CHAPTER 2

Normal Voice
Anatomy and Physiology Throughout the Lifespan

LEARNING OBJECTIVES

After reading this chapter, one should be able to:

- List and define the five aspects of the normal voice.
- List and describe the three processes of normal voice production.
- Identify the structures of respiration.
- Describe the mechanics of respiration.
- List and describe the lung volumes and capacities in reference to resting expiratory level.
- Understand the differences between breathing for life and breathing for speech.
- Describe the effects of aging on the respiratory system and speech breathing.
- Identify the structures of phonation.
- Describe the effects of aging on the laryngeal system.
- Understand the myoelastic aerodynamic theory of vocal fold vibration.
- Describe the factors involved in changing vocal pitch, loudness, and quality.
- Identify the structures of resonance.
- Describe the mechanics of resonance.

This chapter describes the normal voice and how it is produced. It is important to understand the normal voice in order to be able to diagnose and treat the abnormal voice. Few things are so difficult to define or understand as "What is normal and what constitutes normal limits?" Because of maladaptive vocal behaviors and/or disease, many patients present to the clinician with overworked voice production systems. To help the patient to abandon the abnormal functions, the clinician must know how normal voice is produced, and be able to communicate this information appropriately to the patient. Modern-day voice evaluation often involves consultation with medical professionals who are well-grounded in human anatomy and physiology. For these reasons and more, voice clinicians must have a good working knowledge of the structures and functions serving normal and abnormal voice production throughout the lifespan.

NORMAL ASPECTS OF VOICE

Normal voice may be characterized by five aspects, each related to function. First, the voice must be loud enough to be heard. We may refer to this as adequate carrying power. This means that the voice can be heard and speech can be understood over the noise of most everyday environmental sounds such as the television, air conditioning, keyboard typing, transportation noises, and so on. Second, the voice must be produced in a manner that is hygienic and safe, that is, without vocal trauma and resulting laryngeal lesions. Third, the voice should have a pleasant quality, one that is not distracting and thus interferes with verbal communication. Fourth, the normal voice should be flexible enough to accurately express emotion. The human voice can be thought of as a "window into the soul" in that we sometimes judge how a loved one or close friend feels based on the sound of his or her voice. We often think we know if the person is happy, sad, sick, excited, or nervous. Likewise, we sometimes find it hard to mask our own emotional state with our voice. We can also change the meaning of a verbal message by changing the emotional tone of our voice. The sentence, "I am so happy for you," can be said in such a manner as to be sincere or sarcastic just by the tone of voice, even while the words remain the same. The expression, "Oh wonderful," can be said with excitement or with scorn. Last, the voice should represent the speaker well in terms of age and gender. We should not be surprised to meet someone for the first time after speaking to him or her on the phone. Our voice should not portray us as either older, younger, or as less mature than we are. Nor will we likely be pleased if we are mistaken for the opposite gender. The normal voice should represent the speaker faithfully.

Keep the five aspects of loudness, hygiene, pleasantness, flexibility, and representation in mind as we explain in the next section how the normal voice is produced. That the voice can serve us so well through our lifespan is a true testament to the uniquely human aspects of voice we just described.

CHECK YOUR KNOWLEDGE

1. What are the five key aspects of the normal voice?
2. Give an example of how each of these aspects can be abnormal.

NORMAL PROCESSES OF VOICE PRODUCTION

Separating the normal speaking voice into three individual processes (respiration, phonation, and resonance) for purposes of study is helpful, but we must remember that these three components of voice production are highly interdependent. For example, without the expiratory phase of respiration, there would be no phonation or resonance. Without adequate functioning of the velopharyngeal mechanism, there would be an imbalance of oral-nasal resonance. Also, these three processes are constantly changing simultaneously. Let us first consider the structures and function of respiration, particularly as they relate to production of voice.

THE RESPIRATORY SYSTEM

For speech to be possible, humans have learned to use respiration for the purpose of phonation. Both speaking and singing require an exhalation (outgoing air stream) capable of activating vocal fold vibration. When training their voice, speakers or singers frequently focus on developing conscious control of the breathing mechanism. This conscious control must not conflict, however, with the physiological air requirements of the individual. When a problem occurs with respiration, it is often the conflict between the physiological needs and the speaking-singing demands for air that causes faulty usage of the vocal mechanism. Our dependence on the constant renewal of oxygen supply imposes certain limitations on how many words we can say, how many phrases we can sing, or how much loud emphasis we can use on one expiration.

STRUCTURES OF RESPIRATION

Respiration is a vital life-sustaining and voice-enabling process that results from the movement of support structures within the musculoskeletal system. While a complete review of the musculoskeletal components for speech and voice is beyond the scope of this text, an overview is presented here that will provide the student or clinician with core information that can be applied to the diagnosis and management of persons with respiratory-based voice disorders.

The Bony Thorax

The bony thorax includes the vertebrae and vertebral column, the thoracic cage (ribs and sternum, and associated muscles), the pectoral girdle, and the pelvic girdle. The thorax is suspended from the vertebral (spinal) column, a strong but flexible structure that serves many purposes. The vertebral column consists of 33 individual vertebrae stacked loosely on top of each other, forming a strong pillar for the support of the head and trunk. The vertebrae can be grouped into five regions. The 31 pairs of spinal nerves emerge and enter the spinal cord through spaces between each pair of vertebrae, beginning at the thoracic level.

The seven cervical vertebrae are smaller and more delicate than the remaining vertebrae, and within these vertebrae the left and right vertebral arteries course superiorly on their way to joining the basilar artery at the base of the brain. Two of the cervical vertebrae (C1—Atlas, C2—Axis) are unique because they connect the skull to the spinal column and also allow for diverse head movement (e.g., rotate side to side, bend forward and backward). The C7 vertebra—the cervical prominence—can be felt if you pass your fingers down the back of your neck, in between the base of your skull and the top of your spine. In terms of adult landmarks, the base of the nose and the hard palate corresponds to C1, the teeth (when mouth remains closed) correspond to C2, the mandible and hyoid bone corresponds to C3, the thyroid cartilage spans from C4 to C5, and the cricoid cartilage spans from C6 to C7. In infants and children, the laryngeal landmarks are situated higher, at the level of C1 to C3.

The 12 thoracic vertebrae are intermediate in size between those of the cervical and lumbar regions; they increase in size as one proceeds down the spine, the upper vertebrae being much smaller than those in the lower part of the region. The first 12 pairs of spinal nerves emerge from between the thoracic vertebrae.

The thoracic vertebrae provide the basis for the respiratory framework because they form the posterior point of attachment for the ribs (Seikel and colleagues, 2010). The thoracic spine's range of motion is limited due to the many rib/vertebrae connections

The five lumbar vertebrae graduate in size from L1 through L5. These vertebrae bear much of the body's weight and related biomechanical stress. They provide direct or indirect attachment for a number of back and abdominal muscles, as well as for the posterior fibers of the diaphragm (Seikel and colleagues, 2010). The lumbar vertebrae allow significant forward and backward bending at the waist, moderate side bending, and a small degree of rotation.

The sacrum is a large, triangular bone at the base of the spine and at the upper and back part of the pelvic cavity, where it is inserted like a wedge between the two hip bones. Its upper part connects with the last lumbar vertebra, and the bottom part connects with the coccyx (tailbone). It consists of usually five initially non-fused vertebrae that begin to fuse between the ages of 16 and 18 years and are usually completely fused into a single bone by age 34.

The coccyx, commonly referred to as the tailbone, is the final segment of the vertebral column. Comprising three to five separate or fused vertebrae (the coccygeal vertebrae) below the sacrum, it is attached to the sacrum by a joint that permits limited movement between the sacrum and the coccyx.

The thoracic (rib) cage is formed by the thoracic vertebral column, 12 pairs of ribs and their costal cartilages, the sternum, and the internal and external intercostal muscles. Each of the ribs is made up of bone and cartilage, allowing for both strength and mobility. The 12 pairs of ribs can be subdivided into three general classes: true ribs (the first seven pairs), false ribs (the next three pairs) and floating ribs (the last two pairs). The true and false attach to the vertebral column and the sternum, while the floating ribs attach only to the vertebral column. The ribs connected to the thoracic vertebral column and their connecting muscles play an important role in respiration, as we shall see when we discuss respiratory function.

The pectoral girdle is formed by the clavicle and scapula. It supports the upper limbs. It is suspended from the head and neck by the support fibers of the trapezius muscles, which descend from the cervical vertebrae and the skull and are attached to both the clavicle and the scapula (shoulder blade).

The pelvic girdle is formed by the ilium, sacrum, pubic bone, and ischium. The pelvic girdle provides a strong structure for attaching the legs to the vertebral column. By means of this structure, forces generated through movement of the legs are distributed across a mass of bone which, in turn, is attached to the vertebral column (Seikel and colleagues, 2010).

CHECK YOUR KNOWLEDGE

1. List the structures of the bony thorax.
2. List the five vertebral regions and the number of vertebrae in each.

The Muscles of Respiration

We now need to consider the muscles of respiration (see Figures 2.1 and 2.2). When discussing these muscles, it is helpful to think of three major categories: (1) the muscles of the rib cage, (2) the diaphragm, and (3) the muscles of the abdominal wall. Thinking of the muscles of respiration in this way makes it easier to discuss

FIGURE 2.1 A List of Muscles of Respiration

Muscles of the Rib Cage Wall
Sternocleidomastoid
Scalenus group (anterior, medial, posterior)
Pectoralis major
Pectoralis minor
Subclavius
Serratus anterior
External intercostals
Internal intercostals
Transversus thoracis
Lattisimus dorsi
Serratus posterior superior
Serratus posterior inferior
Lateral iliocostals
Levatores costarum
Quadratus lumborum
Subcostals

Muscles of the Diaphragm
Diaphragm

Muscles of the Abdominal Wall
Rectus abdominus
External oblique
Internal oblique
Transversus abdominis

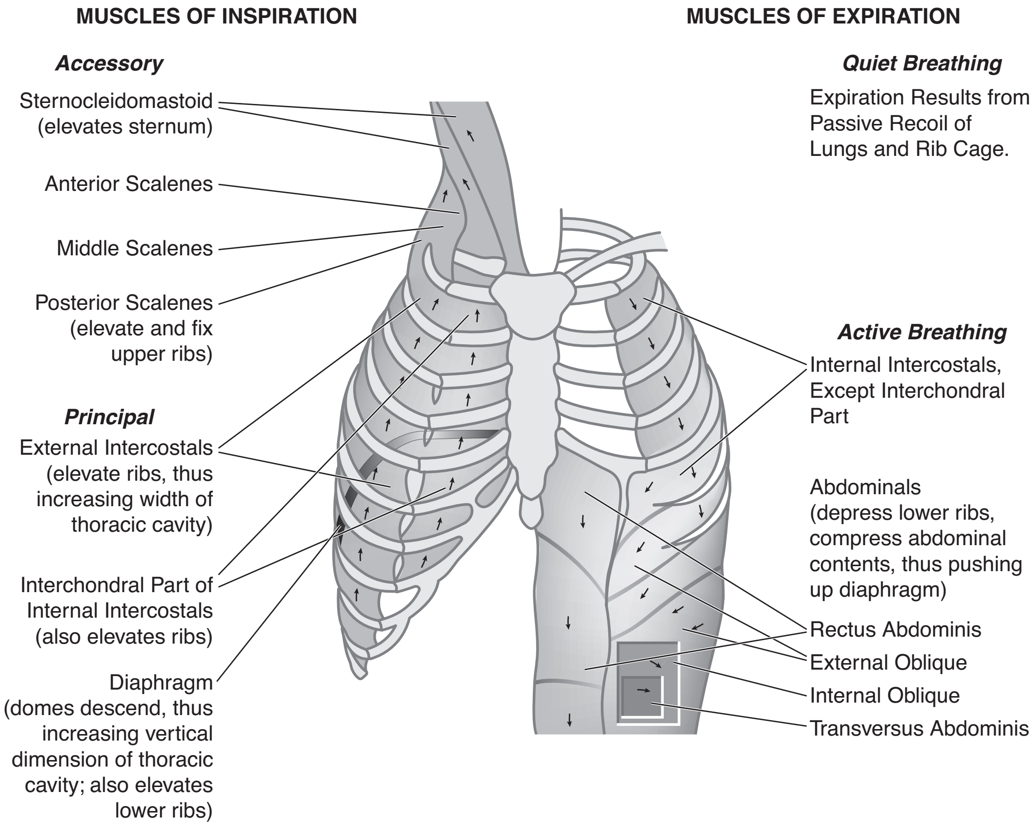
the movements that occur due to the passive and active forces to be discussed later in this chapter, and the adjustment capabilities of the respiratory system for speech. Keep in mind now that the action of the respiratory muscles changes the dimensions of the thoracic cavity, which in turn changes the pressure within the thoracic cavity. The resulting changes in pressure result in the inspiratory-expiratory cycle with which we are all familiar.

The Inspiratory Muscles

The inspiratory muscles can be found within the thorax, back, neck, and upper limbs. The primary inspiratory muscles of the thorax are the diaphragm and external intercostal muscles. These muscles are assisted by accessory muscles in the neck, back, and upper limbs.

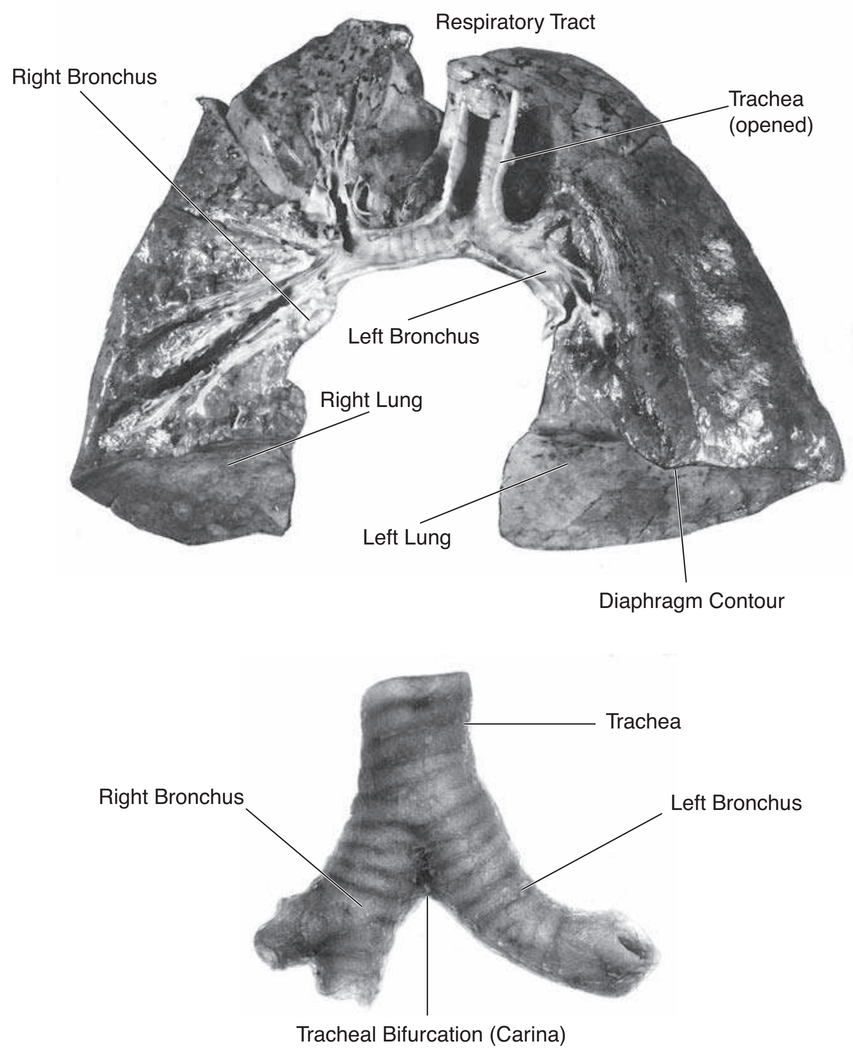
The Diaphragm. The diaphragm is a large (about 250 cm^2 in surface area) dome-shaped muscle that separates the thorax from the abdominal cavity, with openings for the esophagus and assorted arteries (see Figure 2.3 on page 24). The muscle fibers of the diaphragm insert into the sternum and the six lower ribs and their cartilages and into the first three of four lumbar vertebrae. The other ends of these muscle fibers converge to attach to the fibrous central tendon, which is also attached to the pericardium on its upper surface. At rest, the diaphragm is shaped like an inverted bowl. When you are standing and in the mid-phase of respiration, the dome of the diaphragm is at about the same level as the sixth rib. As described in

FIGURE 2.2 Muscles of Respiration



Levitzy (2007), during normal quiet breathing, contraction of the diaphragm causes its dome to descend 1 to 2 cm into the abdominal cavity, with little change in its shape. This elongates the thorax in the cephalacaudal (top to bottom) dimension and increases its volume. These small downward movements of the diaphragm are possible because the abdominal viscera can push out against the relatively compliant abdominal wall. During a deep inspiration, the diaphragm can descend as much as 10 cm. With such a deep inspiration, the limit of the compliance of the abdominal wall is reached, abdominal pressure increases, and the central tendon becomes fixed against the abdominal contents. After this point, contraction of the diaphragm against the fixed central tendon elevates the lower ribs. When a person is in the supine position, the diaphragm is responsible for about two-thirds of the air that enters the lungs during normal quiet breathing. When a person is standing or seated in an upright posture, the diaphragm is responsible for only about one-third to one-half of the tidal volume. Motor and sensory innervation for the diaphragm comes primarily from the two phrenic nerves. These nerves originate in the cervical plexus (grouping) of spinal nerves C3 through C5 of both sides of the spinal cord (Seikel and colleagues, 2010). Thus, innervation to the diaphragm is bilateral, an indication of its biological importance. The diaphragm is under primary control of the autonomic nervous system, although one can place the diaphragm under voluntary control, albeit only temporarily (such as when holding one's breath).

FIGURE 2.3 Lungs and Tracheal Bifurcation



The External Intercostal Muscles. The eleven external intercostal muscles run downward and forward from the lower border of the rib cage above to the upper border of the rib cage below (see Sidebar 2.1). Together, these muscles form a large sheet of muscle that attaches the ribs to one another (Hixon and colleagues, 2008). The external intercostal muscles are positioned so that, when they contract, the entire rib cage elevates and expands (Seikel and colleagues, 2010). As can be seen in Figure 2.4, the true/upper ribs move with a pump-handle motion about the vertebrae. This motion increases the anterior-posterior dimension of the thoracic cavity. That is, it increases the distance between the sternum and the vertebral column (see Sidebar 2.2 on page 26). The distance front to back is increased, leading to an overall increase in volume. The false/middle ribs move with a bucket-handle motion about the vertebrae. This motion increases the horizontal dimension of the thoracic cavity; that is, it makes the chest

SIDEBAR 2.1

These muscles are sometimes referred to as the *front pocket muscles* because the fibers mimic the direction a hand would enter a front pocket.

FIGURE 2.4 Movements of the Thoracic Cavity