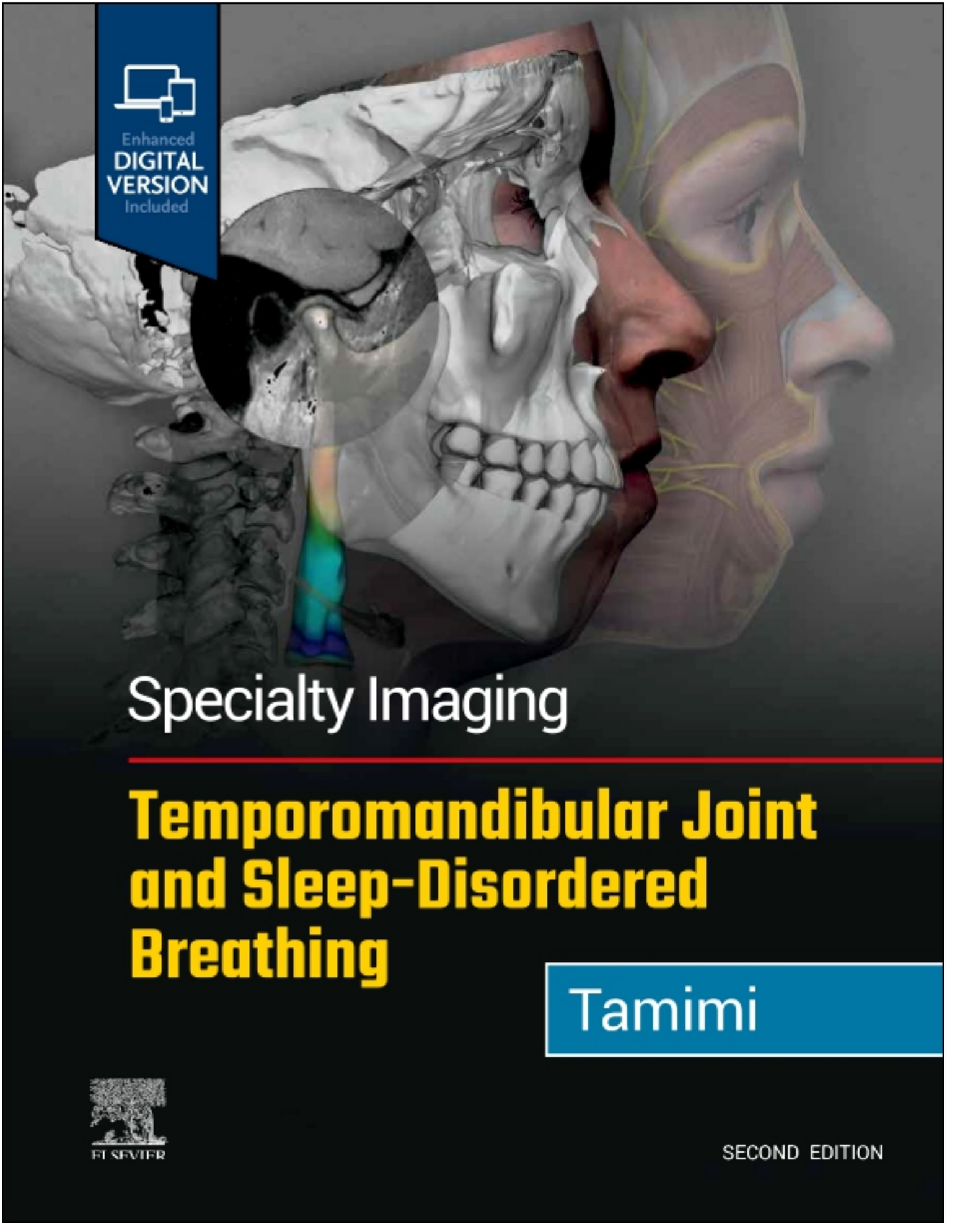


Additional Contributors

Noura Alsufyani, BDS, MSc, PhD
Associate Professor
College of Dentistry
King Saud University
Riyadh, Saudi Arabia
Adjunct Professor
School of Dentistry
University of Alberta
Edmonton, Alberta, Canada

Ronald C. Auvenshine, DDS, PhD
Diplomate, ABOP
Visiting Full Professor
Louisiana State University
School of Dentistry
New Orleans, Louisiana

Ben J. Balough, MD
CAPT, USN, ret
Neurotologist
Department of Head and Neck Surgery
The Permanente Medical Group
Kaiser Permanente Northern California
Kaiser Permanente South Sacramento
Medical Center
Sacramento, California

Steve Carstensen, DDS, FAGD, FACD, FICD
Clinical Assistant Professor
Louisiana State University
School of Dentistry
New Orleans, Louisiana
Premier Sleep Associates PLLC
Bellevue, Washington

Husniye Demirturk, DDS, MS, PhD
Adjunct Assistant Professor
Department of
General Dental Sciences
Marquette University
School of Dentistry
Milwaukee, Wisconsin
Oral and Maxillofacial
Radiology Consultant
Private Practice
Wexford, Pennsylvania

Joanne Ethier, DMD, MBA, MS
Oral and Maxillofacial
Radiology Consultant
Imagix Medical
Montreal, Quebec, Canada

Luigi M. Gallo, MEng, PhD
Full Professor Emeritus
Clinic of Masticatory Disorders
Center of Dental Medicine
University of Zurich
Zurich, Switzerland

Domingo Martín, MD, DDS
Orthodontist
Martín Goenaga Clinic
San Sebastián, Spain

Isabel Moreno-Hay, DDS, PhD
Associate Professor and Division Chief
Orofacial Pain
University of Kentucky
College of Dentistry
Lexington, Kentucky

Jeffrey P. Okeson, DMD
Professor and Dean
University of Kentucky
College of Dentistry
Lexington, Kentucky

Kaan Orhan, DDS, MSc, MHM, PhD, BA
Professor Doctor
Department of
Dentomaxillofacial Radiology
Ankara University
Ankara, Turkey

Soroush Zaghi, MD
ENT, Sleep Surgeon
The Breathe Institute
Los Angeles, California

Seçil Aksoy, DDS, PhD
Associate Professor
Department of
Dentomaxillofacial Radiology
Near East University
Lefkosia, Turkey

Asma'a Al-Ekrish, MDS, Cert. Diag. Sci.
Professor
Department of Oral Medicine and
Diagnostic Science
Division of OMF Radiology
King Saud University
Riyadh, Saudi Arabia

Hakan Amasya, DDS, MSc
Assistant Professor
Department of
Dentomaxillofacial Radiology
İstanbul Üniversitesi-Cerrahpaşa
Istanbul, Turkey

Burak Bilecenoğlu, DDS, PhD
Professor
Department of Anatomy
Ankara Medipol University
Ankara, Turkey

Alberto Canabez, MD
Clinical Assistant Professor
Department of Orthodontics
Complutense University of Madrid
Madrid, Spain
Clinical Assistant Professor
Department of Orthodontics
Barcelona University
Orthodontist
Den Clinica Dental
Barcelona, Spain

Peruze Celenk, DDS, PhD
Department of Oral
and Maxillofacial Radiology
Ondokuz Mayıs University
School of Dentistry
Atakum, Samsun, Turkey

Ryan P. Donahue, PhD
Department of
Biomedical Engineering
University of California, Irvine
Irvine, California

Chirag Govardhan, MD
Research Associate
The Breathe Institute
Los Angeles, California
Resident
Department of Internal Medicine
Icahn School of Medicine
at Mount Sinai
New York, New York

Michael Gunson, DDS, MD
Clinical Assistant Professor
Department of Orthodontics
Boston University Henry M. Goldman
School of Dental Medicine
Boston, Massachusetts
Private Practice
Santa Barbara, California

Reem H. Hossameldin, BDS, MSc, PhD
Associate Professor OMFS
Faculty of Dentistry
Cairo University
Cairo, Egypt

Jerry C. Hu, PhD
Academic Program Management Officer
Department of Biomedical Engineering
University of California, Irvine
Irvine, California

Can Kocasarac, MD
Clinical Assistant Professor
Department of Ophthalmology
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

Jay Harris Levy, DDS
Private Practice
Portland, Oregon

Dann Martin, MD, MS
Assistant Professor of Neuroradiology
Department of Radiology and Radiologic Sciences
Vanderbilt University Medical Center
Monroe Carell Jr. Children's Hospital at Vanderbilt
Nashville, Tennessee

Tugrul Ormeci, MD, MSc, PhD
Professor
Department of Radiodiagnostics
Istanbul Medipol University
Istanbul, Turkey

Ulas Oz, DDS, PhD
Department of Orthodontics
School of Dentistry
Final International University
Nicosia, North Cyprus

Mariano Rocabado, PT, DPT, CCTT
Full Professor
Universidad de Chile
Full Professor
Universidad Andrés Bello
Doctor of Physical Therapy
Director
Instituto Rocabado
Santiago, Chile

Bayram Ufuk Sakul, MD
Prof. Dr. (Anatomy)
Istanbul Medipol University
Istanbul, Turkey

Adina Sirbu, DMD, PhD
Iuliu Hatieganu University of Medicine and Pharmacy
Cluj-Napoca, Romania

Colin J. Stanhope, DDS, MD
Resident
Department of Oral and Maxillofacial Surgery
University of Maryland Medical Center
Baltimore, Maryland

Gürkan Ünsal, DDS, PhD
Assistant Professor
Department of Dentomaxillofacial Radiology
Near East University
Nicosia, Cyprus

Gary Warburton, DDS, MD, FACS
Professor and Chair
Department of Oral and Maxillofacial Surgery
University of Maryland
Baltimore, Maryland

Other Contributors

Yoshimi Anzai, MD, MPH
Byron W. Benson, DDS, MS
Arnaud F. Bewley, MD
Philip R. Chapman, MD
Derek D. Cissell, VMD, PhD, DACVR
Rebecca S. Cornelius, MD, FACR
Julia R. Crim, MD
H. Christian Davidson, MD
Kathryn E. Dean, MD
Kara G. Gill, MD
Bronwyn E. Hamilton, MD
H. Ric Harnsberger, MD
David Hatcher, DDS, MSc
Patricia A. Hudgins, MD, FACR
Troy A. Hutchins, MD
Le W. Huwe, BS
Richard W. Katzberg, MD
Nayela Keen, MD
Bernadette L. Koch, MD
Lisa J. Koenig, BChD, DDS, MS
Nicholas A. Koontz, MD
Donald V. La Barge, III, MD, MBA
Luke N. Ledbetter, MD
Daewoong Lee, MD
Joseph P. McCain, DMD
Daniel E. Meltzer, MD
Louis G. Mercuri, DDS, MS
Michelle A. Michel, MD
Kevin R. Moore, MD
Kristine M. Mosier, DMD, PhD
William T. O'Brien, Sr., DO, FAOCR
Guillermo Ochoa, BDS
Susanne E. Perschbacher, DDS, MSc, FRCD(C)
Cheryl A. Petersilge, MD, MBA
C. Grace Petrikowski, DDS, MSc, FRCD(C)
Nathan J. Pettit, DMD, MSD
C. Douglas Phillips, MD, FACR
Shikha Rathi, BDS, MS
Caroline D. Robson, MBChB
Jeffrey S. Ross, MD
Axel Ruprecht, DDS, MScD, FRCD(C)
Karen L. Salzman, MD
Lubdha M. Shah, MD
Deborah R. Shatzkes, MD
Aparna Singhal, MD
Roya Sohaey, MD
Hilda E. Stambuk, MD
Sara Strauss, MD
Bradley Strong, MD
Margot L. Van Dis, DDS, MS
Surjith Vattoth, MD, FRCR
Richard H. Wiggins, III, MD, CIIP, FSIIM, FAHSE, FACR
Blair A. Winegar, MD

Preface

The first thing that may occur to you when seeing this book title is, "Why TMJ and sleep-disordered breathing (SDB) in one book? Why not dedicate separate tomes to each of these topics?" While each topic is certainly hefty enough to warrant two separate textbooks, the reality is that these topics are interrelated and intertwined in more ways than we previously realized. The answer to this question comes with an unfolding in the evolution of thought and understanding of the craniofacial system and how its different components interact with one another. After consultation with my mentor and previous coauthor, Dr. David Hatcher, it seemed like the obvious evolution and progression of *Specialty Imaging: Temporomandibular Joint*.

The craniofacial-craniocervical complex is a system that has multiple components that interact with one another. This system grows and evolves in specific patterns according to function or dysfunction, cross-talking with itself and with the rest of the body through the myofascial and nervous systems. The dysfunction of one component will affect the other through these relationships. Even though these structures are at an intersection between medicine and dentistry, these concepts may not be mainstream in medical and dental education, and the dialogue for discussing patient care when the area involved lies in the craniofacial complex is often difficult because of the disconnect between the disciplines. This book aims to bring everyone on the same page by presenting knowledge common to each discipline and making it readily available to the other. At the beginning of the book are two abbreviations lists with terminology common to dentistry and medical radiology to get the conversation started by introducing the common lingo in both disciplines.

In order to help the medical or dental reader understand the craniofacial-craniocervical system more fully, I have started the book with an extensive section aimed at helping the understanding of the TMJ and upper respiratory tract as dynamic and functional structures, from the embryology of these structures, their biodynamics, and some concepts that help explain their interactions. The second section deals with anatomy, the king of the sciences when it comes to radiographic evaluation. The third displays the different modalities used for imaging the TMJ and the upper respiratory tract for SDB with new chapters on ultrasonography and dynamic imaging added.

The TMJ diagnosis section contains chapters on most conditions affecting the TMJs. It is followed by a section on conditions that mimic TMD that are not in the direct area of the TMJs, such as temporal bone and cervical spine abnormalities. The cervical spine changes can also affect the upper respiratory tract, and the relevance of a spinal change to SDB is covered in each of the entity chapters. The upper respiratory tract diagnosis chapters identify possible reasons for upper respiratory tract obstruction that are not purely morphological and inflammatory. This is to help the practitioner rule out neoplasia as the reason for the obstruction. The risk factors for SDB in each anatomic location are also presented for completion.

The differential diagnosis section has two components: The TMJ component and the SDB component. Each has two subsections: Clinical and radiographic differential diagnosis. This is to give the clinician and the radiologist a quick reference and list of differentials to consider when faced with a clinical presentation/symptom or radiographic appearance.

The last section of the book deals with the surgical and invasive procedures for the TMJ and SDB and their radiographic considerations. Written by eminent experts in this surgical field, the purpose of this section is to help the radiologist think like the referring surgeon and to understand the anatomic considerations as well as ideal and less-than-ideal outcomes that can present radiographically.

Just like in all my teaching and writing, this book was written to bridge the gap between dentistry and medicine with both dental and medical physicians in mind. It takes a more holistic approach to diagnosis with an understanding of the cause and effect of function and dysfunction on the anatomy and morphology of the craniofacial complex. Just as there is cross-talk in the human body, there should be cross-talk in patient healthcare. I hope this book will help start this conversation.

Dania Tamimi, BDS, DMSc
Oral and Maxillofacial Radiology Consultant
Private Practice
Orlando, Florida

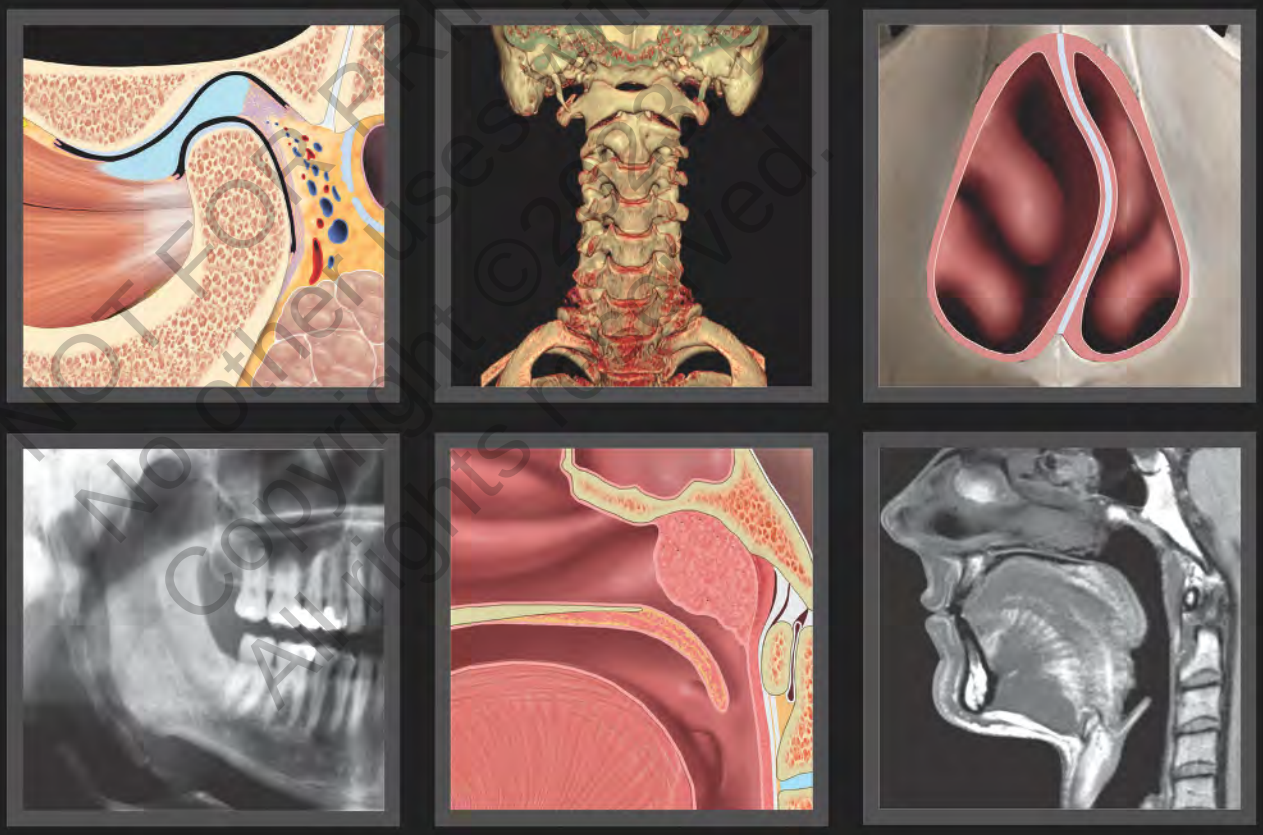


TABLE OF CONTENTS

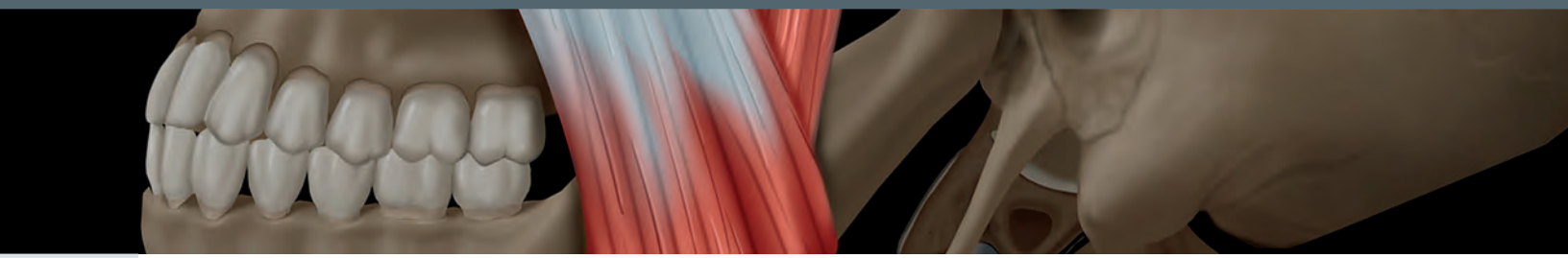


TABLE OF CONTENTS

TABLE OF CONTENTS

SECTION 4: TMJ DIAGNOSES

CLINICAL PRESENTATION OF TMD

CONGENITAL CONDITIONS

DEVELOPMENTAL CONDITIONS

TRAUMA

INFLAMMATORY CONDITIONS

DEGENERATIVE CONDITIONS

DISC DERANGEMENT CONDITIONS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

Identification of At-Risk Individuals

People reporting to a sleep medicine clinic have often been screened for risk of a sleep-related medical disorder. Aware providers, such as dentists, anesthesiologists, primary care doctors, and nurse practitioners, observe behavior &/or ask screening questions to determine whether a referral for a diagnosis is appropriate. Untrained people may also observe excessive sleepiness, drowsy driving, or breathing disorders, such as snoring. The person at risk might notice cognitive difficulties ("brain fog") or feeling unrefreshed in the morning. There are physical signs that the astute clinician can use to guide the history and physical examination, but none are pathognomonic for sleep-disordered breathing.

People may appear sleepy for several reasons. It is common in many cultures to have self-restricted sleep time through lifestyle choices, leading to an insufficient amount of sleep. Poor sleep quality also contributes to excessive daytime sleepiness. If sleep is disturbed by frequent interruptions to normal respiration, the patient is diagnosed with a sleep-related breathing disorder.

Determining the source of the symptoms is first a matter of clinical protocols for screening, then diagnosis of those judged at risk, and finally treatment determined by the diagnosis. This document will focus on sleep-related breathing disorders, but it is important that the clinician realizes there are 3 main categories of sleep disorders: Insomnia, hypersomnia, and unusual sleep-related behaviors. These categories encompass 59 distinct diagnoses listed in the International Classification of Sleep Disorders, version 3 (ICSD-3). The International Classification of Disease (ICD-11) has many more. Coding and descriptions overlap but often do not directly relate between these 2 systems.

Symptoms of Sleep-Related Breathing Disorders

A patient with easily observable symptoms, such as falling asleep in inappropriate circumstances or demonstrating apnea during low-level anesthesia, is sent to physicians trained in the diagnosis of sleep disorders. Most of these are board-certified sleep physicians, a subspecialty of medicine with a 1-year fellowship program added to a primary specialty. Most sleep physicians are pulmonologists or neurologists, but any physician can enroll in a sleep fellowship. Many people have symptoms suggesting poor sleep quality but do not consider themselves to have a medical disorder. Snoring, for example, is a common sign but is uncommonly associated with serious medical risk despite connections to chronic problems, such as carotid atherosclerosis and fatty liver disease. Snoring is often considered a lifestyle problem, low risk if left untreated. For others, the social discord that can accompany loud snoring is the motivating factor for assessment and diagnosis. It is important to determine whether the patient recognizes their level of risk, denies it, or is unaware.

Many clinicians are similarly unaware of obstructive sleep apnea, the most serious level of the sleep-related breathing disorders, or the connection between snoring and medical risk. The figure most often cited is > 80% of adults with moderate to severe obstructive sleep apnea remain undiagnosed despite regular visits to medical and dental providers.

Symptoms of compromised breathing during sleep vary widely, making simple observation unreliable for assessing the severity of medical risk. There are many validated screeners available to the provider to determine risk. The ones most common in use include the Epworth Sleepiness Scale, the Berlin Questionnaire, and the STOP-BANG screener.

Screener Tools

The Epworth Sleepiness Scale is perhaps the most universally recognized screener available. It consists of 8 questions providing a subjective self-assessment of drowsiness. Berlin and STOP-BANG screeners are more oriented toward sleep-related breathing disorders in adults. The fact that every screener available is subjective does not make their results meaningless, but it does require clinical assessment to provoke more specific diagnostic testing. Often the best use of a screener is to move a person from "unaware" to "aware" so they will acknowledge their condition and take action toward their health. It is encouraged to pick a screener that fits the office workflow, ask every adult patient to complete it, and have a diagnosis plan for those identified to be at risk.

Epworth Sleepiness Scale

This screening tool asks the patient the following question: How likely are you to doze off or fall asleep in the situations described below in contrast to feeling just tired? This refers to their usual way of life in recent times. Even if they have not done some of these things recently, they can envision the effect they would have. The patient uses the following scale to choose the most appropriate number for each situation: 0 = would never doze; 1 = slight chance of dozing; 2 = moderate chance of dozing; 3 = high chance of dozing.

- Sitting and reading
- Watching TV
- Sitting inactive in public place (e.g., theatre or meeting)
- As passenger in car for 1 hour without break
- Lying down to rest in afternoon when circumstances permit
- Sitting and talking to someone
- Sitting quietly after lunch without alcohol
- In car while stopped for a few minutes in traffic

The total for all these situations would be tallied and compared to the following scores.

- 0-10 = normal range
- 10-12 = borderline
- 12-24 = abnormal

Common Symptoms of Sleep-Related Breathing Disorder Include

- Snoring loud enough to disturb bed partner or be heard outside bedroom
- Observed apnea events: Person stops breathing or obviously is attempting to breathe, unsuccessfully
- Excessive daytime sleepiness not otherwise explained, e.g., too short of sleep period
- Hypertension, especially if refractory to antihypertensive medications
- Feelings of cognitive difficulty
- Waking unrefreshed
- Frequent wake periods during sleep (sleep maintenance insomnia)
- Nocturia unexplained by other conditions, such as prostate hypertrophy or pregnancy
- Bruxism

Signs to Look for in Clinic

Physical signs of sleep-related breathing disorders are similarly difficult to connect with the disease due to lack of specificity. An example: Worn teeth may be from bruxism, gastric reflux, diet, another cause specific to that person, or a combination of several factors. Bruxism may have its etiologic roots in sleep disturbances, stress, chronic pain, muscle pattern memory, or a neurologic cause. Researchers generally conclude it is multifactorial. If the clinician observes a crowded upper airway, a more detailed medical history and behavioral assessment may prove productive.

- Nasal obstruction: Inability to breathe through the nose for at least 2 minutes, keeping lips together entire time
- Macroglossia: Either true tongue enlargement or normal size tongue surrounded by deficient maxillary and mandibular development
- Narrow palate: Not formed to shape of dorsum of tongue
- Indentations on lateral borders of tongue ("scalloped tongue"), indicating excessive activity of genioglossus muscle pulling tongue forward to clear oropharynx and pressing it against lingual surfaces of teeth
- Excessive overjet and overbite: Clinician must assess position of maxilla and mandible in relation to airway, not stop at alignment of arches of teeth
- Crowded oropharynx: Either from excessive tissue (e.g., tonsillar hypertrophy) or underdeveloped skeletal support from poorly shaped &/or positioned craniofacial bones
- Increased neck circumference (> 40 cm in men, > 35 cm in women)
- Maxillary position: Using observed convex profile, lateral cephalogram, or advanced imaging, judge anteroposterior position and lateral development of maxilla
- Mandibular position: Often, face is judged "retrognathic" while considering only mandible; lower jaw must be assessed from its angle to relative position to hyoid bone to influence it has on facial profile, all in context of how it contributes to support of oropharynx
- Allergic shiners, or venous pooling under eyes, is most seen in children with deficient nasal breathing &/or retrognathic maxilla but may persist into adulthood and support deeper history inquiry; dermatologist and allergist literature rarely mentions skeletal problems, as they address esthetic and inflammatory etiologies
- Worn teeth: If sleep bruxism is etiology, sleep-related breathing disorders belong on differential diagnosis and should be considered prior to recommending night guard
- Obesity: Higher BMI raises risk of narrow oropharynx, but clinician is cautioned that normal and even low BMI people can have sleep-related breathing disorders

Testing

Once the person is judged at risk for breathing disorders during sleep and accepts the referral to the diagnostic facility, the trained physician interviews them with more specific questions to determine the nature of the next set of tests. The technology of gathering biosignals during sleep is rapidly changing.

Traditional polysomnography (PSG) provides a specialized environment where the subject sleeps supervised by a registered polysomnographic technologist. Up to 20 biosignals are gathered during the test period, providing the most detailed assessment of the subject's physiology. PSG provides consistently reliable brainwave signals unavailable with any other sleep testing method. People are generally tested during their normal sleep periods and asked to arrive at the testing center prepared for sleep like they might be at home. Dinner, drinks, exercise habits, all to be carried out as if they were going to their own bedroom for sleep, but in this case, the sleep center. The technologists affix the sensors to the patient: Electroencephalogram (EEG) tabs to the skull, effort belts around the abdomen and chest, oxygen sensor on the finger, electromyogram (EMG) tabs on the submental space and adjacent to the eyes, nasal cannula &/or thermistor to measure airflow through the nose, and a microphone to record sleep sounds and body position, all connected to the computer through a wire bundle. The test subject is instructed to sleep normally and disregard the camera mounted on the wall recording them. This invasive testing system works well for the very sleepy person, but for those who have restless, unsatisfying sleep to begin with, the foreign circumstances often result in misleading sleep study outcomes, confusing the diagnosis.

During the night, the sleep technologist monitors the data and corrects any leads that might be disrupted. Sleep events, such as apnea, hypopnea, movement disorders, and EEG changes, are "scored" by the technologist first, and the scoring is reviewed by the sleep physician later. The camera provides visual correlation, mostly for the body position and limb movements, while the microphone records sleep sounds, such as snoring and bruxism.

The biggest advantage the supervised PSG has is the EEG biosignal. Characteristic brainwaves identify when the patient begins sleep and their normal sleep cycles: How long they remain in 3 non-REM and REM sleep stages. Disruptions to normal sleep cycle patterns, called arousals, are correlated in time with other events, such as respiratory (apnea, hypopnea) and limb movements, to present the clinician with a picture of how the brain is allowed to cycle from wakefulness through deep sleep to REM sleep and back, 3 or 4 cycles per sleep period unless disrupted.

Respiratory parameters that are measured include the number of times (events) airflow is completely interrupted by a blockage in the upper airway, called apnea, or is restricted to a 30% or more reduction in airflow, called a hypopnea, lasting 10 seconds or longer. Oxygen saturation (SpO_2) is also recorded, noting the number and depth of desaturations, with a 3% or 4% drop from the patient's mean counted as an event. Professional organizations have defined hypopnea using different criteria, thus, most systems report using the 2 desaturation criteria. The number of events are added and divided by the sleep time to produce 3 key indices: Apnea-hypopnea index (AHI), nadir SpO_2, and oxygen desaturation index (ODI). Obstructive sleep apnea was defined as a disease based on the AHI, but most sleep physicians today consider it only one of several details used to describe sleep. The PSG report includes many more biosignal data, which the physician correlates with the clinical signs and symptoms to derive a diagnosis.

The AHI represents the average number of apneas and hypopneas experienced each hour during sleep. It is measured by dividing the total number of apneic and hypopneic events by the total number of hours of sleep. To register as an event,

an apnea or hypopnea must last at least 10 seconds or longer. Children are less likely to have sleep apnea episodes. Most specialists see an AHI above 1 as unusual for them. A child typically needs treatment if their AHI is higher than 5. Scores for adults are divided into 3 categories, which correspond to different levels of OSA severity.

- Mild sleep apnea: 5-14 apnea and hypopnea events/hour
- Moderate sleep apnea: 15-29 apnea and hypopnea events/hour
- Severe sleep apnea: > 30 apnea and hypopnea events/hour

Home sleep apnea testing (HSAT) is the most used modality due to portability and low cost. Devices are deployed by the test subject and collect biosignals ranging from simple pulse oximetry to complex air flow measurements and plethysmography data. Since these units are used in the home, people must be trained to apply sensors accurately, which renders HSAT unreliable. Estimates of up to as much as 25% of home sleep tests lack 1 or more biosignals when the data is accessed. Nearly all of them lack the EEG signal that allows the software to determine true sleep time, so events are divided by the total test time. Since the denominator of the equation is usually larger than a true sleep time would provide, the AHI and ODI are often smaller, thus, HSAT is generally thought to undervalue sleep disruption measures. Data is collected from the home testing device by downloading or through a cloud-based portal. Algorithms developed from machine learning and decades of PSG data convert the biosignal information into summaries used by physicians to assess patient sleep in a more familiar environment. Because there is no need for a specialized facility or a sleep technologist, HSAT is a fraction of the cost of in-lab PSG.

The industry is driven by more capable technology, pressure to reduce health care costs, simplifying the process, and the desire for patients to be tested at home. New devices to assess sleep quality, breathing patterns, blood oxygen levels, and autonomic nervous system response appear regularly. It seems likely that technology will provide increasingly accurate assessment of sleep with less complex means. One manufacturer of a sleep assessment device, using data gathered from over 67,000 people and 11.6 million sleep nights, determined the presence of obstructive sleep apnea was over 22% of the global population and that single-night testing misdiagnosed the disease between 20-50% of the time. To gain a true description of a person's sleep may require more than 1 night of testing, whether prediagnosis or when assessing treatment efficacy. Relatively inexpensive diagnostic technology enables clinicians to apply precision medicine principles to their patients.

Population Health Implications

Addressing the global population of people at significant risk to their health and quality of life will require more awareness by every healthcare provider and increased diagnostic efficiency. The market for testing and treatment devices only grows when more people are identified, providing economic incentive to develop the technology. As more tests are done, the total costs of diagnosis and sleep-breathing treatment rises. The American Academy of Sleep Medicine estimated the financial burden of sleep-related breathing disorders is over $150 billion annually. Sleeping without breathing disruptions decreases disease and the need for its management. Along with an improved quality of life, the resulting savings in healthcare dollars will be many multiples of the cost of sleep testing and treatment.

Selected References

1. Gibbings A et al: The EEG correlates and dangerous behavioral consequences of drowsy driving after a single night of mild sleep deprivation. Physiol Behav. 252:113822, 2022
2. He S et al: Using clinical data to predict obstructive sleep apnea. J Thorac Dis. 14(2):227-37, 2022
3. Kryger MH et al: Principles and Practice of Sleep Medicine. 7th ed. Elsevier, 2022
4. Holder S et al: Common sleep disorders in adults: diagnosis and management. Am Fam Physician. 105(4):397-405, 2022
5. Lechat B et al: Multinight prevalence, variability, and diagnostic misclassification of obstructive sleep apnea. Am J Respir Crit Care Med. 205(5):563-9, 2022
6. Pauletto P et al: Sleep bruxism and obstructive sleep apnea: association, causality or spurious finding? A Scoping Review. Sleep. 45(7):zsac073, 2022
7. Song HJ et al: Validity analysis of neck circumference as a screening test for hypoxia occurrence in patients undergoing sedative endoscopy. Healthcare (Basel). 10(4):679, 2022
8. Bahr K et al: The snoring index identifies risk of non-alcoholic fatty liver disease in patients with obstructive sleep apnea syndrome. Biology (Basel). 11(1):10, 2021

App-Based Sleep Rating

Wearable Health Monitor

(Left) *There are dozens of smartphone apps to help people gauge sounds and sleep data. These can be used to motivate toward diagnosis and give objective data about therapy. This one shows snoring levels in decibels.* **(Right)** *24/7 health tracking with heart rate, temperature, sleep data, oxygen levels, and other biosignals are now possible with sophisticated monitors and powerful apps. This ring has sensors to gather biosignals, and the app interprets them for ongoing monitoring of sleep*

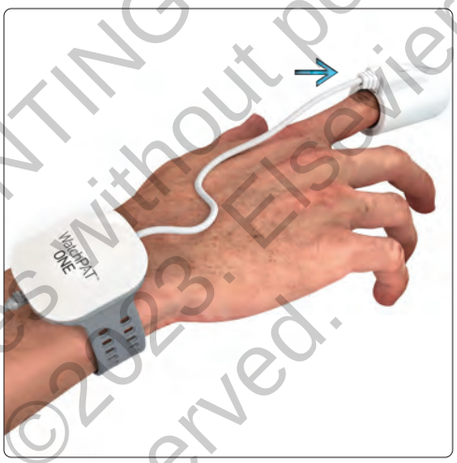
Traditional Home Seep Apnea Test Device

Home Sleep Apnea Test

(Left) *The NoxT3 flow- and effort-based sleep testing device has 2 effort belts that distinguish central vs. obstructive apnea events.* **(Right)** *Clinical photograph shows a type of home sleep apnea test that has an effort belt, a nasal canula to measure flow, and an oximeter. It is FDA cleared to provide data for a sleep apnea diagnosis.*

Detailed Therapy Monitoring

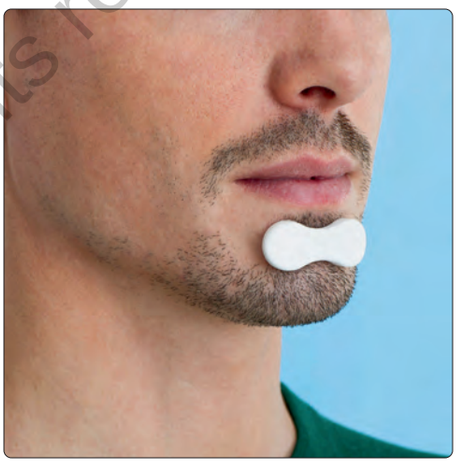
Plethysmography



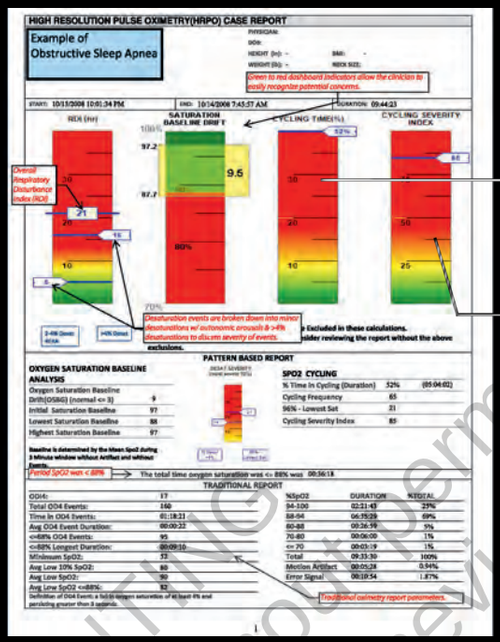
(Left) *Clinical photograph shows a device that combines 2 body-worn patches and oximetry to provide sleep position, sounds, oxygen levels, and other biosignals to both the user and providers.* **(Right)** *This device has a finger probe with a sophisticated bladder that senses changes in blood pressure waves through small vessels. This is not an airflow-based measurement, but it still provides an assessment of sleep apnea events along with other details*

Innovative Sound-Based Monitor

Muscle Movement-Based Diagnosis



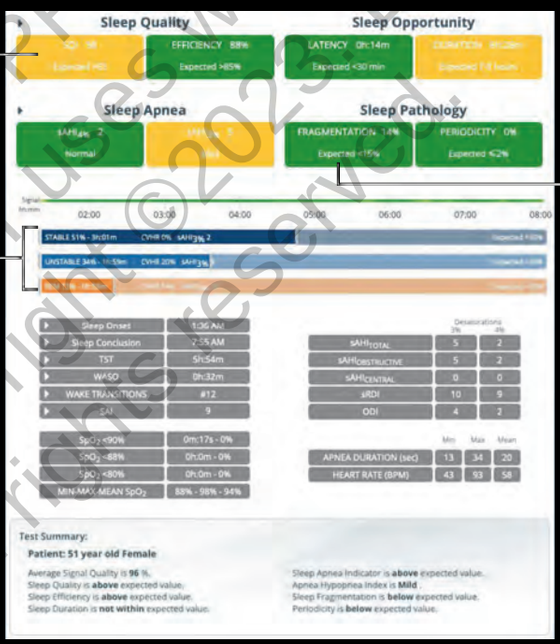
(Left) *Photograph shows an at-home sleep apnea test that uses soundwaves of respiration to assess breathing performance.* **(Right)** *Photograph shows a device that captures movement of the mandible. Software determines sleep stages and interruptions to breathing via AI algorithms from movement patterns.*



Cycling time is measure of arousal threshold; the higher the number, the more sleep time has been spent reacting to changes in CO_2 levels

Cycling severity represents loop gain, measure of ventilatory instability

These boxes color code from green to red to help clinicians and patients visualize results



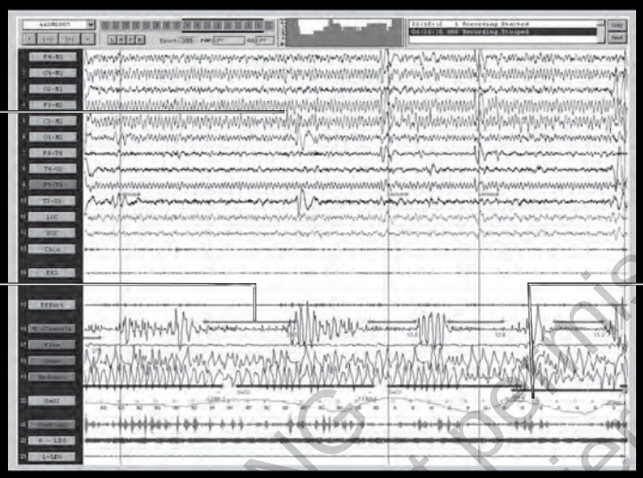
These measure various amounts of sleep conditions based on cardiopulmonary coupling

Fragmented sleep is measure of autonomic nervous system balance and predictor of patient sleep perception; more fragmented yields more daytime sleepiness

(Top) *A report from software interpreting high-resolution pulse oximetry (HRPO) shows some of the ways data from overnight oximetry can be used to assess sleep physiology. Graphs are helpful for patients to visualize their conditions. The 2 columns on the right measure loop gain, or ventilatory instability, and low arousal threshold. HRPO is one of the least expensive and easiest ways to assess sleep.* **(Bottom)** *This report shows typical sleep data from software using biosignals, such as cardiopulmonary coupling and oximetry data, gathered by a ring on the thumb. Note the color codes to help patients comprehend complex data to engage with their therapy. Sleep quality is a compilation of multiple biosignals. This device also can be used to diagnose sleep apnea.*

Note brain responses in various EEG channels and how they correlate with breathing perturbations

Straight line on airflow signal is apnea event; note excessive response as body returns to breathing



Changes in blood oxygen levels follow apnea events as deoxygenated blood makes its way from lungs to measuring site on index finger

Key sleep numbers

Colorful chart for at-a-glance assessment

(Top) *This epoch, or segment, of an overnight sleep study shows some of the data available for diagnosis. A polysomnography study provides the clinician with up to 20 channels of data. AI and trained sleep professionals interpret data from many hours of sleep to assess sleep, which can vary through the night, depending on sleep stages.* **(Bottom)** *This is a summary page of one company's home sleep apnea testing (HSAT). It has convenient color bars and other data with additional details available. Summary pages often are useful to improve patient engagement with their sleep data.*