Thyroid Ultrasound and Ultrasound-Guided FNA

Second Edition

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Foreword

Ultrasound has become established as the diagnostic procedure of choice in guidelines for the management of thyroid nodules by essentially every professional organization of endocrinologists. In this, the second edition of their outstanding text on thyroid ultrasound, Baskin, Duick, and Levine have provided an invaluable guide to the application of gray-scale and color Doppler ultrasonography to state-of-the-art diagnostic evaluation of thyroid nodules, and to the management of thyroid cysts, benign thyroid and parathyroid nodules, and thyroid cancer. Differences with, and additions to, the first edition highlight the extraordinary and dramatic advances in applications of ultrasonography that have occurred in the past decade. The high yield of malignancy in ultrasound-guided fine-needle (FNA) aspirates of nondominant nodules in multinodular glands has altered our mistaken complacency in assuming that palpation-guided FNA only of palpable dominant nodules was adequate for diagnosis. Rather, ultrasound has taught us that the commonly held belief that malignancy is less likely in a multinodular gland is incorrect. Utility of ultrasound has gone far beyond just the initial diagnostic approach, as improved highly sensitive probes allow accurate characterization of the nature of thyroid nodules or lymph nodes, setting priorities for FNA and for serial monitoring for changes in size that could imply malignancy.

Ultrasound is also informing us as to the frequency and significance of thyroid microcarcinomata. The greater sensitivity of modern ultrasonographic (US) technique has opened a Pandora's box in facilitating the detection of small nodules, which then mandate FNA (or serial follow-up at a minimum). Awareness that certain ultrasound characteristics of nodules (e.g., hypoechogenicity, microcalcifications, and blurred nodule margins) are associated with malignancy has allowed us to focus our interest in FNA primarily and selectively on nodules with these characteristics. Many such small nodules with these characteristics are found to constitute microcarcinomas, and their natural history teaches us that they can be as aggressive as tumors that are > 1 cm in size. As a consequence, their earlier detection employing ultrasound has facilitated better outcomes and potential cures. Thus, modern management of thyroid nodules demands the skilled use of ultrasound to identify all nodules in a given thyroid gland and to more definitively guide the needle for aspiration.

The evidence is clear that an ultrasound-based strategy has been shown to be cost-effective in reducing nondiagnostic FNA rates, particularly by targeting those nodules with ultrasonographic characteristics that are more suggestive of malignancy. As a result, unnecessary thyroid surgeries can be avoided and a greater yield of thyroid cancer can be found at surgery. Moreover, in patients with FNA positive for cancer, preoperative baseline neck ultrasound has been shown to be of significant value for the detection of nonpalpable lymph nodes or for guiding the dissection of palpable nodes. Ultrasound-guided FNA of lymph nodes has taught us that anatomic characteristics and not size are better determinants of regional thyroid cancer metastases to lymph nodes. This book is replete with critical assessments of the recent literature on which the above statements are based, and includes the most up-to-date descriptions of newer applications of ultrasound to distinguish benign from malignant nodules such as elastography, as well as practical analytic appraisal of the utility of incorporation of ultrasound to the ablation of both benign and malignant lesions by ethanol instillation, high frequency ultrasound, laser, or radiofrequency techniques. In my view, given the extremely important current and future role of ultrasonography in the diagnosis and management of our patients, endocrinologists, cytopathologists, surgeons, and radiologists are obligated to become familiar with and adopt the approaches and advances described in this volume.

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Preface to First Edition

Over the past two decades, ultrasound has undergone numerous advances in technology, such as gray-scale imaging, real-time sonography, high resolution 7.5–10 Mtz transducers, and color-flow Doppler that make ultrasound unsurpassed in its ability to provide very accurate images of the thyroid gland quickly, inexpensively, and safely. However, in spite of these advances, ultrasound remains drastically underutilized by endocrinologists. This is due in part to a lack of understanding of the ways in which ultrasound can aid in the diagnosis of various thyroid conditions, and to a lack of experience in ultrasound technique by the clinician.

The purpose of this book is to demonstrate how ultrasound is integrated with the history, physical examination, and other thyroid tests (especially FNA biopsy) to provide valuable information that can be used to improve patient care. Numerous ultrasound examples are used to show the interactions between ultrasound and tissue characteristics and explain their clinical significance. Also presented is the work of several groups of investigators worldwide who have explored new applications of ultrasound that have led to novel techniques that are proving to be clinically useful.

To reach its full potential, it is critical that thyroid ultrasound be performed by the examining physician. This book instructs the physician on how to perform the ultrasound at the bedside so that it becomes part of the physical examination. Among the new developments discussed are the new digital phased-array transducers that allow ultrasound and FNA biopsy to be combined in the technique of ultrasound-guided FNA biopsy. Over the next decade, this technique will become a part of our routine clinical practice and a powerful new tool in the diagnosis of thyroid nodules and in the follow-up of thyroid cancer patients.

H. Jack Baskin, MD
Editor

Preface to Second Edition

In the eight years since the publication of the first edition of this book, ultrasound has become an integral part of the practice of endocrinology. Ultrasound guidance for obtaining accurate diagnostic material by FNA is now accepted normal procedure. As the chief editor of *Thyroid* wrote in a recent editorial: "I do not know how anyone can see thyroid patients without their own ultrasound by their side." The widespread adoption of this new technology by clinicians in a relatively short span of time is unprecedented.

While most endocrinologists now feel comfortable using ultrasound for the diagnosis of thyroid nodules, many are reluctant to expand its use beyond the thyroid. Its value as a diagnostic tool to look for evidence of thyroid cancer in neck lymph nodes, or to evaluate parathyroid disease is at least as great as it is in evaluating thyroid nodules. In this second edition, we continue to explore these diagnostic techniques that are readily available to all clinicians.

Since the first edition, clinical investigators have continued to discover new techniques and applications for thyroid and neck ultrasound. Power Doppler has replaced color flow Doppler for examining blood flow in the tissues of the neck. Other new advances in diagnosis include ultrasound contrast media, ultrasound elastography, and harmonic imaging.

The only ultrasound-guided therapeutic procedure addressed in the 2000 edition was percutaneous ethanol injection (PEI), which had not been reported from the United States but was commonly practiced elsewhere in the world. Today, other ultrasound-guided therapeutic procedures such as laser, radiofrequency, and high intensity focused ultrasound (HIFU) are being used for ablation of tissue without surgery. These innovative procedures are discussed by the physicians who are developing them.

We hope that this second edition will inspire clinicians to proceed beyond using ultrasound just for the diagnosis of nodular goiter. The benefits to patients will continue as clinicians advance neck ultrasound to its full potential.

H. Jack Baskin, MD
Editor, 2008

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CHAPTER 1
History of Thyroid Ultrasound

Robert A. Levine

The thyroid is well suited to ultrasound study because of its superficial location, vascularity, size and echogenicity (1). In addition, the thyroid has a very high incidence of nodular disease, the vast majority benign. Most structural abnormalities of the thyroid need evaluation and monitoring, but not intervention (2). Thus, the thyroid was among the first organs to be well studied by ultrasound. The first reports of thyroid ultrasound appeared in the late 1960s. Between 1965 and 1970 there were seven articles published specific to thyroid ultrasound. In the last five years there have been over 1,300 published. Thyroid ultrasound has undergone a dramatic transformation from the cryptic deflections on an oscilloscope produced in A-mode scanning, to barely recognizable B-mode images, followed by initial low resolution gray scale, and now modern high resolution images. Recent advances in technology, including harmonic imaging, contrast studies, and three-dimensional reconstruction, have furthered the field.

In 1880, Pierre and Jacques Curie discovered the piezoelectric effect, determining that an electric current applied across a crystal would result in a vibration that would generate sound waves, and that sound waves striking a crystal would, in turn, produce an electric voltage. Piezoelectric transducers were capable of producing sonic waves in the audible range and ultrasonic waves above the range of human hearing.

The first operational sonar system was produced two years after the sinking of the Titanic in 1912. This system was capable of detecting an iceberg located two miles distant from a ship. A low-frequency audible pulse was generated, and a human operator listened for a change in the return echo. This system was able to detect, but not localize, objects within range of the sonar (3).

Over the next 30 years navigational sonar improved, and imaging progressed from passive sonar, with an operator listening for reflected sounds, to display of returned sounds as a one-dimensional oscilloscope pattern, to two-dimensional images capable of showing the shape of the object being detected.

The first medical application of ultrasound occurred in the 1940s. Following the observation that very high intensity sound waves had the ability to damage tissues, lower intensities were tried for therapeutic uses. Focused sound waves were used to mildly heat tissue for therapy of rheumatoid arthritis, and early attempts were made to destroy the basal ganglia to treat Parkinson's disease (4).

The first diagnostic application of ultrasound occurred in 1942. In a paper entitled "Hyperphonagraphy of the Brain," Karl Theodore Dussic reported localization of the cerebral ventricles using ultrasound. Unlike the current reflective technique, his system relied on the transmission of sound waves, placing a sound source on one side of the head, with a receiver on the other side. A pulse was transmitted, with the detected signal purportedly able to show the location of midline structures. While the results of these studies were later discredited as predominantly artifact, this work played a significant role in stimulating research into the diagnostic capabilities of ultrasound (4).

Early in the 1950's the first imaging by pulse–echo reflection was tried. A-mode imaging showed deflections on an oscilloscope to indicate the distance to reflective surfaces. Providing information in a single dimension, A-mode scanning indicated only distance to reflective surfaces (See Fig. 2.7) (5). A-mode ultrasonography was used for detection of brain tumors, shifts in the midline structures of the brain, localization of foreign bodies in the eye, and detection of detached retinas. In the first presage that ultrasound may assist in the detection of cancer, John Julian Wild published the observation that gastric malignancies were more echogenic than normal gastric tissue. He later studied 117 breast nodules using a 15MHz sound source, and reported that he was able to determine their size with an accuracy of 90%.

During the late 1950s the first two-dimensional B-mode scanners were developed. B-mode scanners display a compilation of sequential A-mode images to create a two-dimensional image (See Fig. 2.2). Douglass Howry developed an immersion tank B-mode ultrasound system, and several models of immersion tank scanners followed. All utilized a mechanically driven transducer that would sweep through an arc, with an image reconstructed to demonstrate the full sweep. Later advances included a hand-held transducer that still required a mechanical connection to the unit to provide data regarding location, and water-bag coupling devices to eliminate the need for immersion (6).

Application of ultrasound for thyroid imaging began in the late 1960s. In July 1967 Fujimoto et al. reported data on 184 patients studied with a B-mode ultrasound "tomogram" utilizing a water bath (8). The authors reported that no internal echoes were generated by the thyroid in patients with no known thyroid dysfunction and nonpalpable thyroid glands. They described four basic patterns generated by palpably abnormal thyroid tissue. The type 1 pattern was called "cystic" due to the virtual absence of echoes within the structure, and negligible attenuation of the sound waves passing through the lesion. Type 2 was labeled "sparsely spotted," showing only a few small echoes without significant attenuation. The type 3 pattern was considered "malignant" and was described as generating strong internal echoes. The echoes were moderately bright and were accompanied by marked attenuation of the signal. Type 4 had a lack of internal echoes but strong attenuation. In the patients studied, 65% of the (predominantly follicular) carcinomas had a type 3 pattern. Unfortunately, 25% of benign adenomas were also type 3. Further, 25% of papillary carcinomas were found to have the type 2 pattern. While the first major publication of thyroid ultrasound attempted to establish the ability to determine malignant potential, the results were nonspecific in a large percentage of the cases.

In December 1971 Manfred Blum published a series of A-mode ultrasounds of thyroid nodules (Fig. 2.1) (5). He demonstrated the ability of ultrasound to distinguish solid from cystic nodules, as well as accuracy in measurement of the dimensions of thyroid nodules. Additional publications in the early 1970s further confirmed the capacity for both A-mode and B-mode ultrasound to differentiate solid from cystic lesions, but consistently demonstrated that ultrasound was unable to distinguish malignant from benign solid lesions with acceptable accuracy (9).

The advent of gray scale display resulted in images that were far easier to view and interpret (7). In 1974 Ernest Crocker published "The Gray Scale Echographic Appearance of Thyroid Malignancy" (10). Using an 8MHz transducer with a 0.5 mm resolution, he described "low amplitude, sparse and disordered echoes" characteristic of thyroid cancer when viewed with a gray scale display. The pattern felt to be characteristic of malignancy was what would now be considered "hypoechoic and heterogeneous." Forty of the eighty patients studied underwent surgery. All six of the thyroid malignancies diagnosed had the described (hypoechoic) pattern. The percentage of benign lesions showing this pattern was not reported in the publication.

With each advancement in technology, interest was again rekindled in ultrasound's ability to distinguish a benign from a malignant lesion. Initial reports of ultrasonic features typically describe findings as being diagnostically specific. Later, reports followed showing overlap between various disease processes. For example, following an initial report that the "halo sign," a rim of hypoechoic signal surrounding a solid thyroid nodule, was seen only in benign lesions (11), Propper reported that two of ten patients with this finding had carcinoma (12). As discussed in Chap. 6 the halo sign is still considered to be one of the numerous features that can be used in determining the likelihood of malignancy in a nodule.

In 1977 Wallfish recommended combining fine-needle aspiration biopsy with ultrasound in order to improve the accuracy of biopsy specimens (13). Recent studies have continued to demonstrate that biopsy accuracy is greatly improved when ultrasound is used to guide placement of the biopsy needle. Most patients with prior "nondiagnostic" biopsies will have an adequate specimen when ultrasound-guided biopsy is performed (14). Ultrasound-guided fine-needle aspiration results in improved sensitivity and specificity of biopsies as well as a greater than 50% reduction in nondiagnostic and false negative biopsies (15).

Current resolution allows demonstration of thyroid nodules smaller than 1 mm; thus ultrasound has clear advantages over palpation in detecting and characterizing thyroid nodular disease. Nearly 50% of patients found to have a solitary thyroid nodule by palpation will be shown to have additional nodules by ultrasound, and more than 25% of the additional nodules are larger than 1 cm (16). With a prevalence estimated between 19% and 35%, the management of incidentally detected, nonpalpable thyroid nodules remains controversial. Several guidelines have been developed to assist in deciding which nodules warrant biopsy and which may be monitored without tissue sampling. These guidelines are discussed in Chap. 7.

Over the past several years the value of ultrasound in screening for suspicious lymph nodes prior to surgery in patients with biopsy proven cancer has been established. Current guidelines for the management of thyroid cancer indicate a pivotal role for ultrasound in monitoring for locoregional recurrence (17).

During the 1980's Doppler ultrasound was developed, allowing detection of flow in blood vessels. As discussed in Chapter 3 the Doppler pattern of blood flow within thyroid nodules has an important role in assessing the likelihood of malignancy. Doppler imaging may also demonstrate the increased blood flow characteristic of Graves' disease (18), and may be useful in distinguishing between Graves' disease and thyroiditis, especially in pregnant patients or patients with amiodarone-induced hyperthyroidism (19).

Recent technological advancements include intravenous sonographic contrast agents, three-dimensional ultrasound imaging and elastography. Intravenous sonographic contrast agents are available in Europe, but remain experimental in the United States. All ultrasound contrast agents consist of microbubbles, which function both by reflecting ultrasonic waves and, at higher signal power, by reverberating and generating harmonics of the incident wave. Ultrasound contrast agents have been predominantly used to visualize large blood vessels, with less utility in enhancing parenchymal tissues. They have shown promise in imaging peripheral vasculature as well as liver tumors and metastases (20), but no studies have been published demonstrating an advantage of contrast agents in thyroid imaging.

Three-dimensional display of reconstructed images has been available for CT scan and MRI for many years and has demonstrated practical application. While three-dimensional ultrasound has recently gained popularity for fetal imaging, its role in diagnostic ultrasound remains unclear. While obstetrical ultrasound has the great advantage of the target being surrounded by a natural fluid interface, 3D thyroid ultrasound is limited by the lack of a similar interface distinguishing the thyroid from adjacent neck tissues. It is predicted that breast biopsies will soon be guided in a more precise fashion by real time 3D imaging (21), and it is possible that, in time, thyroid biopsy will similarly benefit. At the present time, however, 3D ultrasound technology does not have a demonstrable role in thyroid imaging.

Elastography is a new technique in which the compressibility of a nodule is assessed by ultrasound as external pressure is applied. With studies showing a good predictive value for prediction of malignancy in breast nodules, recent investigations of its role in thyroid imaging have been promising. Additional prospective trials are ongoing to assess the role of elastography in predicting the likelihood of thyroid malignancy.

With the growing recognition that real time ultrasound performed by an endocrinologist provides far more useful information than that obtained from a radiology report, office ultrasound by endocrinologists has gained acceptance. The first educational course specific to thyroid ultrasound was offered by the American Association of Clinical Endocrinologists (AACE) in 1998. Under the direction of Dr. Jack Baskin, 53 endocrinologists were taught to perform diagnostic ultrasound and ultrasound-guided fine-needle aspiration biopsy. By the turn of the century 300 endocrinologists had been trained. Endocrine University, established in 2002 by AACE, began providing instruction in thyroid ultrasound and biopsy to all graduating endocrine fellows. By the end of 2006 over 2,000 endocrinologists had completed the AACE ultrasound course. In 2007 AACE and the American Institute of Ultrasound Medicine (AIUM) began a collaborative effort for certification and accredidation in thyroid ultrasound.

In the 35 years since ultrasound was first used for thyroid imaging, there has been a profound improvement in the technology and quality of images. The transition from A-mode to B-mode to gray scale images was accompanied by dramatic improvements in clarity and interpretability of images. Current high-resolution images are able to identify virtually all lesions of clinical significance. Ultrasound characteristics cannot predict benign lesions, but features including irregular margins, microcalcifications, and central vascularity may deem a nodule suspicious (3). Ultrasound has proven utility in the detection of recurrent thyroid cancer in patients with negative whole body iodine scan or undetectable thyroglobulin (17, 22). Recent advances including the use of contrast agents, tissue harmonic imaging, elastography, and multiplanar reconstruction of images will further enhance the diagnostic value of ultrasound images. The use of Doppler flow analysis may improve the predictive value for determining the risk of malignancy, but no current ultrasound technique is capable of determining benignity with an acceptable degree of accuracy. Ultrasound guidance of fine-needle aspiration biopsy has been demonstrated to improve both diagnostic yield and accuracy, and will likely become the standard of care. Routine clinical use of ultrasound is often considered an extension of the physical examination by endocrinologists. High quality ultrasound systems are now available at prices that make this technology accessible to virtually all providers of endocrine care (3).

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CHAPTER 2
Thyroid Ultrasound Physics

Robert A. Levine

SOUND AND SOUND WAVES

Some animal species such as dolphins, whales, and bats are capable of creating a "visual" image based on receiving reflected sound waves. Man's unassisted vision is limited to electromagnetic waves in the spectrum of visible light. Humans require technology and an understanding of physics to use sound to create a picture. This chapter will explore how man has developed a technique for creating a visual image from sound waves (1).

Sound is transmitted as mechanical energy, in contrast to light, which is transmitted as electromagnetic energy. Unlike electromagnetic waves, sound waves require a propagating medium. Light is capable of traveling through a vacuum, but sound will not transmit through a vacuum. The qualities of the transmitting medium directly affect how sound is propagated. Materials have different speeds of sound transmission. Speed of sound is constant for a specific material and does not vary with sound frequency (Fig. 2.1). *Acoustic impedance* is the inverse of the capacity of a material to transmit sound. Acoustic impedance of a material depends on its density, stiffness and speed of sound. When sound travels through a material and encounters a change in acoustic impedance a portion of the sound energy will be reflected, and the remainder will be transmitted. The amount reflected is proportionate to the degree of mismatch of acoustic impedance.

Sound waves propagate by compression and rarefaction of molecules in space (Fig. 2.2). Molecules of the transmitting medium vibrate around their resting position and transfer their energy to neighboring molecules. Sound waves carry energy rather than matter through space.

As shown in Fig. 2.2, sound waves propagate in a longitudinal direction, but are typically represented by a sine wave

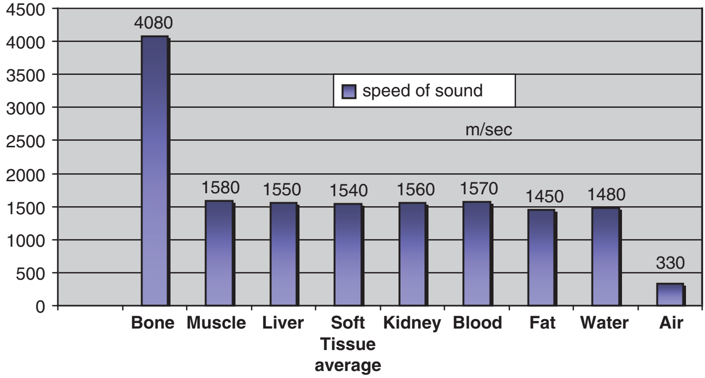


FIG. 2.1. Speed of sound. The speed of sound is constant for a specific material and does not vary with frequency. Speed of sound for various biological tissues is illustrated

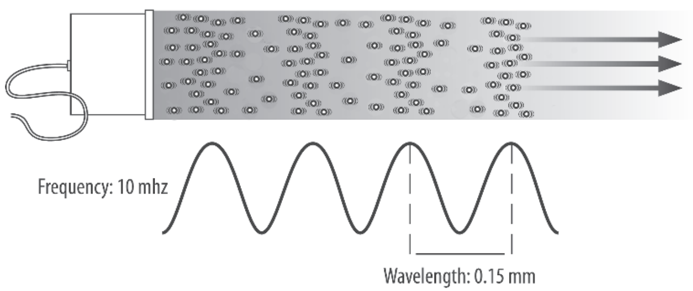


FIG. 2.2. Sound waves propagate in a longitudinal direction but are typically represented by a sine wave where the peak corresponds to the maximum compression of molecules in space, and the trough corresponds to the maximum rarefaction

where the peak corresponds to the maximum compression of molecules in space, and the trough corresponds to the maximum rarefaction. Frequency is defined as the number of cycles per time of the vibration of the sound waves. A Hertz (Hz) is defined as one cycle per second. The audible spectrum is between 30 and 20,000 Hz. Ultrasound is defined as sound waves at a higher frequency than the audible spectrum. Typical frequencies used in diagnostic ultrasound vary between five million and 15 million cycles per second (5 MHz and 15 MHz).

Diagnostic ultrasound uses pulsed waves, allowing for an interval of sound transmission, followed by an interval during which reflected sounds are received and analyzed. Typically three cycles of sound are transmitted as a pulse. The spatial pulse length is the length in space that three cycles fill (Fig. 2.3). Spatial pulse length is one of the determinants of resolution. Since higher frequencies have a smaller pulse length, higher frequencies are associated with improved resolution. As illustrated in Fig. 2.3, at a frequency of 15 MHz the wavelength in biological tissues is approximately 0.1 mm, allowing an axial resolution of 0.15 mm.

As mentioned above, the *speed of sound* is constant for a given material or biological tissue. It is not affected by frequency or wavelength. It increases with stiffness and decreases with density of the material. As seen in Fig. 2.1, common biologic tissues have different propagation velocities. Bone, as a very dense and stiff tissue, has a high propagation velocity of 4,080 meters per second. Fat tissue, with low stiffness and low density, has a relatively low speed of sound of 1,450 m per second. Most soft tissues have a speed of sound near 1,540 m per second. Muscle, liver and thyroid have a slightly faster speed of sound. By convention, all ultrasound equipment uses an average speed of 1,540 meters per second. The distance to an object displayed on an ultrasound image is calculated by multiplying the speed of sound by the time interval for a sound signal to

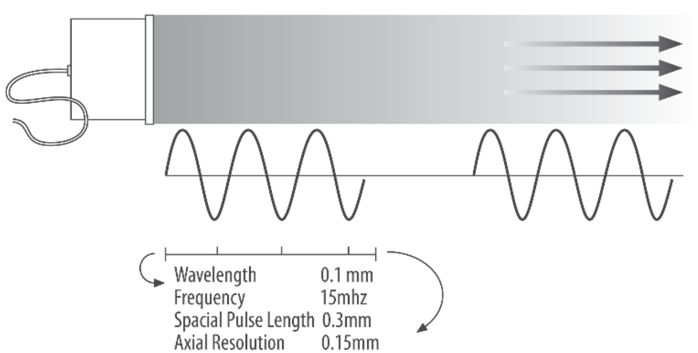
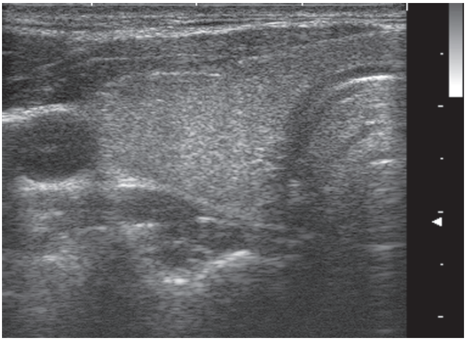
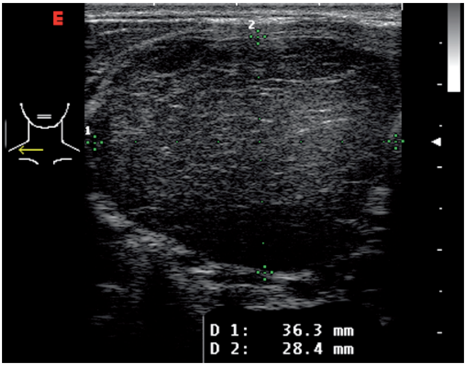
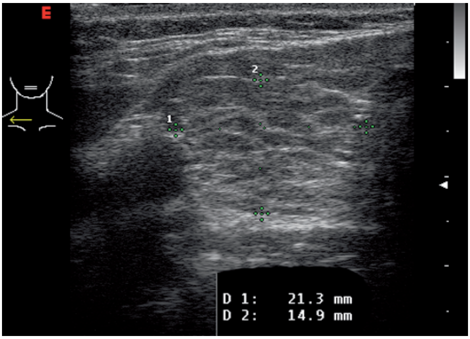


FIG. 2.3. Diagnostic ultrasound uses pulsed waves, allowing for an interval of sound transmission, followed by an interval during which reflected sounds are received and analyzed. Typically three cycles of sound are transmitted as a pulse







FIGS. 2.4–2.6. Most biological tissues have varying degrees of inhomogeneity both on a cellular and macroscopic level. Connective tissue, blood vessels, and cellular structure all provided mismatches of acoustic impedance that lead to the generation of characteristic ultrasonographic patterns. FIG. 2.4. demonstrates the echotexture from normal thyroid tissue. It has a ground glass appearance and is brighter than muscle tissue.

return to the transducer. By using the accepted 1,540 m per second as the assumed speed of sound, all ultrasound equipment will provide identical distance or size measurements.

Reflection is the redirection of a portion of a sound wave from the interface of tissues with unequal acoustic impedance. The greater the difference in impedance, the greater the amount of reflection. A material that is homogeneous in acoustic impedance does not generate any internal echoes. A pure cyst is a typical example of an anechoic structure. Most biological tissues have varying degrees of inhomogeneity both on a cellular and macroscopic level. Connective tissue, blood vessels and cellular structure all provide mismatches of acoustic impedance that lead to the generation of characteristic ultrasonographic patterns (Figs. 2.4–2.6). Reflection is categorized as specular when reflecting off of smooth surfaces such as a mirror. In contrast, diffuse reflection occurs when a surface is irregular, with variations at or smaller than the wavelength of the incident sound. Diffuse reflection results in scattering of sound waves and production of noise.

CREATION OF AN ULTRASOUND IMAGE

The earliest ultrasound imaging consisted of a sound transmitted into the body, with the reflected sound waves displayed on an oscilloscope. Referred to as A-mode ultrasound, these images in the 1960s and 1970s were capable of providing measurements of internal structures such as thyroid lobes, nodules and cysts. Fig. 2.7a shows an A-mode ultrasound image of a solid thyroid nodule. Scattered echoes are present from throughout the nodule. Fig. 2.7b shows the image from a cystic nodule. The initial reflection is from the proximal wall of the cyst, with no significant signal reflected by the cyst fluid. The second reflection originates from the posterior wall. Fig. 2.7c shows the A-mode image from a complex nodule with solid and cystic components. A-mode ultrasound was capable of providing size measurements in one dimension, but did not provide a visual image of the structure.

FIGS. 2.4–2.6. (*Continued*) FIG. 2.5. shows the thyroid from a patient with the acutely swollen inflammatory phase of Hashimoto's thyroiditis. Massive infiltration by lymphocytes has decreased the echogenicity of the tissue resulting in a more hypoechoic pattern. FIG. 2.6. shows a typical heterogeneous pattern from Hashimoto's thyroiditis with hypoechoic inflammatory regions separated by hyperechoic fibrous tissue

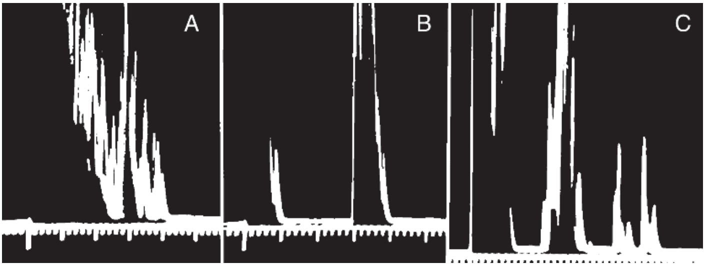


FIG. 2.7. A-mode ultrasound images. **a**. shows an A-mode ultrasound image of a solid thyroid nodule. Scattered echoes are present from throughout the nodule. **b**. shows the image from a cystic nodule. The initial reflection is from the proximal wall of the cyst, with no significant signal reflected by the cyst fluid. The second reflection originates from the posterior wall. **c**. shows the A-mode image from a complex nodule with solid and cystic components

In order to provide a visual two-dimensional image, a series of one-dimensional A-mode images are aligned as a transducer is swept across the structure being imaged. Early thyroid ultrasound images were created by slowly moving a transducer across the neck. By scanning over a structure and aligning the A-mode images, a two-dimensional image is formed. The two-dimensional image formed in this manner is referred to as a B-Mode scan (Fig. 2.8). Current ultrasound transducers use a series of piezoelectric crystals in a linear array to electronically simulate a sweep of the transducer. Firing sequentially, each crystal sends a pulse of sound wave into the tissue and receives subsequent reflections.

The final ultrasound image reflects a cross sectional image through the tissue defined by the thin flat beam of sound emitted from the transducer. Resolution is the ability to distinguish between two separate, adjacent objects. For example, with a resolution of 0.2 mm, two adjacent objects measuring <2 mm would be shown as a single object. Objects smaller than the resolution will not be realistically imaged.

THE USEFULNESS OF ARTIFACTS IN ULTRASOUND IMAGING

A number of artifacts commonly occur in ultrasound images. Unlike most other imaging techniques, artifacts are very helpful in interpreting ultrasound images (2). Artifacts, such as shadows behind objects or unexpected areas of brightness,

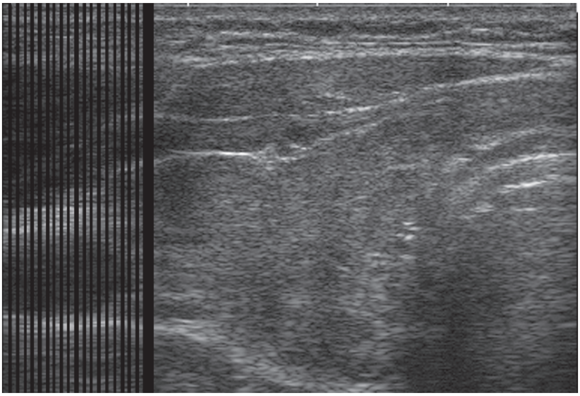


FIG. 2.8. A B-mode ultrasound image is composed of a series of A-mode images aligned to provide a two dimensional image

can provide additional understanding of the properties of the materials being imaged.

When sound waves impact on an area of extreme mismatch of acoustic impedance, such as a tissue-air interface or a calcification, the vast majority of the sound waves are reflected, providing a very bright signal from the object's surface and an absence of imaging beyond the structure. Fig. 2.9 demonstrates *acoustic shadowing* behind a calcified nodule. Fig. 2.10 illustrates a coarse calcification within the thyroid parenchyma with acoustic shadowing behind the calcification. Fig. 2.11 shows the typical appearance of the trachea on an ultrasound image. Because there is no transmission of sound through the air-tissue interface of the anterior wall of the trachea, no imaging of structures posterior to the trachea occurs.

Conversely, a cystic structure transmits sound with very little attenuation, resulting in a greater intensity of sound waves behind it, compared to adjacent structures. This results in acoustic *enhancement* with a brighter signal behind a cystic or anechoic structure. This enhancement can be used to distinguish between a cystic and solid nodule within the thyroid. Fig. 2.12 illustrates enhancement behind a cystic nodule. Enhancement is not limited to cystic nodules, however. Any structure that causes minimal attenuation of the ultrasound signal will have enhancement posterior to it. Fig. 2.13 illustrates enhancement behind a solid parathyroid adenoma. Fig. 2.14 illustrates enhancement behind a benign colloid nodule. Due to the high content of fluid