate decisions about their diving activities is made. The second step is to consider the physical, physiological and psychological challenges that each age category imposes. Although many articles have been written about diving in children and young adults, almost all are opinions and observations. Scuba diving certification agencies have generated programs for young divers. Before considering any diving activities, adequate water skills are essential. These must be coupled with comfort in the water.

Our approach provides thoughtful guidelines for each age category of diving. The guidelines provide information on 1) appropriate dive equipment, 2) environmental considerations, 3) level of supervision required, 4) depth recommendations, 5) fitness recommendations and 6) special concerns such as medical problems of diving and diving with concurrent illnesses for each age category. While growth and maturation exhibit a continuum of changes, the guidelines offer flexibility in application as the diver transitions from one age category to the next. Probably the biggest question to answer is when to begin scuba diving. Breathing with a regulator is probably the easiest challenge. The greatest challenge is deciding whether or not the adolescent diver has sufficient judgment to dive

TABLE 3. Diving type recommendations vs. age

Age Groups	Equipment	Environment	Supervision	Depth Recommendations	Special Considerations
Child 1-5 years	Swim mask and fins	Optimal conditions with warm water, good visibility, shallow depths and no currents or waves; a swimming pool is ideal place to begin this diving activity	One-on-one supervision by an adult diver	Learning to pick up an object on the bottom at a 3 foot (1 meter) depth	Make exposures short, avoid sunburn by wearing protective coverings, encourage breath control and mobility
Preteen 6-12 years	Swim mask, snorkel and fins	Good conditions with diving off the beach or a boat in warm water, good visibility and minimal current, swells or waves	One-on-one adult or a responsible late teen snorkel diving "partner"	Surface dive to explore the bottom at 6 foot (3 meter) depth	Learn how to use a snorkel, avoid hyperventilation before surface dives, become comfortable with middle-ear pressure equilibration with descents, be aware of the marine environment and how marine animals can inflict injuries, teach respect for the underwater environment by seeing rather than touching
Adolescent 13-19 years	Training and supervision with scuba gear	Safe diving conditions with use of appropriate thermal protection suits	Preferably a buddy with equal or greater diving experience	Sixty feet initially or as additional certifications dictate; use no decompression dive profiles with use of dive computer or tables	Always plan the dive, preferably with a dive briefing, including reviewing hand signals before entering the water, following other appropriate recommendations such as ear-clearing techniques and protecting and respecting the environment as mentioned in the other age categories

safely. Excellent preteen snorkel divers easily transition into competent scuba divers. This chapter shows how the younger-aged diver can dive safely, smartly and securely. ■

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About the Authors

MICHAEL B. STRAUSS, M.D., has had a long-time relationship with water activities. He took his first Red Cross (RC) swim class as a 6-year-old under the direction of his father, a frustrated furniture merchant whose teaching and coaching of water-oriented activities was a predominant feature of his life. As a youngster, he rapidly advanced through Junior and Senior Lifesaving and the Boy Scout Lifesaving merit badge as well as the Scout Lifeguard Award. He started swimming competitively when he was 9 years old and continued with this while adding water polo during college. In the summers, he lifeguarded, coached swimming and taught RC swimming lessons. While enrolled in a college RC Water Safety Instructor's course, he so impressed the instructor that he ended up teaching the course while the instructor watched from the sidelines. Immediately before starting medical school, Dr. Strauss played for the U.S. Maccabiah Water Polo Team in Israel. While in medical school in Portland, Oregon, he introduced the sport of water polo to the state.

After entering the US Navy, he was heavily oriented to water-related activities, including submarine school, diving school, a nuclear submarine patrol, diving medical officer for salvage divers in the Philippines and Vietnam, and then with the West Coast UDT and SEAL Teams. While with the UDT and SEAL Teams, he coached the local high school water polo team, played club water polo and was the advisor for an Explorer Scout scuba diving post. After joining the Long Beach Memorial Hyperbaric Medicine Program in Long Beach, California, he organized diving, diving medical programs to more than 20 countries, played for the U.S. Water Polo Team for the World Masters' Games in Australia and remained attached to the Navy Reserve West Coast SEAL Teams for 24 years. In addition, he has almost 50 publications on diving medicine, some of which have appeared in this magazine. He is currently working on the second edition of his *Diving Science* text. Like his father, of blessed memory, his fondness for water-related doings remains unabated.

LIENTRA LU was born and raised in a seaside city in Vietnam. She has been accustomed to the water since childhood. After learning to swim at 7 years old, she enjoyed frequent snorkeling trips with her family every summer in the islands surrounding Nhatrang, Vietnam. Since working with Dr. Strauss, Miss Lu has learned an amazing amount of information about the medical aspects of scuba diving. She is pleased to have collaborated with Dr. Strauss on four dive medicine articles to date and is thrilled with the opportunity help co-edit the upcoming and totally revised 2nd edition of Drs. Strauss and Aksenov's *Diving Science* text. Her next diving goal is to become a certified scuba diver and help others enjoy this sport in a safe and sensible fashion.

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Protective Footwear

Part 4A (of 5) in the Diabetic Wound Prevention series

By Anna M. Tan, Michael B. Strauss, Lientra Q. Lu

Protective footwear is the second line of defense after skin and toenail care for prevention of new and recurrent wounds (Figure 1).[1,2] Any patient who has one or more of the conditions recognized as risk factors for wound development — such as deformity, peripheral vascular disease, history of a previous wound, previous amputation and/or neuropathy — and is ambulatory requires intelligent decision-making for the selection of protective footwear. This line of defense is so important that in 1993, Medicare (Center for Medicare/Medicaid Services) under the direction of Congress, initiated the "Therapeutic Shoe Bill" benefit for diabetic Medicare beneficiaries with risk factors for wounds. Undoubtedly this decision was based on the assumption that the potential benefits to prevent diabetic foot problems outweighed the costs to provide protective footwear.[3,4] Essentially, it is less expensive to prevent a diabetic foot problem from arising by providing therapeutic footwear than it is to treat the complications that arise from not using appropriate footwear. In recognition of this, benefits for protective footwear for diabetic patients were established and will be delineated later in this article.

FIGURE 1. Appropriate footwear selection is the second line of defense against developing new or recurrent foot wounds.

Legend: Selection of appropriate footwear depends on findings from the evaluation. Footwear selection choices lie on a continuum from least expensive/less complex to most expensive/most complex. Medicare provides benefits for diabetic patients who require prescription footwear.

Footwear Selection

Selection of protective footwear is not a matter of fashion. It requires knowledge, insight and experience. There are a large number of options to consider when recommending and prescribing protective footwear including individual adjustments such as casts, orthotics, wedges, fillers, lifts, cut outs, relief areas, bars or other modifications. To simplify matters, the selection of protective footwear can logically be placed in a hierarchy from least to most complex (Figure 2). Factors that determine complexity include availability ranging from off-the-shelf to custom-molded and modifications from simple inserts to specifically placed reliefs and pads. As the complexity increases, the costs increase proportionately. The hierarchy has five levels: 1) quality walking or athletic shoes, 2) off-the-shelf diabetic shoes with cushioned plantar inserts, 3) custom prescriptions added to off-the-shelf diabetic shoes, 4) custom-molded diabetic shoes and 5) Charcot restraint orthotic walkers (CROW boots).

SHOE COMPONENTS AND SOCK CHARACTERISTICS

Shoe Components

To appropriately prescribe protective footwear, it is helpful to be aware of the various components of a shoe, its functions, what alternatives exist for each component and what complications may arise from them. Surprisingly, many options also exist for sock choices. The following is a summary of major shoe components and sock compositions:

1. **Covering materials (outer portions)** are what the outer component of the shoe is made of, give the shoe above the sole portion its shape, and often give the shoe its common name such as leather, house, tennis, athletic, boot, etc. Common components include leather, cloth, netting comprised of various materials, canvas, rubber, synthetic fibers (rigid or flexible) or plastic. Multiple combinations may be used, as is often found in tennis shoes. Leather is desirable for its durability, breathability and malleability to accommodate deformities. Flexible synthetic fibers are desirable because they accommodate changes in foot size due to swelling and are pliable enough to avoid pressure concentrations. Rigid plastic coverings, such as those used in the Charcot restraint orthotic walkers (CROW boot), require padded inner linings.
2. **Fasteners** are the devices that help to keep the shoe on the foot. There are three basic choices: 1) string ties, 2) elastic bands and 3) Velcro® straps. String ties tend to be more secure but require agility and good proprioception to tension properly and tie. If the knot becomes untied, the shoe may loosen, subjecting the patient's skin to shear stresses and the foot and ankle ligaments to sprains. Another hazard of string ties is they can become untied and can cause the patient to trip over a shoelace. Elastic bands or Velcro® straps are more user-friendly and the preferred choice for many patients with comorbidities such as arthritis, obesity and hemiparesis, etc. In patients who retain fluid, the elastic bands may indent the edematous skin and interfere with venous return.
3. **Heels** are elevations that may be added to the back thirds of the shoe sole (discussed below). They may be thick, thin, wedged on either side, extend medially (Thomas heels) or absent, depending on the perceived needs of the hindfoot. Whereas some of the heel modifications are of dubious value, those used to counteract equinus deformities and position the ankle during Achilles tendon healing are of value.
4. **Heel counters** are the parts of the shoe that come in contact with the back of the shoe wearer's heels. They may be low profile, barely covering the back of the patient's heel, or high enough to extend proximal along the back of the Achilles tendon. The higher the heel counter, the greater is the control of the hindfoot. The inside portion of the heel counter may be padded with foam or soft cloth or merely lined with cloth or leather to provide a cosmetic appearance for the shoe covering material. Semirigid plastic inserts may be placed between the layers to add increased rigidity to the heel counter and control of the hindfoot.
5. **Inner linings** may or may not be present. They may increase the cushioning properties of the shoe, absorb moisture or help with the fit of the shoe. In stylish shoes, most are thin leather and added only for their cosmetic effect. In addition to leather, lining materials may be cloth or various types of foam.
6. **Lasts** refer to the shape of the sole portion of the shoe. Usually the last is slightly concave along its medial aspect. For angular deformities (especially metatarsus adductus in children), the lasts may be straight or reversed, that is convex along their medial border.
7. **Shanks** are devices inserted into the sole portion of the shoe to control flexibility. Most often they are rigid steel bars and used for specific occupational needs rather than as modifications for protective footwear.
8. **Shoe heights (upper portion)** designate the portion of the shoe that is attached to the sole and extends over the foot, ankle or leg. Low-cut shoes such as moccasins and flats may cover only the bottom half of the foot. Consequently, they provide minimal support and stability. Intermediate cut shoes, the most frequently prescribed protective footwear, enclose the feet and extend to just below the level of the ankle malleoli. High-top shoes extend above the malleoli, with boots being a good example of this type of footwear. With increasing height of the upper portion of the footwear, protection, support and stability increase. Conversely, the greater the height of the upper portion of footwear, the more difficult it is to don, fasten and remove the shoe. Velcro® straps help to mediate the difficulties of tying the shoes. Specially designed footwear such as CROW boots help to mitigate the difficulty of donning and removing the shoe.
9. **Shoe soles** are the part of the shoe that makes contact with the ground or floor. They may be rigid or flexible. Typically, they may be flat, with or without the addition of a heel portion. Materials used for the soles of shoes include leather, plastic composite materials, wood and rubber. The rocker-bottom sole is a modification that facilitates walking in the presence of severe deformities or joint mobility problems.
10. **Shoe tongues** may or may not be present in protective footwear. Tongues, when present, are usually a separate component that attaches to the toe box (described next). Tongues serve several purposes, including providing protection between the laces and the top of the foot, and improved fit and comfort. Tongues may or may not be padded. Shoes

that do not have tongues usually have overlapping flaps secured with Velcro® straps. These make the shoe easier to don and remove.

11. **Toe boxes** are the portions of the shoe top that cover the forefoot. For most protective footwear, the toe boxes are spacious enough to prevent pressure sores developing from clawed toes and other forefoot abnormalities. Of course, the antithesis of the large toe box is the pointed-toe shoe. In comparison to protective footwear, pointed-toe shoes have many undesirable features that contribute to bunion deformities, hallux valgus, hyperpronation of the great toe, varus plus supination deformities of the little toes and cross-over toes. In conjunction with high heels, pointed-toe shoes contribute to clawed toe deformities, hyperextension contractures of the toes at the metatarsal-phalangeal joint levels, proximal migration of the forefoot fat pads, as well as calluses, bone spurs and ulcerations under the metatarsal heads. When toes or a distal portion of the foot are absent, a filler (or spacer) is usually inserted in the toe box to help with shoe fit and prevent shearing stresses on the skin with movements of the foot.
12. **Sock options** should not be overlooked in conjunction with footwear selection. Knee-length compression stockings with 20- to 30 mmHg tensions are recommended for all patients who have had foot surgeries, lower-extremity edema, mobility problems, venous stasis disease or spend extended periods of time with their feet immobile in the dependent position. Sock fiber choices include cotton, wool, acrylic, polyester, polypropylene or combinations of these fibers. Cotton socks are the least expensive, do not provide very good padding and manage moisture poorly. Wool socks provide good insulation and manage moisture fairly well. Acrylic socks fit well, reduce shear, cushion well and handle moisture well. The other synthetic fibers manage moisture well but do not provide good padding. Blends of these fibers can combine the desirable features of several fiber types. White stockings are especially desirable for those patients with risk factors for wound development because a stain on a white sock will not likely be ignored, as it might be if the patient was wearing dark-colored socks. Finally, stocking cleanliness is desirable, preferably with changes being made daily. Socks from synthetic fibers tend to retain odors and pile with repeated wear.

PROTECTIVE FOOTWEAR OPTIONS

Footwear Choices

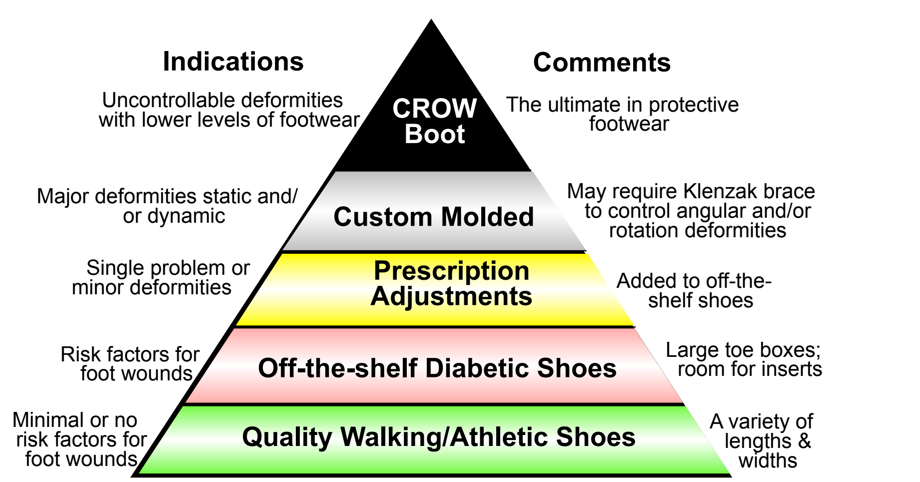
Although nearly a dozen components, as just described, may be considered when prescribing protective footwear, choices can be reduced to five principle types in a hierarchy that ranges from off-the-shelf, least expensive to custom-molded, most expensive (Figure 2). Knowledge of the footwear options and what needs to be achieved with the patient's footwear requirements should always be determinants when prescribing protective footwear. Considerations include the following:

- patient's functional capacity
- characteristics of the foot problem
- modifications available for the five principle protective footwear choices
- patient's goals

In most circumstances this information, except for knowledge of the available modifications, is already available from the patient's initial evaluation or becomes readily obvious with the reevaluation preceding the footwear prescription. The actual protective footwear selection, addition of modifications and fitting should be done by the pedorthotist or orthotist, who is the health-care professional most knowledgeable in this aspect of protective footwear. The following information describes the five principle choices for protective footwear in the hierarchy of complexity and costs. For each upward step in the hierarchy, the costs increase two- to threefold.

Level 1 — Quality walking or athletic shoes: Theses shoes can be purchased without a prescription and usually do not qualify for Medicare Therapeutic Shoe Bill benefits. They are the least expensive and the best looking of the

FIGURE 2. Hierarchy of prescription footwear



Legend: As the foot problems become more complex, the protective footwear options move up the hierarchy and correspondingly become more expensive. **CROW** = Charcot Restraint Orthotic Walkers.

FIGURE 3. Quality walking and athletic shoes vs. a high-fashion shoe

Walking shoe with quality construction, a large toe box, Velcro® fasteners and a thick sole

An athletic shoe with analogous features; it is E width to accommodate the patient's wide foot

A beautiful shoe… but not for the patient with risk factors for foot wounds

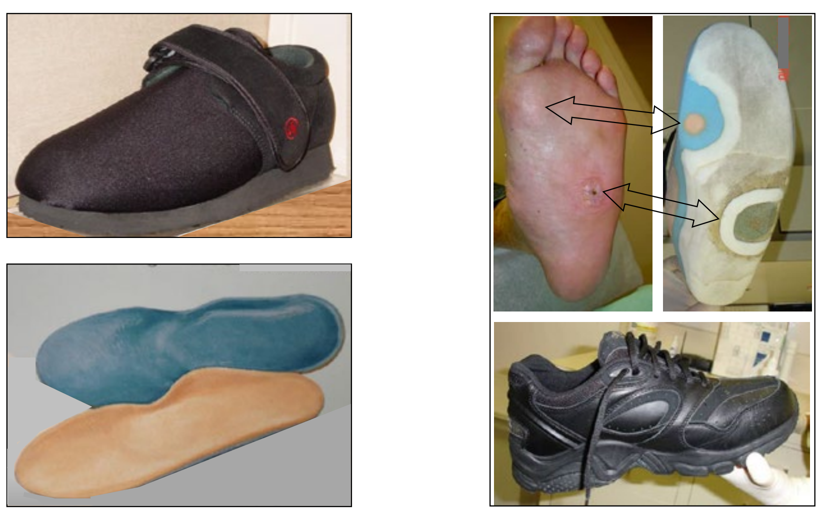
Legend: Quality walking and athletic shoes can be stylish as well as functional, but contrast markedly with the shoe in the right hand figure, which has pointed toes, a thin sole, compressed toe box, and slip-on (moccasin style) fixation to the foot.

footwear options (Figure 3). Not only is the construction of the highest quality, but they are also usually available in a variety of lengths and widths to accommodate a wide range of foot sizes. The insides of these shoes are typically well-padded and the soles fairly rigid. The shoes are generally secured by lace-up ties or Velcro® straps. Many choices have large toe boxes that provide room for clawed or hyperextended toe deformities. This footwear choice is ideal for patients without foot deformities and/or who have only minimal, if any, risk factors for wound development. Prices of quality walking or athletic shoes range from $100 to $200.

Level 2 — Off-the-shelf diabetic shoes with cushioned plantar inserts: As the name implies, these are production model (i.e., mass-produced) shoes that generally are available in most well-stocked specialty footwear and orthotic-prosthetic providers. The shoes are similar to the descriptions given above for quality walking or athletic shoes with the major difference being that there is enough room to accommodate extra-depth inserts (Figure 4). Although these shoes with the prescribed orthotics can be purchased without a prescription, a prescription by a physician is necessary for patients with diabetes to receive Medicare Therapeutic Shoe Bill benefits. There are advantages in obtaining these shoes from sales people trained in the fitting of protective footwear, including 1) improved likelihood of proper size selection, 2) experience with the choices available to comply with the footwear prescription, 3) recognition and management of special needs such as different sized shoes for each foot, 4) preparation and fitting of multidensity inserts (Table 1), 5) ability to stretch and relieve pressure areas that are noted after using the shoes and 6) recourse such as exchanges or refunds if the patient is not satisfied with the footwear that was selected.[5] In general, patients who enter the footwear selection hierarchy at this level have minimal deformities, although they have risk factors for the development of foot wounds.

Durability of Level 2 protective footwear: For household and limited community ambulation needs, off-the-shelf diabetic shoes should remain effective for approximately a year. The Medicare Therapeutic Shoe Bill allows for shoe replacement yearly. With use and time the shoes stretch, become easier to don and remove and, according to the patients, feel more comfortable. Unfortunately, these may be clues that it is time to replace the shoes. Other signs of shoe deterioration include wearing down of the heels or soles so they no longer keep the foot plantigrade, shifting of the upper portion of the shoe on the sole, wearing away of the inner linings especially over bony prominences, separation of seams, and excessive wear and tear of the upper portions. Consequently, if the shoe fits, it does not always mean it should be worn. Multidensity inserts quickly lose their cushioning ability with use. The Medicare Therapeutic

FIGURE 4. Off-the-shelf shoes with cushioned plantar inserts for diabetics



Legend: These shoes have the desirable features of the quality walking and athletic shoes (Figure 3) in addition to providing additional room for inserts. Note the relief areas in the orthotic under the first metatarsal head and lateral side of the midfoot (⟺) in the left half of the figure.

TABLE 1. Materials commonly used for shoe inserts and/or orthotics

	Material	Characteristics	Comments
Natural Varieties	Cork	Porous, lightweight; distributes forces over entire surface, but relatively firm	Often used with leather to provide padding plus durability
Natural Varieties	Felt	A firm woven cloth of wool or cotton with excellent pressure off-loading and distributing characteristics; often used in total contact casting Poor durability; retains odors; difficult to clean	Sliding effect of fibers under pressure areas off-load these areas without cutouts or reliefs
Natural Varieties	Leather	Durable, malleable, relatively rigid; long-wearing just as leather soles and upper portions of shoes are Non-cushioning	More difficult to mold and contour than foams and felt. Useful for lifts and wedges for shoes
Synthetics	Polyethylene	Closed-cell foam; soft; poor cushioning due to bottoming out quickly Moldable with low heat	Useful as padding with more rigid materials
Synthetics	Polypropylene	Rigid, moldable with heat usually after making a plaster foot mold	Often padded with a soft foam
Synthetics	Polyurethane	Soft foam with good elastic properties (i.e. does not bottom out); poor durability and resistance to tearing	Excellent as a skin-contact padding material over more rigid materials
Synthetics	Silicone	A polymer of organic silicon oxides which may be a liquid, gel or solid depending on the degree of polymerization	Excellent padding & skin contact material (especially for prostheses) Gel states excellent for off-loading pressure areas

Shoe Bill provides for replacement inserts as frequently as every four months if they are no longer effective. Prescription footwear with inserts usually costs about two to three times as much as quality walking or athletic shoes or in the $300–$500 range.

Level 3 — Custom prescriptions added to off-the shelf diabetic shoes:

This is the third level in the footwear selection hierarchy (Figure 5). This step of the hierarchy is typically associated with a single fixed (static) or dynamic deformity of the foot or ankle. Generally, shoes from the previous level are used as the foundation for the prescription modifications. A large number of options exist; essentially every shoe component previously discussed can be modified in one way or another (Table 2). When shoe modifications are prescribed, several requirements need to be met. First, the modification should address the structural deformity. The deformity can be as simple as mildly depressed metatarsal heads that require placement of a simple metatarsal pad to as complicated as deformities associated with Charcot neuroarthropathy.[6] Second, the modification needs to provide a stable, plantigrade platform for the bottom of the foot to transfer the patient's body weight to the underlying walking surface. Third, the modification needs to reduce focal areas of pressure as typically found over deformities. Fourth, the modification needs to eliminate shear stresses. For example, the indication for prescribing a filler or spacer for the forefoot after a transmetatarsal amputation (Figure 6).

Bracing for protective footwear:

Another prescription addition that may be required at this level of protective footwear is the use of the metal double upright brace (Klenzak). Whereas plastic ankle foot orthoses (AFOs) have many desirable features such as lightness and ease of application, they do not control angular and rotation deformities very well. They are most suitable for drop foot (peroneal nerve palsy) problems where a single (i.e., lack of foot dorsiflexion), nonangular deformity is present. In addition, AFOs may cause ulcerations not initially perceived by the patient due to their sensory deficits. The Klenzak brace with its distal insertion into a high-quality shoe (frequently with prescribed adjustments) can control angular, rotation, static and dynamic deformities simultaneously. In this respect, despite its weight and unattractiveness, it is a valuable asset in the armamentarium of protective footwear alterations.

FIGURE 5. Custom prescriptions added to off-the-shelf diabetic shoes

Legend: Major customized modifications to control severe lateral instability of the foot and ankle. These modifications made to an off-the-shelf athletic shoe. Note normal height of the medial side of the athletic shoe heel in the photo inset in the upper right side of the figure.

Successful use of protective footwear: Although prescription modifications may be the logical choice for the problem observed in the foot and ankle, they are not always successful. Maintaining the ability to walk and the prevention of new wound problems confirm successful use of the footwear. This is achieved only in conjunction with patient education and proper skin and toenail care. Often revisions and adjustments are needed to make the protective footwear function optimally. Even then, they may be able to only maintain the status quo — that is, prevent the wound from worsening while maintaining the patient's mobility such as in a chronic, stable wound. A second corollary of successful protective footwear modifications is that they may require ongoing adjustments. Frequently, the shape of the foot changes with time. This is especially noted with Charcot neuroarthropathies, posterior tibial tendon insufficiencies and motor neuropathies. The third corollary is to establish whether or not the deformity is static, that is present even when not weight bearing or dynamic, that is it is present only with weight bearing. In general, static deformities are harder than dynamic deformities to control with prescription adjustments. Prescription adjustments for dynamic deformities, however, have a propensity to generate shear stresses when walking and thus are more prone to cause skin ulcers. Shoe modifications/adjustments are another provision of the Medicare Therapeutic Shoe bill for diabetic patients. In general, adding prescription modifications to off-the-shelf shoes triples the costs of the unmodified shoes.

FIGURE 6. Custom prescription for a transmetatarsal amputation

Legend: Extra-depth plastizote insert plus filler for missing forefoot added to an off-the-shelf diabetic shoe that has a large toe box. The filler prevents the shortened foot from sliding forward in the shoe when walking.

Note the slight ridge at the heel portion (long black arrow) of the insert. This helps stabilize the heel. Also , note the darkened spot on the heel portion of the insert. This "dirty" area confirms that the patient has been an active ambulator with the prescription protective footwear.

Level 4 — Customized molded protective footwear: This is the fourth level in the hierarchy of footwear options and is especially suited for patients with multiple deformities that have dynamic as well as static components (Figure 7). These shoes, as the title implies, are custom molded to accommodate unique foot and ankle deformities. Common features of these shoes are their unattractive appearance, their high-topped lengths and their asymmetry with the opposite shoe. Typically, the deformities are unilateral and so severe that the footwear selections from the first three levels of the selection hierarchy are not able to protect (from new ulcerations) and maximize function of the foot and/or ankle. Examples include Boyd amputations (all the foot bones are removed except for the talus and calcaneus), rigid foot deformities in which the majority of the foot bones have fused

TABLE 2. Foot problems manageable by footwear modifications

Problems (Examples)	Modifications	Comments
Foot inversion/eversion, heel varus/valgus, midfoot hyperpronation	Molded arch supports with or without wedges added to edges of the orthotics (or soles of the shoes)	When these problems are severe and have dynamic components, double upright braces (Klenzak) attached to the shoes may be required
Bony deformities (Spurs, bunions, depressed metatarsal heads, bunionettes)	Extra-depth inserts; relief areas of pressure concentration by filing-down, off-loading with pads and/or cutting out portions of the shoe	When bony deformities are not controlled with footwear modifications, surgical correction is indicated
Partial amputations (Toes, rays, transmetatarsal, midfoot, partial heel)	Fillers/spacers; usually constructed of "memory" foams such as polyethylene	Usually attached to a full foot insert Lamb's wool is an effective filler
Rocker bottom and/or hypermobile foot segments	Conforming inserts with rigid rocker bottom shoe soles typically 2 to 4cm thick to equalize limb lengths	Thickness needed to compensate for collapses of foot and ankle bones & provide a rocker bottom platform
Proximal midfoot (Chopart & Boyd) **amputations**	Slipper-like inserts with fillers/spacers attached to them; often with cosmetic appearance to the fillers (e.g. simulated toes)	If inadequate to support foot, then high-topped shoes or orthotics that resemble a prosthesis devoid of the foot/ankle portion
Equinus contractures	Heel wedges for shoes or if mild, added to inserts inside the shoe	Stress concentrations occur on metatarsal heads; extreme precautions required for the neuropathic foot
Abduction/adduction deformities of the forefoot	If flexible, straight and reverse last shoes may control problem, especially in children	When uncontrollable, forefoot/midfoot osteotomies and/or fusions may be required

FIGURE 7. Custom molded protective footwear

Legend: Custom molded shoes to manage major deformities of the feet and ankles. Note the asymmetry of the shoe lasts and upper portions. Regardless of the appearances of the shoes, the patients were thankful that these protective footwear devices allowed them to remain ambulatory and gainfully employed while not developing new wounds.

into a solid mass, and the splayed forefoot in which the medial and lateral toes and rays are widely divergent. The costs of custom-fabricated shoes and/or double upright braces attached to prescription shoes is in the $1,000 to $1,500 range or two to three times the costs of shoes with prescription adjustments.

Charcot restraint orthotic walker (CROW) boots: The CROW boot represents the ultimate in the hierarchy of prescription footwear (Figure 8). When multiple fixed and dynamic deformities are present in the foot and ankle, uncontrollable by other means and the leg is at risk of a below-knee amputation because of them, a CROW boot is indicated. The CROW boot consists of a rigid posterior foot and leg shell that is filled with an injection molded rubberized foam material that conforms to the foot and ankle deformities. The patient steps into the posterior shell with the rubberized lining conforming exactly to the shape of the foot and leg. A padded anterior splint is placed over the front aspect of the foot and leg to close the boot and completely encircle the extremity. The anterior portion of the boot is held securely to the posterior shell with three Velcro® straps. With the uniform contact of the foam lining material, dynamic rotational problems between the foot and leg are controlled. With the elasticity of the lining material and the leeway the Velcro® straps provide in closing the CROW boot, leg swelling from fluid retention can be accommodated. The sole of the CROW boot has a rocker-bottom shape to facilitate walking with its rigid construction.[7] Typically it is 3-4 cm thick, so a thick-soled shoe may be needed on the other foot to equalize lower-extremity lengths.

Usually the deformities that are found in conjunction with the Charcot arthropathy shorten the foot and ankle so much that the thick sole of the CROW boot equalizes the lower-extremity lengths with regular-thickness shoe soles on the other foot.

Indications for a CROW boot: A CROW boot is usually not prescribed until other levels of the footwear hierarchy have been tried and found to be unsuccessful. With the most severe foot and ankle deformities such as those associated with severe deformities from Charcot neuroarthropathy, however, a CROW boot becomes a first line defense to prevent new and recurrent foot wounds and to maximize the patient's walking ability. Clinical judgment is required to make the decision. If the patient has little or no potential for ambulation, there is little indication

FIGURE 8. Charcot restraint orthotic walker (CROW) boot

Legend: The CROW boot is at the apex of the protective footwear hierarchy. Features include a thick rocker bottom sole, a rigid posterior-plantar shell, an injected molded rubberized foam lining that conforms to the patient's foot/ankle deformity, a padded anterior splint that mates with the posterior shell and Velcro® straps.

to order a CROW boot. In this situation, the ambulation goal would be mobility with a wheelchair. If the deformity is controllable by cast wear and the cast makes it possible for the patient to do limited walking, a CROW boot is indicated. As with the other levels of the protective footwear hierarchy, the CROW boot may require adjustments and replacements with time and use as the foot shape changes and the device wears.

Considerations regarding CROW boots: As desirable as the CROW boot is as a functional device for ambulation in patients with the severest of foot and ankle deformities, it has undesirable features. These include its appearance, weight and contraindication for wear when any but the smallest wounds are present. CROW boots cost $1,500 to $2,000. Even when CROW boots are prescribed with the indications given in the previous paragraph, about one-fourth of the patients do not use them. Reasons, in addition to those mentioned above, include worsening infirmities that negate walking and development of new wounds. When sizable wounds are present and/or new wounds develop, surgical options such as complex foot reconstruction or lower-limb amputation must be considered. ■

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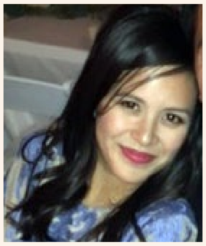
About the Authors

MICHAEL STRAUSS, M.D., an orthopaedic surgeon, is the retired medical director of the Hyperbaric Medicine Program at Long Beach Memorial Medical Center in Long Beach, California. He continues to be clinically active in the program and focuses his orthopaedic surgical practice on evaluation, management and prevention of challenging wounds. Dr. Strauss is a clinical professor of orthopaedic surgery at the University of California, Irvine, and the orthopaedic consultant for the Prevention-Amputation Veterans Everywhere (PAVE) Problem Wound Clinic at the VA Medical Center in Long Beach. He is well known to readers of *WCHM* from his multiple articles related to wounds and diving medicine published in previous editions of the journal. In addition, he has authored two highly acclaimed texts, *Diving Science* and *MasterMinding Wounds*. Dr. Strauss is actively studying the reliability and validity of the innovative, user-friendly Long Beach Wound Score, for which he already has authored a number of publications.



ANNA M. TAN, DPM, is the chief resident of podiatric medicine and surgery at Long Beach Memorial Medical Center. She graduated cum laude from the University of Southern California in 2006 and received the Dean's Award for her undergraduate research on netrin-1, a protein involved in axonal guidance. Subsequently, she attended the California School of Podiatric Medicine at Samuel Merritt University in Oakland, California, receiving her doctor of podiatric medicine degree in 2014. Dr. Tan has special interests in surgical management of problem wounds and limb salvage. In her spare time, she enjoys Bikram yoga, cooking and traveling.

LIENTRA LU is a research coordinator at the VA Medical Center in Long Beach, California, under the guidance of Dr. Ian Gordon, a vascular surgeon, and Dr. Michael Strauss. She is also an administrative assistant in the accounting department of the Southern California Institute for Research and Education (SCIRE). She received a bachelor of science degree in chemical biology at the University of California, Berkeley, in 2015 and subsequently has taken medically related courses at the University of California, Los Angeles. Miss Lu is helping with diabetic foot and venous leg ulcer studies at the VA Medical Center while also serving as an assistant in patient care at the PAVE Clinic there. She also works with the American Red Cross in her other interest, disaster preparedness.

Textbook of Chronic Wound Care: Chapter 1

Textbook of Chronic Wound Care: An Evidence-Based Approach to Diagnosis and Treatment by Drs. Jayesh Shah, Paul Sheffield, and Caroline Fife, editors, is a companion reference book for the *Wound Care Certification Study Guide*, 2nd edition. Due for publication by Best Publishing Company in the first quarter of 2017, this textbook provides the best diagnostic and management information for chronic wound care in conjunction with evidence-based clinical pathways illustrated by case studies and more than 350 pictures. The textbook provides up-to-date information for the challenging chronic wound care problems in an easy-to-understand format. What follows is a reprinted excerpt from Chapter 1, Anatomy of the Skin, written by Herbert B. Slade MD, FAAAAI, and Jamie M. Slade, MD.

Introduction

Skin is an integumentary system at the interface between the human organism and its environment (Table 1). The boundary limits of skin are found at its transition to mucosal surfaces of the respiratory, alimentary, and urogenital systems; at the conjunctival epithelium of the eye; at the ductal epithelium of the lacrimal and mammary ducts; and at the tympanic membrane of the ear.

Anatomically, skin is organized into an outer layer of epidermis covering a deeper layer of dermis, which is further subdivided into papillary dermis and reticular dermis. The epidermal epithelium gives rise during fetal development to the skin appendages, namely the hair follicles and associated sebaceous glands (pilosebaceous units), eccrine and apocrine sweat glands, and nails. Beneath the dermis is the hypodermis or subcutaneous fat layer (the panniculus adiposus). Connections between skin and its underlying hypodermis include ligaments, nerves, blood vessels, and lymphatic vessels.

The gross appearance of skin varies between individuals, within an individual by anatomic location at any point in time, and within an individual over a lifetime. Variation is found with respect to texture, tone, distribution and amount of pigmentation, and expression of hair. For example, scrotal skin is very thin, with readily visible hair roots, specialized sebaceous glands, and few or no elastic fibers but considerably greater laxity compared with skin covering the trunk. By contrast, the glabrous skin of the palms and soles is tightly fixed to the underlying fascia, lacks hair follicles and sebaceous glands, and contains sweat pores opening into ostia located along prominent friction ridges. The epidermis is considerably thicker.

The overall thickness of skin across the body is determined by the thickness of the several layers of epidermis and the thickness of the underlying dermis. Typical thickness in a young adult ranges from the eyelids (epidermis ~50 µm, dermis ~1,000 µm) to the back (epidermis ~40 µm, dermis ~5,000 µm), to the palms of the hands (epidermis ~600 µm).[1-2] The thickness of the outermost cornified layer (the stratum corneum) is greatest in areas of callous but also varies among flexor forearm, thigh, back and abdomen across a range of ~13µm (flexor forearm) to ~8µm (abdomen).[3] Published values for these measurements differ considerably, likely as a result of differences in location of sampling, methods of visualization, and methods of preservation in the case of biopsy material.[4-5]

The structure of the skin (Figure 1) is established through the orchestrated arrival, arrangement, and differentiation of a broad array of cell lineages during embryogenesis and fetal development.[6] When it is fully developed, approximately 20 different types of cells are found in association with a complex extracellular matrix that provides both strength and flexibility[7] (Table 2).

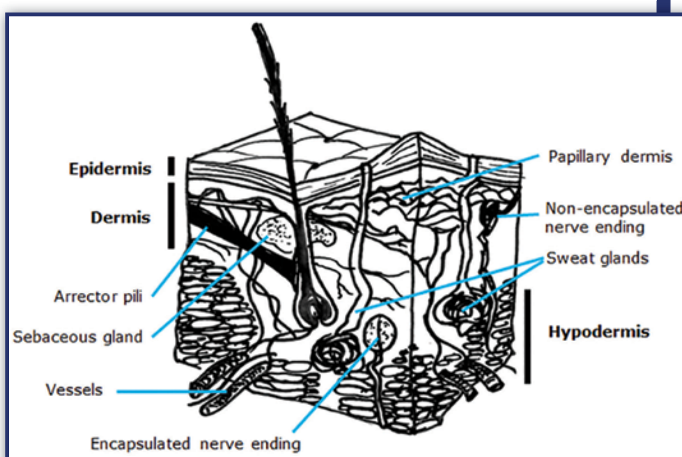


FIGURE 1: Organization of the skin

Courtesy of Jessica A. Slade, ME

I. Epidermis

Full keratinization of the outermost keratinocytes is achieved prior to birth, by gestational weeks 26-28. The epidermis at birth is still relatively thin with only 2-3 cell layers in the stratum spinosum and 5-6 layers in the stratum corneum.[8] The thick whitish "vernix caseosa" covering the epidermis at birth is a product of the sebaceous glands combined with shed periderm and squames. A mixture of water, proteins, antimicrobial enzymes and lipids, the vernix is thought to provide a degree of protection against maceration while the skin is exposed to amniotic fluid, while allowing the skin to hydrate itself more rapidly following birth.[9] Removal of the vernix at birth leaves the stratum corneum drier than adult skin for some time.

Four distinct epidermal layers persist into adult life, with a basal germinative layer resting upon a basement membrane elaborated through cooperative effort between the basal keratinocytes and the underlying mesodermal fibroblasts. A fifth layer of cells can be found beneath friction ridges on the palms of the hand and soles of the feet, between the granular and horny layers. Fully developed epidermis is thus a stratified squamous arrangement consisting of a basal layer of stem and transit-amplifying cells,[10-11] above which are the spinous, granular, clear, and horny layers. The corresponding Latin descriptive terms – stratum basale, stratum spinosum, stratum granulosum, stratum lucidum, and stratum corneum – remain in use. The integrity of epidermis is maintained by various connections between cells and at the basal layer, with the basement membrane. Basal cells use hemidesmosomes, integrins, and anchoring fibrils to maintain contact with the basement membrane, while desmosomes, gap junctions, and adherens junctions keep them connected

TABLE 1. Functions of the integumentary system

Function	Major structure(s) or cells
Waterproofing	Stratum corneum
Protection against minor trauma	Stratum corneum
Prevent entry of toxins	Stratum corneum
Moisture balance	Epidermis
Vitamin D, hormone production	Keratinocytes
Prevention of invasion by pathogens	Epidermis, dermis, lymphatics
Regeneration	Basal epithelium, hair follicles, blood vessels
UV radiation protection	Melanocytes
Physical cushioning	Dermis, subcutaneous fat
Insulation	Hair, subcutaneous fat, arrector pili muscles
Temperature regulation	Vasculature, sweat glands, motor nerves
Sensation	Sensory nerves
Immunity	Dendritic cells, lymphocytes, lymphatic channels

with each other and with cells of the spinous layer. Desmosome, gap junctions, and adherens junctions persist in the spinous layer, while in the granular layer the gap junctions give way to tight junctions. Adherens junctions and desmosomes persist in the granular layer, while in the stratum corneum the predominant connections are corneodesmosomes and tight junctions. Although epidermis is commonly thought of in terms of a "bricks and mortar" organization, cells other than keratinocytes make their way into the epidermis, some of them sending dendritic extensions between the keratinocytes (melanocytes, Langerhans cells) or crawling into and through the epidermis to perform immunologic surveillance.

Melanocytes have a remarkably different shape compared with resting keratinocytes, with long extensions termed "dendrites" passing between and around their keratinocyte neighbors. These cells take up residence in the stratum basale and in the hair bulb. Within the stratum basale, the ratio of melanocytes to basal keratinocytes is approximately 1:10, with each melanocyte associating with 30-40 keratinocytes above the basal layer through dendritic extensions.[12] An essential role of melanocytes is to protect the basal cells from ultraviolet radiation, accomplished through the production and transfer of melanin via melanosomes. The darkness of skin pigmentation does not depend on the number of melanocytes, which is constant across all skin tones, but rather on the extent to which melanin is produced and the size of the melanosomes, which serve as transport vehicles from the melanocytes to the keratinocytes.

Epidermal Langerhans cells are found in the epidermis, replicating there to replace dying cells and cells which have migrated to the draining lymph nodes. There does not appear to be any need for replenishment from the circulation, although circulating monocytes can enter the skin and differentiate into scavenging and antigen presenting dendritic cells.

II. Dermis

Development of the dermis is largely controlled by fibroblasts. Each of the embryonic fibroblast precursor lines is thought to split into distinct lineages, giving rise to "upper lineage" fibroblasts, which include fibroblasts of the papillary dermis, the hair follicle dermal papilla, dermal sheath cells surrounding hair shafts, and the arrector pili muscle. It also includes "lower lineage" reticular fibroblasts, pre-adipocytes, and adipocytes. Cells of the lower lineage are primarily involved in replacement of extracellular matrix following wounding, while cells of the upper lineage support re-epithelialization.[13] The depth of injury determines the types of cells, which become engaged in repair, with lacerations extending into the middle depth of reticular dermis leading to a scarring response. Lacerations of the superficial dermis can repair themselves without visible scarring.[14] In addition to depth of injury, the amount of tension experienced by fibroblasts and the duration of inflammation also affect scarring. Primary closure of lacerations reduces tension, while control of infection limits inflammation, resulting in reduced scarring.

Hair follicles are widely distributed in skin. Epidermal cells form the primitive hair germ, penetrating as a column into the underlying dermis. An invagination or papilla is formed at the column tip into which mesodermal blood vessels and nerve endings develop. Fibroblasts within this dermal papilla seem to induce the follicular epithelial cells in the center of the follicle to undergo differentiation into central cortex cells, which generate the keratinized hair shafts. The dermal papilla and surrounding epithelial matrix cells constitute the bulb of the hair follicle. The hair shaft itself eventually

TABLE 2. Cells found in healthy adult skin

Name	Location	Function	Subsets
Keratinocyte	Epidermis	Regeneration of the stratum corneum, re-epithelialization of denuded skin, acidification of the skin surface, antimicrobial peptide production, inflammatory signaling. Terminally differentiated keratinocyte providing a physical and chemical barrier	Basal, transit amplifying, granular, corneocyte
Fibroblast	Dermis	Generation of extracellular matrix, repair	Papillary, reticular, myofibroblast
Melanocyte	Basal layer of epidermis, hair follicle bulb	Protection against ultraviolet radiation, hair coloration	---
Merkel cell	Epidermis at dermal-epidermal boundary, upper portion of hair follicle	Touch sensation through connection with nerve endings in Touch Domes	---
Endothelial cell	Blood vessel lining, lymphatic vessel lining	Vascular channels	Blood vascular, lymphatic vascular
Pericyte	Abluminal basement membrane of endothelial cells	Support endothelial cells, participate in angiogenesis	---
Neuronal axons	Nerves	Sensory and motor nervous functions	Based on neurotransmitters, end structures, efferent or afferent function
Schwann cell	Surrounding neuronal axons	Create myelin sheaths to insulate nerves	---
Endoneural cell	Surrounding Schwann cells	Protect and support Schwann cells	---
Perineurial cell	Surrounding endoneural cells	Create nerve fascicles	---
Myocytes	Smooth muscles	Express the contents of glands, cause "goosebumps" and hair erection, modulate blood flow	Arrector pili, vascular smooth muscle, glandular smooth muscle
Mast cell	Near blood vessels	Innate immune defense, immune modulation, wound healing, angiogenesis	---
Macrophage	Near blood vessels	Immune surveillance, cell killing, phagocytosis of cell debris	M1, M2
Dendritic cell	Epidermis and dermis	Immune surveillance	Langerhans cells, conventional dendritic cells, plasmacytoid dendritic cells
Lymphocyte	Epidermis and dermis	Immune surveillance, cell killing, regulation of adaptive immune responses	Memory CD4+, memory CD8+, $\gamma\delta$-T cell, invariant $\alpha\beta$-NKT, variant $\alpha\beta$-NKT, anergic CD4+, Tr1 T-regulatory, Th3 T-regulatory
Adipocyte	Hypodermis	Energy storage (triglycerides), thermal insulation, modulation of inflammation (adipokines)	Pre-adipocytes, adipocytes
Stem cell	Hypodermis, basal epithelium, hair follicle "bulge region"	Regeneration of various cell lines	Keratinocyte stem cells, mesenchymal stem cells, skin-derived precursor cells

consists of a medullary core, surrounded by the cortex and hair shaft cuticle.[15]

Along the upper portion of the hair follicle, superficial to what will become the upper cutaneous plexus of blood and lymphatic vessels, one or more small out buddings of the epithelial follicular sheath develop into the dermal sebaceous glands. These glands generate a lipid-rich material (sebum) that rises to the skin surface alongside the hair shaft, lubricating the skin and occluding the shaft. Deeper along the hair follicle below the forming vascular plexus, mesodermal cells give rise to smooth muscle fibers which develop into the arrector pili muscles.[16] These muscle fibers are anchored to the follicle at the “bulge region” of the outer root sheath and superficially to connective tissue beneath the basement membrane, such that a sebaceous gland is often located between the muscle and the hair follicle. Activation of these muscles results in the hairs becoming more vertical and a small amount of sebum being expressed from the glands between the shaft and muscle.

A single hair follicle with its associated sebaceous gland(s), arrector pili muscle, and papilla is termed a pilosebaceous unit. Arrector pili muscles may attach to several adjacent follicles within a follicular unit consisting of 2-6 follicles. Pilosebaceous units serve as reservoirs of Langerhans cells. They are normally absent from the glabrous skin of the palms and soles. Pilosebaceous units differ between the scalp and beard region (terminal units), the axilla and groin (apopilosebaceous units), the face, back, and chest (sebaceous units), and the remainder of the skin (vellus units). Vellus hair follicles extend to the upper or middle reticular dermis, while terminal hair follicles and surrounding dermis protrude down through the interface with the hypodermis.

Eccrine sweat glands (“true” sweat glands) develop over most parts of the skin, beginning in a similar manner to hair follicles with an extension of germinative epidermal cells down into the developing dermis. The coiled secretory gland is located at or below the level of the hair follicle bulb, with a relatively straight dermal portion of duct becoming a spiraled duct as it passes through the epidermis (the acrocyringium).

Apocrine sweat glands develop normally as a third bud from hair follicles, superficial to the sebaceous glands. These are notably present in the axilla and pubic regions, areola and nipple of the breast, eyelids, and circumanal region. With the exception of the modified apocrine glands forming the ciliary glands in the eyelids and the ceruminous glands in the auditory canal, these specialized structures do not begin development until puberty. Other distinguishing features are that the secreted product of apocrine glands normally exit the skin from the hair follicle and includes remnants of the secretory vesicles which are released from the glandular cells. The milk-producing mammary glands are modified apocrine glands. Myoepithelial cells arising from the basal layer of the glands provide a smooth muscle shroud that can squeeze the contents of the gland out through the duct.[17]

Multipotential hematopoietic stem cells arising from the fetal liver and bone marrow give rise to mast cell committed progenitors, which interact with fibroblasts in their environment to determine their differentiation into connective tissue mast cells which are found associated with blood vessels, nerves, and skin appendages of the subpapillary dermis.[18]

III. Dermal-epidermal junction

The boundary separating the epidermis from the dermis is marked by a basement membrane, occupied along its superior border by basal keratinocytes, which bind to basement membrane anchoring filaments. On the inferior aspect of the basement membrane are anchoring fibrils attaching into the extracellular matrix of the papillary dermis. Including the anchoring elements, the "basement membrane zone" is typically described as having four layers:

- A basal keratinocyte hemidesmosome layer
- The lamina lucida
- The lamina densa
- A lamina reticularis (or fibroreticularis)

The epidermis extends into the papillary dermis at regular intervals to form rete pegs, thus increasing the amount of contact between epidermis and dermis. The rete pegs deepen following term birth. On the palms and soles, the dermal-epidermal boundary forms extended ridges and troughs termed friction ridges, most prominently visible at the fingertips (fingerprints).[19]

IV. Hypodermis and dermal attachment

The loose connective tissue beneath the dermis is termed the hypodermis or subcutaneous layer. A prominent feature of this layer is adipocytes (fat cells) organized into prominent lobules separated by fibrous septa containing the blood and lymphatic vessels. Fibroblasts, macrophages, mast cells, and mesenchymal stem cells are also found in the hypodermis. A thin layer of smooth muscle termed the tunica dartos scroti (male) and tunica dartos labia majora (female) is found within the subcutaneous fascia of the genital region, where it will contract in response to cold temperatures to tighten and wrinkle the skin. Muscle fibers are also found in reticular dermis adjacent to the nipple, in the penis, and perineum. Immediately beneath the hypodermis is a more densely fibrous deep fascia. Human skin attaches to underlying skeletal muscle groups indirectly via small fibrous bands termed skin ligaments (retinacular ligaments), extending through the hypodermis to connect the deep reticular dermis with the underlying fascia.[20] Although widely distributed, the skin ligaments are not uniform across the body. In the upper trunk, limbs, head, and neck, the ligaments provide a close association with underlying muscles. Elsewhere, such as the abdominal region and buttocks, attachments are less dense. In particular regions these ligamentous structures are prominent, as with Cooper's suspensory ligaments in the breast. Various degrees of tethering create greater or lesser limits to the movement of skin over the underlying fascial planes.

The depth of sharp debridement can be gauged by key differences in the appearance of these distinctive layers. Bleeding occurs at the papillary dermis and deeper, white collagen bundles are prominent in the reticular dermis, yellow bundles of adipocytes mark the hypodermis, while fascial planes, ligaments, and muscle fibers indicate the lower boundary of the skin.

V. Vascularization

The epidermis contains no blood vessels (Figure 2). Nutrients arrive by diffusion from capillaries in the papillary dermis, while oxygen arrives both by diffusion through tissue and by direct uptake from the atmosphere. It is currently estimated that atmospheric oxygen penetrates to a depth of 250 – 400 μm, which includes the full epidermis and much of the papillary dermis.[21] Atmospheric oxygen flux through skin decreases when more skin capillaries open up, but shutting off capillary flow results in only a small increase in oxygen flux directly from the atmosphere.[22] Thus a lack of vascular perfusion cannot be overcome by direct diffusion except under hyperbaric conditions.

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