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Best Practices

Best Practices for Dual-Energy X-ray Absorptiometry Measurement and Reporting: International Society for Clinical Densitometry Guidance

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Abstract

Dual-energy X-ray absorptiometry (DXA) is a technology that is widely used to diagnose osteoporosis, assess fracture risk, and monitor changes in bone mineral density (BMD). The clinical utility of DXA is highly dependent on the quality of the scan acquisition, analysis, and interpretation. Clinicians are best equipped to manage patients when BMD measurements are correct and interpretation follows well-established standards. Poor-quality acquisition, analysis, or interpretation of DXA data may mislead referring clinicians, resulting in unnecessary diagnostic evaluations, failure to evaluate when needed, inappropriate treatment, or failure to provide medical treatment, with potentially ineffective, harmful, or costly consequences. Misallocation of limited healthcare resources and poor treatment decisions can be minimized, and patient care optimized, through meticulous attention to DXA instrument calibration, data acquisition and analysis, interpretation, and reporting. This document from the International Society for Clinical Densitometry describes quality standards for BMD testing at DXA facilities worldwide to provide guidance for DXA supervisors, technologists, interpreters, and clinicians. High-quality DXA testing is necessary for correct diagnostic classification and optimal fracture risk assessment, and is essential for BMD monitoring.

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Introduction

Dual-energy X-ray absorptiometry (DXA) is a quantitative radiological procedure for measuring bone mineral density (BMD), a major determinant of bone strength *(1)*. DXA measurements are used to diagnose osteoporosis *(2)*, monitor changes in BMD over time *(3)*, and estimate fracture risk, *(4)* and, as such, are often integral to therapeutic intervention recommendations. Indeed, BMD by DXA is a component of osteoporosis treatment guidelines in the United States *(5,6)*, Canada *(7)*, Europe *(8)*, United Kingdom *(9)*, and elsewhere *(10)*. Femoral neck BMD by DXA is an important risk factor input for the World Health Organization (WHO) fracture risk assessment algorithm (FRAX) *(11)*. DXA also has applications beyond BMD testing, including vertebral fracture assessment *(12)*, analysis of body composition *(13)*, hip structural analysis *(14)*, and trabecular bone score determination *(15)*. Physicians rely on DXA measurements to manage patients with skeletal disorders. Poor-quality DXA acquisition/analysis and/or incorrect reporting of the results may result in the ordering of unnecessary diagnostic tests, failing to order needed tests, or inappropriately starting, stopping, or changing treatment. Such errors in clinical practice are unfortunately common, sometimes costly, and potentially harmful to patients *(16–21)*. DXA scans in growing children and adolescents are particularly challenging and errors are common with respect to both data acquisition and interpretation *(22)*. These errors can lead to the inappropriate initiation of skeletal agents, many of which have unknown side effects in pediatric patients, and other inappropriate management decisions.

A central DXA system is composed of a padded table for the patient, an X-ray source, a radiation detector, computer hardware and software, and usually a printer for generating a hard copy of data, graphs, and images *(23)*. These sophisticated scientific instruments are manufactured with rigorous technical standards. Upon completion of the manufacturing process, the DXA system is transported to the end-user facility and assembled by a technician who checks system calibration to assure the accuracy (more correctly referred to as "trueness") of the measurements and makes adjustments as needed. The DXA technologist(s) may receive basic training from the manufacturer (e.g., by an applications specialist) in quality assessment, instrument maintenance, patient positioning, data acquisition, and analysis. Following densitometer installation, there may be local regulatory requirements that apply to the system (e.g., radiation safety standards and inspection) or for the technologist (e.g., training as a radiological technologist, licensure, certification). The physician who is responsible for supervising a DXA facility, interpreting the DXA results, and signing off on the report must have sufficient training to assure that the data are correct and that interpretation and reporting conform to current standards in the field *(24)*. Typically, US state and local regulations do not require any specific qualifications for DXA interpretation *(25)*, despite the important technical aspects of the test discussed here. US Medicare regulations only require some qualifications of supervising physicians in independent diagnostic testing facilities *(26)*, but not in hospital facilities or private clinical practices. In Canada, 3 provinces currently have a requirement for International Society for Clinical Densitometry (ISCD) certification for physicians who are reporting or supervising a DXA facility. In Brazil, certification by the Brazilian Radiology Society (Colégio Brasileiro de Radiologia) is required for any physician to perform DXA acquisition, analysis, and reporting. Technical certification, issued by the Brazilian Society of Radiologic Technologists (Conselho de Técnicos em Radiologia), is required for other allied healthcare professionals to perform DXA acquisitions. Globally, requirements for training, performing, and interpreting DXA scans by healthcare professionals are variable.

The generation of high-quality DXA reports requires an understanding of potential sources of errors, including changes in instrument calibration, improper patient positioning or analysis, recognition of confounding artifacts, and correct selection of reference databases for T- and Z-score calculation, thus requiring skilled technologists and interpreting physicians to assure production of a high-quality report. Over time, densitometer calibration may change due to degradation of the components (e.g., X-ray tube and detector), moving the instrument to a different location, or a variety of other factors. The skills of a DXA technologist may improve with experience or worsen over time, or a highly proficient technologist may leave and be replaced by one who is less skilled. Similarly, a physician involved may be dedicated to very high DXA quality or may view DXA as a sideline to other responsibilities. For all of these reasons, the reliability of DXA measurements and reports is sometimes in doubt, thereby having potential adverse effects on the management of patients *(16–19)*.

The ISCD is an international organization with global membership dedicated to advancing excellence in the assessment of skeletal health by promoting education and understanding of the clinical applications of bone mass measurement and other skeletal health assessment technologies. The ISCD strives to assure proficiency and quality in the assessment of skeletal health through education, certification, and accreditation in bone densitometry. To highlight the essential components of quality DXA testing, the ISCD herein identifies DXA Best Practices (Box). The DXA Best Practices are not meant to be a comprehensive list of all features that characterize a high-quality DXA facility, but rather these practices identify a basic set of essential markers that are consistent with high quality. For the purposes of this document, quality is defined as the degree to which DXA measurements and interpretation are consistent with current professional standards to facilitate desired

Box. DXA Best Practices

Scan Acquisition and Analysis

1.1. At least one practicing DXA technologist, and preferably all, has a valid certification in bone densitometry.
1.2. Each DXA technologist has access to the manufacturer's manual of technical standards and applies these standards for BMD measurement.
1.3. Each DXA facility has detailed standard operating procedures for DXA performance that are updated when appropriate and available for review by all key personnel.
1.4. The DXA facility must comply with all applicable radiation safety requirements.
1.5. Spine phantom BMD measurement is performed at least once weekly to document stability of DXA performance over time. BMD values must be maintained within a tolerance of ±1.5%, with a defined ongoing monitoring plan that defines a correction approach when the tolerance has been exceeded.
1.6. Each DXA technologist has performed in vivo precision assessment according to standard methods and the facility LSC has been calculated.
1.7. The LSC for each DXA technologist should not exceed 5.3% for the lumbar spine, 5.0% for the total proximal femur, and 6.9% for the femoral neck.

Interpretation and Reporting

2.1. At least 1 practicing DXA interpreter, and preferably all, has a valid certification in bone densitometry.
2.2. The DXA manufacturer and model are noted on the report.
2.3. The DXA report includes a statement regarding scan factors that may adversely affect acquisition/analysis quality and artifacts/confounders, if present.
2.4. The DXA report identifies the skeletal site, region of interest, and body side for each technically valid BMD measurement.
2.5. There is a single diagnosis reported for each patient, not a different diagnosis for each skeletal site measured.
2.6. A fracture risk assessment tool is used appropriately.
2.7. When reporting differences in BMD with serial measurements, only those changes that meet or exceed the LSC are reported as a change.

BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry; LSC, least significant change.

health outcomes. These DXA Best Practices are intended to serve as a guide and expectation for DXA supervisors, technologists, interpreters, and clinicians. Following these DXA Best Practices aids patients, referring healthcare providers, and payers by facilitating recognition of high-quality DXA services. DXA Best Practices are applicable worldwide for adult and pediatric DXA testing, recognizing that adaptations may be required according to local circumstances and country-specific standards.

Overview of High-Quality DXA Performance

Quality DXA studies require instrument calibration within an acceptable range of tolerance, rigorous attention to detail in assuring correct scan acquisition and analysis, understanding serial BMD "test–retest" precision, and appropriate application of guidelines for interpretation and reporting. This can be achieved through bone densitometry training and validated by certification for the DXA technologist and interpreting physician; the implementation of what is learned from training can be confirmed through facility accreditation.

Implementation of DXA Best Practices

The ISCD recommends that DXA facilities establish standard operating procedures (SOPs) as a guide for adherence to DXA Best Practices. For others (e.g., patients, referring physicians, and payers) interested in assessing competency of those responsible for bone densitometry, technologist and interpreter certification provides a measure of attaining basic DXA knowledge; DXA facility accreditation provides additional assurance that high-quality DXA is being performed.

Methodology

These DXA Best Practices are derived from the ISCD Official Positions *(13,24,27–34)* that are developed and periodically updated through Position Development Conferences held regularly since 2001. The ISCD is the only organization exclusively dedicated to advancing excellence in the assessment of skeletal health, doing so through education, certification, accreditation, and development of evidence-based quality standards. The ISCD Official Positions have been established through a process of

rigorous review of the best medical evidence by internationally recognized experts in skeletal health assessment, often in collaboration with other stakeholder organizations. Evaluation of the evidence when developing Official Positions is conducted using a modification of the RAND Corporation and University of California at Los Angeles method (RAM) *(35)*. This method has been used worldwide to determine whether medical procedures are expected to provide a specific health benefit that exceeds the potential negative consequences by such a wide margin that the procedure or indication is worth doing. The rationale for use of the RAM in the development of the ISCD Official Positions is based on its ability to combine the best available scientific evidence with the collective judgment of the expert panel consisting of a broad range of professionals within and outside of the ISCD.

Scan Acquisition and Analysis

At Least One Practicing DXA Technologist, and Preferably All, Has a Valid Certification in Bone Densitometry

Rationale. Measurement of BMD by DXA is technically demanding, with reliability of the output (BMD, T-score, and Z-score) dependent on technologist training and skill. By receiving training in DXA acquisition and analysis, passing an examination and receiving certification in bone densitometry, a technologist provides assurance that a basic skill set has been acquired. Keeping the certification current through continuing medical education and/or subsequent examinations demonstrates that these skills have been maintained and evolved with new developments in the field. Ideally all DXA technologists should be fully trained and certified in bone densitometry; however, a single certified technologist at each DXA facility may be capable of educating, supervising, and monitoring the quality of DXA studies by other technologists at the same facility. If children are being scanned at a DXA facility, at least 1 technologist should ideally have undergone additional instruction in pediatric densitometry (ISCD pediatric bone density course or similar training), as the adjustment of Z-score for height and other clinical variables is critically important *(36)*.

Comments. As part of the training and certification process, technologists come to recognize that densitometer maintenance, scan acquisition, and scan analysis must be rigorously conducted according to standard procedures *(24)*. This approach provides the interpreter with valid data needed to generate a correct and clinically useful DXA report, thereby giving the referring healthcare provider appropriate information to make wise patient care decisions. With updates in DXA software, changes in DXA systems, and evolution of quality standards (e.g., reference database standardization for T-score calculation), it is necessary that DXA technologists stay current in the field.

Failure to follow standard procedures may result in invalid data, which can be misleading and potentially harmful for patient care *(16,17,19,37,38)*. Examples of DXA errors abound. These include incorrect patient positioning and/or analysis, failure to consider confounding artifacts that affect BMD values, and inappropriate reference database use for T-score derivation. Additional errors include failure to recognize densitometer drift or shift that could lead to reporting an inappropriate BMD change, thus leading to alteration of therapy, failure to change therapy, and/or unnecessary diagnostic studies. Another common error is failure to perform precision assessment, resulting in inability to distinguish between an apparent BMD difference that is simply within the range of error of the test vs one that is statistically significant.

DXA certification provides evidence that a basic body of knowledge has been acquired. A "valid" certification is one that is currently active (i.e., not expired). Certification should be maintained through proof of continuing education in the DXA field and/or reexamination because of evolving technologies and standards in bone densitometry. Accreditation of a DXA facility by a neutral third party is a formal declaration that the facility meets international standards for development, implementation, and maintenance of the certification program. Examples of accrediting agencies include the National Commission for Certifying Agencies *(39)* and the American National Standards Institute *(40)*. These agencies were developed to ensure the health, welfare, and safety of the public.

Each DXA Technologist Has Access to the Manufacturer's Manual of Technical Standards and Applies These Standards for BMD Measurement

Rationale. There are important manufacturer-specific differences in DXA hardware, software, instrument operation, and requirements for patient positioning *(18)*. DXA systems use complex digital technologies that generate numerical data, the validity of which is highly dependent on the application of appropriate manufacturer-specific standard methods of operation. The manufacturer's manual of instructions, in print or electronic format, is the primary resource for quality control standards, instrument maintenance, patient scanning, and data analysis.

Comments. Each DXA system is delivered with a manual of instructions that may be in printed form, embedded in computer software, on external electronic media, or online. This manual is an important resource to understand proper instrument use. As time passes, some of the information in the manual may be revised or updated. However, accessibility, understanding, and application of the manual's contents by facility staff is likely to vary widely depending on the initial level of interest, changes in staffing, and procedures for assuring continuity of quality standards. Deviations from recommended procedures that may adversely affect the validity of BMD measurements include the use

of a nonstandard phantom (41), failure to recognize and correct changes in instrument calibration (17), and nonstandard patient positioning (42).

Each DXA Facility Has Detailed SOPs for DXA Performance That Are Updated When Appropriate and Available for Review by All Key Personnel

Rationale. Measurement of BMD by DXA is a process that requires integration of procedures that can be placed into 3 categories: pretesting (e.g., patient scheduling, preparation, and education, as well as instrument calibration and maintenance), testing (e.g., selection of skeletal sites to measure, scan mode, patient positioning), and post-testing (e.g., analysis, interpretation, reporting). SOPs that are carefully conceived, drafted, executed, and maintained provide a systematic method for assuring that all components that contribute to quality DXA are recognized and instituted.

Comments. Establishing effective procedures for implementing and maintaining quality standards is an important element of reliability in radiological procedures. Standardization of radiological processes can reduce errors and improve patient safety (43). Individuals involved in all aspects of bone densitometry should participate in the development of SOPs (44). Examples of elements in effective SOPs include a statement of the SOP purpose, scope of the SOPs, related documentation, definitions of terms, responsible staff, exact steps of the procedure, error analysis (i.e., a systematic method to analyze errors for the purpose of improving performance, with correction steps when errors are found), required quality control methods for the procedure, and guidelines for reporting DXA results. Examples of SOPs for some DXA procedures are available online (45).

The DXA Facility Must Comply With All Applicable Radiation Safety Requirements

Rationale. DXA scanning uses ionizing radiation in the form of X-rays, which can theoretically cause harm despite the extremely low radiation dose. For both patient and technologist safety, all applicable radiation safety guidelines and requirements must be followed to minimize the risk from diagnostic radiation.

Comments. Radiation safety issues with DXA have been identified and described (46). While it is not possible to precisely quantitate random effects from the low doses of ionizing radiation associated with DXA, for purposes of radiation protection, there is assumed to be a linear relationship between dose and adverse effects, with no threshold below which adverse effects are not possible (47). The typical level of background radiation to which the general population is exposed, not including radiation due to medical procedures, has been estimated to be about 2.5 mSv/yr (48). A DXA scan is associated with radiation exposure (effective dose) of about 5 μSv or 0.005 mSv. At facilities where young children and adolescents are scanned, these concepts are considered very carefully by radiation safety committees; the scrutiny of clinical and research protocols is often stricter than that for adults.

Three concepts related to DXA scanning should be considered in protecting the public and technologists from radiation harm (46): justification—a DXA scan should not be performed unless there is net benefit to the patient; optimization—radiation exposure should be as low as reasonably achievable by limiting the time of exposure, maximizing the distance from the source of radiation, and using shielding when appropriate; and regulation—adherence to all applicable regulations (e.g., by city, state/province, country) to minimize excessive radiation exposure from diagnostic procedures.

Spine Phantom BMD Measurement Is Performed at Least Once Weekly to Document the Stability of DXA Performance Over Time; BMD Values Must Be Maintained Within a Tolerance of ± 1.5%, with an Ongoing Monitoring Plan That Defines a Correction Approach When the Tolerance Is Exceeded

Rationale. The accuracy and precision of BMD measurements by DXA can be adversely affected by changes in instrument performance that may occur suddenly (calibration "shift") or slowly (calibration "drift"). To detect these changes and know that BMD measurements are stable over time, a phantom (standardized object with known BMD) should be scanned at regular intervals. This provides assurance that the X-ray source, radiation detectors, and software algorithms are operating correctly. The scanning of a phantom verifies densitometer performance and assures that DXA results are stable over time (49).

Comments. Phantom scanning can determine when a DXA system is out of calibration and requires service. Phantom scanning does not calibrate the system but is an independent test object that can be scanned as a patient proxy. This allows monitoring of the system to identify problems within the calibration process itself (49). A suitable quality control program requires periodic scanning of a phantom of known BMD, bone mineral content, and area. The phantom is semianthropomorphic and made of either aluminum or hydroxyapatite. Longitudinal scanning of a phantom over time assures that instrument performance parameters of the entire imaging and processing chain are stable over time.

When a manufacturer recommends phantom scanning at specified intervals, this should be done as advised. BMD, bone mineral content, and areas of the phantom should be plotted on a graph based on Shewhart plots (23,50,51). To construct a Shewhart plot, the anthropometric phantom is scanned 10 times and the mean phantom BMD is established as the baseline. The phantom is then scanned on a regular basis according to manufacturer's directions and/or the DXA facility's SOPs, with the results recorded and monitored. On the Shewhart plot, a band ± 1.5% (±3 standard deviations [SDs]) around the phantom mean BMD

delineates the upper and lower limits *(47,49)*. If the phantom value falls outside the upper or lower control limit, the phantom should be rescanned. If the rescan value also falls outside of acceptable ranges, then patient scanning should be postponed until machine service occurs. The Shewhart plots should be reviewed regularly to assure that there is no short-term shift or long-term drift in BMD values. Following routine preventive or other scanner maintenance, the phantom should be scanned 10 times without repositioning between scans. If the mean BMD of these 10 scans differs from the mean of prior daily phantom scans by more than the established limits, then the machine should be recalibrated and a new mean of 10 further scans is established *(47,49)*. Depending on the DXA manufacturer, the Shewhart plot may be automatically generated or may need to be created manually. Facilities may wish to invoke more rigorous phantom scanning protocols (i.e., daily phantom scanning and tighter phantom limits), as many facilities have long-term CVs <0.5%.

Each DXA Technologist Has Performed In Vivo Precision Assessment According to Standard Methods and the Facility Least Significant Change (LSC) Has Been Calculated

Rationale. All quantitative tests in medicine have inherent uncertainty. With DXA BMD measurement, the main sources of variability are patient factors, the technologist, and the instrument *(52)*. Knowledge of the magnitude of this random uncertainty is essential to determine when a BMD "change" is real *(46)*. BMD precision (i.e., reproducibility of the measurement) is the ability of the same densitometer and technologist to obtain the same result when measuring a patient multiple times over a short period *(46)*. When a follow-up BMD measurement differs by the LSC or more, the clinician can conclude that a real loss or gain in BMD has occurred.

Comments. Determination of LSC requires precision assessment. This involves repeat BMD measurements in individuals representative of the clinic's patient population according to a well-established methodology *(53)*. Generally, this consists of measuring 30 patients twice, or 15 patients 3 times, with repositioning between scans. Precision assessment is not a research study and should not require institutional review board approval *(46)*. However, as precision assessment exposes the patient to additional radiation beyond that of a single DXA, the patient should be informed of the reason for precision assessment and agreement (verbal or written) obtained prior to performing the second scan. Precision error is subsequently calculated as the root mean square SD. The LSC with 95% confidence is the precision error × 2.77; this value is easily determined using online calculators *(54)*. Variation in patient position during scan acquisition and variability in subsequent analysis are important factors that influence BMD precision. When multiple technologists are performing BMD measurements at a facility, it is recommended that the average LSC of all technologists be used *(24)*. If a DXA facility has not performed precision assessment, then quantitative comparison of serial BMD measurements is not possible.

The LSC for Each DXA Technologist Should Not Exceed 5.3% for the Lumbar Spine, 5.0% for the Total Hip, and 6.9% for the Femoral Neck

Rationale. BMD precision error values acceptable for clinical practice were determined by a meta-analysis of published BMD precision studies *(55)*. In the studies comprising this meta-analysis, precision values were reported as percent coefficient of variation (%CV) rather than absolute SD values in gram per square centimeter, the latter of which is recommended in clinical practice *(56)*.

Comments: Technologist precision and quantitative BMD comparisons in clinical practice should use the LSC expressed as an absolute value in gram per square centimeter *(53)*. This is preferable to using %CV as it is less affected by the baseline BMD value; as an example, the same absolute change in BMD with a very low baseline BMD would represent a greater percentage change compared with a higher baseline BMD. DXA precision calculators that are available online *(54)* can be set to express precision as either gram per square centimeter or %CV. As such, it is possible to determine whether the technologists are meeting the precision standards. If a technologist has exceeded these acceptable values, retraining is necessary. If the LSC is very large, then expected changes in BMD over time with disease or treatment cannot be detected within a clinically useful time interval.

Interpretation and Reporting

At Least One Practicing DXA Interpreter, and Preferably All, Has a Valid Certification in Bone Densitometry

Rationale. DXA interpretation requires awareness and understanding of issues that include patient positioning, data analysis, precision assessment and LSC, reference databases, diagnostic criteria, and treatment guidelines. DXA reports must provide information that is correct and meaningful for the referring healthcare provider. By passing an examination and receiving a certification in bone densitometry, an interpreter provides evidence that a basic skill set has been acquired; keeping the certification current through continuing medical education relevant to DXA and/or subsequent examinations shows that these skills have been maintained as the field has evolved. Ideally, all DXA interpreters should be well trained and certified in bone densitometry; however, a single certified interpreter at each DXA facility may be capable of educating, supervising, and monitoring the quality of other interpreters at the same facility.

Comments. Standards for measuring BMD, diagnosing osteoporosis, assessing fracture risk, and treatment

recommendations are continually evolving. Examples of common mistakes (16,17,19,37,38) that could result in an incorrect interpretation of DXA include the following: failure to recognize the presence of an artifact that invalidates BMD measurement, use of an invalid skeletal site for diagnostic classification, reporting a different diagnosis and fracture risk for each skeletal site and region of interest (ROI) measured, reporting T-scores when Z-scores should be used, using an incorrect reference database for generating T-scores or Z-scores, comparing T-scores when interpreting serial DXA studies rather than BMD in gram per square centimeter, entering incorrect information into the FRAX algorithm, and giving inappropriate recommendations for evaluation and treatment due to inadequate understanding of applicable guidelines. In interpreting the scans of children and adolescents with chronic disease (as DXA-derived measures of areal BMD can be confounded by bone size), the Z-score may need adjustment for height, and in some clinical settings, bone age, to ensure that the Z-score is not confounded by delayed skeletal growth and/or maturation (36).

DXA certification provides evidence that a basic body of knowledge has been acquired. A "valid" certification is one that is currently active (i.e., not expired). As standards and guidelines for DXA and osteoporosis management evolve, it is necessary that DXA interpreters stay current in the field. Certification should be maintained through proof of continuing education and/or reexamination because of evolving technologies and standards in bone densitometry.

The DXA Manufacturer and Model Are Noted on the Report

Rationale. There are important differences in hardware, software, reference databases, and operational protocols among DXA manufacturers. A patient with BMD measured on 1 manufacturer's densitometer may have a different BMD and/or T-score when measured on another, even when there is no real difference in BMD. Quantitative comparison with a previous DXA study requires that BMD be measured on the same instrument at the same facility, with knowledge of LSC, unless a cross-calibration study has been done between the different instruments.

Comments. Differences in manufacturer's recommendations for patient positioning, bone edge detection algorithms, calibration methods, ROIs, and reference databases are largely responsible for discrepancies in BMD values measured with DXA systems of different manufacturers (49,57). Comparing results of measurements on different machines requires cross-calibration procedures (29,55), but there is a statistical penalty (i.e., greater LSC with reduced sensitivity for detecting change) paid for these comparisons (58). Identification of the DXA manufacturer is helpful for referring physicians to validate that a quantitative comparison is possible.

The DXA Report Includes a Statement Regarding Scan Factors That May Adversely Affect Acquisition/Analysis Quality and Artifacts/ Confounders, if Present

Rationale. DXA results depend greatly on the skills of the technologist to properly position the patient and subsequently analyze the data for interpretation and reporting. Collectively, these functions are referred to as acquisition and analysis. Manufacturer's training, thorough knowledge of technical manuals, and adherence to SOPs are prerequisites for quality acquisition and analysis. The consequences of faulty acquisition and analysis are well documented (16–18), and at times alter or invalidate DXA interpretation. The interpreter must alert the referring provider of these possibilities and their consequences through a clear statement of scan technical quality. Artifacts that may confound BMD measurements are commonly classified as internal (intrinsic to the patient when disrobed) or external (able to be removed).

Comments. Acquisition and analysis errors may require repeat analysis, repeat scanning, or having the patient return for scan of an additional skeletal site. Important clinical consequences can ensue from these errors, including missed opportunities for treatment, unnecessary treatment, inappropriate laboratory testing, failure to perform appropriate laboratory tests, return visits, and additional healthcare costs (16,17). Lack of awareness of anatomic variation in vertebral segmentation can create confusion with DXA analysis and can have meaningful adverse effects on the interpretation of the results (59). In a 2008 survey, referring physicians thought it important that the DXA interpreter provide information about the technical quality and limitations of the report (60). Internal artifacts can represent common consequences of aging (e.g., degenerative spine changes and aortic calcification) or medical interventions (e.g., hip prosthesis and inferior vena cava filter). External artifacts related to clothing, jewelry, or other man-made objects should be removed, when possible, before proper scan acquisition. Careful preprocedure questioning and astute observation by technologists can mitigate or eliminate impacts of artifacts. Sometimes, serious disease states (e.g., Paget's disease of bone, osteolytic or osteoblastic malignancies) are suggested on the DXA images; these should be noted on the report so that appropriate evaluation can be initiated.

The DXA Report Identifies the Skeletal Site, ROI, and Body Side for Each Technically Valid BMD Measurement

Rationale. The identification of the skeletal site, ROI, and body side (when applicable) documents the exact area scanned; this allows the technologist to scan the same ROI in follow-up studies, provides interpreters with essential information when generating results, and allows referring

healthcare providers to document that the same skeletal sites were used to monitor BMD change over time.

Comment. An important component of DXA interpretation involves scrutinizing the skeletal images to assess patient positioning, correctness of edge detection, potentially confounding artifacts, and placement of margins to delineate ROIs *(49)*. If scanning of any skeletal site is not technically valid, the values for that site should not be reported. Failure to properly identify skeletal sites and use of improper ROIs, particularly on follow-up scanning, can potentially provide incorrect data for use in clinical care. Technical standards exist regarding skeletal sites and ROIs for scanning and reporting *(24)*. For lumbar spine BMD, L1–L4 should be measured, only excluding vertebrae that are affected by local structural change or artifact, using at least 2 vertebrae for diagnostic classification. Anatomically abnormal vertebrae may be excluded from analysis if they are clearly abnormal and nonassessable within the resolution of the system, supported by more than a 1.0 T-score difference between the vertebra in question and adjacent vertebrae *(24)*. Lateral spine BMD measurement should not be used for diagnosis. For hip BMD, only the femoral neck and total proximal femur ROIs should be used for diagnostic classification in adults. The mean hip BMD can be used for monitoring in adults and older adolescents (age >15 yr), with total proximal femur being preferred. However, in children and young adolescents, the hip should generally be excluded as a skeletal assessment site, as positioning in this age group is challenging and skeletal landmarks that guide consistent positioning are not well developed. For forearm DXA measurements, use of the 33% radius (one-third radius) of the nondominant forearm is recommended for diagnosis; other forearm ROIs are not recommended *(24)*. In children and adolescents, total body less head is the recommended assessment site for baseline and ongoing monitoring of bone health. The whole body scan also provides a measurement of body composition, which may be helpful in the ongoing evaluation of youth with chronic diseases.

There Is a Single Diagnosis Reported for Each Patient, Not a Different Diagnosis for Each Skeletal Site Measured

Rationale. The densitometric diagnosis of osteoporosis in clinical practice is made by applying the WHO criteria *(2)* to each appropriate patient using a limited number of skeletal sites *(24)*. This allows for a consistent diagnostic classification for application to treatment guidelines and fracture risk assessment. The WHO criteria are not applicable to premenopausal women, men under age 50 yr, children, and adolescents.

Comment. The ISCD Official Positions state that osteoporosis may be diagnosed in postmenopausal women and in men aged 50 yr and older if the T-score of the lumbar spine, total proximal femur, femoral neck, or 33% radius is ≤–2.5, using a uniform Caucasian (nonrace adjusted) female normative database to derive T-scores for women and men of all ethnic groups *(24)*. This convention should be used in reporting DXA scans; however, application of this recommendation may vary according to local requirements *(24)*. Manufacturers are advised to use National Health and Nutrition Examination Survey III young-adult Caucasian female BMD data as the reference standard for femoral neck and total proximal femur T-score calculation and to continue to use their own reference databases for lumbar spine T-score calculation *(24)*. However, country-specific guidelines related to the use of T-scores may differ from international guidelines *(61)*. As an example, in Japan, T-scores are not used for diagnostic classification *(61)*; therefore, statements regarding T-scores for diagnosis are not applicable in Japan. If local reference data are available, they should be used to calculate Z-scores but not T-scores. Guidelines have been developed for BMD measurement, interpretation, and reporting in children and in adolescents *(34)*, as well as in premenopausal women and in men <50 yr of age *(24)*; interpreters should be aware of, and follow, these guidelines.

A Fracture Risk Assessment Tool Is Used Appropriately

Rationale. In some locations, the therapeutic intervention threshold (i.e., the cut-point at which pharmacologic therapy is recommended) historically was based on the BMD T-score alone. However, the majority of "osteoporosis-related" fractures occur in individuals with low bone mass (osteopenia) or normal BMD *(62,63)*. To improve targeting of interventions to those most likely to sustain fractures, various fracture risk assessment tools have been developed for adult patients. The FRAX tool developed by the WHO is most widely used. It is well studied and has many country-specific versions. FRAX utilizes clinical risk factors with or without femoral neck BMD to estimate the 10-yr risk for major osteoporosis-related fractures (clinical spine, forearm, hip, or shoulder) and for hip fracture alone. Other calculators exist; for example, the Garvan calculator allows inclusion of the number of prior fractures and falls *(64)*. In some regions of the world, therapeutic intervention thresholds are linked to fracture risk estimates. Like all tools, it is important to use these calculators as intended; for example, FRAX is intended to assess fracture risk and to assist in treatment decisions in individuals between the ages of 40 and 90 yr. Additionally, it is important to recognize when to check "yes" in the FRAX calculator for a given clinical risk factor. For example, to consider alcohol consumption as a risk factor, it needs to be 3 or more units per day with 1 unit defined as a 285-mL glass of beer, a 30-mL serving of liquor, or 120 mL of wine. These definitions are listed on the FRAX website and include a useful frequently asked question page that all users should refer to.

Comment. These calculators are not meant to replace clinical judgment and it is not necessary to rigidly follow treatment guidelines based upon such results. While

Table 1
Examples of Resources for DXA Training and Certification/Accreditation

Organization	Description	Weblink
American Bone Health	Limited permit X-ray technician	https://americanbonehealth.org/limited-permit-x-ray-technician-school-bone-densitometry
American College of Radiology	Practice parameter for the performance of DXA	http://www.acr.org/~/media/eb34da2f786d4f8e96a70b75ee035992.pdf
American Registry of Radiologic Technologists	Training and certification for technologists	https://www.arrt.org/pdfs/Disciplines/Handbooks/BD-Handbook.pdf https://www.arrt.org/pdfs/disciplines/clinical-experience/bd-clinical-experience.pdf
American Society of Radiologic Technologists	Training and certification for technologists	http://www.asrt.org/students/study-guides/bone-densitometry https://www.asrt.org/docs/default-source/educators/bonedensitometrycurriculum.pdf http://www.asrt.org/events-and-conferences/event-calendar
Auntminnie.com	Bone densitometry course for technologists	http://www.auntminnie.com/(F(AiaAhFYYF2NIpZ-LQYAK9zBSaE53uNbrdw8TMEotZJ4C_auBzpJsKf51OZTxmuNjXb903IJaUqAs9rhc5QxVyVpLxTkY0MGovcJoYpYoY40DAE80cW6r0WGxQOr8qjHkOA557w2))/index.aspx?sec=lin&sub=def&erd=83
CAR	CAR Bone Mineral Densitometry Accreditation Program	http://www.car.ca/en/accreditation/bmd.aspx
DEXA Solutions	Link to training and certification	http://www.dexasolutions.com/Resources/Certification.aspx
GE Healthcare (Lunar)	DXA training	http://www3.gehealthcare.com/en/education/product_education_-_technical/lunar_bone_densitometry
Hologic	DXA training	http://www.hologic.com/training/dxa-101-basics-bone-densitometry
Swissray (Norland)	DXA training	http://www.swissray.com/product.php?action=view&cid=16
International Society for Clinical Densitometry	Training courses for DXA certification for clinicians and technologists, facility accreditation	http://www.iscd.org/education/cmece-live-courses/osteoporosis-essentials/ http://www.iscd.org/certification/ http://www.iscd.org/accreditation/
Medical Technology Management Institute	Bone densitometry training course	http://www.mtmi.net/courses/reg_BD.php
OAR	Accredited Densitometry Technologist CME	https://cme.oarinfo.ca/cme/uploaded/2015-CBMD-Tech-ADT-2016-brochure.pdf
OAR	OAR Canadian Bone Mineral Densitometry Facility Accreditation	http://cbmd.ca/
Study.com	Bone density technician training and degree program options	http://study.com/articles/Bone_Density_Technician_Training_and_Degree_Program_Options.html

Note: This is not an all-inclusive list. Other organizations in other countries may have excellent resources as well. Inclusion of programs in this table does not represent an endorsement of the ISCD; the quality of training in preparation for certification and/or accreditation may vary.

Abbr: DXA, dual-energy X-ray absorptiometry; CAR, Canadian Association of Radiologists; CME, continuing medical education; OAR, Ontario Association of Radiologists.

Table 2
Examples of Helpful Books on Bone Densitometry

Bonnick SL, Lewis LA. Bone Densitometry for Technologists, Springer, New York, NY. 2012.
Genant KH. Bone Densitometry and Osteoporosis, Springer, New York, NY. 2011.
Guglielmi G (ed.). Osteoporosis and Bone Densitometry Measurements (Medical Radiology), Springer–Verlag Berlin Heidelberg. 2013.
Hamdy RC, Lewiecki EM. Osteoporosis, Oxford University Press, New York, NY. 2013.
Licata AA, Williams SE. A DXA Primer for the Practicing Clinician: a Case-Base Manual for Understanding and Interpreting Bone Densitometry, Springer, New York, NY. 2013.
Sawyer AJ, Bachrach LK, Fung E. Bone Densitometry in Growing Patients: Guidelines for Clinical Practice, Humana Press, Totowa, NJ. 2007.
Saag KG, Morgan SL, Clines GA. Diagnosis and Management of Osteoporosis, Professional Communications Inc, West Islip, NY. 2013.
The American Society for Bone and Mineral Research, Primer on the Metabolic Bone Diseases and Disorders of Mineral Metabolism, 8th ed, John Wiley & Sons, Ames, IA. 2013.
Dual energy X ray absorptiometry for bone mineral density and body composition assessment. IAEA Human Health Series. No. 15. Vienna: International Atomic Energy Agency. 2010.
Body Composition assessment from birth to two years of age. IAEA Human Health Series. No, 22. Vienna: International Atomic Energy Agency. 2013.

Note: This listing of examples is not exhaustive and is only representative; this does not indicate an endorsement of the ISCD.

fracture risk calculators are a substantial step forward, they are not without limitations. For example, the FRAX calculator requires dichotomous (i.e., yes or no) answers for risk factors, which are actually associated with a range of risks depending on modifying factors such as dose, length of exposure, or severity. Additionally, as the number of prior osteoporosis-related fractures increases or the dose of glucocorticoids rises, the risk of future fractures increases, yet these considerations are not included in the FRAX algorithm. In children, the correlation between BMD and fracture risk is not well established; a FRAX algorithm for the pediatric population does not yet exist.

When Reporting Differences in BMD With Serial Measurements, Only Those Changes That Meet or Exceed the LSC Are Reported as a Change

Rationale. To determine when a difference in DXA measured BMD reflects a true biological change vs a simple measurement variability, each facility needs to calculate its individual LSC. Briefly, this is accomplished by measuring a patient twice on the same day using the same instrument with the scans being performed by the same technologist. When 30 patients (60 scans) have been obtained, the LSC can be calculated using the root mean square standard deviation approach. The LSC can also be calculated using 3 scans obtained on 15 patients. The ISCD and others have developed online calculators to facilitate this process *(54)*. Although calculation of LSC by this method may underestimate long-term measurement variability *(65,66)*, it is a widely used pragmatic approach to patient care.

Comment. Once a center has determined LSC values for the clinically relevant sites (usually L1–L4 spine, total proximal femur, and femoral neck), the LSC values should be applied to serial scans. The LSC should be calculated for other ROIs (e.g., L2–L4, L3–L4, 33% radius, and total radius) if serial comparison for any of these is desired. The ISCD Official Positions include operational details on LSC calculation and reporting *(24)*). For comparison, the current BMD measurement is subtracted from the prior scan and the absolute difference is assessed. If the difference is less than the LSC, this is simply measurement variance and should not be identified as a change. Simply put, a "change" that is not statistically significant is no change and should be reported as such. When the difference between scans is greater than the facility LSC, this change should be reported as an increase or decrease in BMD.

Resources to Support DXA Quality

Resources for education in bone densitometry and the conditions evaluated with DXA technology include scientific journals (e.g., *Journal of Clinical Densitometry*, *Journal of Bone and Mineral Research*, *Osteoporosis International*, *Bone*, *Calcified Tissue International*, and *Journal of Clinical Endocrinology and Metabolism*), instructional courses (Table 1), and books (Table 2). A glossary of DXA terminology and common acronyms is provided in Table 3. The ISCD has a selection of instructional courses devoted to various uses of DXA (e.g., vertebral fracture recognition, pediatric DXA, and body composition testing) and collaborates with the International Osteoporosis Foundation to regularly update a course (Osteoporosis Essentials) in bone densitometry and osteoporosis treatment.

Certification is a procedure by which a third party gives written assurance that a product, process, or service

Table 3
Glossary

Terminology
Acquisition. The process of positioning and scanning the patient on the DXA table.
Accreditation of a certification program. Declaration by a neutral third party (e.g., ANCI, NCCA) that the program meets national and/or international standards for development, implementation, and maintenance of the certification program.
Accreditation of a DXA facility. A process through which a DXA facility is validated as providing quality bone density tests.
Analysis. Assessing and correcting, if necessary, computer default selections for bone edges, regions of interest, and intervertebral space markers; selecting reference databases; and generating data for interpretation.
Artifact. Internal or external factors that can alter the DXA measurements.
Certification. Validation that an individual has acquired a basic level of knowledge on bone densitometry.
Calibration. The process of correcting differences between known reference values and actual measured DXA values.
Fracture risk assessment tool. A validated system for estimating fracture risk in populations.
Interpretation. The process of reviewing the images and data of a DXA scan to provide a diagnosis, assessment of fracture risk, and comparison with any previous studies, while recognizing limitations, if any, in the quality of the test.
Least significant change. The smallest change in BMD that is statistically significant.
Phantom. A standardized object with known BMD that is measured regularly to assess the stability of DXA measurements.
Precision assessment. The methodology of scanning multiple patients more than once that provides the data for calculating the LSC.
Reference database. Data for mean BMD and standard deviation of a defined population that is used to calculate T-scores and Z-scores.
Region of interest. A standardized portion of bone(s) for measuring BMD.
Reporting. The translation of data from acquisition and analysis into a clinically useful report.
Shewhart plot. A graph for recording serial phantom measurements to determine the stability of the DXA system.
Sievert. A derived unit of ionizing radiation dose; 1 Sv = 100 rem (Roentgen equivalent man).
Standard operating procedures. A document that provides necessary information for DXA usage for each DXA facility.
T-score. The standard deviation difference between a patient's BMD and that of a young-adult reference population.
Z-score. The standard deviation difference between a patient's BMD and that of an age-, sex-, and ethnicity-matched reference population.

Acronyms
ANSI. American National Standards Institute
ARRT. American Registry of Radiologic Technologists
ASRT. American Society of Radiologic Technologists
BMD. Bone mineral density
DXA. Dual-energy X-ray absorptiometry
FRAX. WHO fracture risk assessment tool
ISCD. International Society for Clinical Densitometry
ISO. International Organization for Standardization
LSC. Least significant change
NCCA. National Commission for Certifying Agencies
NHANES. National Health and Nutrition Examination Survey
ROI. Region of interest
SOPs. Standard operating procedures
Sv. Sievert
WHO. World Health Organization

conforms to specified requirements. Certification in bone densitometry is provided by organizations such as the American Registry of Radiologic Technologists (for radiological technologists) and the ISCD (for technologists and DXA interpreters).

Accreditation of a professional or personnel certification program provides impartial, third-party validation that the program has met recognized national and international credentialing industry standards for development, implementation, and maintenance of the programs. Agencies that accredit certification programs include the National Commission for Certifying Agencies *(39)*, the American National Standards Institute *(40)*, and others that adhere to principles established by the International Organization for Standardization. The International Organization for Standardization is an independent, nongovernmental international organization with a membership of 162 national standards bodies *(67)*. The ISCD programs for Certified Clinical Densitometrist and Certified Bone Densitometry Technologist are accredited by the National Commission for Certifying Agencies.

Facility accreditation is offered by organizations that include the ISCD *(68)*, Ontario Association of Radiologists *(69)*, Canadian Association of Radiologists *(70)*, the Brazilian College of Radiology, and the Brazilian Association of Bone Health Assessment and Metabolism *(71)*. Programs such as these provide the highest level of assurance that essential elements for quality bone density testing have been implemented at a DXA facility.

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References

1. Bouxsein ML, Seeman E. 2009 Quantifying the material and structural determinants of bone strength. Best Pract Res Clin Rheumatol 23:741–753.
2. Kanis JA. 1994 Assessment of fracture risk and its application to screening for postmenopausal osteoporosis: synopsis of a WHO report. WHO Study Group. Osteoporos Int 4:368–381.
3. Miller PD, Bonnick SL, Rosen CJ. 1996 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 58:207–214.
4. Marshall D, Johnell O, Wedel H. 1996 Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. BMJ 312:1254–1259.
5. Cosman F, de Beur SJ, LeBoff MS, et al. 2014 Clinician's guide to prevention and treatment of osteoporosis. Osteoporos Int 25:2359–2381.
6. Grossman JM, Gordon R, Ranganath VK, et al. 2010 American College of Rheumatology 2010 recommendations for the prevention and treatment of glucocorticoid-induced osteoporosis. Arthritis Care Res (Hoboken) 62:1515–1526.
7. Papaioannou A, Morin S, Cheung AM, et al. 2010 2010 Clinical practice guidelines for the diagnosis and management of osteoporosis in Canada: summary. CMAJ 182:1864–1873.
8. Kanis JA, McCloskey EV, Johansson H, et al. 2013 European guidance for the diagnosis and management of osteoporosis in postmenopausal women. Osteoporos Int 24:23–57.
9. Compston J, Bowring C, Cooper A, et al. 2013 Diagnosis and management of osteoporosis in postmenopausal women and older men in the UK: National Osteoporosis Guideline Group (NOGG) update 2013. Maturitas 75:392–396.
10. Wang M, Bolland M, Grey A. 2015 Management recommendations for osteoporosis in clinical guidelines. Clin Endocrinol doi:10.1111/cen.13000; (Oxf) Epub.
11. Kanis JA, Oden A, Johansson H, et al. 2009 FRAX(R) and its applications to clinical practice. Bone 44:734–743.
12. Lewiecki EM, Laster AJ. 2006 Clinical applications of vertebral fracture assessment by dual-energy X-ray absorptiometry. J Clin Endocrinol Metab 91:4215–4222.
13. Shepherd JA, Baim S, Bilezikian JP, Schousboe JT. 2013 Executive summary of the 2013 International Society for Clinical Densitometry Position Development Conference on Body Composition. J Clin Densitom 16:489–495.
14. Broy SB, Cauley JA, Lewiecki ME, et al. 2015 Fracture risk prediction by non-BMD DXA measures: the 2015 ISCD Official Positions part 1: hip geometry. J Clin Densitom 18: 287–308.
15. Silva BC, Broy SB, Boutroy S, et al. 2015 Fracture risk prediction by non-BMD DXA measures: the 2015 ISCD Official Positions part 2: trabecular bone score. J Clin Densitom 18:309–330.
16. Lewiecki EM, Lane NE. 2008 Common mistakes in the clinical use of bone mineral density testing. Nat Clin Pract Rheumatol 4:667–674.
17. Lewiecki EM, Binkley N, Petak SM. 2006 DXA quality matters. J Clin Densitom 9:388–392.
18. Watts NB. 2004 Fundamentals and pitfalls of bone densitometry using dual-energy X-ray absorptiometry (DXA). Osteoporos Int 15:847–854.
19. Messina C, Bandirali M, Sconfienza LM, et al. 2015 Prevalence and type of errors in dual-energy X-ray absorptiometry. Eur Radiol 25:1504–1511.
20. Kim TY, Schafer AL. 2016 Variability in DXA Reporting and other challenges in osteoporosis evaluation. JAMA Intern Med 176:393–395.
21. Fenton JJ, Robbins JA, Amarnath AL, Franks P. 2016 Osteoporosis overtreatment in a regional health care system. JAMA Intern Med 176:391–393.
22. Gafni RI, Baron J. 2004 Overdiagnosis of osteoporosis in children due to misinterpretation of dual-energy X-ray absorptiometry (DEXA). J Pediatr 144:253–257.
23. Bonnick SL, Lewis LA. 2013 Bone Densitometry for Technologists. New York, London: Springer.
24. Shepherd JA, Schousboe JT, Broy SB, et al. 2015 Executive summary of the 2015 ISCD position development conference on advanced measures from DXA and QCT: fracture prediction beyond BMD. J Clin Densitom 18:274–286.
25. MultiState Associates Incorporated. Semi-weekly reports to the International Society for Clinical Densitometry on state legislative and regulatory activity relating to DXA or bone density studies. 2006–2015; Data on file.
26. Centers for Medicare & Medicare Services. 2011 Code of Federal Register. Billing and Enrollment Guideline for PHYS-078 Independent Diagnostic Testing Facilities (IDTF).

Available at: https://downloads.cms.gov/medicare-coverage-database/lcd_attachments/23448_6/CBGPHYSMED078 April09.pdf. Accessed March 15, 2016.
27. Lenchik L, Leib ES, Hamdy RC, et al. 2002 Executive summary: International Society for Clinical Densitometry Position Development Conference, Denver, Colorado, July 20–22, 2001. J Clin Densitom 5(Suppl):S1–S3.
28. The Writing Group for the International Society for Clinical Densitometry Position Development Conference. 2004 2004 Executive summary: International Society for Clinical Densitometry Position Development Conference. J Clin Densitom 7:7–12.
29. Binkley N, Bilezikian JP, Kendler DL, et al. 2006 Official positions of the International Society for Clinical Densitometry and executive summary of the 2005 Position Development Conference. J Clin Densitom 9:4–14.
30. Baim S, Binkley N, Bilezikian JP, et al. 2008 Official positions of the International Society for Clinical Densitometry and executive summary of the 2007 ISCD Position Development Conference. J Clin Densitom 11:75–91.
31. Gordon CM, Bachrach LK, Carpenter TO, et al. 2008 Dual energy X-ray absorptiometry interpretation and reporting in children and adolescents: the 2007 ISCD pediatric official positions. J Clin Densitom 11:43–58.
32. Hans DB, Kanis JA, Baim S, et al. 2011 Joint official positions of the International Society for Clinical Densitometry and International Osteoporosis Foundation on FRAX((R)) executive summary of the 2010 Position Development Conference on Interpretation and Use of FRAX((R)) in Clinical Practice. J Clin Densitom 14:171–180.
33. Schousboe JT, Shepherd JA, Bilezikian JP, Baim S. 2013 Executive summary of the 2013 International Society for Clinical Densitometry Position Development Conference on Bone Densitometry. J Clin Densitom 16:455–466.
34. Crabtree NJ, Arabi A, Bachrach LK, et al. 2014 Dual-energy X-ray absorptiometry interpretation and reporting in children and adolescents: the revised 2013 ISCD pediatric official positions. J Clin Densitom 17:225–242.
35. Fitch K, Bernstein SJ, Aguilar B, et al. 2001 The RAND/UCLA Appropriateness Method User's Manual. Santa Monica, California: The RAND Corporation.
36. Gordon CM, Leonard MB, Zemel BS, International Society for Clinical Densitometry. 2014 2013 Pediatric position development conference: executive summary and reflections. J Clin Densitom 17:219–224.
37. Morgan SL, Lopez-Ben R, Nunnally N, et al. 2008 The effect of common artifacts lateral to the spine on bone mineral density in the lumbar spine. J Clin Densitom 11:243–249.
38. El Maghraoui A, Roux C. 2008 DXA scanning in clinical practice. QJM 101:605–617.
39. Institute for Credentialling Excellence. 2014 NCCA Accreditation. Available at: http://www.credentialingexcellence.org/ncca. Accessed March 15, 2016.
40. American National Standards Institute. 2016 Accreditation Services. Available at: https://www.ansica.org/wwwversion2/outside/Default.asp. Accessed March 15, 2016.
41. Frimeth J, Galiano E, Webster D. 2010 Some physical and clinical factors influencing the measurement of precision error, least significant change, and bone mineral density in dual-energy X-ray absorptiometry. J Clin Densitom 13:29–35.
42. Cheng XG, Nicholson PH, Boonen S, et al. 1997 Effects of anteversion on femoral bone mineral density and geometry measured by dual energy X-ray absorptiometry: a cadaver study. Bone 21:113–117.
43. Donnelly LF, Dickerson JM, Goodfriend MA, Muething SE. 2009 Improving patient safety: effects of a safety program on performance and culture in a department of radiology. AJR Am J Roentgenol 193:165–171.
44. Larson DB, Kruskal JB, Krecke KN, Donnelly LF. 2015 Key concepts of patient safety in radiology. Radiographics 140277.
45. International Society for Clinical Densitometry. 2015 Test Study Material. Available at: http://www.iscd.org/certification/test-study-material. Accessed March 15, 2016.
46. Baim S, Wilson CR, Lewiecki EM, et al. 2005 Precision assessment and radiation safety for dual-energy X-ray absorptiometry: position paper of the International Society for Clinical Densitometry. J Clin Densitom 8:371–378.
47. Khan AA, Colquhoun A, Hanley DA, et al. 2007 Standards and guidelines for technologists performing central dual-energy X-ray absorptiometry. J Clin Densitom 10:189–195.
48. Ramalingaswami V. Iodine and thyroid cancer. 1969;12:111.
49. The Writing Group for the International Society for Clinical Densitometry Position Development Conference. 2004 2004 International Society for Clinical Densitometry Position Development Conference. Technical standardization for dual-energy X-ray absorptiometry. J Clin Densitom 7:27–36.
50. Pearson D, Cawte SA. 1997 Long-term quality control of DXA: a comparison of Shewhart rules and Cusum charts. Osteoporos Int 7:338–343.
51. Bonnick SL. 2010 Bone Densitometry in Clinical Practice: Application and Interpretation. New York, NY: Humana.
52. Bennett HS, Dienstfrey A, Hudson LT, et al. 2006 Standards and measurements for assessing bone health-workshop report co-sponsored by the International Society for Clinical Densitometry (ISCD) and the National Institute of Standards and Technology (NIST). J Clin Densitom 9:399–405.
53. Lenchik L, Kiebzak GM, Blunt BA, International Society for Clinical Densitometry, Position Development Panel, Scientific Advisory Committee. 2002 What is the role of serial bone mineral density measurements in patient management? J Clin Densitom 5(Suppl):S29–S38.
54. International Society for Clinical Densitometry. 2015 ISCD Calculators. Available at: http://www.iscd.org/resources/calculators/. Accessed March 15, 2016.
55. Shepherd JA, Lu Y, Wilson K, et al. 2006 Cross-calibration and minimum precision standards for dual-energy X-ray absorptiometry: the 2005 ISCD official positions. J Clin Densitom 9:31–36.
56. Leslie WD, Manitoba Bone Density Program. 2006 The importance of spectrum bias on bone density monitoring in clinical practice. Bone 39:361–368.
57. Boonen S, Kaufman JM, Reginster JY, Devogelaer JP. 2003 Patient assessment using standardized bone mineral density values and a national reference database: implementing uniform thresholds for the reimbursement of osteoporosis treatments in Belgium. Osteoporos Int 14:110–115.
58. Shepherd JA, Morgan SL, Lu Y. 2008 Comparing BMD results between two similar DXA systems using the generalized least significant change. J Clin Densitom 11:237–242.
59. Peel NF, Johnson A, Barrington NA, et al. 1993 Impact of anomalous vertebral segmentation on measurements of bone mineral density. J Bone Miner Res 8:719–723.
60. Binkley N, Krueger D. 2009 What should DXA reports contain? Preferences of ordering health care providers. J Clin Densitom 12:5–10.
61. Soen S, Fukunaga M, Sugimoto T, et al. 2013 Diagnostic criteria for primary osteoporosis: year 2012 revision. J Bone Miner Metab 31:247–257.

62. Schuit SC, van der Klift M, Weel AE, et al. 2004 Fracture incidence and association with bone mineral density in elderly men and women: the Rotterdam Study. Bone 34:195–202.
63. Wainwright SA, Marshall LM, Ensrud KE, et al. 2005 Hip fracture in women without osteoporosis. J Clin Endocrinol Metab 90:2787–2793.
64. Garvan Institute. 2016 Fracture Risk Calculator. Available at: http://www.garvan.org.au/bone-fracture-risk/. Accessed March 15, 2016.
65. Hangartner TN. 2007 A study of the long-term precision of dual-energy X-ray absorptiometry bone densitometers and implications for the validity of the least-significant-change calculation. Osteoporos Int 18:513–523.
66. Leslie WD. 2008 Factors affecting short-term bone density precision assessment and the effect on patient monitoring. J Bone Miner Res 23:199–204.
67. International Organization for Standardization. 2016 Standards. Available at: http://www.iso.org/iso/home/standards.htm. Accessed March 15, 2016.
68. International Society for Clinical Densitometry. 2014 Facility Accreditation. Available at: http://www.iscd.org/accreditation/. Accessed March 15, 2016.
69. Ontario Association of Radiologists. 2016 Canadian BMD Facility Accreditation Program. Available at: https://oarinfo.ca/cbmd/resources. Accessed March 15, 2016.
70. Canadian Association of Radiologists. 2016 Accreditation Programs: Bone Mineral Density (BMD). Available at: http://www.car.ca/en/accreditation/bmd.aspx. Accessed March 15, 2016.
71. Associação Brasileira de Avaliação Óssea e Osteometabolismo. 2005 Programma de Controle de Qualidade em Densitometria Clinica. Available at: http://www.proquad.org.br/index_proquad.php. Accessed March 15, 2016.