Bone Densitometry in Clinical Practice
The third edition of Bone Densitometry in Clinical Practice by Dr. Sydney Lou Bonnick is the crown jewel in her seminal efforts to educate us all in the fundamentals as well as the advanced applications of bone densitometry. This edition shares common themes of her life’s work: accuracy in all she does and precision in her science. One cannot, put very simply, find another book on bone densitometry that compares to the thoroughness of her work, and, in that regard, this book should be on the shelf of every medical library, medical student, house-officer, academic faculty member, practicing clinician, and radiology technologist – this edition offers each and every one at every level the latest and greatest in bone densitometry.

Since her pioneering work in bone densitometry which preceded by years the publication of her First edition of Bone Densitometry in Clinical Practice in 1998, Dr Bonnick has provided us an enduring education of how the science of DXA can be applied in the management of osteoporosis as well as distinctly different metabolic diseases traditionally not considered for DXA use. These include, for example, aortic calcium scoring in assessing risk for cardiovascular disease and the associations between BMD levels and breast cancer; body composition with assessment of visceral fat, an increasingly important measurement in the diagnosis and management of the “metabolic syndrome” as science keys in on the links between the adipocyte and bone metabolism. Body composition measurements also take on more importance at the other extreme: in the management of diseases associated with very low body mass index (e.g. anorexia, bulimia, the athletic triad) and will evolve as a means to study the associations between muscle mass and bone mass as pharmaceuticals are developed that influence the sarcomlemma and bone cells. The expanded DXA application of hip structural analysis (HSA) has now allowed DXA to be used in measuring interventions that affect the cross-sectional moment of inertia and cortical bone size by assessing the effect of newer pharmacologials and the mechanostats that influence bone strength by mechanisms independent of areal BMD.

There is more guidance in this third edition in assessing fracture risk beyond bone mineral density measurements alone but still emphasis that the highly under detected prior vertebral fracture, like all low-trauma fractures, carries the greatest weight in fracture risk prediction. Thus, DXA’s improved application of vertebral fracture assessment (VFA) using higher resolution imaging is the best and lowest radiation technique to detect the highly prevalent non-clinical vertebral compression fracture. Wider implementation of VFA, whose CMS recognized indications for performance were spear-headed by The International Society for Clinical Densitometry (ISCD), should enable all involved in the management of osteoporosis patients to better select those patients at highest fracture risk. In that regard, Dr. Bonnick discusses the evolution as well as the pros and cons of the available fracture risk assessment tools that incorporate independent risk factors for fracture risk assessment (such as FRAX™ and FRAX™ precursors) as well as the National Osteoporosis Foundation’s Clinicians Guide, that help guide clinicians in deciding on pharmacological intervention for osteoporosis at a broader level than simply provided by FRAX™.
In this pivotal textbook there are new chapters on radiation safety and assessment for secondary causes of bone fragility – issues that are important to all primary care and specialists who perform bone mass measurements and advise patient management decisions.

Finally, Dr. Bonnick has incorporated the recent ISCD Position Development Conferences (PDCs), both the fourth adult and the first pediatric into her text and has an entire appendix entirely devoted to the PDCs, which serve to advance the unanswered questions concerning DXA applications.

Bone densitometry quality control and performance and its subsequent clinical application are an entire science in their own right. If individuals performing DXA follow the advice provided by Dr. Bonnick in this third edition, patient care will be elevated to a very high quality. Health care professionals and payers of medical services who study this book will realize that DXA output goes far, far beyond a printed computer sheet. Proper DXA performance demands detail and clinical application and Dr. Bonnick’s text provides the steps to achieve this excellence.

As I stated in the final sentences of the FOREWORD of her second edition, I am deeply honored to be asked by her to contribute to this introduction of a text that is symbolic of Dr. Sydney Bonnick’s devotion to this field. I continue to learn from her and anyone who is privileged enough to know her and also read this outstanding piece of work will also benefit from her tremendous grasp of bone densitometry science and clinical application.

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Bone densitometry is a fascinating field of medicine. Even in its earliest phases of development, densitometry incorporated aspects of imaging, physics, quantitative analysis, statistics, and computer technology that were applied in the diagnosis and management of multiple disease states. This extraordinary combination of attributes, however, left densitometry without a well-defined niche in clinical medicine. Imaging has traditionally been the purview of the radiologist. Quantitative analysis is more familiar to the pathologist. Metabolic bone disease has been the concern of the internist, rheumatologist, or endocrinologist and occasionally the nephrologist and orthopedist. And of course, physics, statistics, and computer technology have been left to those hardy souls who enjoy such things.

In 1988, when X-ray-based densitometers began to rapidly replace isotope-based densitometers, the door was opened for any medical specialty to perform densitometry. And yet, without a well-defined niche, without a specialty to champion the technology, there were no physicians who, by training, were immediately experts in the utilization of the technology.

In 1983, when I began working with dual-photon absorptiometry, the manufacturers provided a 4-hour inservice at the time of machine installation along with a brief operator’s manual and the promise of technical support whenever it was needed. There were no ongoing programs of continuing education in the performance of densitometry or in the interpretation of the data that it generated. There was no supply of trained densitometry technologists. Conferences on osteoporosis were infrequent and lectures on densitometry were decidedly rare. As a clinical tool, densitometry was viewed with skepticism. None of the notable fracture trials had yet been published. Indeed, these would not come for approximately 10 years. Clinicians, unable to noninvasively measure bone density in the past, saw little need for the ability to do so. The one disease in which densitometry seemed most applicable, osteoporosis, was largely viewed as an unalterable component of aging making the measurement of bone density superfluous.

Certainly much has changed since then, both for good and for ill. With the ability to measure bone density, many disease states are now known to be characterized, at least in part, by demineralization. Suddenly, it is not only osteoporosis for which the technology can provide information crucial to disease management. And osteoporosis itself is certainly no longer viewed as unassailable. The fracture trials are published. Therapeutic and preventive efficacy of many drugs has now been documented. And the disease itself can now be defined based on the measured level of bone density. Although the technology is still properly viewed as a quantitative analytical technique, imaging with densitometry is progressing so rapidly that the time has come when some aspects of plain skeletal radiography are being superseded by imaging densitometry.

But as strange as it may seem, the technology itself is in danger of becoming so devalued that improvements in accessibility and advances in applications may be lost. Although densitometry is still underutilized, the number of devices has steadily increased. The number of individuals involved in the performance of densitometry has
steadily increased. But insistence on quality densitometry has not kept pace. There are those who perform bone densitometry for whom it is ultimately of little importance. There may be no attention to quality control of the devices, no learned supervision of the technologist, and little concern for the ramifications of inaccurate or obsolete reporting of densitometry results. In these circumstances, little value and attention is given to bone densitometry. Not surprisingly then, third party payers, the public, and our non-densitometrist physician colleagues have begun to attach little value to densitometry as well. This is a tragedy, as the advances of the last 20 years may be potentially wasted.

In 1990, Dr. Paul Miller and I independently began teaching courses in bone densitometry for the physician and technologist. The physicians who attended these courses came from all specialties. The technologists were RTs, MRTs, RNs, PAs, and nursing assistants. With the publication of the first edition of Bone Densitometry in Clinical Practice in 1998, I hoped to reach many more physicians and technologists who wished to become proficient in the application and interpretation of bone densitometry. In 2002, my technologist, Lori Lewis, and I published the first edition of Bone Densitometry for Technologists. This volume was intended solely for technologists, regardless of background, who worked in the field of densitometry. Although much of the requisite information and skill in densitometry are common to physicians and technologists alike, the unique demands placed on the densitometry technologist made such a volume both appropriate and necessary. The second edition of Bone Densitometry for Technologists was published in 2006. The second edition of Bone Densitometry in Clinical Practice was published in 2004.

Some, but not all, of our concerns in 2009 are vastly different from 1998. Unlike the situation in 1998, there are few locales in which bone densitometry is not available. Many physicians, clinics, and hospitals own densitometers. The number and types of devices have proliferated at a remarkable rate. It is rare to encounter a physician who does not yet know that fracture risk can be predicted with a single bone mass measurement. Our concerns are no longer access to densitometry and convincing the practicing physician that fracture risk can be predicted. But some concerns remain the same. Should every woman have a bone density measurement and if so, when? Can the World Health Organization criteria for the diagnosis of osteoporosis in postmenopausal Caucasian women be used to diagnose osteoporosis in women of other races or men of any race? Should the diagnosis of osteoporosis be restricted to bone density measurements of the proximal femur? Can peripheral skeletal sites be used to diagnose osteoporosis? How should an individual’s risk of fracture be expressed? Can or should bone densitometry be used to determine efficacy of therapeutic agents in the treatment of osteoporosis? None of these concerns are new or esoteric. They go straight to the heart of how and when we use densitometry and interpret the data in the care of our patients. Whether you are new to the field or have worked in densitometry for 20 years, the issues are the same. All of us must ensure that quality control procedures are instituted and followed, precision studies are done, and data are properly interpreted. In 2009, however, perhaps because we are victims of our own success, the increase in the number of devices and number of individuals involved in densitometry has contributed to occasional misuse of the technology and lapses in quality, which have raised the specter of devaluation.

The third edition of Bone Densitometry in Clinical Practice is substantially larger than the first. New chapters have been added, even since the second edition of the book, which reflect both the new applications for densitometry and the evolving needs of the
densitometrist. Chapter 1 is a review of densitometry technologies that spans the earliest attempts to quantify bone density in the mandible in the late 1800s to the modern technologies of DXA, QCT, and QUS. Chapter 2 looks at the unique aspects of gross skeletal anatomy in densitometry and aspects of bone physiology relevant to the interpretation of bone density data. Chapter 3, which deals with statistics, is intended as an overview only. While most clinicians are familiar with statistical concepts like the mean, standard deviation, and significance, there are few if any areas of clinical medicine in which the application of statistical principles has assumed such a prominent role as in bone densitometry. As the reader will find, an understanding of some basic statistical concepts is imperative in the practice of densitometry. Chapter 3 is not intended to replace a review of more thorough statistical texts, but it is intended to ease the pain that the contemplation of such texts can engender. Chapter 4 reviews issues of machine quality control that are often underappreciated in clinical settings but which profoundly affect the validity of the data generated by the densitometers. Chapter 5 is new to this edition and is a review of radiation safety issues for the non-radiologist. Although radiation safety in clinical practice is not a major concern for the densitometrist, knowledge of radiation safety issues is requisite in the practice of densitometry. Chapter 6 addresses the differences in bone density measurements among the various manufacturers and the attempts at standardization of bone density measurements among manufacturers when bone density is measured at the same skeletal site on devices from different manufacturers.

Two of the last eight chapters in this edition are new to this volume. Chapters 7 and 8 deal with the selection of patients for densitometry measurements. Chapter 7 discusses and compares the guidelines from major organizations as they have evolved over the years. Chapter 8 deals with the various questionnaires and indices that have been developed to help patients identify themselves as candidates for bone mass measurements. These indices are deceptively simple in their final form, belying the very complex development process behind them. Consequently, the initial skepticism with which most of these indices have been met is understandable. Nevertheless, they are extremely useful in many circumstances. Chapters 9, 10, and 11 deal with the specific densitometry applications of diagnosis of osteoporosis, fracture risk prediction, and monitoring changes in bone density. Diagnosis and fracture risk prediction are separate entities and both remain the subject of some controversy, as previously noted. Chapter 11, which deals with monitoring changes in bone density, has been updated and expanded and includes a discussion of the statistical concept of regression to the mean and its relevance, or lack thereof, to monitoring bone density. It is an important concept to understand as it is still incorrectly used to diminish the value of monitoring changes in bone density. Chapter 12, which addresses secondary causes of bone loss, is new to this edition, replacing the chapter in earlier editions in which various articles relating to causes of bone loss were abstracted. When low bone density or osteoporosis is identified, the referring physician may look to the densitometrist for guidance in the evaluation of the patient to exclude secondary causes of bone loss. In this chapter, some of the more common differential diagnoses and the relevant evaluations to exclude each are reviewed. Chapter 12 is intended for the non-metabolic bone disease specialist densitometrist. Chapter 13 is also new to this edition and focuses on the new applications for DXA such as vertebral fracture assessment, aortic calcification scoring, hip structure analysis, and assessment of visceral fat. Finally, the challenge of bringing all this information to bear on the interpretation of the numerical densitometry data is addressed in Chapter 14. Although it is
one of the shorter chapters in the book, its importance should not be underestimated. The reality is that an inadequate or unread report will negate the expertise of the densitometrist and technologist as well as the promise of the technology. Finally, in Chapter 15, the technical specifications of densitometry devices currently approved for use in the United States are listed. These specifications may change without notice; so, the reader is encouraged to contact the manufacturer directly if more information is desired. Contact information for the various manufacturers can be found in Appendix I.

The appendices are an attempt to pull together reference information in a convenient location to enable the physician to refer to the information quickly, without searching the text. An entire appendix, Appendix V, has been devoted to the 2007 ISCD guidelines. The 1998 NHANES III reference database and native databases from the major manufacturers of central DXA devices will be found in Appendices IX-XII. The CD-ROM that accompanies this book contains several files that the densitometrist should find useful in every day practice as well as a study guide that can be completed for continuing education credit. The contents of the CD are described in Appendix XIV.

In a few circumstances in this text, data has been presented from published abstracts, rather than from peer-reviewed, published articles. This was done in the interest of providing information rapidly. The reader should be cautioned that data presented in abstract form might change slightly when it is finally published in a peer-reviewed journal. Some data presented in abstract form is never published in a peer-reviewed journal for a variety of reasons.

As this text has evolved over the years, it has essentially become a text on the use of DXA in clinical practice. Other technologies are discussed and should not be dismissed by the clinician. Some technologies provide measurements that are biologically different from those obtained with DXA. All of the technologies are remarkably accurate and when utilized correctly, very precise. But the evolution of the clinical criteria for the diagnosis of osteoporosis and the prediction of fracture risk have created a circumstance in which DXA measurements of the spine and proximal femur are the measurements that are ultimately clinically useful. It is perhaps unfortunate that this is so, in that truly remarkable technologies consequently have little practical clinical use. Nevertheless, it is the circumstance in which we find ourselves and is reflected in the focus of this book.

Bone densitometry is an extraordinary clinical tool. It provides a safe, non-invasive window to the skeleton. Through that window a physician can obtain vital clinical information that enhances the management of the patient that cannot currently be obtained in any other way. So, to whom in medicine does densitometry belong? To no one specialty in particular and to every specialty in general as long as the physician and technologist are committed to learning the unique aspects of this technology and the proper interpretation of the data that it generates. The technology itself is superb. Bone density can be measured with superior accuracy in virtually every region of the skeleton. The machines are capable of the finest precision of any quantitative technique in use in clinical medicine today. But the machines will perform only to the level of the expertise of those who operate them. And the data that they generate will only be as useful as the clarity of the interpretation that is provided by the densitometrist. It is hoped that this volume will be useful in helping the densitometrist fulfill the potential that the technology holds for contributing to the highest quality of patient care and disease prevention and management.

Sydney Lou Bonnick, MD, FACP
Acknowledgments

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I would also like to thank those authors and publishers who allowed me to reproduce their work in the interest of continuing education.

And a special word of thanks to my editor, Paul Dolgert of Humana Press.
DEDICATION

For Margery Winston and Eliza Calvert Hall
and Cora Jane Spiller and Lynn Niedermeier, who helped me find them.
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CONTINUING MEDICAL EDUCATION

RELEASE DATE
September 1, 2009

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September 1, 2012

ESTIMATED TIME TO COMPLETE
30 Hours

ACCREDITATION

We are pleased to award category 1 credit(s) toward the AMA Physician’s Recognition Award. By reading the instructions in Appendix XIV and by completing the review in the CD-ROM companion, you are eligible for up to 30 hours of category 1 credit. After answering all of the questions correctly, complete the review evaluation and enter the required identifying information on the certificate of course completion. This certificate is not valid until signed with authorized signature at the Foundation for Osteoporosis Research. The certificate may be printed one time only. Send the certificate and the required fee to the Foundation for Osteoporosis Research and Education for awarding of continuing education credits.

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This activity has been planned and implemented in accordance with the essential areas and policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint sponsorship of the Foundation for Osteoporosis Research and Education and Humana Press, a part of Springer Science+Business Media. The Foundation for Osteoporosis Research and Education is accredited by the California Medical Association to provide continuing medical education for physicians.

METHOD OF PARTICIPATION

Read the book carefully. Complete the posttest and evaluation/certificate to be found on the companion CD-ROM. There is a $150 fee for this activity. Credit for the activity
is available until September 1, 2012. Additional directions for obtaining credit can be found on the companion CD-ROM.

**Faculty and Disclosure**

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Denton, Texas

Faculty for CME activities are expected to disclose to the activity audience any real or apparent conflict(s) of interest related to the content of the material they present. The following relationships have been disclosed:

Dr. Bonnick has nothing to disclose.

**Provider Disclosure**

The Foundation for Osteoporosis Research and Education is an independent organization that does not endorse specific products of any pharmaceutical concern and therefore has nothing to disclose. Humana Press does not endorse specific products of any pharmaceutical concern and therefore has nothing to disclose.

**Intended Audience**

This book is designed for physicians and technologists involved in the application of bone densitometry.

**Overall Goal**

The overall goal of this activity is to update the scientific knowledge and skills of physicians and technologists who manage patients with established osteoporosis or patients who may be at risk for developing osteoporosis.

**Learning Objectives**

Upon completion of this continuing medical education activity, participants should have improved overall knowledge, skills, and attitudes concerning the use of bone densitometry. Specifically, the objectives are:

1. To review the most clinically relevant aspects of interpreting bone density data.
2. To familiarize the physician with the resources found in the third edition of *Bone Densitometry in Clinical Practice*.
3. To emphasize potential pitfalls in interpreting and reporting densitometry results.
4. To familiarize the physician with current recommendations and standards for patient selection for testing and for densitometry reporting
5. To review the similarities and differences among the various densitometry techniques used in clinical practice
6. To review aspects of human anatomy unique to the field of densitometry

UNLABELED/UNAPPROVED USE DISCLOSURE

In accordance with ACCME standards for commercial support, the audience is advised that this CME activity may contain references to unlabeled or unapproved uses of drugs or devices.
Clinical densitometry is relatively new but densitometry itself is actually quite old. It was first described over 100 years ago in the field of dental radiology as dentists attempted to quantify the bone density in the mandible (1, 2). With today’s techniques bone density can be quantified in almost every region of the skeleton. The extraordinary technical advances in recent years have expanded the realm of densitometry from that of a quantitative technique to that of an imaging technique as well. But even the oldest techniques remain both viable and valuable with computer modernization. Densitometry technologies have evolved as our understanding of relevant disease processes has increased. In a complimentary fashion, our understanding of the disease processes has increased as the technologies have evolved.

**PLAIN RADIOGRAPHY IN THE ASSESSMENT OF BONE DENSITY**

The earliest attempts to quantify bone density utilized plain skeletal radiography. When viewed by the unaided eye, plain skeletal radiographs can only be used in an extremely limited fashion to quantify bone density. Demineralization becomes visually apparent only after 40% or more of the bone density has been lost (3). If demineralization is suspected from a plain film, a great deal of demineralization is presumed to have occurred. A more precise statement cannot be made. Plain radiographs have been used for qualitative and quantitative skeletal morphometry. Plain radiographs were also used to assess bone density based on the optical densities of the skeleton when compared to simultaneously X-rayed standards of known density
made from ivory or aluminum. With the advent of photon absorptiometric techniques, most of these early methods, as originally performed, have fallen into disuse. Nevertheless, a brief review of these techniques should enhance the appreciation of the capabilities of modern testing and provide a background for understanding modern technologies.

QUALITATIVE MORPHOMETRY

Qualitative Spinal Morphometry

Qualitative morphometric techniques for the assessment of bone density have been in limited use for over 50 years. Grading systems for the spine relied on the appearance of the trabecular patterns within the vertebral body and the appearance and thickness of the cortical shell (4). Vertebrae were graded from IV down to I as the vertical trabecular pattern became more pronounced with the loss of the horizontal trabeculae and the cortical shell became progressively thinned. The spine shown in Fig. 1-1 demonstrates a pronounced vertical trabecular pattern. The cortical shell appears as though it was outlined in white around the more radiotranslucent vertebral body. These vertebrae would be classified as Grade II.

Fig. 1-1. Quantitative spine morphometry. The vertebrae on this lateral lumbar spine X-ray demonstrate marked accentuation of the vertical trabecular pattern and thinning of the cortical shell. This is a Grade 2 spine.
The Singh Index

The Singh Index is a qualitative morphometric technique that was similarly based on trabecular patterns, but based on those seen in the proximal femur (5). Singh and others had noted that there was a predictable order in the disappearance of the five groups of trabeculae from the proximal femur in osteoporosis. Based on the order of disappearance, radiographs of the proximal femur could be graded 1–6 with lower values indicating a greater loss of the trabecular patterns normally seen in the proximal femur. Studies evaluating prevalent fractures demonstrated an association between Singh Index values of 3 or less and the presence of fractures of the hip, spine, or wrist. Figure 1-2 shows a proximal femur with a Singh Index of 2. Only the trabecular pattern known as the principle compressive group, which extends from the medial cortex of the shaft to the upper portion of the head of the femur, remains. This patient was known to have osteoporotic spine fractures as well as a contralateral proximal femur fracture. Later attempts to demonstrate an association between Singh Index values and proximal femur bone density measured by dual-photon absorptiometry were not successful (6).

![Fig. 1-2. The Singh Index and calcar femorale thickness. A Grade 2 Singh Index would be assessed based on having only remnants of the principle compressive group visible. This is indicative of osteoporosis. The arrow points to the calcar femorale, which measured 4 mm in thickness. Values <5 mm are associated with hip fracture. This patient had experienced a contralateral hip fracture.](image)

Both of these qualitative morphometric techniques are highly subjective. In general, the best approach to their use required the creation of a set of reference radiographs of the various grades of vertebrae for spinal morphometry or proximal femurs for the Singh Index to which all other radiographs could be compared.
QUANTITATIVE MORPHOMETRIC TECHNIQUES

Calcar Femorale Thickness

A little known quantitative morphometric technique involved the measurement of the thickness of the calcar femorale. The calcar femorale is the band of cortical bone immediately above the lesser trochanter in the proximal femur. In normal subjects, this thickness is greater than 5 mm. In femoral fracture cases, it is generally less than 5 mm in thickness (7). The arrow seen in Fig. 1-2 is pointing to the calcar femorale. This patient had previously suffered a femoral neck fracture. The thickness of the calcar femorale measured 4 mm.

Radiogrammetry

Radiogrammetry is the measurement of the dimensions of the bones using skeletal radiographs. Metacarpal radiogrammetry has been in use for almost 50 years. As originally practiced, the dimensions of the metacarpals were measured using a plain radiograph of the hand and fine calipers or a transparent ruler. The total width and medullary width of the metacarpals of the index, long, and ring fingers were measured at the midpoint of the metacarpal. The cortical width was calculated by subtracting the medullary width from the total width. Alternatively, the cortical width could be measured directly. A variety of different calculations were then made such as the metacarpal index (MI) and the hand score (HS). The MI is the cortical width divided by the total width. The HS, which is also known as the percent cortical thickness, is the metacarpal index expressed as a percentage. Measurements of the middle three metacarpals of both hands were also made and used to calculate the six metacarpal hand score (6HS). Other quantities derived from these measurements included the percent cortical area (%CA), the cortical area (CA), and the cortical area to surface area ratio (CA/SA). The main limitation in all of these measurements is that they were based on the false assumption that the point at which these measurements were made on the metacarpal was a perfect hollow cylinder. Nevertheless, using these measurements and knowledge of the gravimetric density of bone, the bone density could be calculated. The correlation between such measurements and the weight of ashed bone was good, ranging from 0.79 to 0.85 (8,9). The precision of metacarpal radiogrammetry was quite variable depending upon the measurement used.\(^2\) The measurement of total width is very reproducible. The measurement of medullary width or the direct measurement of cortical width is less reproducible because the delineation between the cortical bone and medullary canal is not as distinct as the delineation between the cortical bone and soft tissue. Precision was variously

\(^1\)Correlation indicates the strength of the association between two values or variables. The correlation value is denoted with the letter “r.” A perfect correlation would be indicated by an r-value of +1.00 or −1.00.

\(^2\)Techniques are compared on the basis of accuracy and precision, which can be described using the percent coefficient of variation (%CV). The %CV is the standard deviation divided by the average of replicate measurements expressed as a percentage. The lower the %CV, the better the accuracy or precision. See Chapters 3 and 11 for a detailed discussion of precision and accuracy.
reported as excellent to poor, but in expert hands it was possible to achieve a precision of 1.9% (10).

Although metacarpal radiogrammetry is an old technique and somewhat tedious to perform, it remains a viable means of assessing bone density in the metacarpals. Metacarpal radiogrammetry demonstrates a reasonably good correlation to bone density at other skeletal sites measured with photon absorptiometric techniques (11). The technique is very safe as the biologically significant radiation dose from a hand X-ray is extremely low at only 1 mrem.

Radiogrammetry can also be performed at other sites such as the phalanx, distal radius, and femur (12–14). Combined measurements of the cortical widths of the distal radius and the second metacarpal are highly correlated with bone density in the spine, as measured by dual-photon absorptiometry (12).

Today, plain films of the hand and forearm can be digitized using flatbed optical scanners and radiogrammetry performed with computerized analysis of the digitized images. Using such a digital radiogrammetry (DXR) system, Bouxsein et al. (15) evaluated the utility of metacarpal radiogrammetry in predicting fracture risk and the correlation between metacarpal DXR-BMD and BMD measured by other techniques at other sites. The authors used a case–cohort approach to identify three groups of 200 women based on their having experienced a hip fracture, wrist fracture, or spine fracture during the first 5 years of the Study of Osteoporotic Fractures (16). DXR-BMD of the metacarpals was strongly correlated with distal and proximal radial BMD measured by single-photon absorptiometry\(^3\) \((r = 0.68\) and 0.75, respectively). The correlation with femoral neck and lumbar spine BMD measured by dual-energy X-ray absorptiometry\(^3\) was more modest \((r = 0.50\) and 0.44, respectively). Metacarpal DXR-BMD predicted spine and wrist fracture risk as well as single-photon absorptiometry BMD measurements of the distal or proximal radius or heel or dual-energy X-ray absorptiometry of PA lumbar spine or femoral neck. The increase in risk for wrist fracture was 1.6 for each standard deviation decline in DXR-BMD and 1.9 for spine fracture. Although femoral neck BMD was the strongest predictor of hip fracture risk, metacarpal DXR-BMD predicted hip fracture risk as well as the other BMD measurements with an increase in risk of 1.8 for each standard deviation decline in BMD. This type of DXR system is available commercially from Sectra Pronosco in Denmark as part of a PACS\(^4\) system.

### The Radiologic Osteoporosis Score

The radiologic osteoporosis score combined aspects of both quantitative and qualitative morphometry (14). Developed by Barnett and Nordin, this scoring system utilized radiogrammetry of the femoral shaft and metacarpal as well as an index of biconcavity of the lumbar vertebrae. In calculating what Barnett and Nordin called a peripheral score, the cortical thickness of the femoral shaft divided by the diameter of the shaft and expressed as a percentage was added to a similar measurement of the metacarpal. A score of 88 or less was considered to indicate peripheral osteoporosis. The biconcavity index was calculated by dividing the middle height of the third lumbar vertebra by

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\(^3\)This technique is discussed later in this chapter.

\(^4\)Picture Archiving and Communications System.
its anterior height and expressing this value as a percentage. A biconcavity index of 80 or less indicated spinal osteoporosis. Combining both peripheral score and biconcavity index resulted in the total radiologic osteoporosis score, which indicated osteoporosis if the value was 168 or less.

**Radiographic Texture Analysis (RTA) and Spatial Anisotropy Analysis Utilizing Plain Radiography**

The Singh Index (5), which was described earlier in this chapter, utilized plain radiographs of the proximal femur to assign a grade, based on the orderly disappearance of trabecular bundles in the femoral neck. Although the index was not characterized at the time in terms of radiographic texture analysis (RTA) or spatial anisotropy, it was not far removed in concept from today’s approaches which utilize sophisticated mathematics such as fractal analysis, principal component analysis, and fast Fourier transform analysis of images from skeletal radiographs (17–21). The logistical advantage to these approaches, just as was the logistical advantage of the Singh Index, is the utilization of both existing and widely available non-invasive technology to acquire the original data. The logistical disadvantage of these newer approaches is that the mathematical iterations generally require specific expertise and exportation of the image into complex computer programs, which are not widely available. RTA and spatial anisotropy are not measurements of density; they are included here because they represent a highly sophisticated return to plain radiography in the assessment of bone strength.

**Radiographic Texture Analysis**

Radiographic texture analysis (RTA) of either plain films or DXA images is an analysis of patterns in the two-dimensional images of three-dimensional bones rather than an analysis of individual trabeculae. Fractal mathematics is used to quantify qualitative changes in the texture patterns. These patterns can differ between strong and fragile bones. RTA has been shown in cross-sectional studies to differentiate between patients with vertebral fracture and non-fractured controls, based even in subgroups with overlapping proximal femur bone density values (17). Pothauad et al. employed fractal mathematics to analyze plain films of the calcaneus in 39 postmenopausal women with vertebral crush fractures compared to 39 non-fractured postmenopausal women. The area under the receiver-operating curve (AUROC) for the fractal statistic, called the $H_{mean}$ (Hurst exponent mean), was statistically significantly greater than for femoral neck BMD. Interestingly, in a sub-group analysis, the $H_{mean}$ was significantly lower in the fracture patients compared to controls, even though the femoral neck and trochanteric bone densities were overlapping. In a larger cross-sectional study, Benhamou et al. (18) utilized plain films of the calcaneus and fractal analysis to perform RTA in 197 controls and 107 fracture patients. BMD was measured with DXA. The fracture patients had experienced spine, hip, or wrist fractures. In this study, the $H_{mean}$ was significantly lower in the spine and hip fracture patients compared to controls, even after adjustment for spine or femoral neck BMD.

$^{5}$ See Chapter 3 for a discussion of the AUROC.