

The American College of Radiology, with more than 30,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice guidelines and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice guidelines and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice guideline and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review, requiring the approval of the Commission on Quality and Safety as well as the ACR Board of Chancellors, the ACR Council Steering Committee, and the ACR Council. The practice guidelines and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice guideline and technical standard by those entities not providing these services is not authorized.

2008 (Resolution 33)*

ACR PRACTICE GUIDELINE FOR THE PERFORMANCE OF QUANTITATIVE COMPUTED TOMOGRAPHY (QCT) BONE DENSITOMETRY

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines 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 physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the guidelines, 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 the guidelines 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 the guidelines. However, a practitioner who employs an approach substantially different from these guidelines 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 these guidelines 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 these guidelines is to assist practitioners in achieving this objective.

I. INTRODUCTION

Quantitative computed tomography (QCT) bone densitometry is a clinically proven method of measuring bone mineral density (BMD) in the spine, proximal femur, distal forearm, and whole body. QCT is used primarily to assess disease states that may be characterized by abnormal BMD, as well as to monitor response to therapy for these conditions. This guideline outlines the principles of performing high quality QCT.

QCT has some advantages over dual-energy X-ray absorptiometry (DXA). DXA BMD estimates may be biased significantly 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. DXA results are more likely to be affected by body habitus; QCT is often more accurate in patients with extreme obesity or low body mass index.

For pediatric applications, see section III.B.

II. GOAL

The goal of QCT is to measure BMD accurately and reproducibly, and to compare that measurement to reference population standards and/or to an individual's previous bone densitometry examination(s). This comparison contributes to the diagnosis of osteoporosis in asymptomatic individuals, an estimate of future fracture risk, and guidance for appropriate therapy and fracture prevention programs. It is also useful in evaluating the effectiveness of prior or current therapy.

III. INDICATIONS, CONTRAINDICATIONS, AND CAUTIONARY REMARKS

BMD measurement is indicated whenever a clinical decision to intervene will be directly influenced by the result of the test. QCT is indicated in, but not limited to, the following patient populations:

A. Indications in Adults

Individuals with established or suspected low BMD, or at risk for low BMD, including:

1. All women age 65 years and older and men age 70 years and older (asymptomatic screening).
2. Women younger than age 65 years who have additional risk for osteoporosis, based on medical history and other findings. Additional risk factors for osteoporosis that might be considered include:
 - a. Estrogen deficiency.
 - b. A history of maternal hip fracture that occurred after the age of 50 years.
 - c. Low body mass (less than 127 pounds).
 - d. History of amenorrhea (more than 1 year before age 42 years).
3. Women younger than age 65 years or men younger than age 70 years who have additional risk factors including:
 - a. Current use of cigarettes
 - b. Loss of height, thoracic kyphosis.
4. Individuals of any age with radiologic evidence of low bone mass (osteopenia), including the presence of vertebral compression fractures.
5. Individuals age 50 years and older who develop a wrist, hip, spine, or proximal humerus fracture with minimal or no trauma.
6. Individuals of any age who develop 1 or more insufficiency fractures.

7. Individuals receiving (or expected to receive) glucocorticoid for more than 3 months.
8. Individuals beginning or receiving long-term therapy with medications known to adversely affect BMD (e.g., anticonvulsant drugs, androgen deprivation therapy, aromatase inhibitor therapy, or chronic heparin).
9. Individuals with an endocrine disorder known to adversely affect BMD (e.g., hyperparathyroidism, hyperthyroidism, or Cushing's syndrome).
10. Hypogonadal men older than 18 years.
11. Individuals with metabolic and/or other 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. Conditions associated with secondary osteoporosis, such as gastrointestinal malabsorption or malnutrition, osteomalacia, vitamin D deficiency, endometriosis, acromegaly, chronic alcoholism or established cirrhosis, and multiple myeloma.
 - g. Individuals who have had gastric bypass for obesity.
12. Individuals being considered for pharmacologic therapy for osteoporosis.
13. Individuals being monitored to assess response to or effectiveness of osteoporosis drug therapy.

B. Pediatric Indications and Considerations

Assessment of and indications for performing BMD examinations in children differ significantly from those in adults. Measuring and interpreting BMD in children are complicated by the issue of the rapidly growing skeleton. Studies have shown that DXA is unable to take into account large changes in body and skeletal size during growth, limiting its use in longitudinal studies in children. Because QCT can assess both volume and density of bone in the axial and appendicular skeleton without influence from body or skeletal size, it may be more useful than DXA in children. QCT technology has been used in preterm infants, as well as adolescents in whom increases in DXA areal BMD are more likely a reflection of vertebral size than actual changes in density.

Caution must be used in making the diagnosis of osteoporosis based on nonvolumetric measurements. Consequently, QCT may be a better method for measuring changes in bone density resulting from various pathologic processes that may affect children and their growing skeletons. This includes patients who have been treated with radiation or chemotherapy for malignancies; patients who have been treated for bone disorders such as primary or secondary hyperparathyroidism, osteogenesis imperfecta, or osteopetrosis; and patients who have been treated for growth hormone deficiency, inflammatory bowel disease, or HIV.

QCT may also demonstrate the effect of race and gender on the developing skeleton more than DXA. In the axial skeleton, African American children have greater cancellous bone density, but similar cross-sectional area of vertebral bodies. In contrast, in the appendicular skeleton, African American children have greater femoral cross-sectional area but similar cortical area and cortical bone density. Such variations may contribute to racial differences in the prevalence of osteoporosis and fracture in adult populations.

C. Relative Indications

Central and peripheral BMD may be discordant. Individuals at high risk for osteoporosis who have a normal peripheral examination should be further evaluated by central QCT.

QCT may be indicated in the diagnosis, staging, and follow-up of individuals with conditions that result in pathologically increased BMD, such as osteopetrosis or prolonged exposure to fluoride.

Other individuals who may benefit from BMD and body composition analysis include high performance athletes.

D. Contraindications

QCT is generally contraindicated for patients who are pregnant or may be pregnant.

For the pregnant or potentially pregnant patient, see the [ACR Practice Guideline for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation](#).

E. Other Considerations

The following are examples of conditions that may influence the accuracy and/or precision of QCT bone mass measurements. QCT examination results obtained under these conditions may be suitable for a general assessment of bone density, but degradation of measurement accuracy and/or precision under these

conditions may limit the utility of such measurements for detecting significant change in BMD via serial study comparisons:

1. Recent administration of IV contrast.
2. Severe fracture deformity in the measurement area.
3. Radio-opaque implants in the measurement area, most commonly at the spine or hip.
4. Patient's inability to attain correct position and/or remain motionless for the measurement.
5. Extreme obesity resulting in an inability to position a patient completely within the scan field-of-view of the CT scanner.

IV. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

For physician, medical physicist, radiologist assistant, and radiologic technologist qualifications see the [ACR-SPR Practice Guideline for General Radiography](#). Additional specific qualifications and responsibilities include:

A. Physician

1. The examination must be performed under the supervision of and interpreted by a licensed physician with the following qualifications:
 - a. Knowledge and understanding of bone structure, metabolism, and osteoporosis.
 - 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 BMD values.
 - c. Knowledge and understanding of reporting parameters, including, but not limited to: bone density measurements, percent of mean, T-score, Z-score, fracture risk, and the World Health Organization (WHO) classification system.
 - d. Knowledge and understanding of the criteria for accurate and precise comparison of serial measurements, including limitations of comparing measurements made by different techniques and different devices, the rationale behind precision testing, and the statistical significance of serial changes in BMD.
 - e. Knowledge and understanding of alternative bone density techniques, such as central and peripheral DXA, radiographic absorptiometry (RA), single X-ray absorptiometry, and quantitative ultrasound (QUS), to fulfill a consultative role in recommending

additional or serial bone density examinations. Additionally, the interpreting physician should report and make clinically appropriate recommendations about incidental findings on QCT images, such as mass lesions, adenopathy, and bowel abnormalities.

2. The supervising physician shall be 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

The technologist should have:

1. Documented formal training in the use of the QCT equipment, including performance of all manufacturer-specified quality assurance (QA) procedures.
2. Knowledge of and familiarity with the manufacturer's operator manual for the specific scanner model being used.
4. Responsibility for patient comfort and safety, preparing and properly positioning the patient, placement of regions of interest for assessment of BMD measurements, monitoring the patient during the procedure, and obtaining the measurements prescribed by the supervising physician.
5. Responsibility for performing routine quality assurance procedures and precision testing, including determining precision error and calculating least significant change (LSC) (see sections VIII.C and VIII.D).

Certification by the American Registry of Radiologic Technologists (ARRT) is also desirable.

V. SPECIFICATIONS 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)

B. A QCT spine examination should include a lateral localizer image of the lumbar spine. The localizer should be reviewed by the radiologic technologist to determine if specific sites within the lumbar spine should be excluded from analysis. The lateral localizer should also document the spine region scanned and should span the entire lumbar spine with sufficient resolution for assessing biomechanical integrity (i.e., vertebral fracture assessment).

C. In children, QCT examination usually consists of an examination of the lumbar spine. Evaluation of other anatomic regions in children can be performed, but is not routine or standardized.

D. Positioning and soft-tissue-equivalent devices issued by the manufacturer should be used consistently and properly. Comfort devices, such as pillows under the head or knees, should not interfere with proper positioning and should never appear in the scan field.

E. Anatomic areas of prior surgery or known prior fracture and all fractured vertebrae should be excluded from measurement. If a vertebra is anatomically intact and review of the source images confirms the absence of a lytic or blastic process, it may be included in the densitometry.

F. If there is significant unexplained discordance between 2 measured areas, additional QCT acquisitions (e.g., opposite proximal femur) or other BMD measurement techniques (e.g., DXA) should be considered.

G. For postmenopausal women and men age 50 and older, BMD measurements should be compared with young adult reference population values. Comparisons should be reported as T-scores for QCT hip measurements. Comparisons of QCT spine measurements may or may not be reported as T-scores, but QCT spine T-scores generally should not be used to assign a diagnostic category using WHO (DXA) guidelines.

There are well-documented differences in the response of cortical and trabecular bone to aging and therapeutic interventions. Volumetric QCT spine BMD measurements are used to characterize only trabecular bone, while hip area-density measurements obtained using either QCT or DXA predominantly characterize cortical mineral. There

are currently no consensus standards for assigning diagnostic categories based on QCT spine BMD measurements. Current consensus standards emphasize hip fracture risk and hip fracture risk mitigation. While it is established that QCT spine BMD measurements provide a significant indication of hip fracture risk, they provide a more sensitive indication of spine fracture risk. The prevalence of spine fractures is much greater than hip fractures, and spine fractures tend to occur earlier in life than hip fractures. Approximately 20% of women and men age 60 to 69 exhibit spine fractures. Assigning a WHO diagnostic category based on a QCT spine T-score may result in overstating a patient's risk of hip fracture.

Consequently, it is advised that a WHO diagnostic category be assigned based on consideration of only the QCT hip T-score in a standard QCT study. However, if only a QCT spine BMD measurement is available, then the following category definitions are suggested for assigning a diagnostic category approximately equivalent to WHO diagnostic categories used with hip BMD measurements:

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 are 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 hip QCT 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.

H. Comparison of QCT BMD measurements with population-specific age-matched values (Z-scores) is often performed, and should be done routinely for children, premenopausal women, and men younger than age 50.

I. Comparison should be made to any prior comparable QCT examinations of the same site. The precision error and calculated least significant change of the specific scanner(s) should be checked to determine if measured changes are statistically significant. 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.

It should be noted that a complete QCT “unit” includes a CT scanner, as well as calibration phantoms and software used in determining BMD estimates and population comparisons. Alterations in any of these components can affect BMD determinations. After such changes QA procedures should be performed, including precision testing, with determination of appropriate statistical parameters.

VI. DOCUMENTATION

Reporting should be in accordance with the [ACR Practice Guideline for Communication of Diagnostic Imaging Findings](#).

- A. A permanent record shall be maintained, including:
 1. Patient identification, facility identification, examination date, image orientation, and unit manufacturer and model.
 2. Clinical notes or patient questionnaire containing any pertinent history.
 3. Positioning, anatomical information, and/or technique settings needed for performing serial measurements.
 4. Printouts of the images and regions of interest, if provided by the unit and the BMD values obtained.
- B. For postmenopausal women and men age 50 and older, reports should include the BMD (in g/cm²) for area density, T-score, and WHO diagnostic classification at the hip; and BMD (in mg/cm³) for trabecular volume density at the spine. A statement about fracture risk should be reported; once methodologies have been standardized, absolute fracture risk is preferable to relative fracture risk. Additional epidemiologic factors may also be reported.
- C. For premenopausal women, men younger than age 50, and children, the BMD and Z-score should be reported for each site examined. The WHO classification does not apply to these patient populations. Z-scores above -2.0 are within the expected range. Individuals with Z-scores of -2.0 and lower are considered to have low bone density. T-scores should not be reported for children.
- D. The 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. Reports may also reference the standard database(s) used for calculating the T-score and Z-score and estimating fracture risk.

VII. EQUIPMENT SPECIFICATIONS

The 3 methods of performing QCT are:

1. Acquisition of volumetric CT data with simultaneous scanning of the patient and a calibration device.
2. Acquisition of single axial images through a vertebral body or peripheral site, with simultaneous scanning of a calibration device.
3. Acquisition of single axial images through a vertebral body or peripheral site, with separate scanning of a calibration device.

All 3 of these methods provide accurate BMD determinations suitable for assessing bone status. There are, however, significant differences in their precision resulting 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 reduced dependence on operator skills such as patient positioning and data processing.

Multiple equipment designs are available that can accurately and precisely measure bone density using QCT. The equipment should include or provide the following:

1. Software with normal young adult and age-matched and sex-matched control population standards specific to the equipment. Some population standards are matched for ethnicity, weight, and body mass index.
2. A phantom or other calibration standard to evaluate the accuracy and precision of BMD measurement.
3. Labeled images of the anatomic site measured and relevant measurements for permanent patient records.
4. Precision error of measurements of the phantom or standard that do not exceed the specifications or recommendations of the manufacturer and are less than 1%. In-vitro (phantom) precision should not be equated with in-vivo (patient) precision, as the role of the technologist in patient positioning and scan analysis is critical.

VIII. EQUIPMENT QUALITY CONTROL

QCT quality control is extremely important for accuracy in sequential monitoring of the effectiveness of therapy or progression of disease. 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. 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. 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.

C. Measurement precision is influenced by CT scanner model, QCT method, and the skill of the radiological technologist. While facilities may rely on measurement precision data provided by the QCT manufacturer or other published performance data when assessing differences in BMD measurements for a given patient, confidence in such assessment can be improved by precision testing. Each facility should perform precision testing to determine its precision error and calculate its least significant change (LSC). Estimation of LSC based on a 95% confidence interval is suggested. If a facility has more than 1 technologist, these values should represent an average of pooled data from all technologists. The facility should assess the need for informed consent of the subjects prior to undertaking precision testing.

D. Recalculation of LSC should be considered for the following instances: replacement of a CT scanner, replacement of the CT X-ray tube, recalibration of the CT scanner, addition of CT scanner software revisions, and/or modifications to the QCT accessory components.

E. Equipment performance monitoring should be in accordance with the [ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography \(CT\) Equipment](#).

IX. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, radiologic technologists, and all supervising physicians have a responsibility to minimize radiation dose to individual patients, to staff, and to society as a whole, while maintaining the necessary diagnostic image quality. This concept is known as “as low as reasonably achievable (ALARA).”

Facilities, in consultation with the medical physicist, should have in place and should adhere to policies and procedures, in accordance with ALARA, to vary examination protocols to take into account patient body habitus, such as height and/or weight, body mass index, or lateral width. The dose reduction devices that are available on imaging equipment should be active; if not, manual techniques should be used to moderate the exposure while maintaining the necessary diagnostic image quality. Periodically, radiation exposures should be measured and patient radiation doses estimated by a medical physicist in accordance with the appropriate ACR Technical Standard. (ACR Resolution 17, adopted in 2006 – revised in 2009, Resolution 11)

X. 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 page (<http://www.acr.org/guidelines>).

ACKNOWLEDGEMENTS

This guideline was revised according to the process described under the heading *The Process for Developing ACR Practice Guidelines and Technical Standards* on the ACR web page (<http://www.acr.org/guidelines>) by the Guidelines and Standards Committee of the Commission on General, Small and Rural Practice.

Principal Drafters

J. Keenan Brown, PhD
Sue C. Kaste, DO
Stephen Strum, MD
Fred S. Vernacchia, MD
Jean Weigert, MD

Guidelines and Standards Committee

Julie K. Timins, MD, Chair
William R. Allen, Jr., MD
Damon A. Black, MD

Richard A. Carlson, MD
James P. Cartland, MD
Mark F. Fisher, MD
Frank R. Graybeal, Jr., MD
Louis W. Lucas, MD
Matthew S. Pollack, MD
Diane C. Stollo, MD
Fred S. Vernacchia, MD
Susan L. Voci, MD
Geoffrey G. Smith, MD, Chair, Commission

Suggested Reading (Additional articles that are not cited in the document but that the committee recommends for further reading on this topic)

1. AACE Osteoporosis Task Force. American Association of Clinical Endocrinologists medical guidelines for clinical practice for the prevention and treatment of postmenopausal osteoporosis: 2001 edition, with selected updates for 2003. *Endocr Pract* 2003;9:544-564.
2. Ahmed AI, Ilic D, Blake GM, Rymer JM, Fogelman I. Review of 3,530 referrals for bone density measurements of spine and femur: evidence that radiographic osteopenia predicts low bone mass. *Radiology* 1998;207:619-624.
3. Bachrach LK. Bare-bones fact – children are not small adults. *N Eng J Med* 2004 351:924-6
4. Bachrach LK. Dual energy X-ray absorptiometry (DEXA) measurements of bone density and body composition: promise and pitfalls. *J Pediatr Endocrinol Metab* 2000;13:Suppl 2:983-988.
5. Bachrach LK. Osteoporosis and measurement of bone mass in children and adolescents. *Endocrinol Metab Clin North Am* 2005;34:521-535.
6. Baim S, Wilson CR, Lewiecki EM, Luckey MM, Downs RW, Lentle BC. Precision assessment and radiation safety for dual-energy x-ray absorptiometry: position paper of the International Society for Clinical Densitometry. *J Clin Densitom*, 2005;8:371-378.
7. Baran DT, Faulkner KG, Genant HK, Miller PD, Pacifici R. Diagnosis and management of osteoporosis: guidelines for the utilization of bone densitometry. *Calcif Tissue Int* 1997;61:433-440.
8. Bates DW, Black DM, Cummings SR. Clinical use of bone densitometry: clinical applications. *JAMA* 2002;288:1898-1900.
9. Blake GM, Gluer CC, Fogelman I. Bone densitometry: current status and future prospects. *Br J Radiol* 1997;70:S177-S186.
10. Bonnick SL, Shulman L. Monitoring osteoporosis therapy: bone mineral density, bone turnover markers, or both? *Am J Med* 2006;119:S25-S31.
11. Bonnick SL, Johnston CC, Kleerekoper M, et al. Importance of precision in bone density measurements. *J Clin Densitom*, 2001;4:105-110.

12. Brown JP, Josse RG, Scientific Advisory Council of the Osteoporosis Society of Canada. 2002 clinical practice guidelines for the diagnosis and management of osteoporosis in Canada. *CMAJ* 2002;167:S1-S34.
13. Cadarette SM, Jaglal SB, Murray TM, et al. Evaluation of decision rules for referring women for bone densitometry by dual-energy X-ray absorptiometry. *JAMA* 2001;286:57-63.
14. Cooper C, Atkinson EJ, Jacobsen SJ, O'Fallon WM, Melton LJ. Population-based study of survival after osteoporotic fracture. *Am J Epidemiol* 1993;137:1001-1005.
15. Cummings SR, Bates D, Black DM. Clinical use of bone densitometry: scientific review. *JAMA* 2002;288:1889-1897.
16. Cummings SR, Black DM, Nevitt MC, et al. Bone density at various sites for prediction of hip fractures. The Study of Osteoporotic Fractures Research Group. *Lancet* 1993;341:72-75.
17. Fogelman I, Ryan P. Measurement of bone mass. *Bone* 1992; 13:S23-S28.
18. Franck H, Munz M, Scherrer M. Bone mineral density of opposing hips using dual energy X-ray absorptiometry in single-beam and fan-beam design. *Calcif Tissue Int* 1997;61:445-447.
19. Gafni RI, Baron J. Overdiagnosis of osteoporosis in children due to misinterpretation of dual-energy X-ray absorptiometry (DEXA). *J Pediatr* 2004;144:253-257.
20. Genant HK, Grampp S, Gluer CC, et al. Universal standardization for dual X-ray absorptiometry: patient and phantom cross-calibration results. *J Bone Miner Res* 1994;9:1503-1514.
21. Genant HK. Universal standardization for dual X-ray absorptiometry: patient and phantom cross-calibration results. *J Bone Miner Res* 1995;10:997-998.
22. Genant HK, Engelke K, Fuerst T, et al. Noninvasive assessment of bone mineral and structure: state of the art. *J Bone Miner Res* 1996;11:707-730.
23. Genant HK, Guglielmi G, Jergas M. *Bone Densitometry and Osteoporosis*. New York, NY: Springer; 1997.
24. Gluer CC, Blake G, Lu Y, et al. Accurate assessment of precision errors: how to measure the reproducibility of bone densitometry techniques. *Osteoporos International*. 1995;5:2:62-270.
25. Hawkinson J, Timins J, Angelo D, Shaw M, Takata R, Harshaw F. *Technical White Paper: Bone Densitometry*, 2006. Available at: www.crcpd.org/pubs/bonedensitometrywhitepaper.pdf. Accessed July 26, 2007.
26. He YF, Ross PD, Davis JW, Epstein RS, Vogel JM, Wasnich RD. When should bone density measurements be repeated? *Calcif Tissue Int* 1994;55:243-248.
27. Henderson RC, Lark RK, Newman JE, et al. Pediatric reference data for dual X-ray absorptiometric measures of normal bone density in the distal femur. *AJR* 2002;178:439-443.
28. International Society for Clinical Densitometry. *Updated 2005 official positions of the International Society for Clinical Densitometry*. Available at www.ISCD.org. Accessed July 26, 2007.
29. Jacobson JA, Jamadar DA, Hayes CW. Dual X-ray absorptiometry: recognizing image artifacts and pathology. *AJR* 2000;174:1699-1705.
30. Jaovisidha S, Sartoris DJ, Martin EM, De Maeseneer M, Szollar SM, Deftos LJ. Influence of spondylopathy on bone densitometry using dual energy X-ray absorptiometry. *Calcif Tissue Int* 1997;60:424-429.
31. Jergas M, Genant HK. Spinal and femoral DXA for the assessment of spinal osteoporosis. *Calcif Tissue Int* 1997;61:351-357.
32. Johnston CC Jr, Slemenda CW, Melton LJ. Clinical use of bone densitometry. *N Engl J Med* 1991;324:1105-1109.
33. Kanis JA, Delmas P, Burckhardt P, Cooper C, Torgerson D. Guidelines for diagnosis and management of osteoporosis. The European Foundation for Osteoporosis and Bone Disease. *Osteoporosis Int* 1997;7:390-406.
34. Kanis JA. Diagnosis of osteoporosis and assessment of fracture risk. *Lancet* 2002;359:1929-1936.
35. Kanis JA, Melton LJ, Christiansen C, Johnston CC, Khaltaev N. The diagnosis of osteoporosis. *J Bone Miner Res* 1994;9:1137-1141.
36. Kaste SC, Kasow, KA, Horwitz EM. Quantitative bone mineral density assessment in malignant infantile osteopetrosis. *Pediatr Blood Cancer*, 2006 Jan 18; [Epub ahead of print]
37. Kaste SC, Tong X, Hendrick JM, et al. QCT versus DXA in 320 survivors of childhood cancer: association of BMD with fracture history. *Pediatr Blood Cancer* 2006;47:936-943.
38. Kemmler W, Engelke K, Weineck J, Hensen J, Kalender WA. The Erlangen Fitness Osteoporosis Prevention Study: a controlled exercise trial in early postmenopausal women with low bone density — first-year results. *Arch Phys Med Rehabil* 2003;84:673-682.
39. Klein GL, Bachrach LK, Holm IA. Effects of pharmacologic agents on bone in childhood: an editorial overview. *Pediatrics* 2007;119:S125-S130.
40. Lai K, Rencken M, Drinkwater BL, Chestnut CH 3rd. Site of bone density measurement may affect therapy decision. *Calcif Tissue Int* 1993;53:225-228.
41. Lenchik L, Rochmis P, Sartoris DJ. Optimized interpretation and reporting of dual X-ray absorptiometry (DXA) scans. *AJR* 1998;171:1509-1520.
42. Lenchik L, Sartoris DJ. Current concepts in osteoporosis. *AJR* 1997;168:905-911.

43. Lentle BC, Prior JC. Osteoporosis: what a clinician expects to learn from a patient's bone density examination. *Radiology* 2003;228:620-628.
44. LoCascio V, Bonucci E, Imbimbo B, et al. Bone loss in response to long-term glucocorticoid therapy. *Bone Miner* 1990;8:39-51.
45. Lodder MC, Haugeberg G, Lems WF, et al. Radiographic damage associated with low bone mineral density and vertebral deformities in rheumatoid arthritis: the Oslo-Truro-Amsterdam (OSTRA) collaborative study. *Arthritis Rheum* 2003;49:209-215.
46. Lyles KW, Gold DT, Shipp KM, Pieper CF, Martinez S, Mulhausen PL. Association of osteoporotic vertebral compression fractures with impaired functional status. *Am J Med* 1993;94:595-601.
47. Massie A, Reid DM, Porter RW. Screening for osteoporosis: comparison between dual energy X-ray absorptiometry and broadband ultrasound attenuation in 1,000 perimenopausal women. *Osteoporosis Int* 1993;3:107-110.
48. Melton LJ, Atkinson EJ, O'Fallon WM, Wahner HW, Riggs BL. Long-term fracture prediction by bone mineral assessed at different skeletal sites. *J Bone Miner Res* 1993;8:1227-1233.
49. Melton LJ 3rd. Osteoporosis: a worldwide problem. In: *Proceedings of the Third International Symposium on Osteoporosis*. District of Columbia: Osteoporosis Foundation/ National Institutes of Health; 1994:23.
50. Melton LJ, Kan SH, Wahner HW, Riggs BL. Lifetime fracture risk: an approach to hip fracture risk assessment based on bone mineral density and age. *J Clin Epidemiol* 1988;41:985-994.
51. Meunier PJ. *Osteoporosis: Diagnosis and Management*. London, England: Martin Dunitz; 1997.
52. Miller PD, Bonnicksen SL, Rosen CJ. Consensus of an international panel on the clinical utility of bone mass measurements in the detection of low bone mass in the adult population. *Calcif Tissue Int* 1996;58:207-214.
53. Mundy GR. *Bone Remodeling and its Disorders*. 2nd edition. London, England: Martin Dunitz; 1997.
54. National Osteoporosis Foundation Advisory Board. *Physician's Resource Manual on Osteoporosis*. District of Columbia: National Osteoporosis Foundation; 1994:7.
55. Pocock NA, Noakes KA, Griffiths M, et al. A comparison of longitudinal measurements in the spine and proximal femur using lunar and hologic instruments. *J Bone Miner Res* 1997;12:2113-2118.
56. Pouilles JM, Ribot C, Tremollieres F, Bonneau M, Brun S. Risk factors of vertebral osteoporosis: results of a study of 2,279 women referred to a menopause clinic. *Rev Rhum Mal Osteoartic* 1991;58:169-177.
57. Pouilles JM, Tremollieres F, Ribot C. Spine and femur densitometry at the menopause: are both sites necessary in the assessment of the risk of osteoporosis? *Calcif Tissue Int* 1993;52:344-347.
58. Rand T, Seidl G, Kainberger F, et al. Impact of spinal degenerative changes on the evaluation of bone mineral density with dual energy X-ray absorptiometry (DXA). *Calcif Tissue Int* 1997;60:430-433.
59. Rehman Q, Lang T, Modin G, Lane NE. Quantitative computed tomography of the lumbar spine, not dual x-ray absorptiometry, is an independent predictor of prevalent vertebral fractures in postmenopausal women with osteopenia receiving long-term glucocorticoid and hormone-replacement therapy. *Arthritis Rheum* 2002;46:1292-1297.
60. Reid IR, Evans MC, Wattie DJ, Ames R, Cundy TF. Bone mineral density of the proximal femur and lumbar spine in glucocorticoid-treated asthmatic patients. *Osteoporosis Int* 1992;2:103-105.
61. Rizzoli R, Slosman D, Bonjour JP. The role of dual energy X-ray absorptiometry of lumbar spine and proximal femur in the diagnosis and follow-up of osteoporosis. *Am J Med* 1995;98:33S-36S.
62. Rosen CJ. *Osteoporosis: Diagnostic and Therapeutic Principles*. Totowa, NJ: Humana Press; 1997.
63. Ross PD, Davis JW, Epstein RS, Wasnich RD. Pre-existing fractures and bone mass predict vertebral fracture incidence in women. *Ann Intern Med* 1991;114:919-923.
64. Ross PD, Genant HK, Davis JW, Miller PD, Wasnich RD. Predicting vertebral fracture incidence from prevalent fractures and bone density among non-black, osteoporotic women. *Osteoporosis Int* 1993;3:120-126.
65. Rubin SM, Cummings SR. Results of bone densitometry affect women's decisions about taking measures to prevent fractures. *Ann Intern Med* 1992;116:990-995.
66. Shore RM, Langman CB, Donovan JM, Conway JJ, Poznanski AK. Bone mineral disorders in children: evaluation with dual x-ray absorptiometry. *Radiology* 1995;196:535-540.
67. Siris ES, Miller PD, Barrett-Connor E, et al. Identification and fracture outcomes of undiagnosed low bone mineral density in postmenopausal women: results from the National Osteoporosis Risk Assessment. *JAMA* 2001;286:2815-2822.
68. Slosman DO, Casez JP, Pichard C, et al. Assessment of whole-body composition with dual-energy x-ray absorptiometry. *Radiology* 1992;185:593-598.
69. Southard RN, Morris JD, Mahan JD, et al. Bone mass in healthy children: measurement with quantitative DXA. *Radiology* 1991;179:735-738.
70. Verheij LF, Blokland JA, Papapoulos SE, Zwinderman AH, Pauwels EK. Optimization of

follow-up measurements of bone mass. *J Nucl Med* 1992;33:1406-1410.

71. Wahner HW, Fogelman I. *Clinical Bone Density*. London, England: Martin Dunitz; 1994.
72. Wahner HW, Fogelman I. *The Evaluation of Osteoporosis: Dual Energy X-ray Absorptiometry in Clinical Practice*. London, England: Martin Dunitz; 1998.
73. The WHO Study Group. *Assessment of Fracture Risk and its Applications to Screening for Postmenopausal Osteoporosis*. Geneva, Switzerland: World Health Organization; 1994.
74. Wong WW, Hergenroeder AC, Stuff JE, Butte NF, Smith EO, Ellis KJ. Evaluating body fat in girls and female adolescents: advantages and disadvantages of dual-energy x-ray absorptiometry. *Am J Clin Nutr* 2002;76:384-389.
75. Wren TA, Liu X, Pitukcheewanont P, Gilsanz V. Bone densitometry in pediatric populations: discrepancies in the diagnosis of osteoporosis by DXA and CT. *J Pediatr* 2005;146:776-779.

*Guidelines and standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For guidelines and standards published before 1999, the effective date was January 1 following the year in which the guideline or standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Guideline

2008 (Resolution 33)

Amended 2009 (Resolution 11)