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ACR–SPR–SSR PRACTICE PARAMETER FOR THE PERFORMANCE OF MUSCULOSKELETAL QUANTITATIVE COMPUTED TOMOGRAPHY (QCT)

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner in light of all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of this document is to assist practitioners in achieving this objective.

[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, ___ N.W.2d ___ (Iowa 2013) Iowa Supreme Court refuses to find that the *ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures* (Revised 2008) sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

I. INTRODUCTION

This practice parameter was revised collaboratively by the American College of Radiology (ACR), the Society for Pediatric Radiology (SPR), and the Society of Skeletal Radiology (SSR).

Musculoskeletal quantitative computed tomography (QCT) can be used to accurately and reproducibly measure bone mass [1-12] or muscle mass [13-17]. QCT is a clinically proven method of measuring bone mineral density (BMD) in the spine and proximal femur. QCT is used primarily in the diagnosis and management of osteoporosis and other disease states that may be characterized by abnormal BMD, as well as to monitor response to therapy for these conditions.

For BMD measurement, QCT has some advantages over dual-energy X-ray absorptiometry (DXA). DXA measurements may be significantly biased by severe degenerative changes of the hip or spine, vascular calcifications, oral contrast agents, and foods or dietary supplements containing significant quantities of calcium or other heavier minerals or elements [18-20]. QCT is also accurate in patients with extremely high or low body mass index [21-24].

There are well-documented differences in the response of cortical and trabecular bone to aging and therapeutic interventions. QCT spine BMD measurements are used to characterize only trabecular bone, while hip area-density measurements obtained using QCT predominantly characterize cortical bone. QCT spine BMD measurements provide a sensitive indication of spine fracture risk and a somewhat less sensitive indication of hip fracture risk [25,26].

For pediatric applications, see section II.B. It should be noted that peripheral QCT (pQCT) is commonly performed in children. It has the advantage of lower radiation dose [27].

This practice parameter outlines the principles of performing high-quality musculoskeletal QCT.

II. INDICATIONS AND CONTRAINDICATIONS

Musculoskeletal QCT measurement is indicated whenever a clinical decision is likely to be directly influenced by the result of the test. For measurement of BMD, QCT may be considered in place of or in addition to DXA in the following circumstances [28-35]:

A. Indications for QCT include, but are not limited to, individuals with suspected abnormal bone or muscle mass including:

1. All women 65 years and older and men 70 years and older (asymptomatic screening).
2. All postmenopausal women younger than 65 years and men younger than 70 years who have risk factors for osteoporosis including:
    a. A history of fracture; a wrist, hip, spine, or proximal humerus fracture with minimal or no trauma, excluding pathologic fractures
    b. Family history of osteoporotic fracture
    c. Low body mass (less than 127 lbs or 57.6 kg)
    d. Current use of cigarettes
    e. Excessive use of alcohol
    f. Loss of height, thoracic kyphosis
3. Individuals of any age with findings suggestive of demineralization [36] or fragility fractures on imaging studies, such as radiographs, computed tomography (CT), or magnetic resonance imaging (MRI) examinations.
4. Individuals receiving (or expected to receive) glucocorticoid therapy for more than 3 months.
5. Individuals beginning or receiving long-term therapy with medications known to adversely affect BMD (eg, anticonvulsant drugs, androgen deprivation therapy, aromatase inhibitor therapy, or chronic heparin).

6. Individuals with an endocrine disorder known to adversely affect BMD (eg, hyperparathyroidism, hyperthyroidism, or Cushing's syndrome).
7. Postpubertal hypogonadal males with surgically or chemotherapeutically induced castration [37,38].
8. Individuals with medical conditions associated with abnormal BMD, such as:
    a. Chronic renal failure
    b. Rheumatoid arthritis and other inflammatory arthritides
    c. Eating disorders, including anorexia nervosa and bulimia
    d. Gastrointestinal malabsorption or sprue
    e. Osteomalacia
    f. Acromegaly
    g. Chronic alcoholism or established cirrhosis
    h. Multiple myeloma
    i. Gastric bypass surgery
    j. Organ transplantation
    k. Prolonged immobilization
9. Individuals being monitored to:
    a. Assess the effectiveness of osteoporosis drug therapy [39-41]
    b. Follow-up medical conditions associated with abnormal BMD
10. Individuals with extremely high obesity or low body mass index, in whom DXA measurements of BMD may not be accurate.
11. QCT of muscle may be indicated as a tool to measure sarcopenia (eg, for patients with cancer) [42].

B. Pediatric Indications and Considerations

Indications for performing BMD examinations and its subsequent assessment in children differ significantly from those in adults. Interpreting BMD measurements in children is complicated by the growing skeleton [43,44]. DXA is unable to take into account changes in body and skeletal size during growth, limiting its usefulness in longitudinal studies. For example, an increase in DXA-measured areal BMD in the spine is more likely a reflection of change of vertebral size than a change in BMD [45]. Because QCT can assess both volume and density of bone in the axial and appendicular skeleton, it may be more useful than DXA in children [46]. Due to its lower radiation dose, pQCT, which assesses the extremities, may be preferable to central QCT in pediatric patients.

In children and adolescents, BMD measurement is indicated whenever a clinical decision is likely to be directly influenced by the result of the test. Indications for QCT/pQCT include, but are not limited to [47]:

1. Individuals receiving (or expected to receive) glucocorticoid therapy for more than 3 months.
2. Individuals receiving radiation or chemotherapy for malignancies.
3. Individuals with an endocrine disorder known to adversely affect BMD (eg, hyperparathyroidism, hyperthyroidism, growth hormone deficiency or Cushing's syndrome).
4. Individuals with bone dysplasias known to have excessive fracture risk (osteogenesis imperfecta, osteopetrosis) or high BMD, such as prolonged exposure to fluoride
5. Individuals with medical conditions that could alter BMD, such as:
    a. Chronic renal failure
    b. Rheumatoid arthritis and other inflammatory arthritides
    c. Eating disorders, including anorexia nervosa and bulimia
    d. Organ transplantation
    e. Prolonged immobilization
    f. Sprue, inflammatory bowel disease, malnutrition
    g. Cystic fibrosis
    h. Osteomalacia
    i. Acromegaly
    j. Cirrhosis
    k. HIV infection, prolonged exposure to fluorides
    l. Hematologic disorders (Thalassemia, Sickle cell disease)

C. Contraindications

1. There are no absolute contraindications to performing QCT. However, a QCT examination may be of limited value or require modification of the technique or rescheduling of the examination in some situations, including:
   a. Administration of intravascular iodinated contrast. If a QCT of the spine and contrast enhanced examination of the abdomen are performed simultaneously, the bone or muscle may be altered by the contrast enhancement [48].
   b. Pregnancy
   c. Severe degenerative changes or fracture deformity in the measurement area
   d. Implants, hardware, devices, or other foreign material in the measurement area
   e. Inability to position the patient completely within the scanning field of view

2. For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [49].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

For the physician, medical physicist, and radiologic technologist qualifications, see the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [50]. Additional specific qualifications and responsibilities include:

A. Physician [51]

1. The examination must be performed under the supervision of and interpreted by a licensed physician with the following qualifications:
   a. Documented training in and understanding of the physics of X-ray absorption and radiation protection, including the potential hazards of radiation exposure to both patients and personnel and the monitoring requirements.
   b. Knowledge and understanding of the process of QCT data and image acquisition, including proper patient positioning and placement of regions of interest, and artifacts and anatomic abnormalities that may falsely increase or decrease measured values.
   c. Knowledge and understanding of the analysis and reporting of QCT, including, but not limited to: BMD values, T-score, Z-score, and fracture risk.
   d. Knowledge and understanding of the criteria for comparison of serial measurements, including limitations of comparing measurements made by different techniques and different devices.
   e. Knowledge and understanding of other bone densitometry techniques, including DXA, peripheral DXA, pQCT, and quantitative ultrasound, to fulfill a consultative role in recommending further bone densitometry studies, future serial measurements, or diagnostic procedures to confirm suspected abnormalities seen on QCT images.

2. The supervising physician is responsible for overseeing the QCT facility and its equipment quality control program. The physician accepts final responsibility for the quality of all QCT examinations.

B. Radiologic Technologist

1. The examination must be performed by a technologist with the following responsibilities and qualifications:
   a. Ensuring patient comfort and safety, preparing and properly positioning the patient, placing regions of interest, monitoring the patient during the procedure, and obtaining the measurements prescribed by the supervising physician.
   b. Determining the precision error of the equipment (see section VII).
   c. Documented formal training in the use of the QCT equipment, including performance of all manufacturer-specified quality assurance (QA) procedures.

d. Knowledge of and familiarity with the manufacturer's operator manual for the specific scanner model being used.
e. State licensure and/or certification, if required.
f. Certification by the American Registry of Radiologic Technologists in CT is also desirable.

2. Continuing Medical Education
The technologist's continuing medical education should be in accordance with the national registry or state licensure requirements, where applicable.

IV. SPECIFICATIONS AND ANALYSIS OF THE EXAMINATION

A. The written or electronic request for a QCT examination should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 35, adopted in 2006 – revised in 2016, Resolution 12-b)

B. QCT

For BMD measurement, QCT may involve phantom-based or phantomless acquisition. Most commonly, adults may have QCT of the spine and/or hip. Children usually have only a spine QCT or pQCT. Anatomic areas of prior surgery or known fracture should be excluded from measurement.

1. Phantom-based QCT acquisition
   a. Phantom-based QCT acquisition can be performed with simultaneous scanning patient and phantom or with asynchronous scanning of patient and phantom:QCT has historically been performed with simultaneous scanning of the patient and a calibration phantom. There are a number of different techniques, with technical parameters dependent on manufacturer [52]. The QCT software uses known phantom densities and measured CT attenuation to calculate BMD of the spine or hip. The primary advantage of this technique is that any variation in CT scanner output is corrected for by the simultaneous scan.
   b. Asynchronous techniques allow for scanning of the calibration phantom at a different time from the scanning patient. This is possible because of greater stability of x-ray output by modern CT scanners [11,52,53]. The temporal decoupling of phantom and patient scanning allows more convenient scanning because there is no need to use the phantom for each patient scan. In addition, BMD can be calculated from CT examinations originally obtained for purposes other than BMD measurement (opportunistic screening).

2. Phantomless QCT Acquisition
Various phantomless techniques for QCT are gaining in popularity [11,52]. All of these techniques have the obvious benefit of not requiring a calibration phantom. One technique uses the patient's muscle and fat for calibration when calculating BMD [54]. Another technique estimates BMD by performing calcium material decomposition using dual-energy CT acquisition [55]. Other phantomless techniques do not attempt to measure BMD, but instead use the actual CT attenuation values to screen for osteoporosis [56]. This technique has broad appeal in that it can be easily performed by measuring the mean CT attenuation on PACS viewers. However, CT attenuation of bone can vary significantly with varying CT parameters

such as kVp [57]. Like asynchronous techniques, phantomless techniques can be applied to CT examinations originally obtained for purposes other than BMD measurement (opportunistic screening).

C. Diagnosis of osteoporosis

1. Hip QCT measurements
Two-dimensional areal BMD of the proximal femur can be obtained from 3-D QCT. This technique (CTXA) generates a 2-D image that is analogous to hip DXA image and can be analyzed using the same regions of interest [9,58]. The CTXA femoral neck T-scores can be directly compared to DXA T-scores that use the NHANES reference data [39]. WHO diagnostic categories should only be assigned based on CTXA hip T-score, not spine QCT T-score. The femoral neck CTXA BMD measurement can also be used to determine fracture risk using the Fracture Risk Assessment Tool (FRAX) [59].

Unlike spine QCT measurements, which are optimally obtained using noncontrast CT examinations, CTXA values from both enhanced and unenhanced CT scans can be used [60].

2. Spine QCT measurements
Currently there are no consensus standards for assigning diagnostic categories based on spine QCT measurements. Although some QCT software manufacturers provide spine T-scores, these should not be used to assign a diagnostic category using the World Health Organization (WHO) DXA guidelines. Instead, the following diagnostic cut points may be used for assigning a spine QCT diagnostic category approximately equivalent to the WHO guidelines

QCT Trabecular Spine BMD Range	Equivalent WHO Diagnostic Category
BMD > 120 mg/cm^3	Normal
80 mg/cm^3 ≥ BMD ≥ 120 mg/cm^3	Osteopenia
BMD < 80 mg/cm^3	Osteoporosis

The above categories were derived by selecting thresholds that result in approximately the same fraction of the population being assigned to a specific category based on QCT spine T-score as would be assigned based on QCT hip T-score. The use of T-scores has been avoided in this categorization to reinforce the fact that QCT spine T-scores and hip T-scores are frequently different. Assigning a WHO diagnostic category based on a QCT spine T-score may result in overestimating a patient's fracture risk.

D. For premenopausal women and men younger than 50 years, the BMD and Z-score should be reported for each skeletal site examined. The WHO classification does not apply to these individuals (except for women in menopausal transition). Z-scores above −2.0 are considered within the expected range for age. Individuals with Z-scores of −2.0 and lower are considered to have low bone density for their age.

E. For children and adolescents, T-scores should not be reported. The WHO classification does not apply; the terms "osteopenia" and "osteoporosis" should not be used. When BMD Z-scores are less than or equal to −2.0, "Low bone mineral mass or bone mineral density" is the preferred terminology for pediatric QCT reports [64].

F. For follow-up examinations, comparison should be made to any prior comparable QCT examinations of the same site. The precision error of the specific scanner(s) should be determined to identify whether any changes are statistically significant [65]. Comparable scans include, in order of decreasing validity:

1. Previous examinations on the same well-maintained unit.
2. Previous examinations on another unit from the same manufacturer.
3. Previous examinations on a unit from another manufacturer, with results reported in standardized units.

G. Because of radiation dose considerations, least significant change parameters are not used for clinical evaluations, although they may be obtained for research purposes. Appropriate quality assurance procedures should be performed according to hardware and software manufacturers' guidelines. In children, QCT protocols should be modified and optimized to minimize radiation exposures [66].

H. When assessing muscle mass using QCT, additional factors should be considered:

1. Muscle is the largest protein reservoir in the body and is considered an important biomarker of a patient's physiologic reserves.
2. Muscle depletion may be seen with numerous conditions, including age-related sarcopenia and cancer-related cachexia, and is associated with increased risk for adverse outcomes including functional decline and mortality[67].
3. Most commonly measured muscle metrics on QCT are muscle cross-sectional area (in cm2) and muscle attenuation (in HU) [68].
4. A single-axial abdominopelvic CT image at the L3 or L4 level commonly used to segment the psoas, the paraspinous, or all visualized muscles on the image.
5. There is no consensus on analytic protocols (eg, measurement level, anatomy measured, software used) and diagnostic cut-points normalization for age, sex, height, and ethnicity) [68]. For example, the L3 Skeletal Muscle Index values for diagnosing sarcopenia (measured in cm2/m2) are often stratified by sex, BMI, and disease (eg, for patients with cancer, <41 for women, <34 for normal or underweight men, <53 for overweight or obese men) [69]. Low muscle attenuation has also been used to help diagnose sarcopenia, with diagnostic cut points ranging from 30 HU [70] to 41 HU [69].
6. Intravenous contrast administration and the timing of subsequent CT image acquisition can significantly change the attenuation values of muscles [71].
7. QCT for the diagnosis of sarcopenia is expected to grow because of a new ICD- 10 diagnostic code (M62.84) [72], many pharmaceutical agents in development [73,74], and the evolution of machine learning techniques for automated image analysis [75].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [76].

A. For evaluation of osteoporosis in postmenopausal women and men older than 50 years using phantom-based QCT, reports of the hip should include the BMD (in g/cm²) for area density, T-score, and WHO diagnostic classification while reports of the spine should include BMD (in mg/cm^3) for trabecular volumetric density.

B. QCT hip BMD (CTXA) may be used to obtain a fracture risk using the FRAX tool.

C. In premenopausal women, men younger than 50, and children, the QCT reports should include BMD values and Z-scores. Z-scores above −2.0 are within the expected range. Z-scores of −2.0 or lower are considered to be below the expected range for age.

D. In children and adolescents, QCT reports should include BMD values and Z-scores. Z-scores should be height adjusted, when possible. Z-scores above −2.0 are within the expected range. Z-scores of −2.0 or lower are considered to be below the expected range for age. The terms “osteopenia” and “osteoporosis” should not be used in QCT reports [77]. T-scores should not be reported.

E. The QCT report should indicate whether artifacts or other technical issues may have influenced the reported BMD measurement(s). A statement comparing the current study to prior available comparable studies should include an assessment of whether any changes in measured BMD are statistically significant. Recommendations for and the timing of follow-up QCT studies may be included. When appropriate, recommendations for alternative modality densitometry examinations, ancillary imaging tests, or other diagnostic measures should be provided.

F. The QCT report should mention relevant incidental finding, such as vertebral compression fractures or other fragility fractures. These findings may result in initiation of treatment for osteoporosis, regardless of the measured BMD. Guidance regarding reporting of additional incidental findings not related to bones can be found elsewhere [78].

VI. EQUIPMENT QUALITY CONTROL

QCT quality control is extremely important for accuracy in sequential monitoring of the effectiveness of therapy or progression of disease. All three of the methods for acquiring QCT provide accurate BMD determinations suitable for assessing bone status. There are, however, differences in their precision, which results in different sensitivities in detecting significant change in BMD through serial measurement comparisons. Precision is typically best when the patient and the calibration standard are imaged simultaneously, and volumetric QCT units often have better precision because of their reduced dependence on operator skills, such as patient positioning and data processing.

Quality control is generally implemented at 2 levels. The first is maintenance of the CT system used to acquire image data. The second is maintenance of the QCT software, phantoms, and associated accessories.

A. CT System – For the CT system, basic quality control procedures, as specified by the manufacturer, should be performed and recorded by a trained technologist. The results should be interpreted immediately upon completion according to the guidelines provided by the manufacturer to ensure proper system performance. If a problem is detected according to manufacturer guidelines, the service representative should be notified, and patients should not be examined until the equipment has been cleared for use.

B. QCT Phantoms – Precision error measurements of the phantom or standard should be performed on a schedule according to manufacturer's specifications and the results recorded. The results of the phantom measurements should not exceed the specifications or recommendations of the manufacturer and generally should be within 1%.

C. For the QCT software, basic quality control procedures, as specified by the manufacturer, should be performed and recorded by a trained technologist. The results should be interpreted immediately upon completion according to the guidelines provided by the manufacturer to ensure proper system performance. If a problem is detected according to manufacturer guidelines, the service representative should be notified, and patients should not be examined until the software has been cleared for use.

D. Equipment performance monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [79].

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, registered radiologist assistants, radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel that work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection and application of dose limits) and the principles of proper management of radiation dose to patients (justification,optimization and the use of dose reference levels)
http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf

Nationally developed guidelines, such as the ACR's Appropriateness Criteria® should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure.

Facilities should have and adhere to policies and procedures that require varying ionizing radiation examination protocols (plain radiography, fluoroscopy, interventional radiology, CT) to take into account patient body habitus (such as patient dimensions, weight, or body mass index) to optimize the relationship between minimal radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used whenever appropriate. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available at the Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org) websites. These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be measured and patient radiation dose estimated for representative examinations and types of patients by a Qualified Medical Physicist in accordance with the applicable ACR technical standards. Regular auditing of patient dose indices should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry, the NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends. (ACR Resolution 17 adopted in 2006 – revised in 2009, 2013, Resolution 52).

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR web site (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards).

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