Choosing the Correct Radiologic Test

Case-Based Teaching Files

Gary X. Wang
Mark A. Anderson
Lauren Uzdienski
Susanna I. Lee

Second Edition

Springer

Choosing the Correct Radiologic Test

Gary X. Wang • Mark A. Anderson
Lauren Uzdienski • Susanna I. Lee

Choosing the Correct Radiologic Test

Case-Based Teaching Files

Second Edition

Springer

Gary X. Wang
Department of Radiology
Massachusetts General Hospital
Boston, MA
USA

Lauren Uzdienski
Independent Scholar
Boston, MA
USA

Mark A. Anderson
Department of Radiology
Massachusetts General Hospital
Boston, MA
USA

Susanna I. Lee
Department of Radiology
Massachusetts General Hospital
Boston, MA
USA

ISBN 978-3-030-65184-8 ISBN 978-3-030-65185-5 (eBook)
https://doi.org/10.1007/978-3-030-65185-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Few areas in medicine have undergone the dramatic expansion of technical capabilities experienced in diagnostic imaging or radiology over the past 50 years. As precision cross-sectional and molecular imaging has rendered older diagnostic tests obsolete, radiology has become one of the fastest expanding and rapidly changing components of healthcare, providing clinicians with powerful and precise tools to diagnose and treat illness. The ultimate beneficiaries have been patients, who enjoy earlier detection of and improved outcomes from disease.

Unfortunately, the training of healthcare providers has failed to keep pace with these rapid advances in radiologic imaging. Medical education, training, and recertification requirements for physicians, nurse practitioners, and physician assistants rarely include provisions to insure current knowledge on the utility and the risks and benefits of radiologic exams. Yet correct imaging utilization, when integrated into patient management algorithms, often expedites diagnosis, enables cost-effective treatment planning, and offers longitudinal monitoring of therapies for safety and efficacy.

This textbook is a guide to appropriate image ordering for the general healthcare provider. The chapters are organized by organ system or patient demographics and focus on commonly encountered clinical scenarios. These chapters cover breast, cardiac, thoracic, gastrointestinal, urologic, women's, pediatric, vascular, musculoskeletal, and neurologic imaging. The teaching is structured in a case-based multiple-choice quiz format. The practitioner is presented with a patient with a specific complaint, physical exam finding, or clinical need (e.g., cancer staging) and asked to choose a radiologic exam that is most likely to be appropriate. Once a choice has been made, the usefulness of each option is evaluated according to the American College of Radiology (ACR) Appropriateness Criteria as "usually," "may be," or "usually not" appropriate. In the answer key, an exam type is described as the "most" appropriate when it is both usually appropriate and preferred over all other answer choices. In some cases, when imaging is not indicated, "no ideal imaging exam" may be the correct answer. Each case is accompanied by an image from the correct radiologic exam choice, illustrating a possible diagnosis for the patient presented in the case, and a brief explanation of the answer. While the goal is to offer advice that is applicable internationally, some of the advanced technologies (e.g., magnetic resonance imaging, positron emission tomography) may not be available in limited resource settings.

Boston, MA, USA Gary X. Wang
Boston, MA, USA Mark A. Anderson
Boston, MA, USA Lauren Uzdienski
Boston, MA, USA Susanna I. Lee

Contents

1 Introduction

1.1 ACR Appropriateness Criteria

The ACR Appropriateness Criteria (American College of Radiology n.d.-a) are practice guidelines for healthcare providers on how to best use imaging in caring for patients with common clinical problems. For each clinical scenario, possible radiology exam choices are evaluated as "usually," "may be," or "usually not" appropriate as defined in Table 1.1. They have been devised by a series of expert panels comprised of radiologists and treating physicians, with each panel devoted to a specific medical specialty or organ system (e.g., pediatric imaging, neurologic imaging). When available, recommendations for exam ordering are derived from clinical research results published in the peer-reviewed literature. However, in the absence of relevant evidence, recommendations are drawn as a consensus expert opinion of the panel members. The guidelines are freely available online and are kept current, with updates every 2–3 years.

Table 1.1 Exam appropriateness rankings

Appropriateness ranking	Definition
Usually appropriate	Imaging is indicated, and the exam choice is likely to benefit the patient The most preferable exam choice in this category is described as the "most appropriate" in the answer key
May be appropriate	Imaging is indicated, and the exam choice is second line to another more likely to benefit the patient Imaging may be indicated, and the exam choice may benefit the patient
Usually not appropriate	Imaging is indicated, but the exam choice is unlikely to benefit the patient Imaging is probably not indicated, and the exam choice is unlikely to benefit the patient
No ideal imaging exam	Imaging is not indicated

G. X. Wang et al., *Choosing the Correct Radiologic Test*,
https://doi.org/10.1007/978-3-030-65185-5_1

While comprehensive, the Appropriateness Criteria is far from exhaustive. On many clinical issues where no or little research evidence or expert consensus is available (e.g., posttreatment surveillance, chronic pain), the Appropriateness Criteria, as well as this textbook, is silent. Finally, for many scenarios, the underlying assumption is that the referring practitioner has evaluated the patient and determined that a radiologic exam may be indicated. Only rarely do the guidelines speak to the question, “Should imaging be undertaken at all?” Few cases that address this query define specific clinical criteria (i.e., patient complaints or physical exam findings) that should be present before imaging has been shown useful.

1.2 Imaging Modalities

Radiologic exams are generally classified by the imaging modality. These include X-ray plain film (also called radiography) and fluoroscopy, ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine scan (also called scintigraphy) and positron emission tomography (PET), and image-guided interventional procedures. As diagnostic tests, each carry known advantages and disadvantages. The language of radiology, like that for all other medical specialties, is replete with acronyms. Those commonly used in this textbook have been defined in Table 1.2.

1.2.1 X-ray and Fluoroscopy

X-ray plain film (also called radiography) is the oldest and most widely available radiologic modality. Evaluation of many body parts (e.g., chest, abdomen, extremities) is possible at the bedside at many sites. Images of reasonable diagnostic quality can be obtained even in patients who cannot cooperate with breath-holding instructions as acquisition times are on the order of seconds. Extremely high resolution allows for optimal evaluation of bone and lung. Exams deliver 0.001–1 mSv of ionizing radiation, well below the average annual radiation dose of 3 mSv from background radiation (RadiologyInfo.org n.d.).

With fluoroscopy, the patient is evaluated in real time with X-ray. Thus, movement such as that of bowel, diaphragm, or the joints can be assessed. Enteric contrast, either barium-based (non-water soluble) or iodine-based (water soluble), is administered orally (e.g., X-ray swallow exam) or rectally (e.g., X-ray contrast enema) for the visualization of the esophagus, stomach, and small bowel or the colon, respectively. X-ray fluoroscopy confers higher radiation doses than plain film with effective doses of 6–8 mSv for abdominal exams (RadiologyInfo.org n.d.). Because exams require that the patient be able to follow swallowing, positioning, and breath-holding instructions, it cannot be used effectively to evaluate the critically ill or debilitated patients.

Table 1.2 List of acronyms

ACR	American College of Radiology
AJCC	American Joint Committee on Cancer
β-HCG	β-Human chorionic gonadotropin
CCHR	Canadian CT head rule
CCR	Canadian C-spine rules
CT	Computed tomography
CTA	Computed tomography angiogram
DMSA	Dimercaptosuccinic acid
DTPA	Diethylenetriaminepentaacetic acid
ERCP	Endoscopic retrograde cholangiopancreatogram
F-18	Fluorine-18
FAST	Focused assessment with sonography for trauma
FDG	Fluorodeoxyglucose
FIGO	International Federation of Gynecology and Obstetrics
Ga-67	Gallium-67
GCS	Glasgow coma scale
HMPAO	Hexamethylpropyleneamine oxime
HU	Hounsfield units
I-123	Iodine-123
In-111	Indium-111
MAA	Macroaggregated albumin
MAG3	Mercaptoacetyltriglycine
MDP	Methylene diphosphonate
mGy	Milli-Gray
MIBG	Metaiodobenzylguanidine
MIP	Maximum intensity projection
MRA	Magnetic resonance angiogram
MRCP	Magnetic resonance cholangiopancreatogram
MRI	Magnetic resonance imaging
mSv	Milli-Sievert
NEXUS	National emergency X-radiography utilization study
NOC	New Orleans criteria
PECARN	Pediatric emergency care network
PET	Positron emission tomography
PSA	Prostate-specific antigen
SPECT	Single-photon emission computerized tomography
Tc-99m	Metastable technetium-99m
US	Ultrasound
V/Q	Ventilation-perfusion
Xe-133	Xenon-133

1.2.2 Ultrasound

Ultrasound (US) is a modality that is widely available and can be performed at the bedside for critically ill patients. It also has the advantage that no ionizing radiation is involved. No biologic effects have been documented from diagnostic US exams, even in the fetus, despite widespread use over several decades. With Doppler, the theoretical risks to a fetus from heat and cavitation are a consideration; hence, it is used judiciously, minimizing the exposure time and acoustic output. Intravenous contrast is an option available for specific indications (e.g., liver or renal mass characterization) but is not administered in the routine diagnostic US exam.

US as an imaging tool is hampered by its inability to penetrate through many tissues (e.g., typically <10 cm in soft tissue, 0 cm through air or bone). Also, the width of the image is limited by the transducer which is typically <15 cm. This limited field of view means US is not useful as a comprehensive search tool for the whole body or even a body part. In essence, you find what you are looking for where you are looking for it, but rarely anything more. Image acquisition protocols are not standardized, and most practices do not acquire volumetric cine images of the target body part, meaning that test results rely on real-time operator assessment. Consequently, it is challenging to test the reported diagnostic accuracies for reproducibility or inter-reader agreement. In this sense, US is more analogous to an extension of the physical exam rather than a diagnostic test.

1.2.3 Computed Tomography

Computed tomography (CT) is widely available in both outpatient and inpatient settings. Exams are well tolerated, as imaging a given body part typically requires <15 s on most scanners. Thus, even in a patient who is unresponsive or unable to cooperate with breathing instructions, CT has a high likelihood of yielding diagnostic quality images. Imaging involves an X-ray beam capable of penetrating through most tissue types (metallic implants being the notable exception) and yields large field-of-view images for complete assessment of the entire body. Bone, soft tissue, fluid, fat, and air are all imaged with high resolution and reproducibility. Intravenous contrast is iodine based and is administered to evaluate vessels and to improve soft tissue contrast of the solid and hollow viscera, renal collecting systems, and neoplasms.

Ionizing radiation exposure is the most significant drawback of CT. While effective doses administered by a diagnostic CT exam (1–20 mSv in adult) have not been directly shown to pose a health risk, extrapolation from higher levels estimate, for instance, an added fatal cancer risk of approximately 1:1000 in an adult undergoing an abdomen CT exam (RadiologyInfo.org n.d.; National Research Council 2006). While this may seem negligible in the context of the general lifetime risk of 1:5 for fatal cancer, this risk is thought to be additive with each exam. The risk is also likely to be higher in the pediatric population and in the fetus.

Intravenous iodinated contrast is associated with a 3% incidence of allergic reaction, the vast majority of which are mild (e.g., itching, hives) and self-limited (American College of Radiology n.d.-b). However, 0.004–0.04% incidence of severe reactions (e.g., laryngeal edema, hypotension) requiring hospitalization has been reported. In patients with end stage renal disease (i.e., estimated glomerular filtration rate [eGFR] less than 30 mL/min/1.73 m^2), transient acute kidney injury (AKI) also represents a potential complication. The pre-disposing risk factors that should trigger a measurement of renal function before iodinated contrast administration is a history of kidney disease (e.g., chronic kidney disease, AKI, kidney surgery, or albuminuria) or diabetes.

1.2.4 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) affords the best soft tissue contrast of any of the radiologic modalities and involves no ionizing radiation. Brain and spinal cord, bone marrow, joints, muscles, and abdominopelvic solid organs (e.g., liver, kidneys, uterus, prostate) are all optimally depicted with MRI. The electromagnetic field, which is the basis for scanning, allows for multiplanar imaging with a large field of view. Application of multiple electromagnetic pulse sequences (e.g., T1-, T2-, proton density-weighted) enables differentiation of a large variety of soft tissues. For some indications, intravenous contrast that is gadolinium based is administered to better evaluate the vessels, solid viscera, and neoplasms. However, even in a patient who cannot receive intravenous contrast, specific flow-sensitive pulse sequences can be used to evaluate the blood vessels.

Disadvantages of MRI include limited access to the scanner itself or the radiologist expertise to implement and interpret the exams in some practice settings. Most exams entail that the patient lie still in an enclosed scanner for up to 20–40 min, although wider bore or "open" scanners if available can be used for some indications. For pediatric patients who are too young to cooperate or lie still sedation may be necessary. In critically ill patients, monitoring and supportive-care equipment that are usually incompatible with high field strength magnets would be a contraindication to scanning. Even in conscious patients, concerns such as claustrophobia or inability to lie still or cooperate with breath-holding procedures can hinder successful image acquisition.

Intravenous gadolinium contrast is associated with a much lower incidence (0.07%) of allergic reactions than iodinated contrast (3%) (American College of Radiology n.d.-b). Incidence of severe reactions requiring hospitalization is reported as <0.005%. However, gadolinium contrast administration in patients with renal failure has been associated with nephrogenic systemic fibrosis (NSF), a syndrome resulting in progressive fibrosis of the skin, joints, eyes, and organs, which is uniformly fatal. While the newer macrocyclic class of gadolinium agents now in use have not been associated with NSF, gadolinium is still considered relatively contraindicated in patients with end stage renal disease (i.e., eGFR less than 30 mL/min/1.73 m^2).

1.2.5 Nuclear Medicine Scan

Nuclear medicine scanning and positron emission tomography (PET) employs the physiologic and biochemical processes in the body to image-specific organs and their functions. Radiopharmaceuticals are administered, most often intravenously, but for some exams by other means such as inhalation (^{133}Xe into lung) or by catheter (^{99}Tc-pertechnetate into bladder). Their uptake and/or excretion by various tissues are then imaged by computer-aided detectors that can acquire and present the information in planar (e.g., anteroposterior, lateral) or tomographic (e.g., single-photon emission computerized tomography [SPECT], PET) format.

Because a physiologically active radiotracer is used, many nuclear medicine scans have the distinct advantage of being able to provide functional as well as anatomic information. Examples include cardiac myocardial perfusion (^{99}Tc-sestamibi), bone turnover (^{99}Tc-MDP), lung ventilation (^{133}Xe) and perfusion (^{99}Tc-MAA), and glucose metabolism (^{18}FDG). These are each tailored to answer a defined diagnostic question. Effective radiation doses range from 1 to 20 mSv and, hence, are comparable to a CT exam (RadiologyInfo.org n.d.). Because the imaging source is emitted from the body, rather than being external, whole-body evaluation is possible.

The major disadvantage of a nuclear medicine exam is poor spatial resolution, which for some exams has been mitigated by fusing the nuclear medicine images with concurrently acquired anatomic images (e.g., PET-CT). Availability of many exam types is often limited because a radiopharmacy and, for specific isotopes, a cyclotron, must be nearby to deliver isotopes with half-lives on the order of several minutes to days. Finally, image acquisition requires table times of 30 min to several hours rendering many exams unsuitable for the uncooperative or critically ill patient.

1.2.6 Interventional Procedures

Image-guided interventional procedures in diagnostic radiology typically use fluoroscopy, US, or CT to introduce a catheter or a needle into a particular anatomic space, such as a blood vessel (angiogram), a joint space (arthrogram), the spinal canal (myelogram), or a hollow viscera (e.g., cystogram, hysterosonogram). Contrast material is then introduced, thereby allowing for high-contrast visualization of the opacified lumen. Biopsies comprise the other general category of diagnostic radiologic interventions. Here an aspiration and/or cutting needle is introduced into the lesion or organ of interest under imaging guidance to obtain samples for histology, culture, or other laboratory studies.

Most image-guided interventions are performed as same-day outpatient procedures. Procedures on superficial targets (e.g., skin, breast) or joints can be performed on cooperative patients without sedation. Angiograms and deep tissue biopsies, however, usually require conscious sedation for which the patient will need to fast before and be monitored after the procedures. Major complications requiring hospitalization are very rare (Society of Interventional Radiology Standards of Practice

Committee 2003). Minor complications include bleeding (usually self-limited), localized infection, and allergic reaction to administered contrast.

Bibliography

American College of Radiology. ACR Appropriateness Criteria. n.d.-a. Available at https://acsearch.acr.org/list. Accessed 20 Mar 2020.

American College of Radiology committee on drugs and contrast media. ACR manual on contrast media, version 10.2. n.d.-b. Available at https://www.acr.org/-/media/ACR/Files/Clinical-Resources/Contrast_Media.pdf. Accessed 20 Mar 2020.

National Research Council committee to assess health risks from exposure to low levels of ionizing radiation. Health risks from exposure to low levels of ionizing radiation: BEIR VII phase 2. Washington, DC: National Academies Press; 2006.

RadiologyInfo.org. Radiation dose in X-ray and CT exams. n.d.. Available at https://www.radiologyinfo.org/en/info.cfm?pg=safety-xray. Accessed 20 Mar 2020.

Society of Interventional Radiology Standards of Practice Committee. Quality improvement guidelines for image-guided percutaneous biopsy in adults. J Vasc Interv Radiol. 2003;14:S227–30.

2 Breast Imaging

2.1 Palpable Breast Lump

A 54-year-old woman with a palpable breast lump.

a. Mammography diagnostic
b. US breast
c. MRI breast without and with contrast
d. FDG-PET breast
e. No ideal imaging exam

G. X. Wang et al., *Choosing the Correct Radiologic Test*,
https://doi.org/10.1007/978-3-030-65185-5_2

A woman 40 years of age or older, initial evaluation.

a. *Mammography diagnostic* is the most appropriate.
b. US breast may be appropriate as the initial imaging exam if the patient has had a mammogram within the past 6 months.
c. MRI breast without and with contrast is usually not appropriate.
d. FDG-PET breast is usually not appropriate.

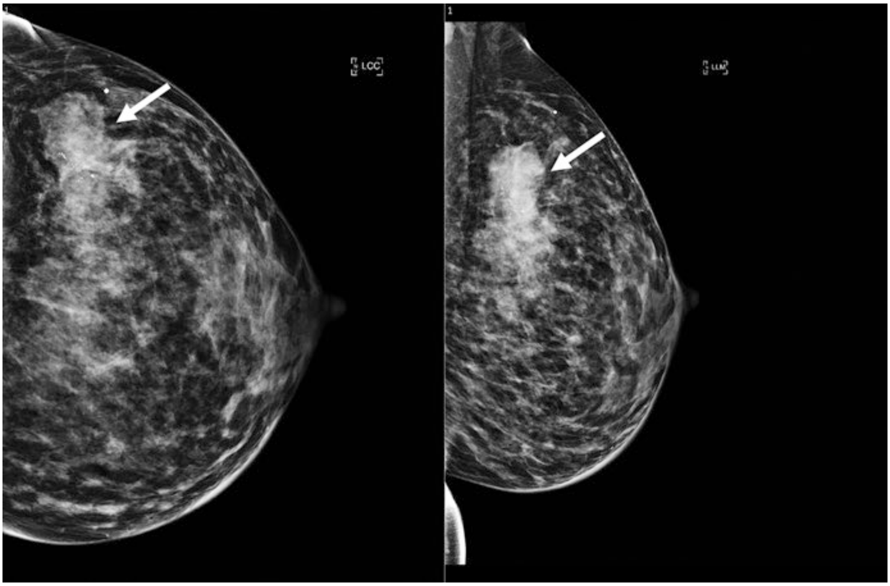

Fig. 2.1 Breast cancer. Diagnostic mammography craniocaudal (left) and mediolateral (right) views of the left breast show an irregular mass at the site of a palpable lump (arrows). Core needle biopsy of the mass revealed invasive ductal carcinoma

Solution
Diagnostic mammography is the primary exam for initial imaging assessment of a palpable lump and is performed under the direct supervision of a radiologist. A small radio-opaque marker is placed on the skin overlying the lump to identify its position. If a clearly benign correlate is identified, then mammography alone may be enough. Otherwise, additional imaging with another modality is indicated.

A 54-year-old woman with a palpable breast lump. Mammography shows a finding suspicious for malignancy.

a. US breast
b. MRI breast without and with contrast
c. FDG-PET breast
d. Image-guided fine needle aspiration breast
e. No ideal imaging exam

A woman 40 years of age or older, mammography finding suspicious for malignancy.

a. *US breast* is the most appropriate.
b. MRI breast without and with contrast is usually not appropriate.
c. FDG-PET breast is usually not appropriate.
d. Image-guided fine needle aspiration breast is usually not appropriate.

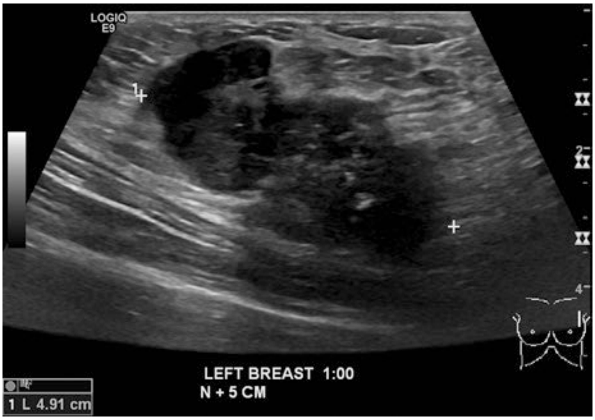

Fig. 2.2 Breast cancer. Breast US shows a 4.9 cm irregularly shaped mass (calipers). Core needle biopsy diagnosed invasive ductal carcinoma

Solution

US may help characterize a suspicious mammographic finding and identify additional lesions not evident on mammography. If a US correlate to the mammographic finding is identified, then biopsy can be performed under sonographic guidance. US-guided biopsy may be better tolerated by some patients than mammographic-guided biopsy and allows biopsy of areas difficult to access mammographically.

A 57-year-old woman with a palpable breast lump. Mammography is negative.

a. US breast
b. MRI breast without and with contrast
c. FDG-PET breast
d. Image-guided core biopsy breast
e. No ideal imaging exam

A woman 40 years of age or older, mammography is negative.

a. *US breast* is the most appropriate.
b. MRI breast without and with contrast is usually not appropriate.
c. FDG-PET breast is usually not appropriate.
d. Image-guided core biopsy breast is usually not appropriate.

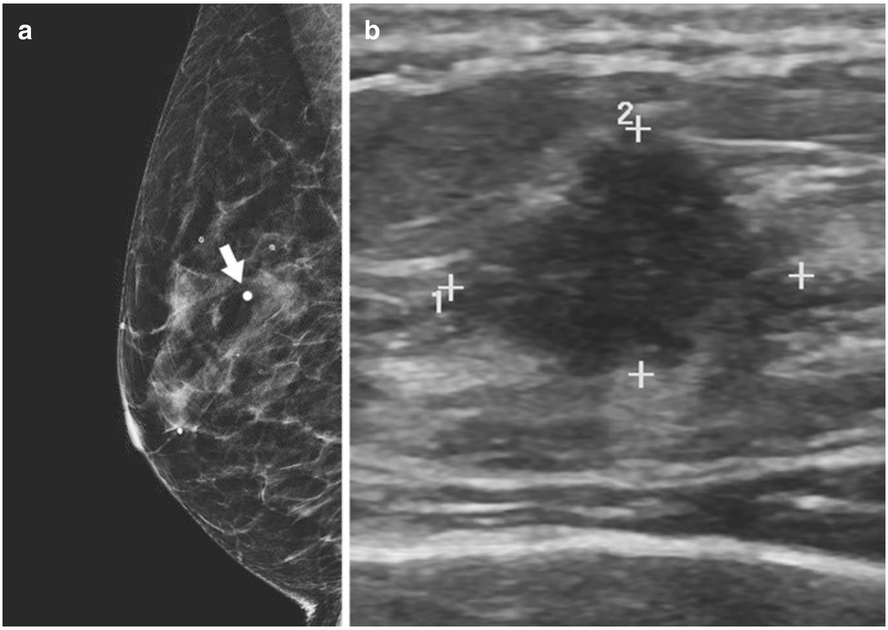

Fig. 2.3 Breast cancer. Diagnostic mammography mediolateral view of the right breast (**a**) shows scattered fibroglandular tissue without focal abnormality at the site of a palpable lump indicated by a radio-opaque marker (arrow). Breast US (**b**) found an irregularly shaped mass (calipers) that was obscured by surrounding breast tissue on mammogram. Core needle biopsy diagnosed invasive ductal carcinoma

Solution

US allows direct correlation of the palpable lump with imaging findings. When both mammography and US are negative or benign in the evaluation of a palpable breast lump, the negative predictive value excluding malignancy is very high, over 97%.

A 29-year-old woman with a palpable breast lump.

a. Mammography diagnostic
b. US breast
c. MRI breast without and with contrast
d. Image-guided fine needle aspiration breast
e. No ideal imaging exam

A woman younger than 30 years of age, initial evaluation.

a. Mammography diagnostic is usually not appropriate.
b. *US breast* is the most appropriate.
c. MRI breast with contrast is usually not appropriate.
d. Image-guided fine needle aspiration breast is usually not appropriate.

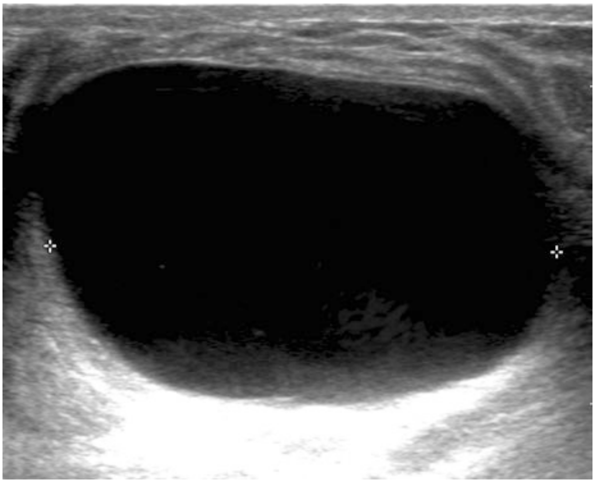

Fig. 2.4 Breast cyst. Breast US shows a simple cyst (calipers) corresponding to the palpable lump

Solution
US is the preferred exam because it avoids ionizing radiation and because of the low incidence of breast cancer in women age <30 years. In addition, most benign lesions in young women are not visualized on mammography.

A 22-year-old woman with a palpable breast lump. US shows a probably benign finding.

a. Mammography diagnostic
b. US breast follow-up in 6–12 months
c. MRI breast without and with contrast
d. Image-guided core biopsy breast
e. No ideal imaging exam

A woman younger than 30 years of age, US findings probably benign.

a. Mammography diagnostic is usually not appropriate.
b. *US breast follow-up in 6–12 months* is the most appropriate.
c. MRI breast without and with contrast is usually not appropriate.
d. Image-guided core biopsy breast is usually not appropriate.

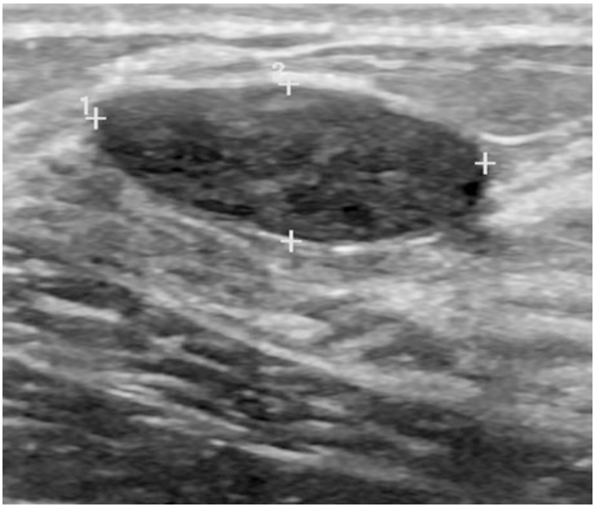

Fig. 2.5 Fibroadenoma. Breast US shows an oval circumscribed hypoechoic mass oriented parallel to the chest wall, corresponding to the palpable lump. This was stable on 2 years of US follow-up, consistent with a benign lesion, and presumptively diagnosed as a fibroadenoma

Solution

For women aged <30 years, US follow-up is an appropriate alternative to biopsy for palpable solid masses with benign US features if the clinical evaluation also suggests a benign etiology. Benign US features include an oval or round shape, well-defined margin, homogenous echogenicity, orientation parallel to chest wall, and lack of posterior acoustic shadowing. Follow-up is usually at 6–12 months intervals for 2–3 years.

A 28-year-old woman with a palpable breast mass. US is negative.

a. Mammography diagnostic
b. US breast short-interval follow-up
c. MRI breast without and with contrast
d. FDG-PET breast
e. No ideal imaging exam

A woman younger than 30 years of age, US negative.

a. Mammography diagnostic is usually not appropriate.
b. US breast short-interval follow-up is usually not appropriate.
c. MRI breast without and with contrast is usually not appropriate.
d. FDG-PET breast is usually not appropriate.
e. *No ideal imaging exam* is the correct answer.

Solution
Mammography following a negative US is usually not appropriate in women aged <30 years unless clinical findings are highly suspicious for malignancy.